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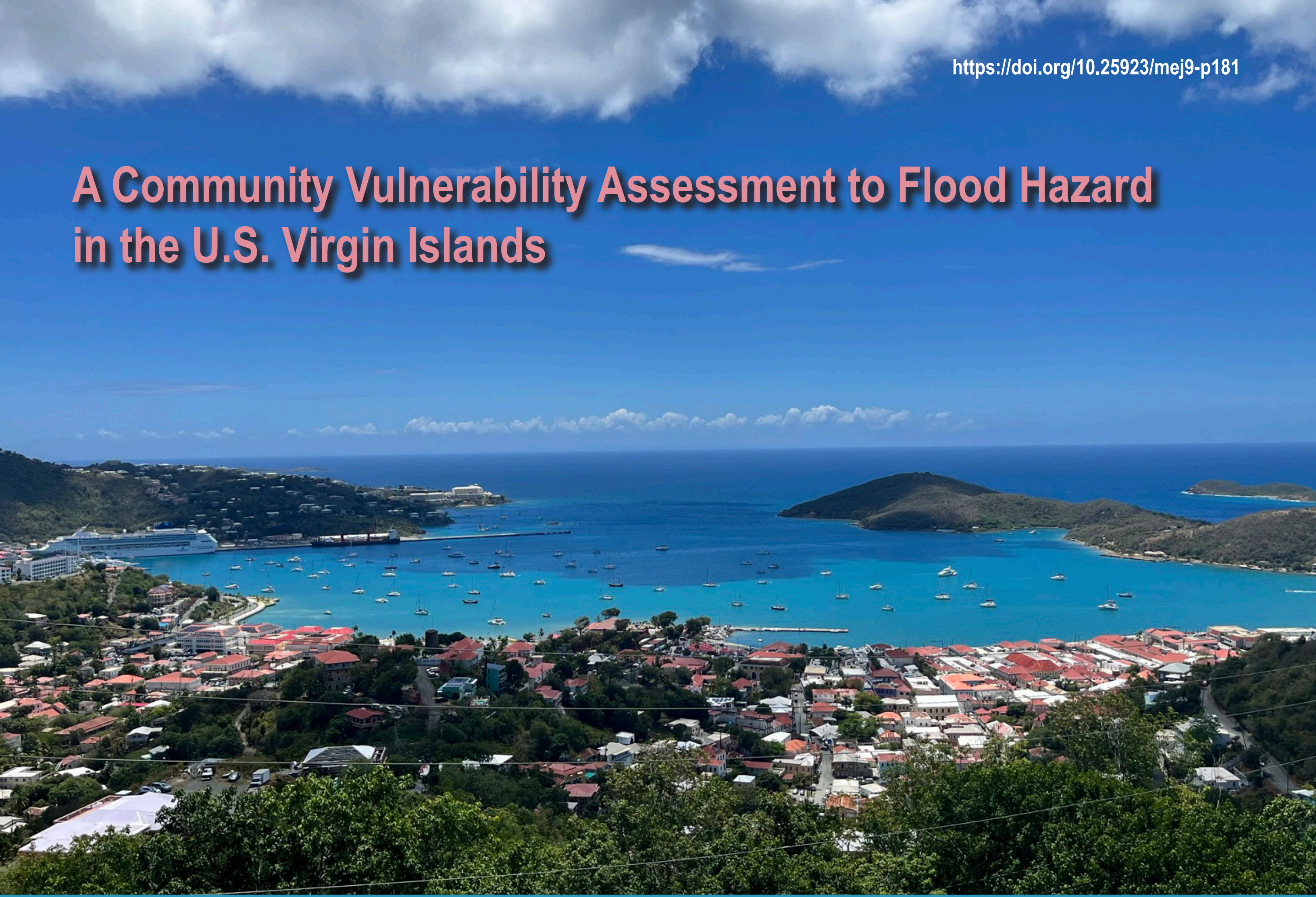
A Community Vulnerability Assessment to Flood Hazard in the U.S. Virgin Islands



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Data will be publicly accessible and linked via the project webpage when available.

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Disclaimer

A Community Vulnerability Assessment to Flood Hazard in the U.S. Virgin Islands

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November 2024

NOAA NOS NCCOS TECHNICAL MEMORANDUM 344

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Executive Summary

Coastal populations are exposed to erosion, flooding, and other climate hazards, but damaging hazard events are not experienced equitably across the country. The degree of vulnerability and exposure for people is related to structural social inequalities, and communities that are marginalized, underserved, and overburdened are less able to prepare for or recover from natural hazard events. The United States Virgin Islands (USVI) is exposed to a number of climate hazards, including heavy rains, high temperatures, strong winds, and significant flooding concerns, and its resident populations are at increasing risk.

This report supports the first goal of the USVI's current draft Hazard Mitigation and Resilience Plan (USVI Hazard Mitigation and Resilience Plan, 2024, Ch. 7) to "Manage natural hazard risk by applying risk reduction (mitigation) policies to prevent new risk, reduce existing risk, and adapt to the future risk associated with climate change by strengthening infrastructure, critical facilities, and lifelines." It presents background, methodology, findings, and map products from a community vulnerability assessment conducted for estates within the USVI. This spatial assessment is the first implemented under the National Centers for Coastal Ocean Science's (NCCOS) new programmatic research portfolio and NCCOS's fifth assessment overall. This assessment developed indicators of vulnerability, exposure, and hazard and intersected them spatially to produce maps of risk and co-occurrence. All assessment components and decisions were informed by the best available scientific methodologies, best available existing datasets, and partner and stakeholder engagement, feedback, and priority workshops.

Assessment Components: A **social vulnerability index** was provided by a collaboration between University of the Virgin Islands and the USVI Department of Planning and Natural Resources. A **structural exposure index** was developed from three sub-indices of communications infrastructure, transportation infrastructure, and utilities infrastructure. A **structural vulnerability index** was developed from two sub-indices of housing characteristics and vacancy metrics. A **nearshore environment protection benefits index** ultimately used orbital velocity data. A **compounded flood hazard index** comprised 2-ft sea level rise estimates, Category 5 storm surge, and a seven-indicator stormwater flooding sub-index. A **waterborne toxins and contaminants index** included six indicators related to wastewater, drinking water violations, solid waste, and industry. A **vegetation index** used high-resolution imagery data to calculate a visible atmospherically resistant index. Lastly, a **potential walkability index** included seven indictors related to road characteristics, land use, and amenities.

Additional partner and stakeholder feedback determined priority intersections of the above components. These were organized by co-vulnerabilities, risk in relation to flood hazard, nearshore environment interactions, and other important relationships. This report examines these interactions and base assessment components in detail; however, some key findings are outlined below:

- USVI communities are at risk of flooding, toxins, and contaminants, overall, but some estates have higher risk than others.
- Some of the territory's most socially vulnerable populations have increased risk of waterborne toxin and contaminant exposure, more vulnerable housing, and increased risk of flooding.
- Many of the territory's industrial and waste management sites are in coastal areas at risk of flooding. Adjacent and downstream communities should exercise increased caution when flood events occur.
- Much of the territory's critical infrastructure is in areas of high flood risk and also overlaps with areas of increased structural vulnerability, including around Charlotte Amalie, Frederiksted, and Christiansted. Since the majority of critical infrastructure services not only nearby areas but often the entire island, damage or loss of this infrastructure can have devastating effects on the territory.
- Higher social vulnerability, structural vulnerability, and structural exposure often occur in similar areas, including around Cyril E. King Airport and parts of Charlotte Amalie on St. Thomas; southern Cruz Bay, northern Coral Bay, and around Carolina, Calabash Boom, and Mandahl on St. John; and parts of west-central St. Croix from around Plessen to Sunny Isle, as well as Frederiksted southeast and south of the pier, and parts of Christiansted.
- Compounded flooding impacts broader parts of the territory than coastal flooding alone.
- Areas of repeated co-occurrence suggest the need for adaptation action, but also present an opportunity to develop and implement innovative strategies that mitigate multiple concerns simultaneously.

- Identified estates of co-occurrence might be candidate areas for future adaptation projects. Ideal projects depend on specific needs and technical expertise but might include efforts to:
    - Improve plumbing and kitchen facilities (both in the home and supporting infrastructure) in estates with higher structural vulnerability;
    - Update or improve critical infrastructure in estates at increased risk of flooding;
    - Implement coastal gray-green hybrid solutions for improved flood mitigation in estates with reduced nearshore environment protection benefits or those at increased risk of flooding;
    - Restore or increase onshore vegetation to improve natural flood attenuation in estates with limited vegetation and increased risk of flooding;
    - Systematically upgrade potable water systems through pilot initiatives to serve those most vulnerable in estates with increased social vulnerability and increased risk of waterborne toxins and contaminants;
    - Increase greening efforts in estates with high walkability potential but lower vegetation to improve walkability; or
    - Increase walkability potential in estates with higher social vulnerability to serve those most vulnerable.

The potential efforts mentioned above support the goals of the territory's 2019 Hazard Mitigation Plan (Virgin Islands Territorial Emergency Management Agency, 2019) or the 2024 draft update (USVI Hazard Mitigation and Resilience Plan, 2024), are mentioned explicitly as recommendations within one or both of these documents, and/or support overall well-being and quality of life in the USVI.

This assessment provides an estate-level integration of vulnerability, exposure, hazard, and risk within the USVI. This research identifies priority geographies that warrant further investigation for future climate adaptation and improvement projects. The variety of assessment outputs allows for management action based on various time horizons, management needs, levels of political and public support, and availability of funding. This assessment can also be used to inform or improve communications and outreach materials for emergency response planning, public awareness campaigns, and other purposes. Additionally, it can support grant applications by demonstrating need and advocating for climate action. The results provide meaningful information to better protect, advance, and manage climate change impacts within the territory's local communities.

Sailboats and old dock posts, U.S. Virgin Islands (USVI). Credit: Chloe Fleming (CSS Inc./NOAA NCCOS)

1. Introduction

1.1 Portfolio Overview

Coastal populations are exposed to erosion, storms, and flooding. More concerning, climate change is exacerbating these and other natural hazards, such as wildfire, drought, heavy precipitation, and heat waves (Intergovernmental Panel on Climate Change, 2023). Climate change is a national crisis, but damaging hazard events are not experienced equitably across the country. Impacts vary due to differences in topography, risk profiles, and local geographic and climatic influences but also due to social factors (Frazier et al., 2014). The degree of vulnerability and exposure for people is related to structural social inequalities that are produced and reinforced by society. Socially disadvantaged communities that are marginalized, underserved, and overburdened are less able to prepare for or recover from natural hazard events and are often at higher risk due to inequitable historic development patterns.

While national tools exist to screen for vulnerable populations potentially exposed to hazards (e.g., EJScreen [Environmental Protection Agency, 2024a], Social Vulnerability Index [Agency for Toxic Substances and Disease Registry, 2024], National Risk Index [Federal Emergency Management Agency, 2024]), these often do not provide information at a scale or resolution that is meaningful for local action. Additionally, national metrics often limit their input data to those available for the entire nation, typically excluding local datasets and masking local nuance. In the case of the U.S. Territories and Alaska, national tools sometimes exclude these geographies entirely or lack local buy-in.

To bridge these information gaps and help coastal communities understand and document their vulnerability to climate hazards, the National Centers for Coastal Ocean Science (NCCOS) has been conducting place-based integrated community vulnerability assessments since 2014 (Fleming et al., 2017; Fleming et al., 2022; Freitag et al., 2022; Messick et al., 2016; Miller et al., 2023). For each assessment, vulnerability is defined as "the propensity or predisposition of assets to be adversely affected by hazards" (U.S. Climate Resilience Toolkit, 2021). Researchers developed a transferable and integrated community vulnerability assessment framework (Figure 1) that uses a place-based vulnerability framework (e.g., Cutter and Finch, 2008) to examine social, structural, and environmental vulnerability to climate variability and impacts. Advancing methods used by Wu et al. (2002), the framework relies primarily upon available secondary data supplemented with stakeholder-derived primary data to develop vulnerability indicators and indices (Fleming et al., 2022). These indices are then layered with hazard indices, and the resulting maps highlight areas and communities of high and low risk.

Because this research is place-based and each assessment takes 1–3 years, the number of NCCOS community vulnerability assessments has been limited. In 2022, NCCOS took steps to streamline its assessment portfolio. Within the current programmatic execution, assessments now focus primarily on social and structural vulnerability in relation to flood hazard, with structured room for additional local analytical needs. Each assessment directly engages local partners and stakeholders at strategic points in the research process, including during development of assessment goals and product development and review. Their iterative inclusion aims to provide assessment outcomes that are regionally relevant for effective, equitable planning. Each assessment programmatically executed by NCCOS's community vulnerability assessment uses the best available secondary data in concert with local partner feedback to deliver key spatial data (Table 1).

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Partner engagement	**Indicator development**	**Assess vulnerability and hazard**	**Assess risk**	**Conduct place-based analysis**	**Develop and release products**
Determine project advisory committee. Hold workshop meeting(s) to determine project goals and prioritize local needs.	Gather local and national data to develop indicators and indices, using partner/stakeholder input.	Develop maps of each vulnerability (or exposure) and hazard index. Present for key partner feedback.	Spatially assess risk by intersecting vulnerability (and/or exposure) with hazard. Present for key partner feedback.	Develop additional place-based indices and intersect with other assessment maps. Present for key partner feedback.	Develop products. Present findings and products to full list of partners and stakeholders. Revise and finalize.

Figure 1. NCCOS community vulnerability assessment framework steps.

Introduction

In 2023, NCCOS initiated its first programmatic community vulnerability assessment (and 5th application overall)[1] for the United States Virgin Islands (USVI) in collaboration with the U.S. Environmental Protection Agency (EPA) Region 2, the Virgin Islands Department of Planning and Natural Resources, and the University of the Virgin Islands.

1.2 Study Area Overview

The USVI is a U.S. Caribbean territory located approximately 40 mi east of Puerto Rico and over 1,000 mi southeast of Miami, Florida (Figure 2). The territory includes the three main islands of St. Thomas and St. John, located directly east of Puerto Rico, and St. Croix, approximately 40 mi south of the two northern islands, as well as several smaller surrounding islands, including inhabited Water Island. St. Croix is the largest of the islands (85 sq. mi) compared to St. Thomas and St. John (32 and 20 sq. mi, respectively) (Dobson et al., 2020). The territory's geomorphology includes coastal plains, coastal dry forests, and central mountains, with more tropical, mountainous terrain concentrated on St. Thomas and St. John, and more arid, drier terrain on St. Croix (Mckayle et al., 2019). Larger wetland areas are present along the coastal plains, estuaries, and coastlines (U.S. Army Corps of Engineers, 2022), and coastal fringes, tidal riverine areas, and coastal basins are dominated by mangroves (Mckayle et al., 2019).

Table 1. Assessment components – Portfolio standards and present assessment.

Portfolio standards	Present assessment
Social vulnerability, structural vulnerability and/or structural exposure	Social vulnerability (partner led)
	Built environment: Structural vulnerability and structural exposure
	Marine environment: Nearshore environment protection benefits
Flood hazard (e.g., coastal flooding, stormwater flooding, riverine flooding, projected sea level rise, storm surge)	Sea level rise
	Hurricane storm surge
	Stormwater flooding
	Compounded flood hazard
Relative risk through the intersection of vulnerability, exposure, and hazard	Relative risk through the intersection of vulnerability, exposure, and hazard
At-risk communities or community in relation to flood hazard	At-risk communities or community in relation to flood hazard
Up to two place-based analyses that support additional local vulnerability needs	Waterborne toxins and contaminants
	Vegetation
	Walkability (three components justified because social vulnerability was partner led)

[1] For more information on the broader research portfolio, visit: https://coastalscience.noaa.gov/project/programmatic-execution-of-nccos-vulnerability-assessments/.

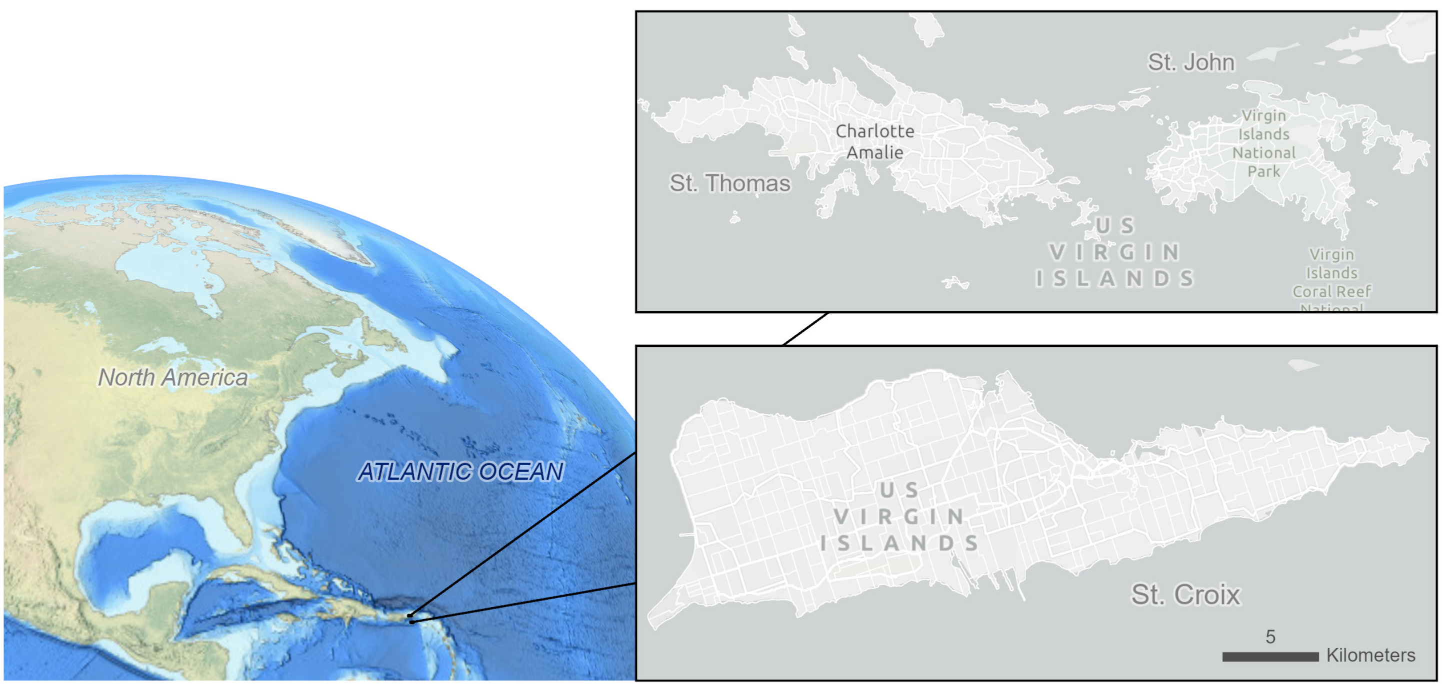

Figure 2. Location and estates of the U.S. Virgin Islands (USVI).

The islands are largely undeveloped, with 80–96% of each island designated as natural area as of 2013 (Gould et al., 2013). Among these natural areas is the Virgin Islands National Park, covering approximately half of St. John and managed by the National Park Service (Mckayle et al., 2019). The USVI has nearly 77 mi of coastline (Dobson et al., 2020), and the majority of these coastlines are fringed by coral reef and seagrass habitat (Mckayle et al., 2019).

1.2.1 Demographics, Economy, and Infrastructure

The islands are divided into a total of 336 community estates with a total population of 87,146 per the 2020 Census (U.S. Census Bureau, 2023j) (Figure 2). A slight majority of the population lives on the northern islands (42,261 on St. Thomas [including inhabitants of Water Island] and 3,881 on St. John), with the remainder on St. Croix (41,004) (U.S. Census Bureau, 2023j). In 2020, 10.4% of the territory's population was under 10 years of age, and over 21% of the territory's population was aged 65 or older. The majority of the population (71.4%) identifies as Black or African American, including almost 12% Caribbean, while 13.3% identifies as White, and 18.4% identifies as Hispanic or Latino (U.S. Census Bureau, 2023j).

The territory is largely dependent on imported consumer goods and has a relatively high cost of living. The territory's Consumer Price Index rose 9.8% in 2022 (following an 8.6% increase in 2021), with the highest impacts to food, housing, clothing, and transportation (USVI Bureau of Economic Research, 2023), and in 2021, the unemployment rate was 8.8% (USVI Bureau of Economic Research, 2022). St. Thomas is the territory's center of tourism, commerce, trade, finance, and government, and hosts the territory's capital Charlotte Amalie (Congressional Research Service, 2020). Though residents are employed in a variety of government and private sectors, tourism is one of the territory's largest sources of revenue, and the territory sees more than two million visitors annually, largely from the cruise ship industry (Congressional Research Service, 2020). Cruise ships dock in Charlotte Amalie harbor and shuttle systems bring visitors to some of St. Thomas's most popular beaches and resorts. Beyond St. Thomas, the scenery of nearby St. John also provides opportunities for both land- and marine-based tourism and the quieter island is also known for its luxurious villas and high-end hotels (Mckayle et al., 2019) and hosts the Virgin Islands National Park. A quick ferry ride encourages excursions between the two northern islands. In contrast, St. Croix sees less tourism than its northern counterparts but still welcomes visitors by ferry and short flights.

Despite its financial benefits, tourism in the USVI strains the territory's already at-risk infrastructure and ecosystems. The majority of the territory's physical infrastructure, including its roads, electrical systems, buildings, etc., are operating beyond their intended service life (Culbertson, 2020), and landfills on St. Thomas and St. Croix are near capacity, have numerous violations, and serve as a critical source of pollution (Culbertson, 2020). Construction of large resorts and vacation homes to support tourism has required the development of numerous unpaved roads that enable travel and construction across the islands. Though unpaved, these roads still increase sediment transportation and runoff, stressing offshore coral reef communities (Rudge, 2021).

St. Croix's flatter terrain was historically used for agriculture, but the island now serves as the territory's manufacturing and industrial center, centered on rum production at the Cruzan and Diageo distilleries, and intermittent and controversial oil production at the refinery (Congressional Research Service, 2020).

Charlotte Amalie and cruise ships, St. Thomas (top; Chloe Fleming, CSS Inc./NOAA NCCOS); oil refinery, St. Croix (bottom left; Uzma Aslam, CSS Inc./NOAA NCCOS); USVI beach (bottom right; C.Fleming, CSS Inc./NOAA NCCOS)

When owned and operated by Hovensa, the refinery was a major employer for the island prior to its closure in 2012. Hovensa filed for bankruptcy in 2015 and was later purchased and renovated by Limetree Bay (Congressional Research Service, 2020). In February 2021, the refinery resumed operations before significant air pollutant and oil releases resulted in its closure that May (Environmental Protection Agency Region 2, 2021). Following another bankruptcy, ownership was transferred to the West Indies Petroleum Limited and Port Hamilton Refining and Transportation, LLLP. The EPA issued a series of permitting requirements and inspections prior to operations resumption and in August 2022, a petroleum coke fire was reported on the premises. In 2023, the EPA oversaw the removal of ammonia, amines, and liquified natural gas from the refinery (Environmental Protection Agency, 2024b). At the time of publication, it was not in operation.

1.2.2 Weather, Hazards, and Climate Change

Rainfall in the territory averages 39 inches per year with significant variations across the islands. The wet season is prone to thunderstorms and hurricanes, which increase chances of flooding, especially in low-lying areas that tend to drain slowly (Dobson et al., 2020). It is common for parts of the territory to experience above-average precipitation and flooding in a given year, and drought or near-drought conditions the year following (RMSI, 2021). This is compounded by a limited groundwater supply that requires residents to ration their water use. As a result, many residents have personal cisterns. In 2019, it was reported that greater than 90% of households have the capability of collecting rainwater through cisterns (Voth-Gaeddert et al., 2022), influenced by a 1964 law, later revised in 1996 and reauthorized in 2019 (V.I. Code tit. 29, § 308), that required all dwellings to install personal cisterns unless they were connected to the public water supply (Solomon and Smith, 2007). A study of water-use habits found that 21% of households used cistern water as their primary source of drinking water (Rao et al., 2022), and another assessment found that between 33% and 40% of the households receive water from the Virgin Islands Water and Power Authority (Klise et al., 2022).

Temperatures vary with location, altitude, and time of year, but average around 88°F during the day and 76°F at night (RMSI, 2021). Average temperatures in the USVI are expected to rise between 33.4°F and 37.2°F by years 2081–2100 relative to years 1986–2005 (Mckayle et al., 2019). Higher temperatures and reduced water availability during the dry season already impact human health and well-being, but rising temperatures will increase these and other impacts, leading to increased cases of heatstroke and dehydration, as well as mosquito-borne disease and illness (Intergovernmental Panel on Climate Change, 2023). Rising temperatures are in addition to other major threats caused by a changing climate. Sea level rise, ocean warming, ocean acidification, shifting rainfall patterns, and decreased freshwater availability are only some of the projected concerns within the region (Environmental Protection Agency, 2016). Coastal waters around the USVI have already warmed by nearly 2°F since 1901, and the sea level has been rising by about an inch every 10 years (Environmental Protection Agency, 2016). Increasing seawater temperatures have resulted in severe coral reef bleaching, with mass bleaching events in 2005, 2010, 2012, and 2019 (Ennis et al., 2020), and more recently in 2020, 2021, and 2023 (Coral Reef Watch, 2024). Coral cover loss from bleaching events is compounded with loss from coral diseases, including from stony coral tissue loss disease, which was first sighted in the USVI in 2019 (Brandt et al., 2021).

Sargassum buildup, St. Croix (top; Uzma Aslam, CSS Inc./NOAA NCCOS); front page of St. Croix newspaper, 2023 (bottom; Seann Regan, CSS Inc./ NOAA NCCOS).

Impacts from coral bleaching and disease have resulted in up to 75% coral cover loss over the past five years, and declines from the combined effects of bleaching and disease show no signs of abating (M. Brandt, personal communication, June 25, 2024).


Bleached coral in St. Croix, 2005. Credit: NOAA NCCOS

Sea level rise is likely to jeopardize coastal communities and infrastructure alike. Access roads, transportation infrastructure, electric utilities, and water treatment buildings in the USVI are at particular risk (Bove et al., 2020), and much of the territory's built infrastructure, including many government buildings, schools, police and fire stations, airports, power plants, wastewater treatment plants, and underground power supply lines, will be impacted by as little as 1 ft of sea level rise by the year 2050 (Mckayle et al., 2019). Further, the territory's coastlines and beaches are susceptible to wave erosion. St. Croix is the most exposed, followed by St. John. Although mostly sheltered by the neighboring British Virgin Islands, it is still impacted by higher waves from the southeast and eastern Atlantic. St. Thomas benefits from the most protection from both St. John and the British Virgin Islands (Guannel et al., 2023).

With rising sea levels and increases in air and water temperatures, hurricanes pose a major concern for the USVI as towns, roads and ports are vulnerable to the impacts of both winds and water during storms. Despite their small size, the USVI are often frequented by tropical storms. Some of these storms, such as Hurricane Hugo, a Category 4 hurricane when its center crossed St. Croix in 1989 (NOAA National Hurricane Center, n.d.-a), and Hurricanes Irma and Maria (both Category 5 when impacting the territory) in 2017, caused massive devastation (Cangialosi et al., 2021; Pasch et al., 2023). For instance, Hurricane Maria resulted in storm surge recordings of up to 2.85 ft[3] on St. Croix; however, these sensors went offline and may not have recorded peak surge (Pasch et al., 2023). Beyond storm surge, Hurricane Maria's high winds caused downed trees, roof damage, and total destruction of many homes, and excessive rainfall resulted in catastrophic flooding and mudslides (Pasch et al., 2023). Storms have other impacts as well, including fatalities, extended power outages, and impacts to water storage, pressure, and sanitation (Klise et al., 2022), often costing billions of dollars in recovery efforts (Pasch et al., 2023).

1.3 Territory Research Efforts

In order to build upon existing related research and avoid duplication, the research team conducted a literature review as summarized here. The USVI updated its Territorial Hazard Mitigation Plan in 2019 (Virgin Islands Territorial Emergency Management Agency, 2019), identified key mitigation actions recommended for each island, and was in the process of again updating this plan concurrent with this assessment. McKayle et al. (2019) analyzed sensitivity, adaptive capacity, vulnerability, and adaptation strategy planning related to USVI hazards, socioeconomics, policy, tourism, agriculture, and critical infrastructure. Dobson et al. (2020) conducted a coastal resilience assessment for the territory that provided community exposure and fish and wildlife indices, as well as identified resilience hubs. Guannel et al. (2023) developed a coastal vulnerability index for all shoreline areas of the USVI. The index incorporated coastal geomorphic type, coastal infrastructure, and flood risk estimates from sea level rise, storm surge, and wave climate, and the resulting maps concluded that St. Croix's shoreline is the most vulnerable of the three islands. Some studies have focused on one area of hazard or vulnerability. For example, a stormwater flooding modeling study was recently completed for the territory, estimating impacts to buildings and critical infrastructure exposed to high-intensity rainfall scenarios (RMSI, 2021). Guannel et al. (2022) developed a social vulnerability index for the territory that adapted the Centers for Disease Control and Prevention (CDC) Agency for Toxic Substances and Disease Registry methodology to USVI estates using 2015 socioeconomic data, and this index was updated in 2024 with 2020 Decennial Census data. Some local research has had a narrower geographic focus, including a 2005 study assessing the vulnerability of St. John's Virgin Islands National Park (Pendleton et al., 2005) and a 2022 Natural Resource Condition Assessment of the Virgin Islands National Park and Coral Reef National Monument (Ogurcak et al., 2022).

The USVI has also been included in larger regional studies of the Caribbean or Southeast, such as the South Atlantic Coastal Study (U.S. Army Corps of Engineers, 2022) and the Southeast Conservation Adaptation Strategy's Southeast Conservation Blueprint (2023).

The above studies were conducted at a variety of spatial resolutions best suited to each project's needs, and public availability of input and output data from each study varies. Continued and enhanced assessment with open access data is needed to support local climate adaptation action and planning within the territory. NCCOS's Community Vulnerability Assessment Portfolio provides the capacity and opportunity to integrate a nuanced collection of analytical components at a consistent spatial scale across the territory. As the NCCOS approach includes an assessment of social vulnerability, the project team coordinated with researchers at the University of the Virgin Islands to incorporate their updated social vulnerability index (N. Beck, personal communication, March 19, 2024, updated from Guannel et al. [2022], publication forthcoming).

1.4 Partner and Stakeholder Engagement

In March of 2023, members of the research team traveled to the USVI to meet with project partners and learn about the territory's climate vulnerability needs to inform project goals. In May, the research team held a series of virtual scoping workshops with local project partners and stakeholders (26 participants) to familiarize the research portfolio and USVI assessment with a wider stakeholder group and to gather feedback from local agencies and practitioners to better understand the territory's needs and to modify and improve the planned project scope. Multiple workshop sessions were offered to facilitate small-group conversations and provide all interested parties a voice in the research process. Each workshop session asked participants to prioritize themes of social and structural vulnerability, flood hazards of greatest importance, and additional place-based analysis topics (formed from initial partners conversations and the project's March site visit). Sessions also collected known data sources, reports, and ongoing research and policy efforts related to climate vulnerability within the territory. The workshops utilized polling, ranking exercises, Google Jamboard sticky notes, and facilitated discussion. A detailed summary of these workshop sessions is included in Appendix A. The workshop findings were used to develop a draft project scope, and after partner review and data feasibility checks, the project scope was finalized in early summer.

In January and February of 2024, the research team presented preliminary index maps for each assessment component to project partners before making revisions based on their feedback. In March, the team held a second series of virtual workshops with both partners and the wider stakeholder group (21 participants) to present preliminary assessment components and gather feedback for improvement, prioritize index combination preferences for risk assessment, and prioritize story map messaging. The workshops utilized matching exercises, facilitated discussion, and Google Jamboard sticky notes. A detailed summary of these workshop sessions is included in Appendix B. Later that year, partners and stakeholders were given opportunities to review products and suggest revisions.

Coastal seawall, USVI. Credit: Seann Regan (CSS Inc./NOAA NCCOS)

2. Assessment Components

Building upon territory needs, existing research, partner and stakeholder feedback, and data feasibility checks (see Section 1. Introduction), this assessment identified and integrated measures of social vulnerability, structural vulnerability and exposure, flood hazard, green space, toxins and contaminants, and transportation.[2] Each component was assessed individually using the best publicly available existing input data. For a full list of data sources, resolutions, and notes for all analyses within this assessment, please see Appendix C: Data Sources. Component scores were then renormalized using a min-max normalization approach (following ArcGIS best practices (ESRI, 2024)) and aggregated to the estates shown in Figure 2. Estates are then categorized into statistical quantile breaks to communicate relative scores across each index (i.e., low, medium, high). Figure 3 demonstrates some common approaches to grouping data. Statistical quantile breaks were chosen for two reasons. First, the findings from this analysis show relative rankings of indicator values across the territory. Second, statistical quantile breaks allow for bivariate choropleth mapping of groups of data with an equal number of observations per class. This differs from equal interval classification, which groups the data by equal size classes (such as 0–1, 1–2, 2–3, etc.), but the amount of data in each class can vary (ESRI, n.d.). As a result, each component map communicates which estates are more or less likely to experience hazard or vulnerability, as compared to other estates within the territory. Estate-level aggregation also allows for eventual intersection with other components as presented in Section 3. All maps in this section are available as full-page graphics in Appendix D for improved resolution.

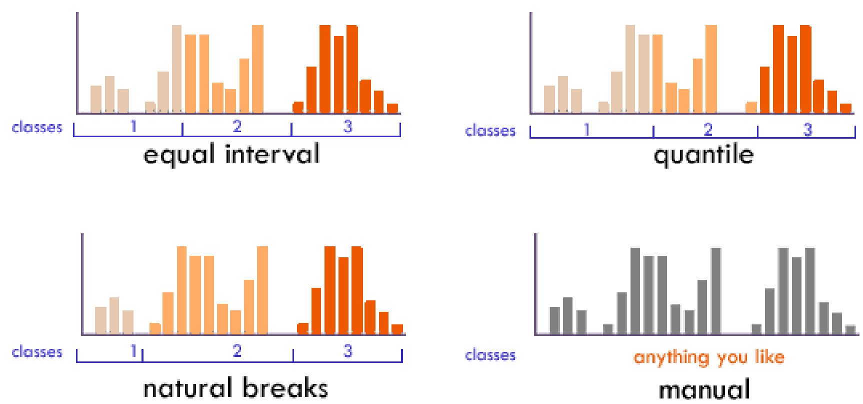

Figure 3. Description of how quantiles are determined. Credit: Cartography Guide by Axis Maps is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License.

2.1 Social Vulnerability

Social vulnerability analysis was conducted by University of the Virgin Islands project partners, using the CDC's social vulnerability index methodology (N. Beck, personal communication, Mar 19, 2024, updated from Guannel et al. [2022], publication forthcoming). This methodology incorporates variables such as poverty, unemployment, per capita income, educational attainment, age, race, English proficiency, and access to transportation. Though there are 336 populated estates across the territory, data were suppressed by the census in low-population areas. As a result, the final social vulnerability index was developed for 311 estates (Figure 4).[3]

2.2 Structural Vulnerability and Exposure

The research team investigated structural vulnerability and exposure within the foundation of the community resilience screening index (CRSI) (Summers et al., 2020). This index comprises over 100 variables across five domains of resilience; however, one of these domains is centered on measures related to the built environment. The CRSI Built Environment domain provides a quantification of the built environment that supports resilience within a community and includes 26 indicators across five indices: 1) communications infrastructure, 2) housing characteristics, 3) transportation infrastructure, 4) utilities infrastructure, and 5) vacant structures. Due to the USVI's unique context, data availability limitations, and partner needs, some of the input indicators were modified from the original index and are noted throughout this section. Project partners also emphasized the importance of highlighting natural and nature-based infrastructure as well as constructed and submerged aquatic infrastructure and their role in structural exposure, vulnerability, and mitigation. To address this, an additional nearshore environment protection benefits index was developed.

[2] Because partners led development of the social vulnerability index, the assessment team was able to incorporate a third place-based analysis type.

[3] Please note that this figure's legend uses a 4-point scale from less vulnerable to more vulnerable, with estates in the top 10th percentile as an additional 5th point. This visualization aligns with the approach used by the authors of the social vulnerability index (N. Beck, personal communication, Mar 19, 2024, updated from Guannel et al. [2022], publication forthcoming), and deviates from the other maps shown in the present report.

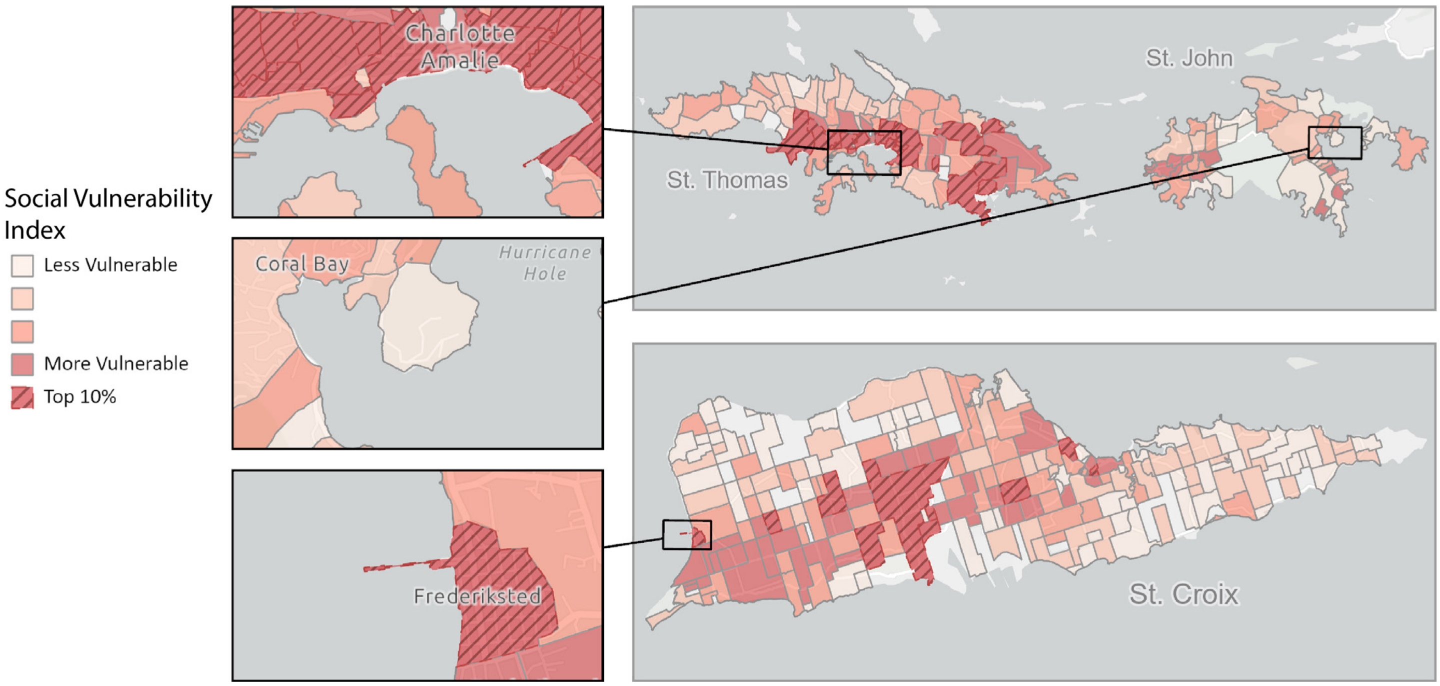

Figure 4. Final social vulnerability index.

2.2.1 Built Environment

All indicators used in measuring the CRSI Built Environment indices were available as point data or estate-level resolution with the exception of vacant structure variables, which were available only for census tracts. For each of the indices described below, any missing values for each indicator were populated with either zeros or nulls.[4] All variables were aggregated to the estate geography, normalized to 0–1 using a min-max rescaling approach, and adjusted for directionality so that 0 equaled least exposure/vulnerability and 1 equaled greatest exposure/vulnerability. Scores were calculated for each index by taking the mean of its indicators, excluding nulls from the calculation.

The communications infrastructure index included seven indicators: cell service towers, land mobile broadcast towers, internet service access, paging transmission towers, radio broadcast transmission towers, microwave service towers, and TV station transmitters (Figure 5) (U.S. Census Bureau, 2023g; U.S. Department of Homeland Security, 2023). This index highlights the infrastructure needed to support communication activities within a community before, during, and after a natural hazard event (Summers et al., 2020). No modifications were made to this index, and higher values correspond to estates with critical communications infrastructure and increased exposure potential (Figure 6).

Charming architecture details of the USVI. Credit: Seann Regan (CSS Inc./NOAA NCCOS)

[4] Nulls were applied for missing values within the roadway bridge structural and functional assessment ratings, median age of residential housing, non-permanent or mobile residential structures, and housing value. All other missing values were assigned a zero.

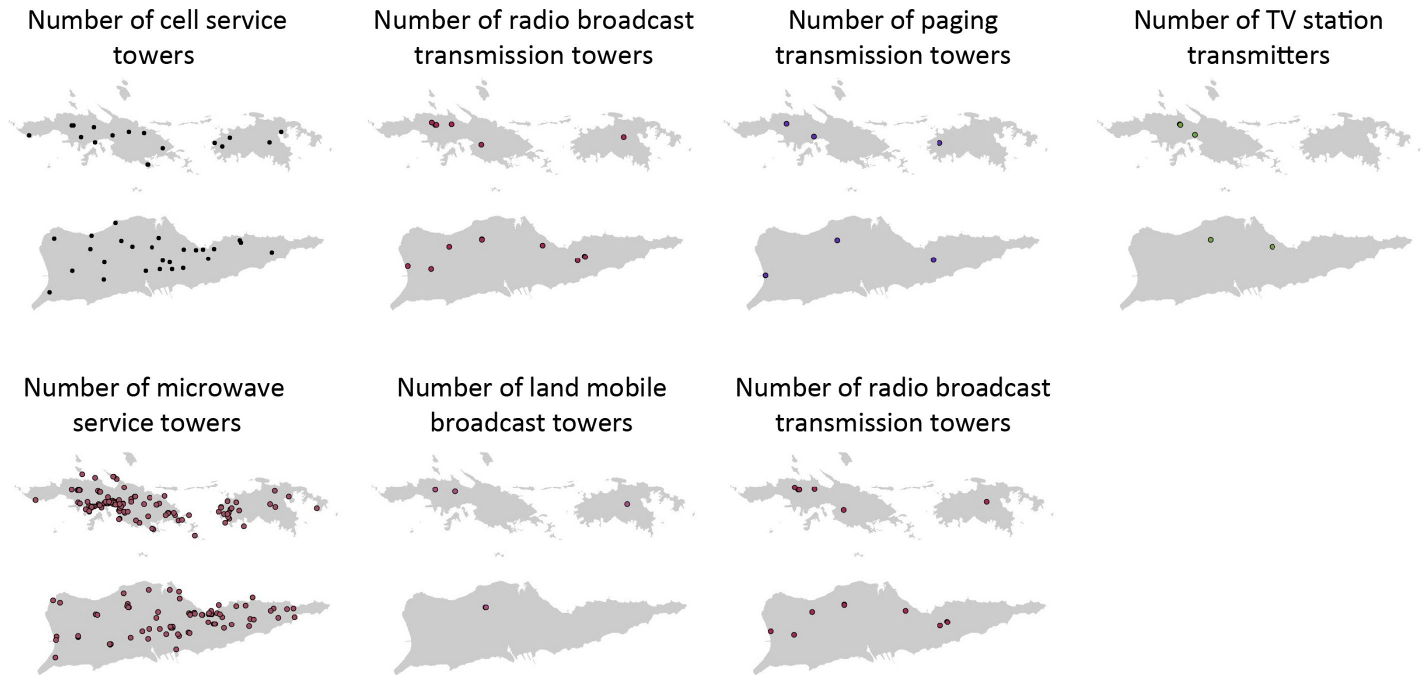

Figure 5. Indicators within the communications infrastructure index.

Figure 6. Communications infrastructure index.

The utilities infrastructure index includes four indicators: public drinking water supply facilities, power generating facilities, wastewater treatment facilities, and waste management sites (landfills and bin sites)[5] (Figure 7) (USVI Hazard Mitigation and Resilience Plan, 2023b). This index highlights the infrastructure needed to manage critical utilities within a community (Summers et al., 2020). Higher values correspond to estates with more critical utilities infrastructure present and increased exposure potential (Figure 8).

The transportation infrastructure index includes 5 indicators: air access points (including airports, helicopter transport, and seaplanes), bridge structures, bridge structural and functional assessment ratings, total miles of urban and rural roads, and ocean access points (including boat ramps, marinas, ports, and ferry terminals)[6] (Figure 9) (Federal Highway Administration, 2023; U.S. Department of Homeland Security, 2023; U.S. Department of Transportation, 2023; USVI Hazard Mitigation and Resilience Plan, 2023b; VInow, n.d.). These metrics highlight resources that support the flow of people, goods, and services (Summers et al., 2020). Higher values correspond to estates with more critical transportation infrastructure and increased exposure potential (Figure 10).

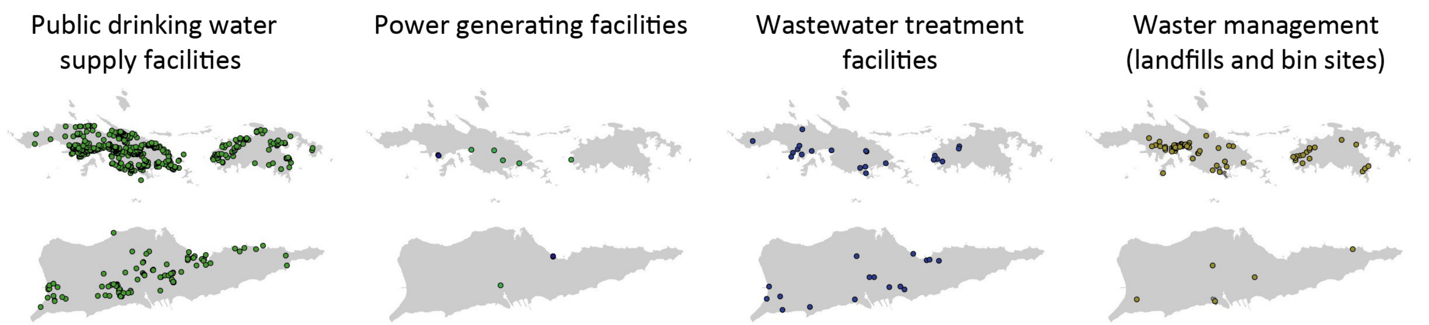

Figure 7. Indicators within the utilities infrastructure index.

Figure 8. Utilities infrastructure index.

[5] Waste management sites were added due to their importance within the territory.

[6] Two indicators were dropped from the original collection (miles of operating freight rails and highway access points) because they were inapplicable to the territory. These were replaced by ocean access points, such as marinas, boat ramps, ports, and ferry terminals.

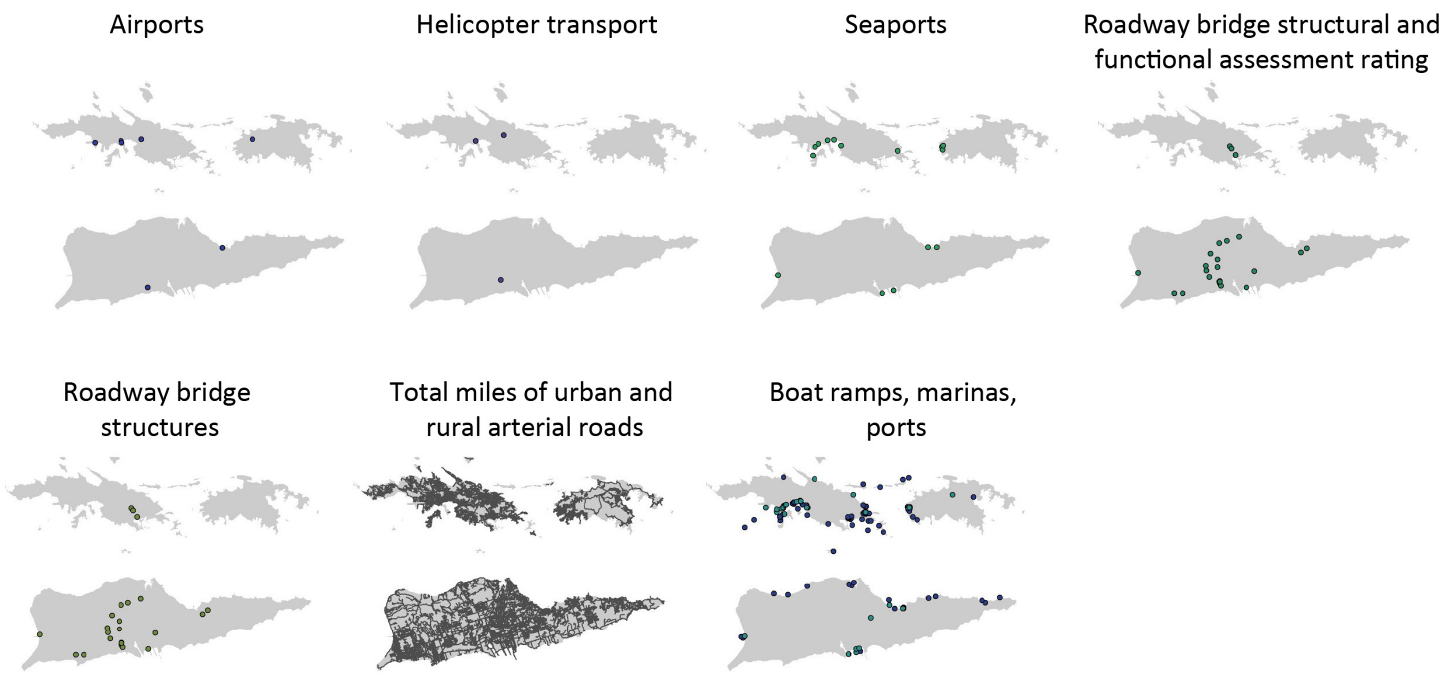

Figure 9. Indicators within the transportation infrastructure index.

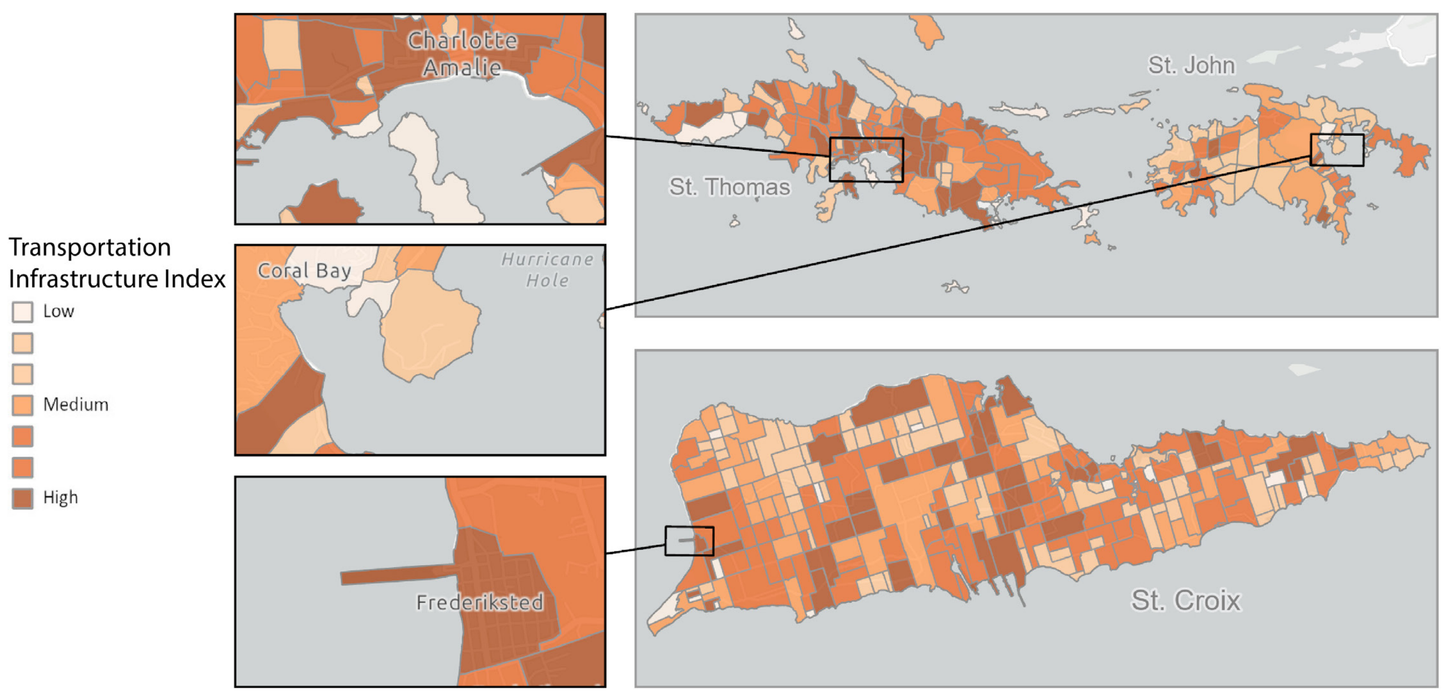

Figure 10. Transportation infrastructure index.

The housing characteristics index includes six indicators: home overcrowding, homes with inadequate plumbing and kitchen facilities[7], median age of residential housing, homes per square mile, non-permanent or mobile residential structures, and median housing value[8] (Figure 11) (U.S. Census Bureau, 2023a, 2023b, 2023c, 2023d, 2023e, 2023f, 2023h). These metrics highlight housing features that contribute to structural vulnerability (Summers et al., 2020). Higher values correspond to estates with more vulnerable housing characteristics (e.g., more overcrowding, less adequate plumbing and kitchen facilities, older buildings, less stable housing types) that lead to increased structural vulnerability potential (Figure 12).

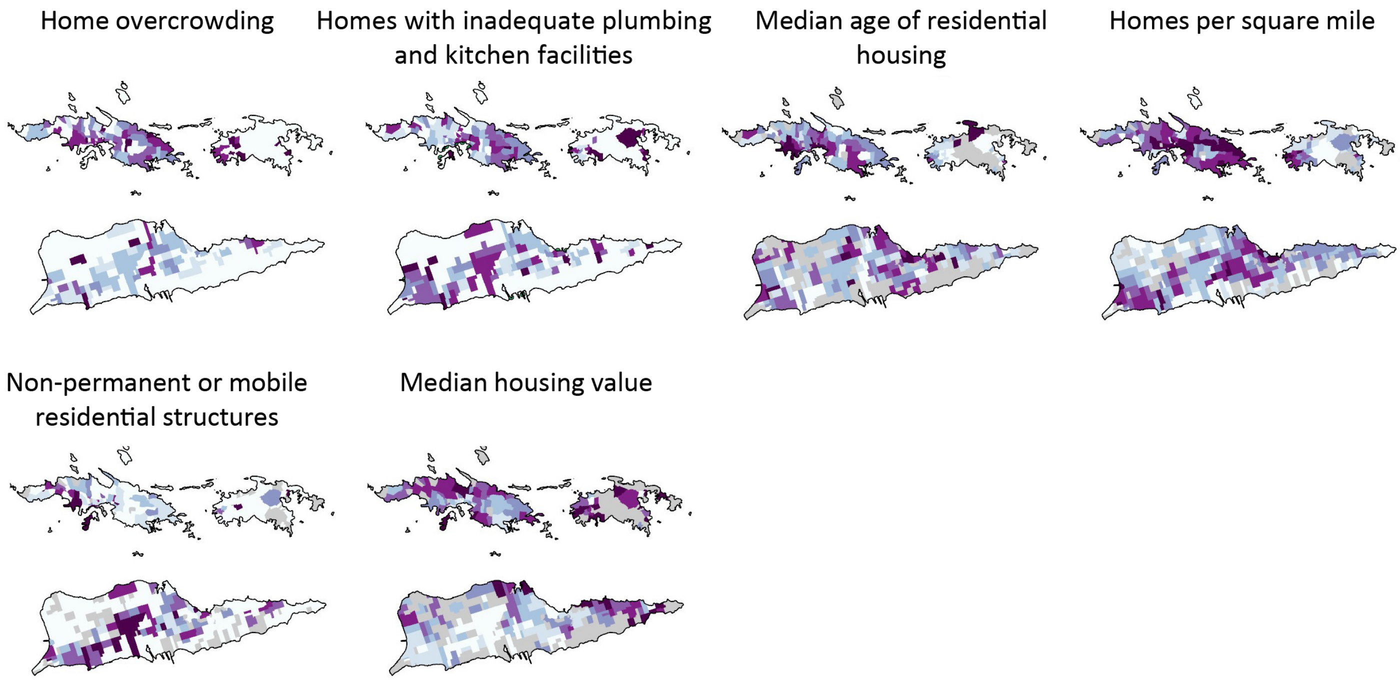

Figure 11. Indicators within the housing characteristics index.

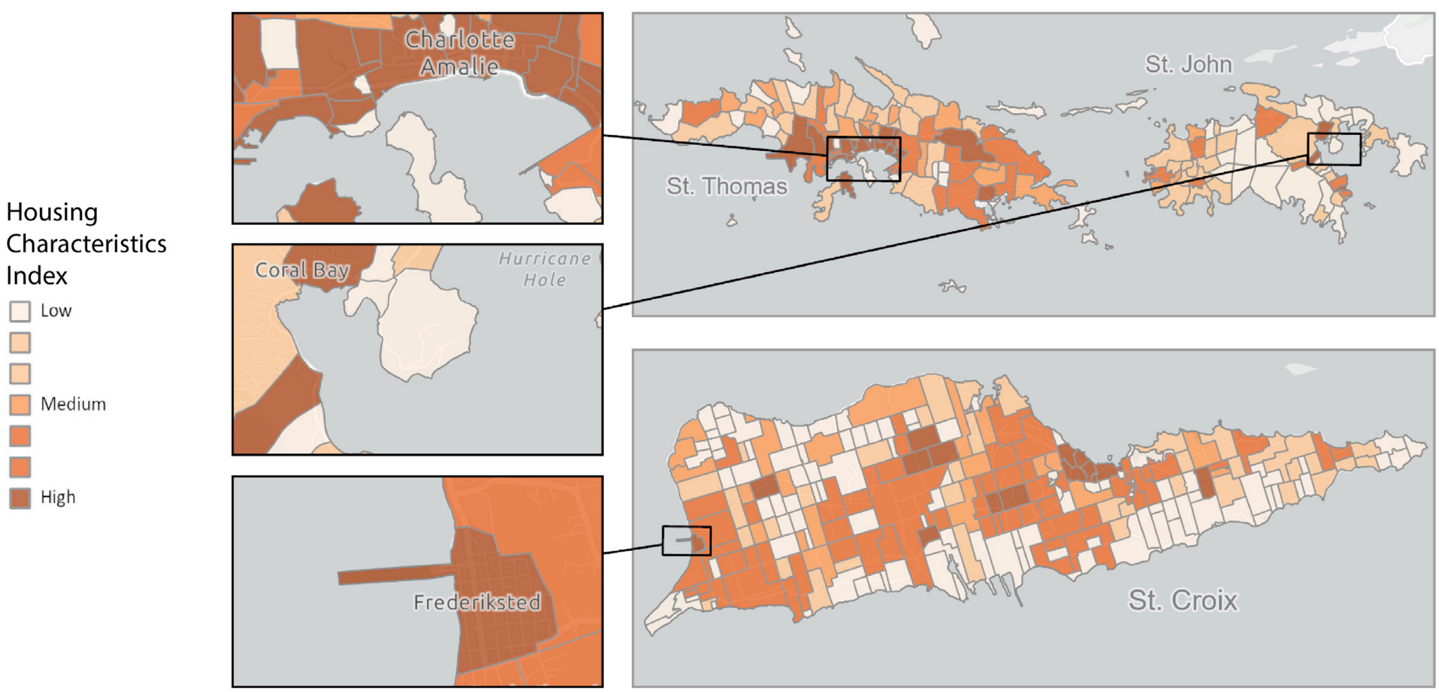

Figure 12. Housing characteristics index.

[7] Inadequate plumbing and kitchen facilities signifies a lack of at least one of the following in the home: hot and cold running water, a bathtub or shower, a sink with a faucet, a stove or range, and a refrigerator (United States Census Bureau (n.d.).

[8] Median housing value was added due to local request and was inverted prior to analysis.

The vacant structures index included three vacancy indicators: vacant residential structures, vacant business structures, and vacant "other" structures (Figure 13) (U.S. Department of Housing and Urban Development, 2020). Occupancy data are collected by the U.S. Postal Service to support an efficient mail delivery system and quantify whether addresses are occupied and require mail service or are vacant and do not. To calculate vacancy metrics, the U.S. Department of Housing and Urban Development considers all residential and business addresses that are recorded by the U.S. Postal Service and marks addresses on urban routes that have not collected their mail for 90 days or longer as vacant (U.S. Department of Housing and Urban Development, 2020). Addresses may also be marked as no-stat for a variety of reasons (e.g., rural route addresses that have been vacant for 90 days or longer, homes under construction, addresses whose residents collect mail at P.O. Boxes instead of through regular delivery) (U.S. Department of Housing and Urban Development, 2020); however, these were omitted from analysis because they are inconsistently monitored and/or not physically located at the house or business. The resulting vacancy variables used in this assessment highlight blighted residential, business, and other structures that are typically more likely to be at risk of hazard impacts due to disrepair from a lack of maintenance and are also more likely to result in danger (e.g., fire, illicit activities) to the surrounding community (Summers et al., 2020). This impact may be amplified after a hazard event when these structures are also less likely to be monitored. Higher values correspond to estates with more vacancy and higher structural vulnerability (Figure 14).

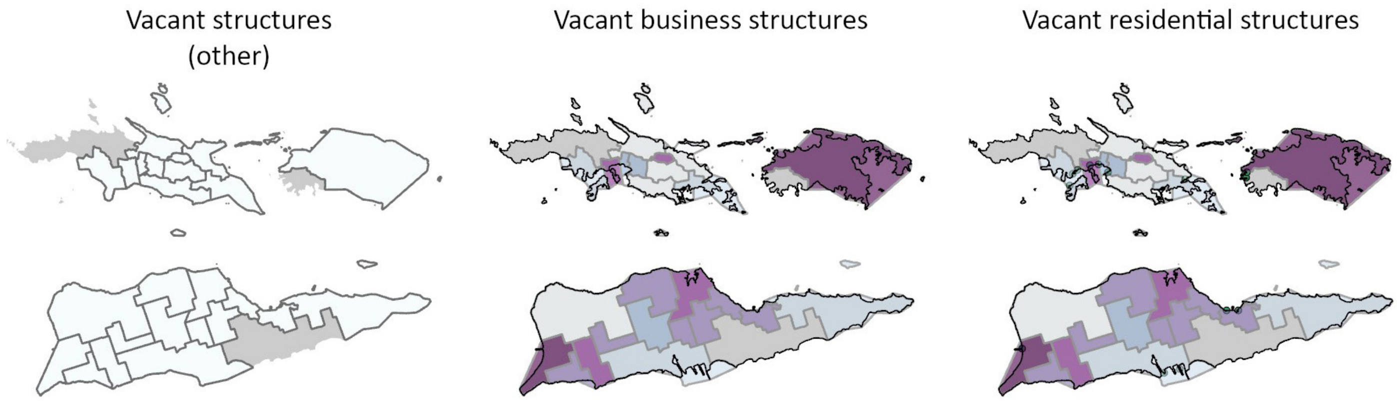

Figure 13. Indicators within the vacant structures index.

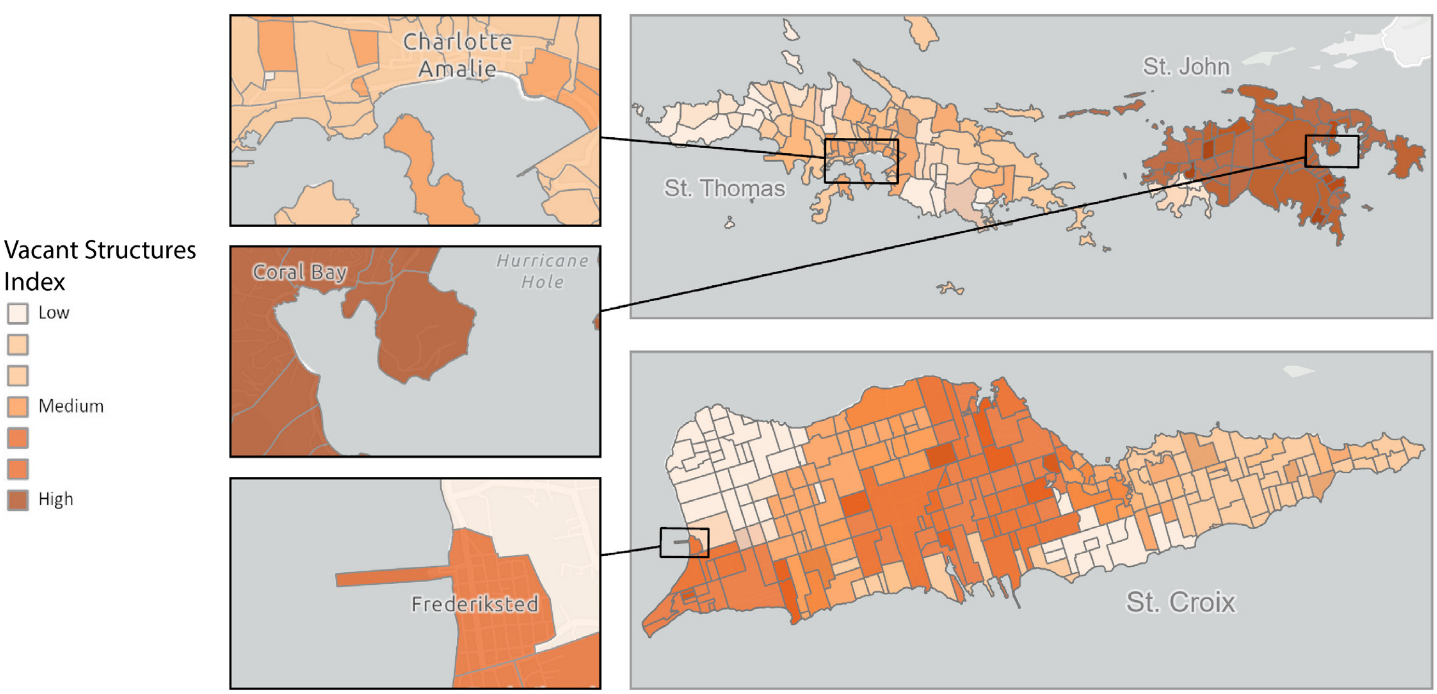

Figure 14. Vacant structures index.

The five built environment structural indices described above were then aggregated to create two final indices of structural exposure and structural vulnerability. The composite structural exposure index (Figure 15) sums the scores of the communications, transportation, and utilities infrastructure sub-indices and highlights areas of greater resilience-supporting infrastructure that may be at risk of damage or loss if impacted by a hazard event. The composite structural vulnerability index (Figure 16) sums the scores of the housing characteristics and vacancy sub-indices and highlights vulnerability of built structures.

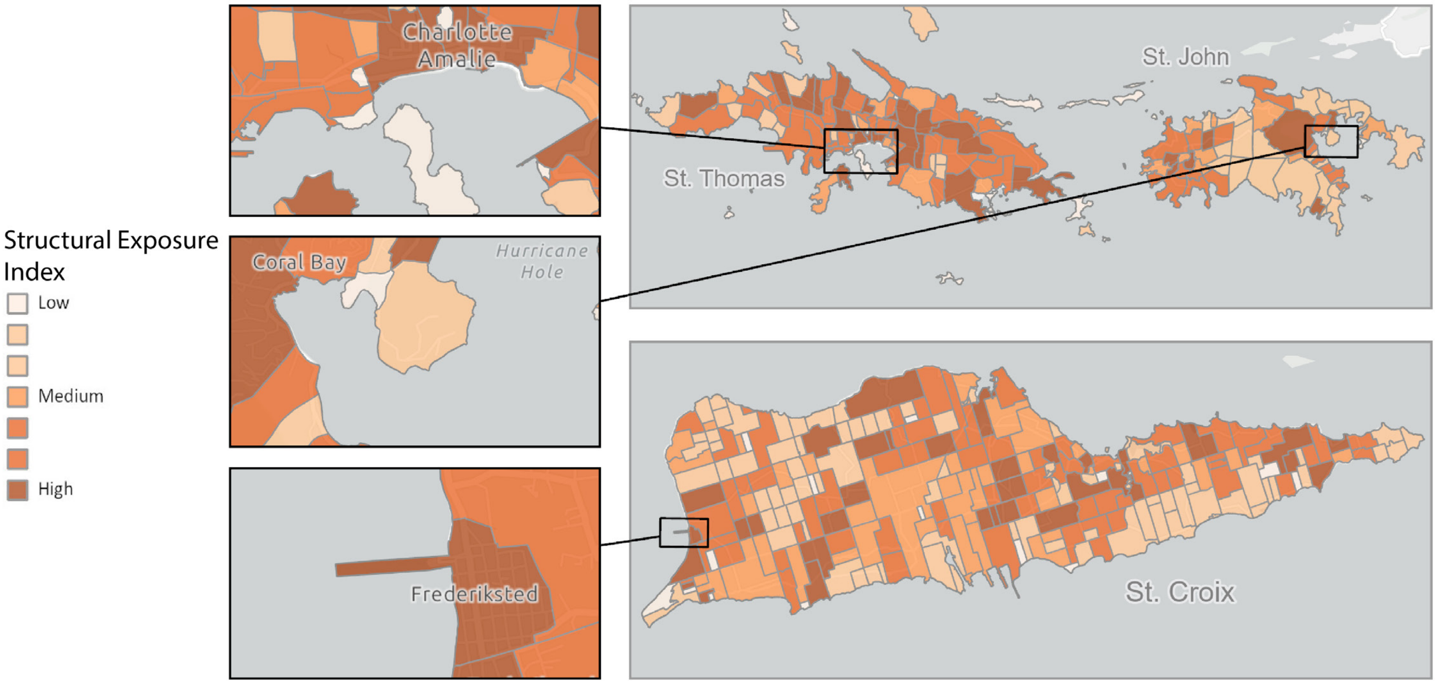

Figure 15. Final structural exposure index.

Figure 16. Final structural vulnerability index.

2.2.2 Marine Environment

Offshore and coastal natural infrastructure has been shown to provide coastal protection, flood attenuation, erosion control, and other hazard mitigation services across a variety of coastal landscapes (Arkema et al., 2013; Narayan et al., 2016; Sutton-Grier et al., 2015, 2018). Around the world, scientists have documented coral reefs' ability to reduce wave energy and provide shoreline protection benefits to nearby communities (Burke and Spalding, 2022; Principe et al., 2012); however, the type and height of reef, distance from shore, interaction with other habitat types, and other factors such as habitat health influence actual protection values (Guannel et al., 2016). Nearshore environments are complex systems that are affected by bathymetry, wave-current interactions, friction, sediment transport, and other geomorphic and hydrological processes (Kirby, 2017; Reguero et al., 2018; Van der Westhuysen, 2012). To incorporate nearshore environments into this assessment's structural vulnerability and exposure components, the research team tested a series of methodological approaches.

In the first attempt, the team adapted methods from Burke and Spalding (2022) to assign distance buffers to all estate boundaries and then assigned each estate a score based on its proximity to benthic habitat types. Some of the output estate scores drew confusion and criticism from local experts, so the team modified their approach to incorporate depth, rugosity, and wave energy dissipation values found in van Zanten et al. (2014). Given prior reviews, the research team expanded their methodological review to experts in wave dissipation, coral restoration, and coral resilience, who further cautioned against the oversimplification of wave energy dissipation values from coral habitats alone. They suggested broadening to overall benthic habitat interactions. Through collaboration within NCCOS (K. Huebert, personal communication, April 2, 2024), orbital bottom velocity was calculated following an approach developed for the NCCOS USVI Coral Reef Prioritization Digital Atlas (NOAA National Centers for Coastal Ocean Science, n.d.), as follows. Significant wave height and wave period were obtained from Caribbean Coastal Ocean Observing System (CARICOOS) Simulating Waves Nearshore (SWAN) simulations for 2012–2021 at 0.01° spatial resolution and 3-hr temporal resolution (CARICOOS, 2022). Model output was averaged by calendar day, then by calendar month, and then across months. The resulting annual mean values were reprojected with linear interpolation to match high-resolution (approximately 10 m) bathymetry grids for St. Thomas/St. John and St Croix. Wavelength was calculated using Hunt's approximation (Coastal Engineering Research Center, 1985), and representative (i.e., root mean square) orbital bottom velocity was calculated with significant wave height limited to 0.78 x bottom depth (due to wave breaking), following Wiberg and Sherwood (2008, Equation 2 and Figure 1). The resulting bottom orbital wave velocity values are shown in Figure 17.

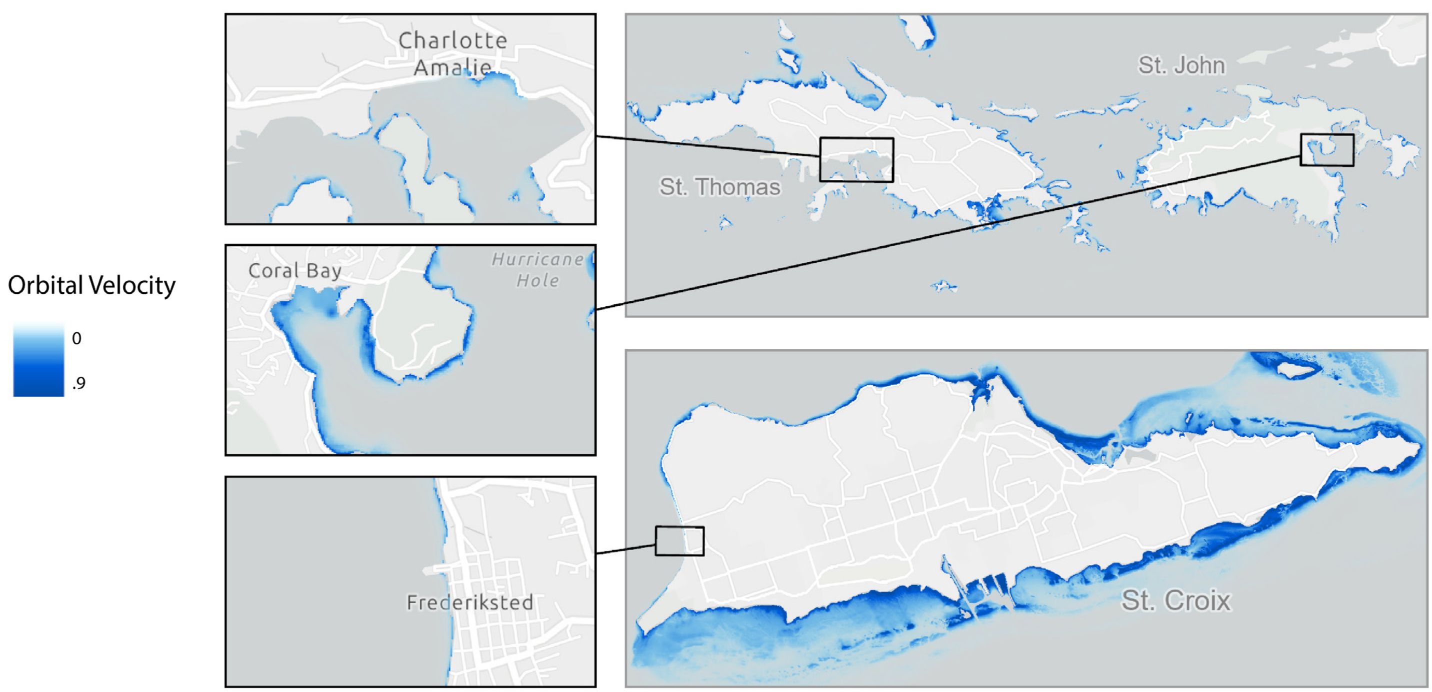

Figure 17. Input data (orbital velocity) to capture nearshore environment impacts.

Coast-adjacent estates were assigned the sum of bottom orbital wave velocity value. Estate values were then normalized and inverted so that higher values corresponded to decreased orbital wave velocity. The resulting index (Figure 18) shows the relative impact of nearshore bathymetric benthic environments on each coastal estate. Areas of darker coral pink have more nearshore environment protection benefits (from lower orbital velocity values), and areas of light sandy tan have fewer nearshore environment protection benefits (from higher orbital velocity values). Though full estates are shown in this figure, the nearshore environment protection benefits are likely concentrated along shoreline areas of each estate.

Figure 18. Final nearshore environment protection benefits index.

2.3 Flood Hazard

This assessment incorporates four categories of flood hazard: sea level rise inundation, storm surge from a Category 3 and Category 5 hurricane, stormwater flooding from precipitation, and a measure of compounded flooding.

2.3.1 Sea Level Rise

The local scenarios within NOAA's Sea Level Rise viewer projects 1.61-ft sea level rise by year 2060 for Lime Tree Bay on St. Croix and 1.64-ft sea level rise by year 2060 for Charlotte Amalie on St. Thomas (NOAA Office for Coastal Management, 2023). In response to these estimates and local requests, the research team rasterized projections of 1- and 2-ft sea level rise (NOAA Office for Coastal Management, 2024) and then attempted to average them to approximate 1.6 ft; however, this yielded errors because the differences between the two projections were too similar (i.e., they overlapped or were a single pixel apart). As a result, this assessment used the 2-ft projection as this was closest to the desired inundation level. Figure 19 shows this projection but with an amplified line thickness in order to see the inundation areas at the presented resolution.

Figure 19. Projected 2 ft of sea level rise.

2.3.2 Storm Surge

Storm surge is modeled by NOAA's National Hurricane Center using the Maximum of the Maximum Envelope of High Water (MOM), which estimates the worst-case storm scenario using forward speed, trajectory, and initial tide level (NOAA National Hurricane Center, n.d.-c). The MOM models are combined into basin-wide storm surge estimates as part of the Sea, Lake, and Overland Surges from Hurricane (SLOSH) model, which incorporates location-specific geography such as shoreline, bay, and river configurations, water depths, bridges, roads, levees, and other physical infrastructure (NOAA National Hurricane Center, n.d.-b). During stakeholder prioritization conversations, Category 3 and Category 5 hurricanes were chosen as priority storm strengths for this assessment. Figure 20 and Figure 21 show storm surge modeling from Category 3 and Category 5 hurricanes for the territory.

2.3.3 Stormwater Flooding

Though rain-induced flood modeling efforts were recently completed for the territory (RMSI, 2021), the research team was unable to obtain these data. To provide an alternative dataset for public use, this assessment identified areas of potential stormwater flooding hazard through application of the "FIGUSED" methodology (Kazakis et al., 2015). This methodology incorporates seven indicators commonly used to identify areas of high flood potential, including: "F" – flow accumulation, "I" – rainfall intensity, "G" – geology (hydrologic soil groups), "U" – land use, "S" – slope, "E" – elevation, and "D" – distance from the drainage network. For each of these indicators, a value of 1 corresponds to higher flood potential, while values closer to zero (or null) correspond to lower flood potential.

Pedestrian bridge over drainage ghut, Christiansted, St. Croix. Credit: Chloe Fleming (CSS Inc/NOAA NCCOS)

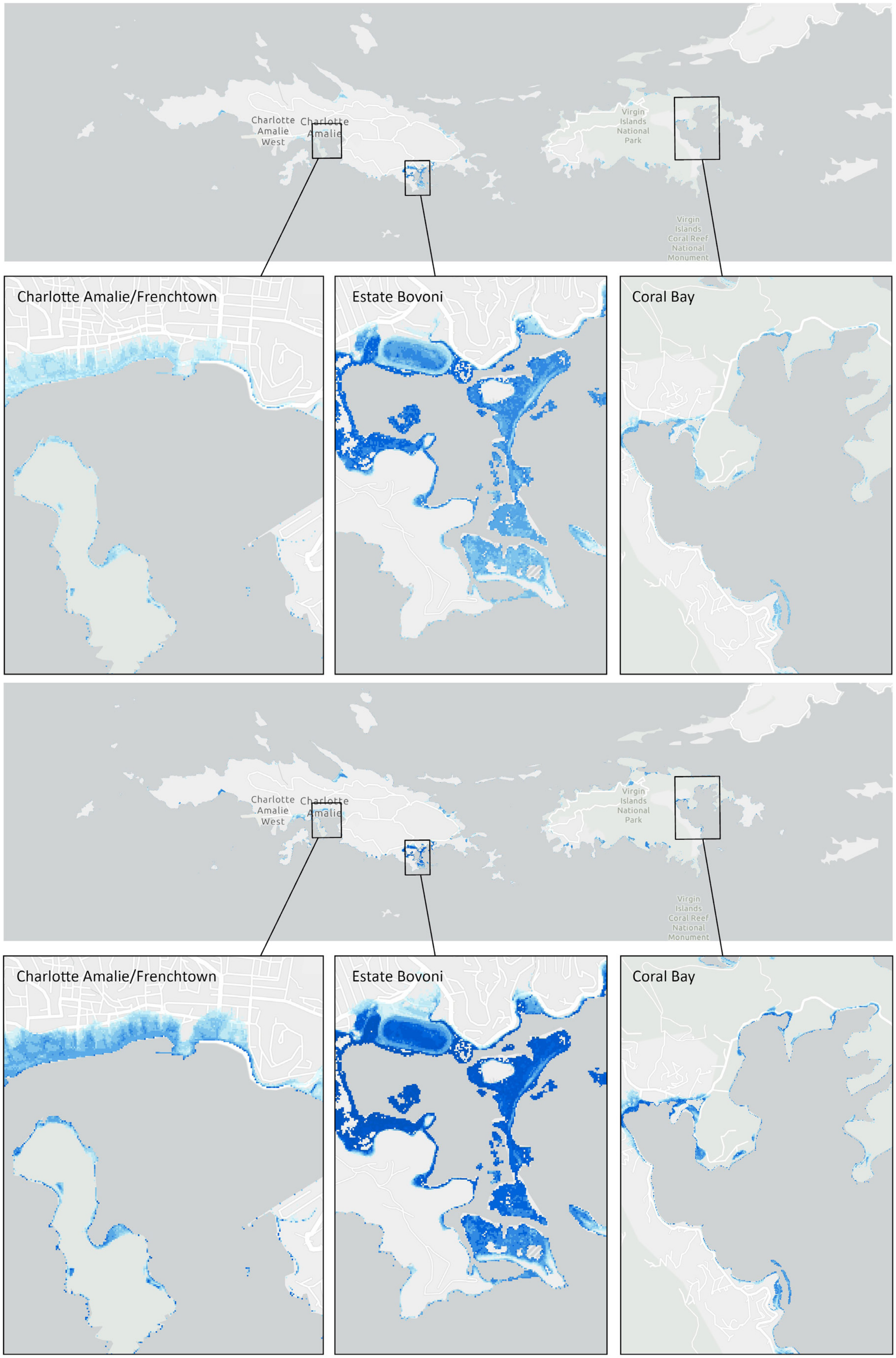

Figure 20. Projected Category 3 (top) and Category 5 (bottom) storm surge for St. Thomas and St. John.

Figure 21. Projected Category 3 (top) and Category 5 (bottom) storm surge for St. Croix.

Flow accumulation is a quantitative measure used to delineate a drainage area (Jenson and Domingue, 1988). Each grid cell of a digital elevation model (DEM) is assigned a value based on the number of cells identified as flowing into that particular cell. A flow accumulation raster was created for the USVI first by filling sinks, or imperfections, in the data, and then calculating the flow direction of a 10 × 10 m resolution DEM (NOAA National Geophysical Data Center, 2010). The resulting flow accumulation raster was normalized from 0 to 1, with higher values indicating drainage areas with higher flow accumulation (Figure 22).

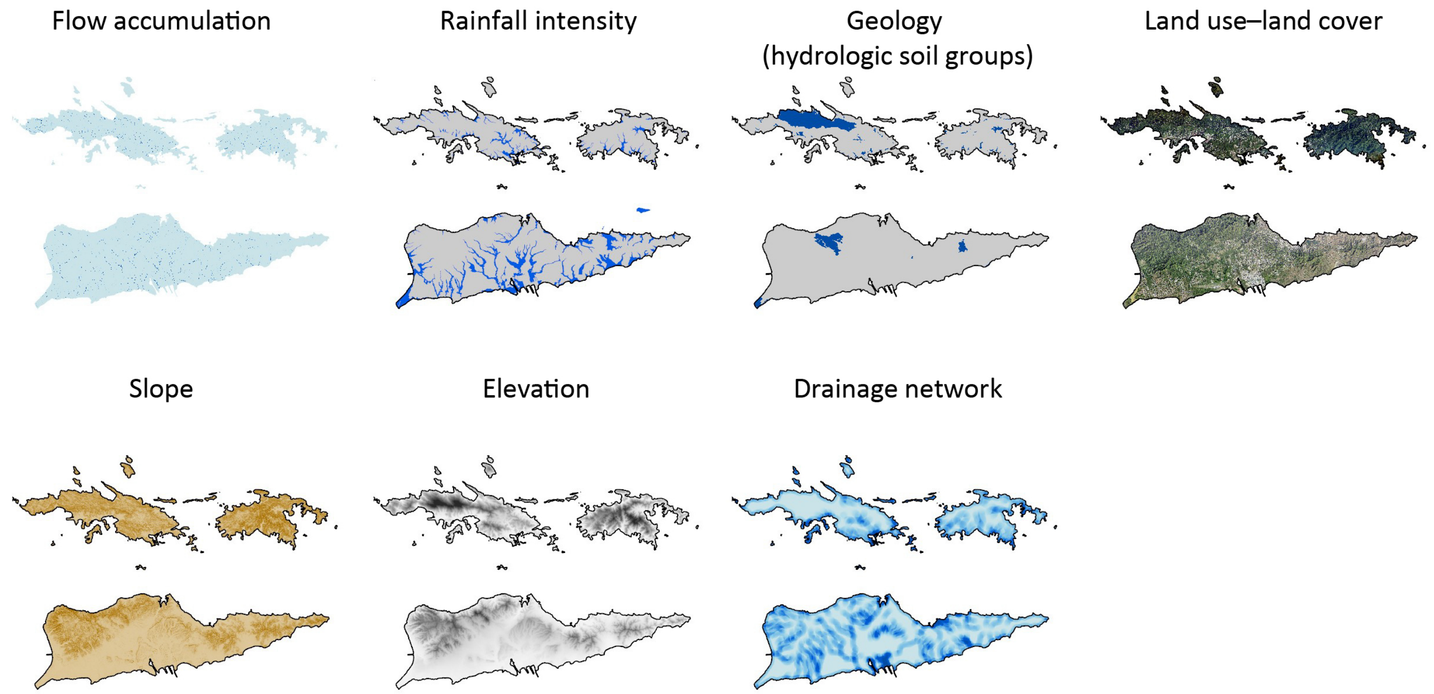

Figure 22. FIGUSED indicators within the stormwater flooding hazard index.

Rainfall intensity is a measure of the amount of rain fallen within a given amount of time, and at peak values, can be indicative of a high runoff rate (Conkle et al., 2006). A 1% annual precipitation-based flood layer developed by Dewberry (USVI Hazard Mitigation and Resilience Plan, 2023a)[9] was rasterized, and areas within the flood hazard zone were assigned a value of 1, while areas outside this zone were assigned a null value (Figure 22).

Hydrologic soils groups are defined by the U.S. Department of Agriculture as categorizations of soils according to their permeability and runoff potential (National Resources Conservation Service Soil Survey Staff, 2023). There are four major hydrologic soil groups (Group A, Group B, Group C, and Group D) and three dual hydrologic groups (A/D, B/D, and C/D). Groups C and D represent soils, such as clays, that have a lower permeability and thus higher runoff potential than that of Groups A and B. Dual groupings are determined based on the presence and depth of the water table, and primarily represent wet soils that may potentially fall within Group D but are contingent on precipitation conditions. Using data from the U.S. Department of Agriculture Soil Surveys (National Resources Conservation Service Soil Survey Staff, 2023), survey areas with soil hydrologic groups A and B were assigned a value of 0, while areas with groups C, D, A/D, B/D, and C/D and those void of data were assigned a value of 1 (Figure 22).

Land cover data developed by the Coastal Change Analysis Program (NOAA Office for Coastal Management, 2015) were reclassified from their original 21 classes to a scale of 0–1 to reflect variation in land cover types (Table 2), with more flood-prone or commonly wetland cover types assigned values closer to 1 (Figure 22).

[9] A 1% annual precipitation-based flood layer is the same as a 1% likelihood of a rainfall event of a given intensity occurring within any given year, also known as a 100-year flood (U.S. Geological Survey, 2018).

Areas with flatter slopes and low elevations are more likely to experience flooding due to slower drainage and higher water tables (Fleming et al., 2017). Elevation data were normalized inversely from 0 to 1, with lower elevations assigned higher values closer to 1. A slope grid was created from the same U.S. Geological Survey DEM used to derive the elevation and flow accumulation index parameters. The slope grid was reclassified inversely from 0 to 1 following the classes per the FIGUSED methodology (Kazakis et al., 2015) where steep slopes (greater than 35%) were reclassified to a value of 0.2, and flatter slopes were reclassified to values closer to 1 (Table 3) (Figure 22).

Lastly, using the theory that areas closer to drainage sources will be more likely to flood (Kazakis et al., 2015), a drainage-network density grid was created from National Hydrology Dataset flowline data (USGS National Hydrography, 2010) to identify areas with a higher prevalence of rivers, streams, and drainage sources. This was then normalized from 0 to 1, with higher values corresponding to areas with a higher density of drainage networks (Figure 22).

Table 2. Landcover types, classifications, and reclassification values.

Landcover type	Classification	Reclass value
Background	0	Ignore
Impervious	2	1
Palustrine Forested Wetland	13	1
Palustrine Scrub/Shrub Wetland	14	1
Palustrine Emergent Wetland	15	1
Estuarine Forested Wetland	16	1
Estuarine Scrub/Shrub Wetland	17	1
Estuarine Emergent Wetland	18	1
Open Water	21	1
Palustrine Aquatic Bed	22	1
Unconsolidated Shore	19	0.8
Bare Land	20	0.8
Cultivated Crops	6	0.6
Pasture/Hay	7	0.6
Developed, Open Space	3, 4, 5	0.5
Grassland/Herbaceous	8	0.4
Deciduous Forest	9	0.2
Evergreen Forest	10	0.2
Mixed Forest	11	0.2
Scrub/Shrub	12	0.2

Together, the above seven FIGUSED indicators were combined in an additive index, where each variable was equally weighted (Figure 23). The final index values range from 0 to 7, with higher values indicating areas with a higher likelihood of stormwater flooding. These values were normalized 0–1 when aggregated to the estate-level geographies.

Table 3. Slope values, percents, and reclassification values.

Slope degree	Slope percent	Reclassified value
0.00–1.15	0–2	1.0
1.15–2.86	2–5	0.8
2.86–8.53	5–15	0.6
8.53–19.29	15–35	0.4
19.29–81.98	>35	0.2

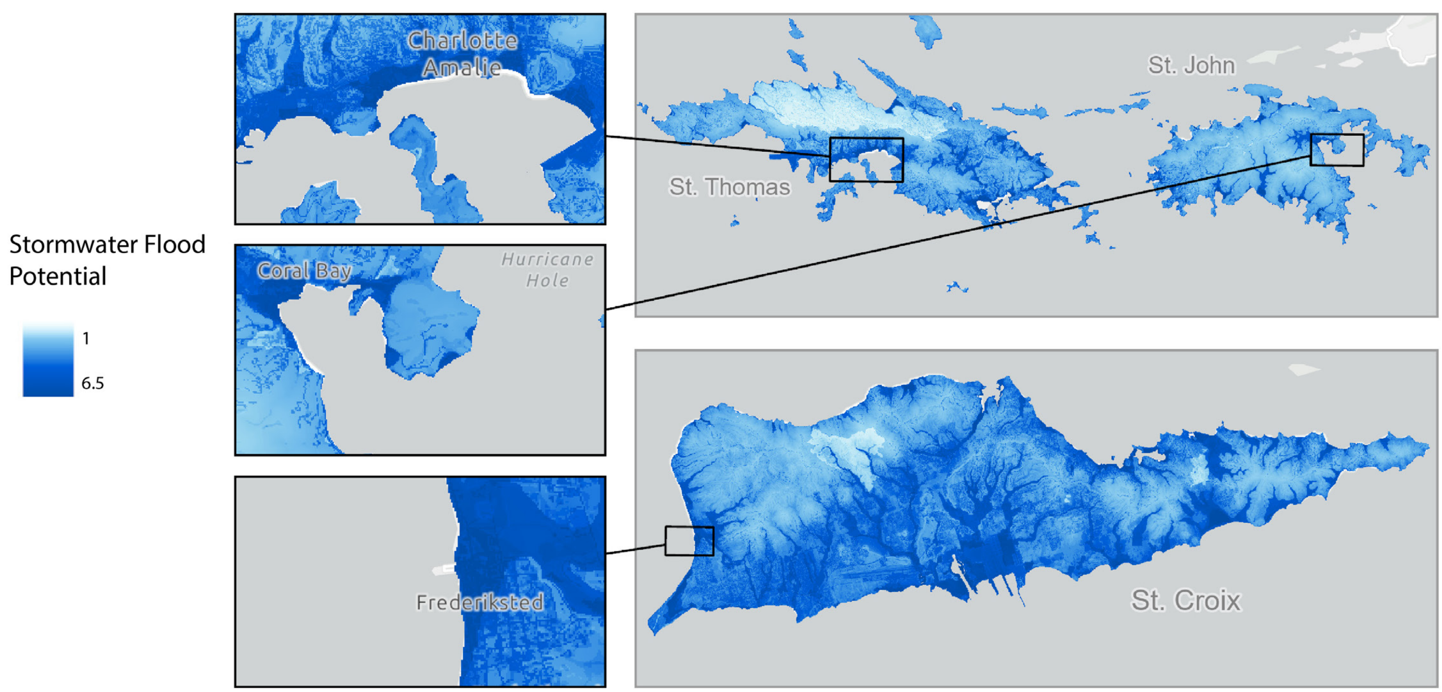

Figure 23. Final stormwater flooding hazard index.

2.3.4 Compounded Flooding

Compounded flooding captures the impacts of simultaneous flooding or consecutive hazard events. In response to partner and stakeholder needs, two representative compounded flooding scenarios were developed: (1) near-term-moderate compounded flooding (current sea level with additive stormwater flooding potential and Category 3 storm surge) and (2) projected-high compounded flooding (additive projected sea level rise, stormwater flooding potential, Category 5 storm surge) (Figure 24). These two compounded flooding scenarios were then aggregated to the estate by taking the mean value of each estate and renormalizing from 0 to 1. For estates with null values, the mean was assigned as zero because there were no contributing variables from the combined flood hazard layers. When aggregated to estates, the visual differences between the two resulting indices were minimal (i.e., low to high delineations were nearly identical), so the projected-high compounded flooding scenario was used as the final compounded flooding index for this assessment (Figure 25).

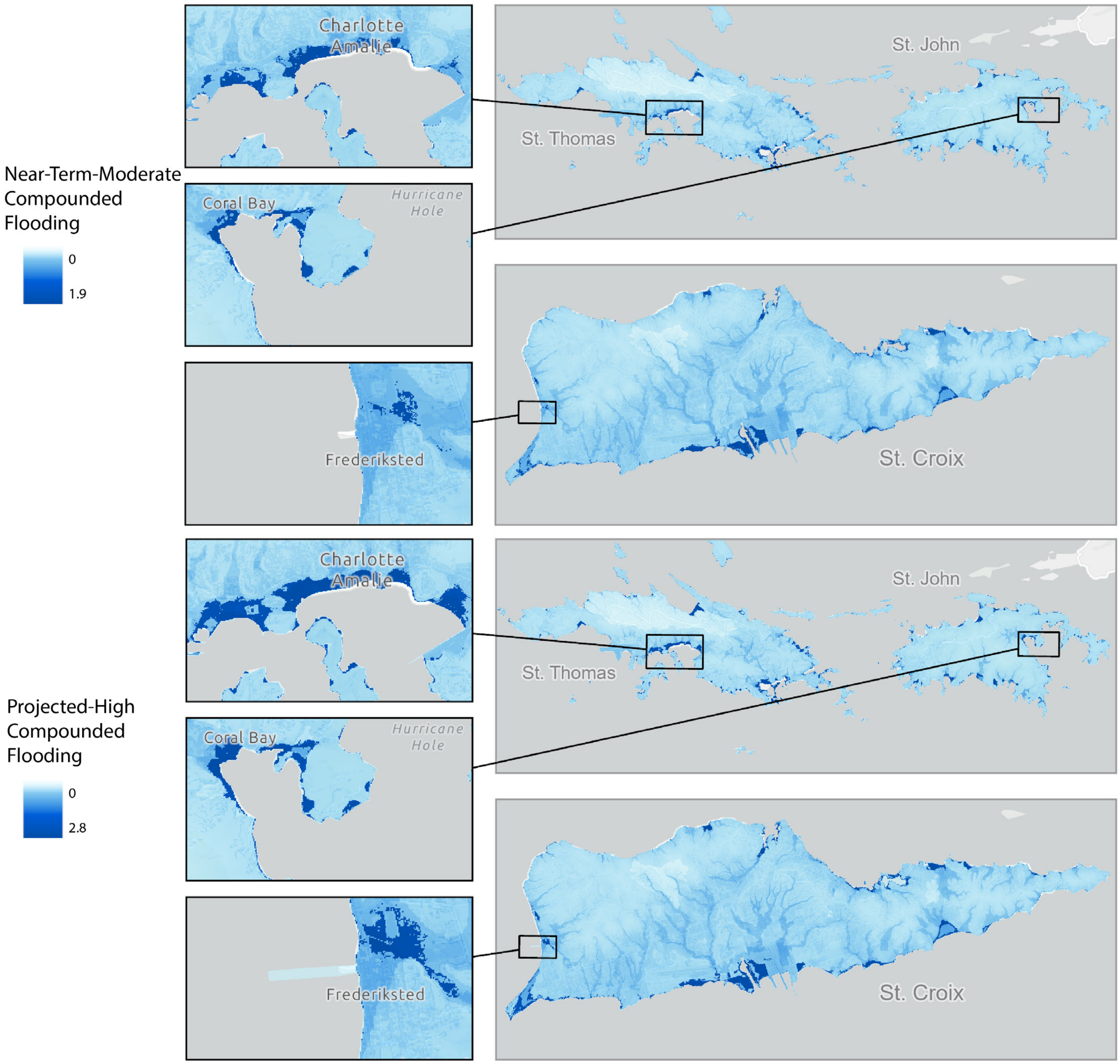

Figure 24. Near-term-moderate compounded flooding (top) and projected-high compounded flooding (bottom) scenarios.

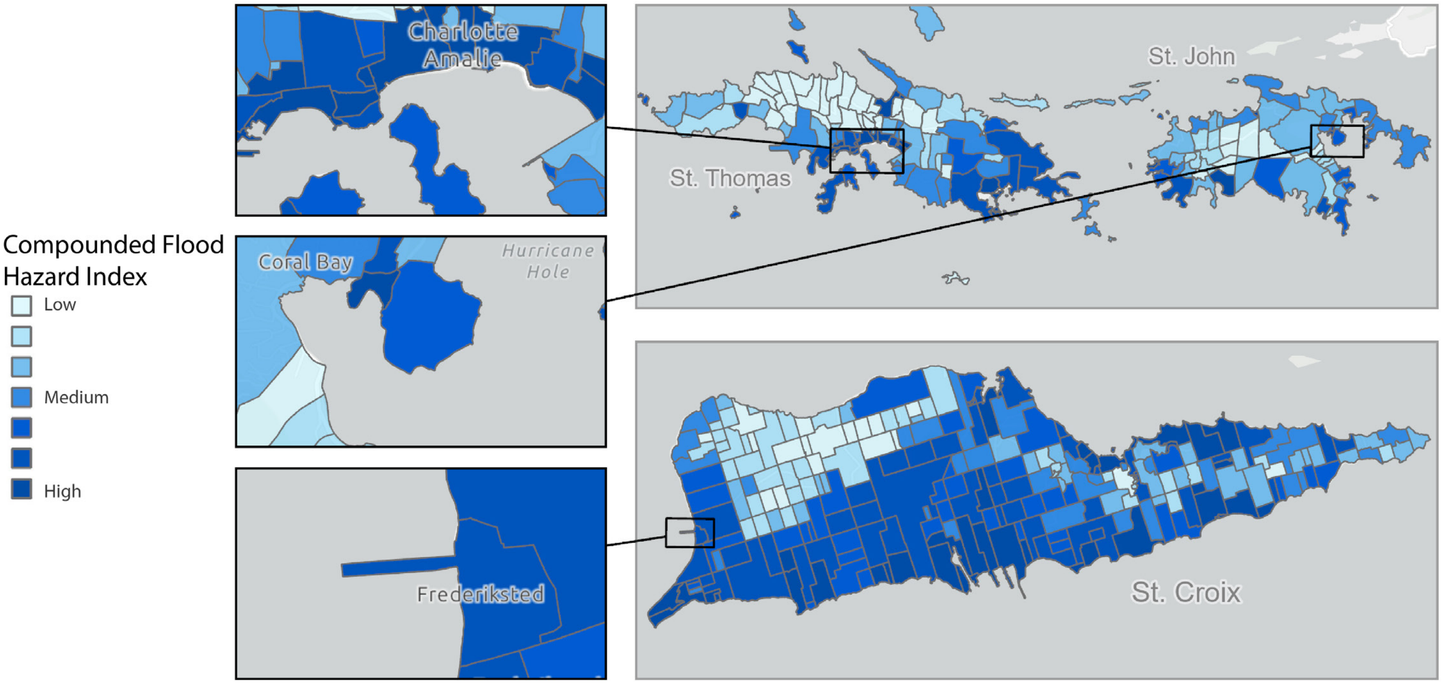

Figure 25. Final compounded flooding index.

To accomplish these compounded flooding scenarios, some assumptions were made. First, this additive index does not reflect hydrological modeling or incorporate sediment transfer or other flow modeling. As a result, the compounded flood hazard index serves as a proxy for true combined flooding. Second, compounded sea level rise scenarios used present-day estimates for stormwater flooding and storm surge, and these do not account for potential future land use changes (e.g., coastal development, erosion) or hydrologic water flows (e.g., how storm surge patterns may change with higher sea levels). Despite these limitations, this index still emphasizes areas of the territory that are more or less likely to encounter coastal and stormwater flooding through increased flood hazard potential.

2.4 Toxins and Contaminants: Waterborne

Human exposure to toxins and contaminants is often complex with a variety of sources, including both point source and nonpoint source (McHale et al., 2018). These sources and their impacts vary temporally and geographically and are often compounded. While the category of toxins and contaminants broadly contains many potential components (e.g., waterborne, airborne, vector borne), this assessment focused on waterborne measures to best align with team capacity and local priorities. Monitoring contaminants of emerging concern is notoriously difficult due to the frequency of new types of chemicals and the cost associated with screening for a large number of potential contaminants (Maruya et al., 2016). These difficulties are amplified for the present assessment that requires highly spatially resolute data across the entire territory, a broad geography for consistent monitoring efforts. As a result, the research team assessed the list of toxin and contaminant measures identified during project scoping against available datasets, selected indicators, and then developed a spatial index of waterborne toxins and contaminants as well as non-index supporting metrics.

The waterborne toxins and contaminants index included six indicators: wastewater stations, drinking water violations, discharge facilities, landfills, bin sites, and industrial zones. For each of these indicators, variables were aggregated to the estate geography and normalized to 0–1 using a min-max rescaling approach before additively creating overall index values.

Wastewater treatment stations were included because they are known sources of pollution of nitrogen, phosphorus, and any contaminants that can escape the treatment process at that facility (Environmental Protection Agency, 2023a). They are registered as potential polluters in the National Pollutant Discharge Elimination System permit program under the Clean Water Act (1972), administered by the EPA, and are therefore considered a point source of pollution. Management and technological interventions can largely impact a facility's effluent water retention, so actual contaminant burden near these discharge sites combines both distance from the discharge and efficacy of the treatment system (Carey and Migliaccio, 2009). Without data on efficacy, this indicator assumes equal exposures by each permitted facility and was calculated by summing the count of wastewater stations per estate (Figure 26).

Solid waste stations such landfills, incineration stations, and transfer stations are also known point sources of pollution leaching from the solid waste and sometimes escaping control technologies employed (Youcai, 2018). In the USVI, landfills and bin sites are employed for a territory-wide solid waste management system through the Virgin Islands Waste Management Authority, though some industry sites have their own solid waste disposal mechanisms. For the landfills indicator, the research team calculated the area of landfill per each estate (Figure 26) (USVI Hazard Mitigation and Resilience Plan, 2023b). For bin sites, total capacity within each estate was calculated based on the volume estimates provided in the bin site dataset (USVI Hazard Mitigation and Resilience Plan, 2023b), assuming standard dumpster sizes (Figure 26). Bin sites located within landfills or proposed sites were left as nulls and did not count towards estate aggregation.

Oil in water along dock, Christiansted, St. Croix. Credit: Chloe Fleming (CSS Inc./NOAA NCCOS)

Industrial zones are also potential sources of effluents, depending on the operation and materials handled (Bullard, 1996). The territorial status of the Virgin Islands makes it especially vulnerable to slipping between regulatory jurisdictions and allowing contamination from industry and military operations to proliferate (Thomson and Samuels-Jones, 2022). For this indicator, the research team calculated the percent of each estate zoned as either light or heavy industrial (Figure 26). The Department of Planning and Natural Resources dataset (ArcGIS Living Atlas, 2024) names specific business types that can operate in each of the areas classified as industrial per Virgin Islands code (Virgin Islands Zoning and Subdivision Law, 2019).

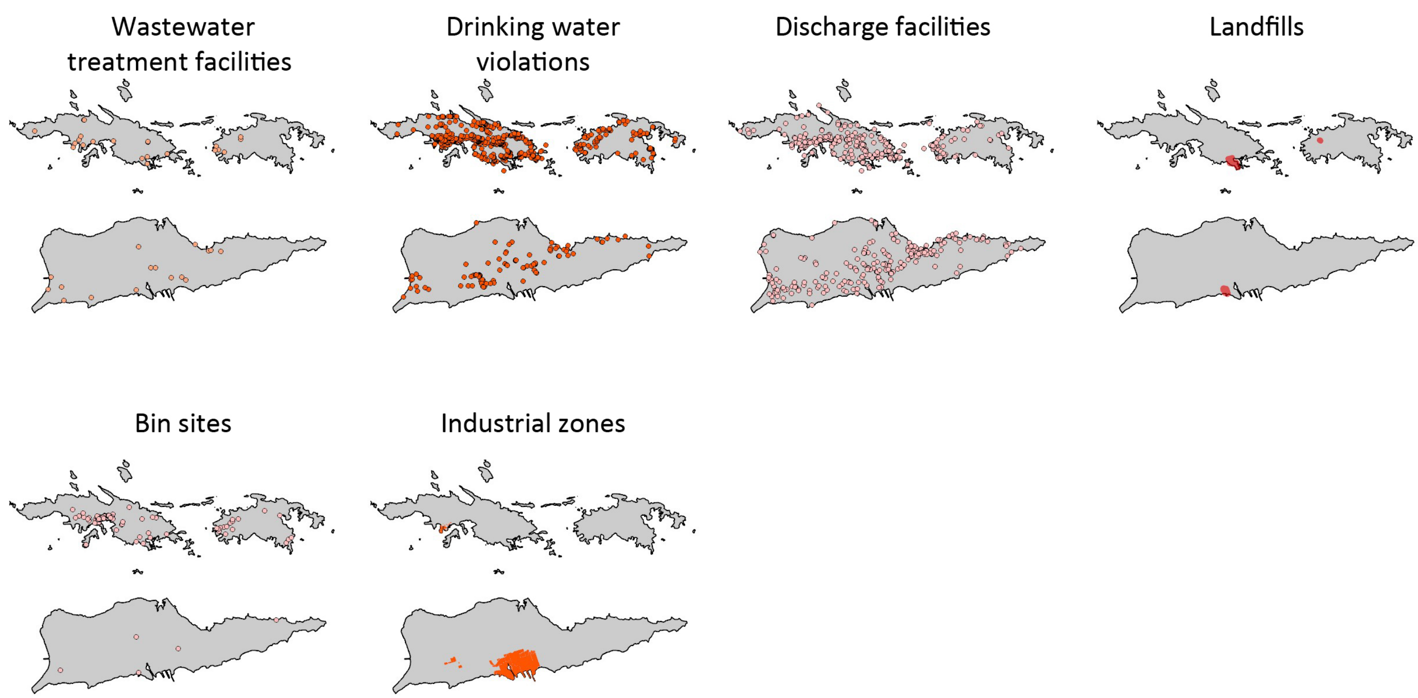

Figure 26. Indicators within the waterborne toxins and contaminants index.

To incorporate drinking water violations, the research team incorporated quarterly reports by the EPA's Safe Drinking Water Information System (SDWIS) database that summarize drinking water violations of registered water supplies (Environmental Protection Agency, 2024c). Despite cisterns' potential for carrying contaminants (e.g., Rao et al., 2022), cisterns are often privately owned, not monitored, and therefore excluded from this database. Quarterly SDWIS reports (Environmental Protection Agency, 2022) were joined to the drinking water supply geospatial layer (described in the structural vulnerability index) by the PWS ID column, and those with a status of "Active" but not listed on the violations report were assigned a value of zero. Data from all four quarters of 2022 were averaged to generate an annual number of violations reported across all monitored drinking water sources per estate (Figure 26). The number of violations was stable throughout the year for the majority of monitoring sites, indicating continuing issues that had not been addressed. Had there been more quarterly variation, a sum of violations for the year may have been more appropriate.

Lastly, facilities registered in the EPA's Federal Reporting Service under one of several water-based contaminant management laws were incorporated as potential sources of water-based pollutants. These laws include the Small Business Liability Relief and Brownfields Revitalization Act (2002); the Federal Insecticide, Fungicide, and Rodenticide Act (1996); the Toxic Substances Control Act (1976) as amended by the Frank R. Lautenberg Chemical Safety for the 21st Century Act (2016); the Resource Conservation and Recovery Act (1976); as well as the Toxic Release Inventory Program under Section 313 of the Emergency Planning and Community Right-to-Know Act (1986) and the Integrated Compliance Information System–National Pollutant Discharge Elimination System permit program under the Clean Water Act (1972). These facilities serve as potential sources of drinking water contaminants if in proximity to drinking water supplies. To account for this risk, the count of EPA-registered facilities per estate was calculated (Figure 26).

All six waterborne toxins and contaminants indicators summarized in Figure 26 were renormalized to 0 to 1 using a min-max scaling approach and then combined into an additive index (Figure 27).

In addition to the final waterborne toxins and contaminants index, four supporting metrics were assessed and incorporated contextually: hazardous household waste, electronics waste, coastal contaminants, and sargassum. These metrics either had spatial data but were inaccessible to the research team, or were accessible but lacked spatial data or had limited spatial extent (i.e., only covered parts of the territory.)

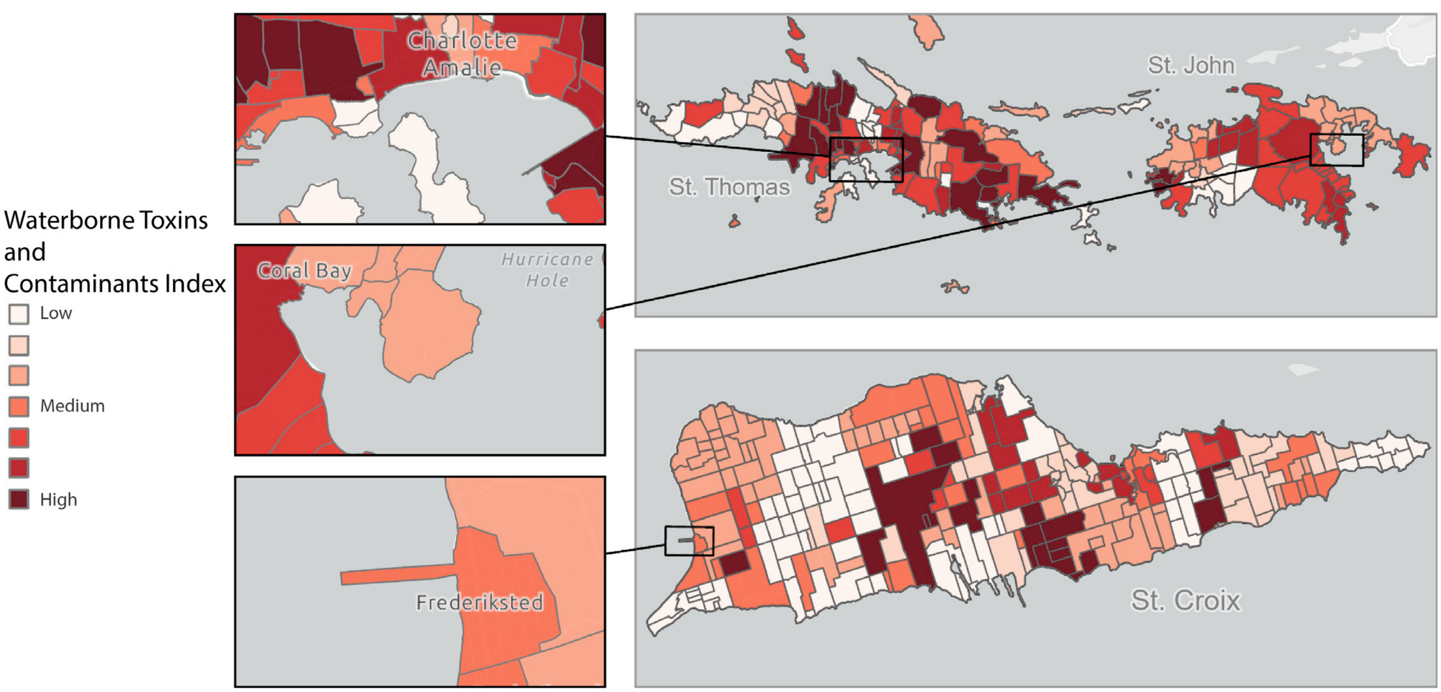

Figure 27. Final waterborne toxins and contaminants index.

Hazardous household waste and its management is a concern for the territory, but this issue isn't well studied. Anecdotal evidence suggests that residents likely collect and store hazardous waste materials (e.g., paint cans, cleaning supplies, batteries) at home until an opportunity for collection arises, or else dispose of hazardous waste alon with other waste headed for landfills (T. Kelley, personal communication, May 18, 2023). In support of this theory, devastation from Hurricane Maria in 2017 brought household hazardous waste to the forefront as part of the response and recovery planning efforts. In respnse, the EPA organized hazardous household waste pickups and transported it to treatment facilities in Florida (Z. Bain, peronal communication, October 2023). After that program ended, the Virgin Islands Waste Management Authority continued pickups at their major transfer stations and landfills (Virgin Islands Waste Management Authority, n.d.), but capacity is already strained in the territory, and hazardous waste collection has been rumored to be inconsistent as the Virgin Islands Waste Management Authority directs its available resources at more pressing matters (Virgin Islands Waste Management Authority communications team, personal communication, October 31, 2023).

Additionally, larger household waste items, such as appliances, vehicles, and car parts, can commonly be observed disposed of and abandoned throughout the territory (Figure 28). These large items contain various chemical waste that can leach into the surrounding environment and downstream, in addition to blocking ghut systems (Gardner, 2008). Without systematic geographic data on this distributed system, the best available way to incorporate these measures indirectly is through linked systems: landfills, bin sites, and water supply contaminants.

Figure 28. Examples of abandoned household waste. Credit: Sean Regan (CSS Inc./NOAA NCCOS)

A subcomponent of household hazardous waste is electronic waste or e-waste. As of November 2023, the Virgin Islands Waste Management Authority reports e-waste collection at their Mandahl facility on St. Thomas (Virgin Islands Waste Management Authority, 2023),[10] suggesting that at least some territory e-waste can be captured via the landfills indicator (Figure 26). Another approach is to consider electronics imports from the continental U.S. as this is the main source of electronics for the territory. Electronics imports often replace older models, which are likely disposed or discarded, and will also likely enter the waste stream themselves when eventually replaced by newer models in the future. These data can therefore serve as a contextual proxy to understand e-waste trends within the territory, despite lacking spatial data. For example, Figure 29 shows that 22,367 smartphones, 3,286 modems, 5,269 headphones, and 8,966 digital televisions were imported to the territory in 2022 (U.S. Census Bureau, 2023i, p. 345).

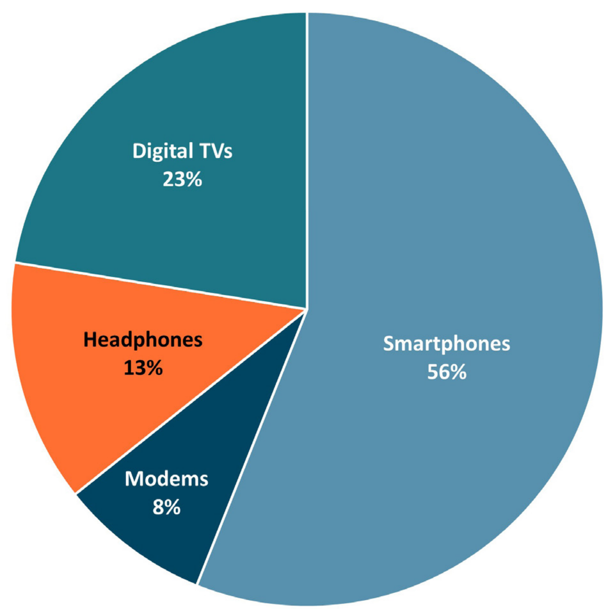

Figure 29. 2022 U.S. electronics imports to the USVI.

[10] Note that as of 20 June 2024, this information is no longer displayed on the Authority's webpage.

Since land-originating contaminants eventually find their way into the coastal zone, one of the best ways to measure the cumulative stresses of contaminants is to survey for them within coastal waters (Whitall et al., 2014). This is done by screening for a long list of potential contaminants at each study site to determine what set of contaminants is entering the coastal ecosystem. While such a survey doesn't exist for the entirety of the territory, some important locations have been tested by NCCOS as an indicator of ecosystem health. One such site tested by the NCCOS team overlaps with an area of interest identified in this project's stakeholder prioritization process: Coral Bay. Of all the potential contaminants screened (Table 4), only copper and chlordane exceeded sediment quality guidelines in Coral Bay, and copper also exceeded guidelines in nearby Fish Bay (Whitall et al., 2014, Ch. 4). Figure 30 shows copper concentrations for both bays, where each dot shows a testing site, color coded by the level of copper detected. In both sites shown, higher levels of analytes tended to occur in the inner portions of each bay. The source of this copper is not necessarily land based, as Coral Bay also has inputs of pollutants from moored boats and boats that sunk during hurricanes; sources of pollution are likely varied and collectively accumulated to the totals identified. Importantly, not all contaminants have sediment quality guidelines. These data are not included in the final spatial index because they are not available for the entirety of the territory.

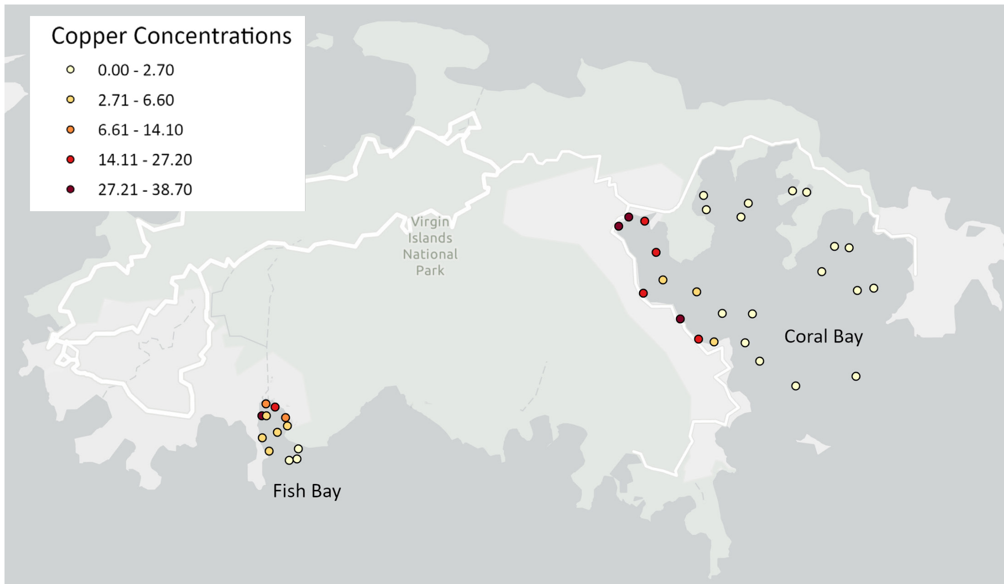

Figure 30. Copper concentrations (µg/L) at testing sites in Coral Bay and Fish Bay, St. John.

Lastly, sargassum inundation can be a nuisance in coastal environments, even though it serves an important role as habitat in the open ocean. Sargassum that washes onshore impacts coastal communities by disrupting recreational and tourism activities, blocking drainage systems, and requiring clean-up efforts; however, sargassum also bioaccumulates micropollutants such as the chemicals and heavy metals shown in Table 4 (Devault et al., 2021). As beached sargassum decomposes, these micropollutants have been documented to leach arsenic and other potentially toxic heavy metals into the environment (Olguin-Maciel et al., 2022). Airborne toxins (though excluded from the present assessment) also pose high health risks.

Table 4. List of potential contaminants for testing.

Chemicals	Heavy Metals		
Total Polycyclic Aromatic Hydrocarbons (PAHs)	Aluminum	Copper	Nickel
Total Chlordane	Antimony	Iron	Selenium
Total Dichlorodiphenyltrichloroethane (DDT)	Arsenic	Lead	Silicon
Total Polychlorinated Biphenyls (PCBs)	Cadmium	Mercury	Tin
Total Tributyltin	Chromium	Manganese	Zinc

A clinical study in 2018 found neurological, digestive, and respiratory disorders associated with mass beaching events and concluded that the toxicological syndrome induced by sargassum exposure mirrors the toxidrome associated with acute hydrogen sulfide exposure (Resiere et al., 2021).

Sargassum buildup along shoreline. Credit: Seann Regan (CSS Inc./NOAA NCCOS)

The USVI had a total of 28 recorded sightings of beached sargassum in 2022 (Sargassum Monitoring, 2023), largely in the northern part of the territory. These data are spatially resolute and available to view on Sargassum Monitoring's website, but the research team was unable to access these proprietary data for integration into the final index. Since this website largely uses public webcam footage, the territory could consider establishing its own database of sargassum sitings, or a data purchase agreement with Sargassum Monitoring could be explored.

Oceanic sargassum is also tracked using satellite imagery and can be viewed through time via NOAA's ERDDAP data portal (NOAA CoastWatch, n.d.). Figure 31 shows a 7-day cumulative Alternative Floating Algae Index from March 2024 (NOAA ERDDAP, 2024). From these satellite data, Hu et al. (2023) estimated the total biomass of sargassum within 100 km of the USVI islands over time (Figure 32), documenting that oceanic sargassum presence is increasing. While areas of high oceanic sargassum may result in on-shore nuisance algae, the ERDDAP dataset excludes the nearshore landscape, and these data were not incorporated into the final index.

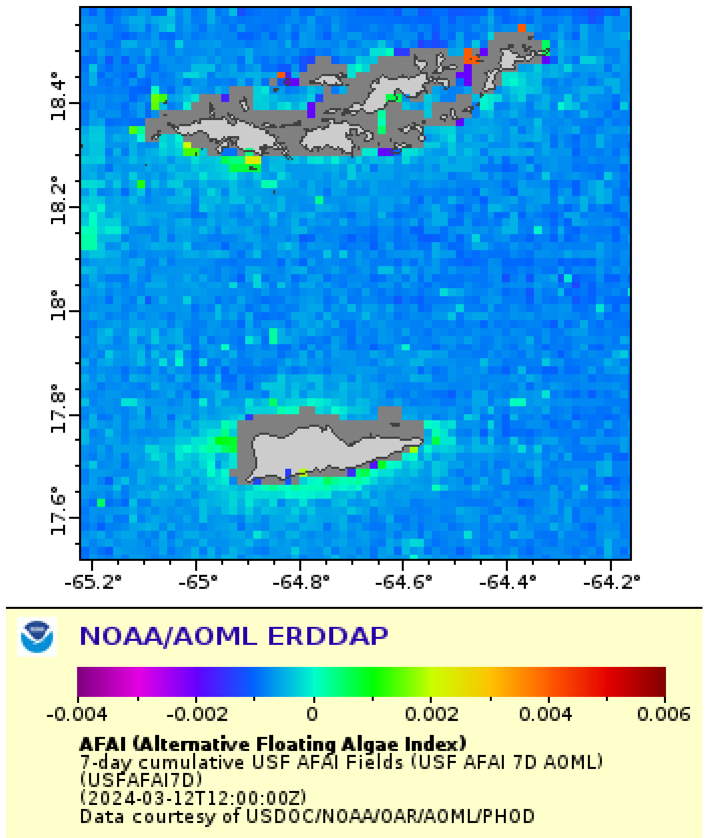

Figure 31. Oceanic sargassum map showing a 7-day cumulative Alternative Floating Algae Index. Image credit: NOAA ERDDAP, 2024.

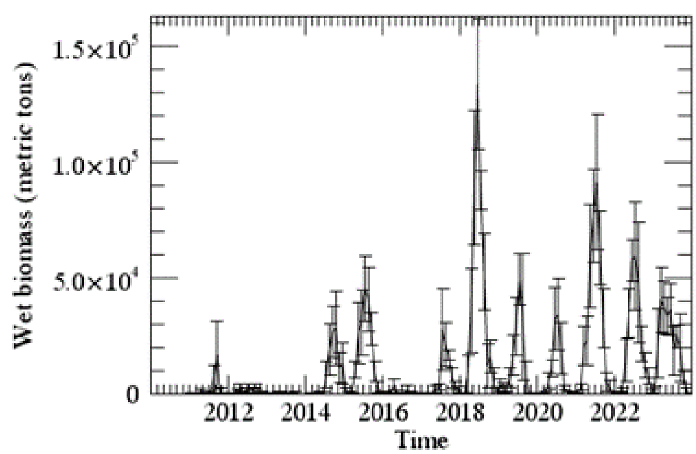

Figure 32. Total sargassum biomass offshore the territory over time. Image credit: Courtesy of Chuanmin Hu (C. Hu, personal communication, March 20, 2024).

2.5 Green Space: Vegetation

Green spaces provide an array of benefits, from reducing urban heat effects to a range of public health benefits (Gunawardena et al., 2017; Nutsford et al., 2013). A 2015 review found that greenness is consistently linked with better mental health outcomes, cardiovascular health outcomes, lower mortality, and healthier birth weights (James et al., 2015). Trees provide important ecosystem services such as protecting against soil erosion and cooling ground temperatures (Zuazo and Pleguezuelo, 2009).

For this assessment, the research team explored multiple remotely sensed metrics of assessing vegetation and greenness. A normalized difference vegetation index (NDVI) was calculated using high-resolution aerial imagery data from the National Agriculture Imagery Program, with a spatial resolution of approximately 0.6 × 0.6 m (NOAA Office for Coastal Management Partners, 2024). These data contain red, green, and blue visible light data as well as infrared values. NDVI can be used to measure relative biomass or greenness by contrasting chlorophyll pigment absorptions or reflectance in the visible red band (Red) of a multispectral raster dataset with the high reflectivity of plant materials in the near-infrared reflectance (NIR) band of that same dataset using the following equation (Pettorelli et al., 2005).

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Where, NIR = pixel values from the near-infrared band
Red = pixel values from the red band

The NDVI mosaic was converted into a continuous raster, and the raster was then clipped to the territory boundary of the USVI. After preliminary review, stakeholders identified an area of St. Croix that appeared to have significantly lower than expected vegetative value. Shadows from satellite or aerial imagery have been shown to sometimes impact standard NDVI values through the misclassification of shadowed areas as lower vegetation density (Silva et al., 2018). This is especially pronounced in hilly terrain where certain areas of a landscape receive less sunlight due to obstructions caused by mountains or steep topography, and elevated terrain features can block the path of sunlight, casting shadows over lower areas (Silva et al., 2018). National Agriculture Imagery Program orthoimagery consists of composite digital orthophoto quadrangle tiles, over multiple flight paths, and thus, calculation of sun azimuth (for shadow detection and influence on NDVI) is problematic. To combat the influence of shadows on the vegetation index, the research team instead calculated a visible atmospherically resistant index (VARI), which is less susceptible to atmospheric interference (Figure 33), using the following equation (Gitelson et al., 2002). Orthographic Imagery from 2020 with sub-meter precision (USVI Hazard Mitigation and Resilience Plan, 2020) was also used as the VARI equation does not require the infrared (IR) band.

$$VARI = \frac{(Green - Red)}{(Green + Red - Blue)}$$

Where, Green = pixel values from the green band
Red = pixel values from the red band
Blue = pixel values from the blue band

The VARI index is designed to emphasize vegetation in the visible portion of the spectrum, while mitigating illumination differences and atmospheric effects (Gitelson et al., 2002). It is more suitable for color images (images using the red-green-blue color modes) as opposed to NIR and IR as it utilizes all three color bands more uniformly. This correction process emphasizes the importance of local expert review. The corrected Vegetation Index or VARI raster was then aggregated to the territory estates using the mean VARI value of each estate, resulting in a final vegetation index for the territory that communicates overall vegetation levels for use in various planning activities (Figure 34).

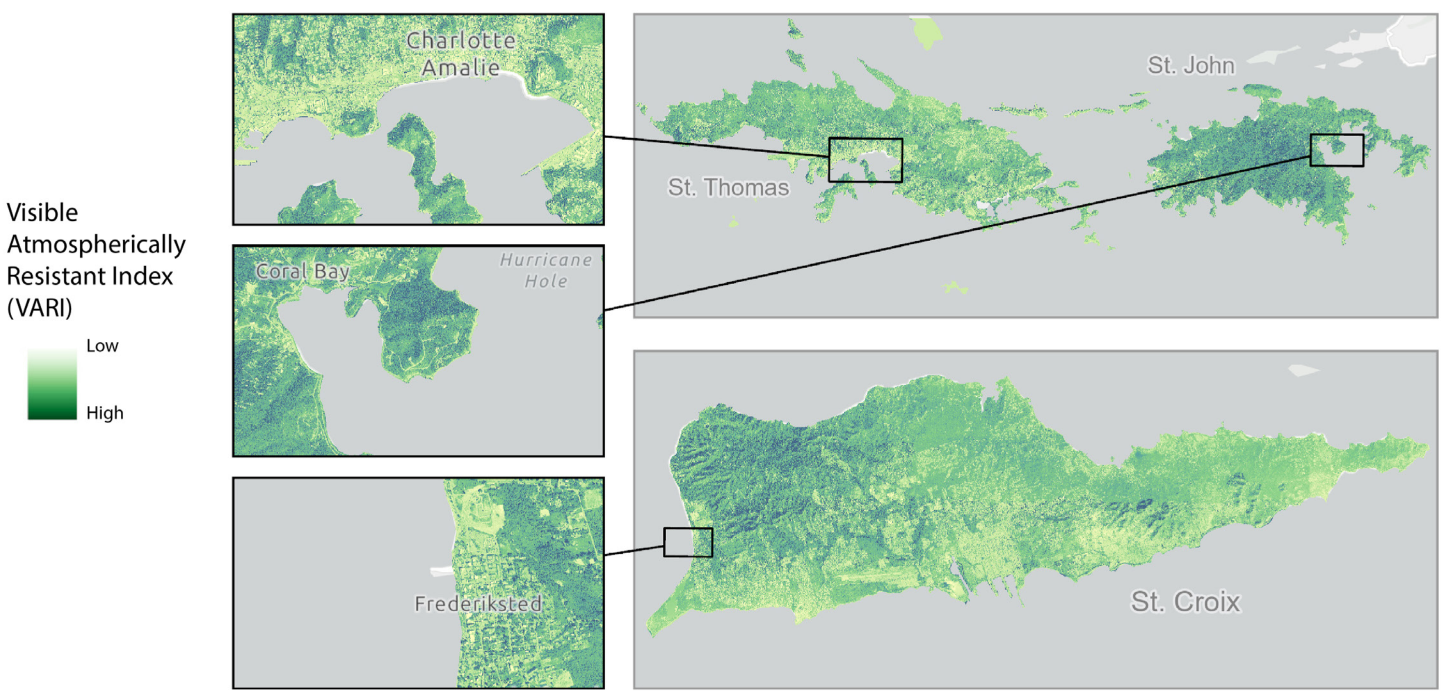

Figure 33. Visible atmospherically resistant index (VARI) raster data.

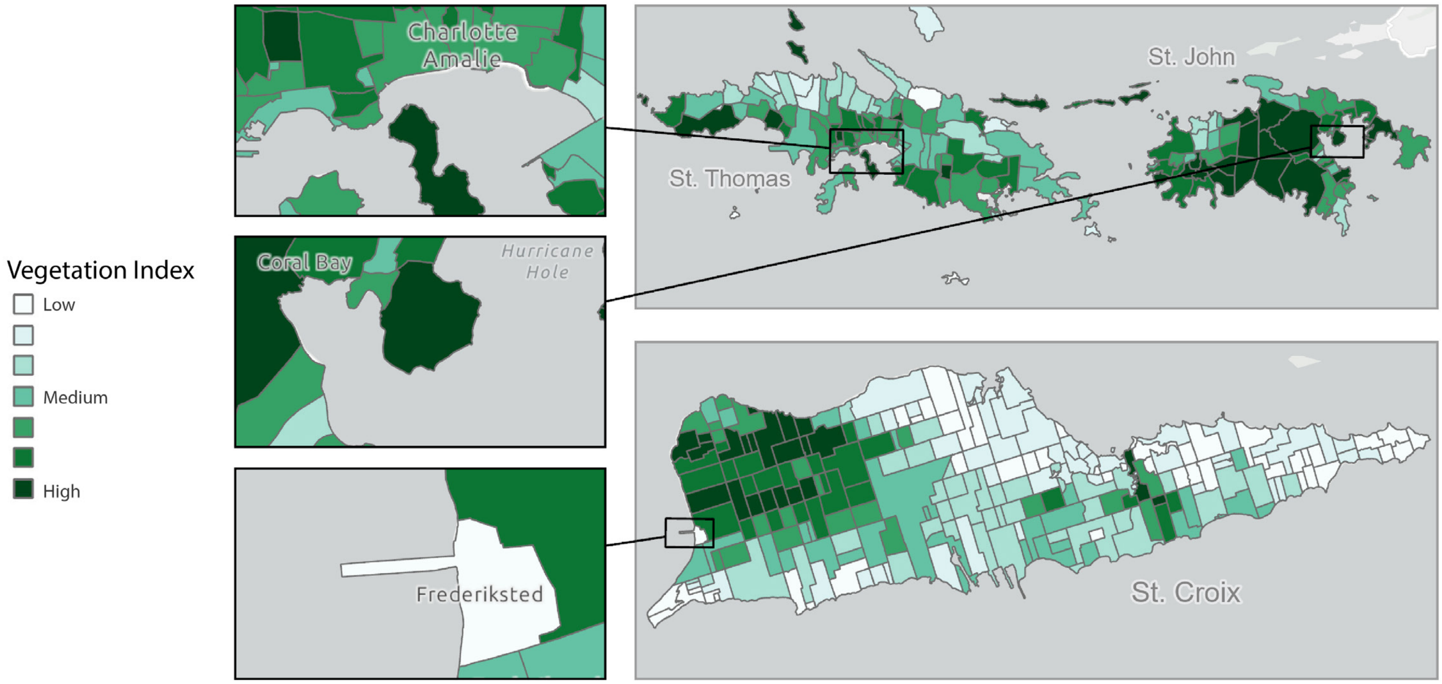

Figure 34. Final vegetation index.

2.6 Transportation: Walkability

Local partners expressed interest in a transportation assessment during the 2023 workshops, citing limited walkability to food and other necessities, a lack of public transportation, limited sidewalks, and poor road quality. In response, the research team created a walkability index for the territory.

A walkability index is typically defined as a measure that can be used to better understand the pedestrian experience within neighborhoods or cities. Walkability indices vary in their input variables but often consider proximity of essential amenities, the presence and condition of sidewalks, the connectivity and accessibility of streets, and land use mix, and may include location-specific data such as crime rates or the availability of public transportation options (Frank et al., 2010). Higher walkability index scores reflect communities that have prioritized and accommodated pedestrian needs in their urban planning and development (Carr et al., 2010). A well-designed, walkable environment encourages social interactions, promotes physical activity, and reduces reliance on vehicular transportation, consequently contributing to lower carbon emissions and improved air quality. This, in turn, fosters a more sustainable environment and more positive health outcomes (Watson et al., 2020). Walkability also plays a crucial role in promoting equity, as it highlights areas where pedestrian infrastructure may benefit from improvements.

The research team developed a potential walkability index from seven indicators: road slope, street connectivity, land use mix, building density, sidewalk presence, road quality, and public transportation access (Fg. Safety metrics (e.g., crime rates, public perceptions of safety), traffic and street design features (e.g., crosswalks, pedestrian signals), and amenity proximity (e.g., grocery stores, schools, parks) were considered but ultimately excluded due to data availability limitations. This index reflects amenity-based walkability from the behavioral health literature as this type of walkability has been shown to influence everyday walking potential. For each of the walkability indicators, any null values were converted to 0 prior to further analysis. All metrics were aggregated to the estate geography, normalized to 0–1 using a min-max rescaling approach, and adjusted for directionality.

To calculate the average slope of roads within each estate, a series of DEMs were first mosaiced into a continuous raster DEM with elevation values for the territory (Figures 35 and 36) (NOAA National Geophysical Data Center, 2010). Average elevation values for road segments were then calculated per estate, using road data from the USVI Department of Public Works (USVI Hazard Mitigation and Resilience Plan, 2023b). Since more-moderate slopes are more suitable for pedestrians (Fonseca et al., 2021), lower slope scores correspond to higher walkability.

Street connectivity was determined by identifying road vertices (i.e., intersections) and calculating the total count of vertices per estate (Figure 36), using the same road data above (USVI Hazard Mitigation and Resilience Plan, 2023b). Since well-connected road networks tend to be more pedestrian friendly than sprawling layouts (Carr et al., 2010), high connectivity scores correspond to higher walkability.

Figure 35. Elevation data by roadways.

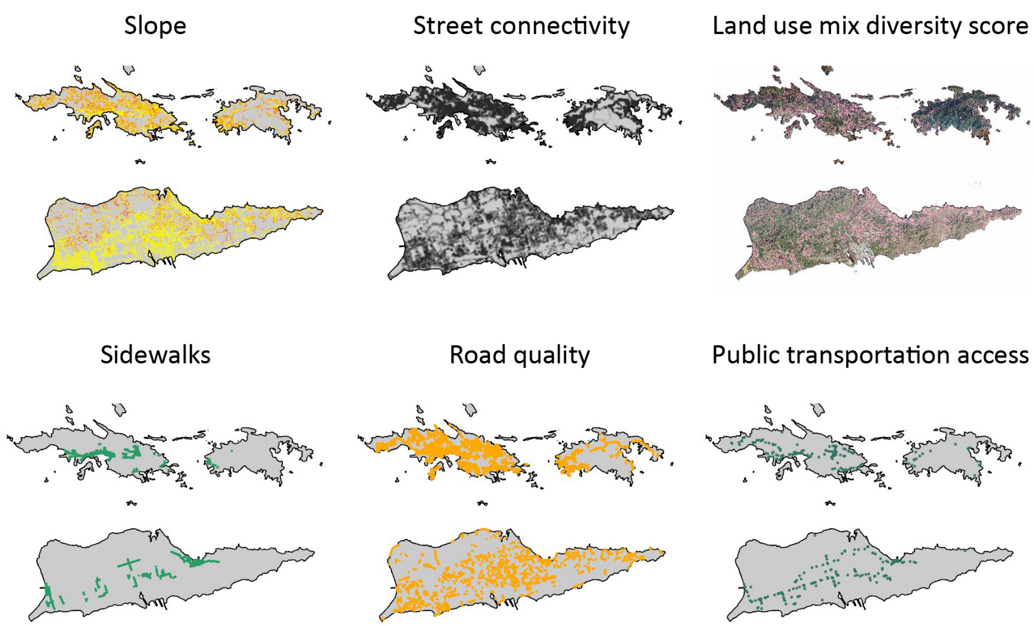

Figure 36. Indicators within the potential walkability index.

Land use mix was estimated by developing a Shannon diversity index (Figures 36 and 37), using high-resolution land use–land cover data from NOAA Coastal Change Analysis Program (NOAA Office for Coastal Management, 2015) (land cover types are described earlier in Table 2). The Shannon diversity index (see equation below with present analysis application shown in reverse italics) is widely used in conservation science for species diversity metrics (Peet, 1975) but at its core is a measure of diversity across a population or geography. In the present analysis, it is used to measure the diversity of land use types to calculate high and low areas of diversity (Honnay et al., 2003). For example, an area with a low diversity score might be an area with limited land use cover types such as entirely forested space, whereas an area with a high score might have urban land use, rural land use, and developed open space, all in close proximity. Mean values from the Shannon diversity index were then applied to each estate. Since a higher land use diversity (i.e., a mix of residential, commercial, and recreational lands) can enhance walkability by reducing vehicular travel (Carr et al., 2010), higher land use diversity scores correspond to higher walkability.

$$H' = -\sum_{i-1}^{S} p_i \ln p_i$$

*Where, S = number of species (***land use cover types***)*
*p = proportion (n/N) of individuals (***geographical units***) of one species (***land use cover type***)(n)*
*divided by the total number of individuals (***geographical units***) (N)*

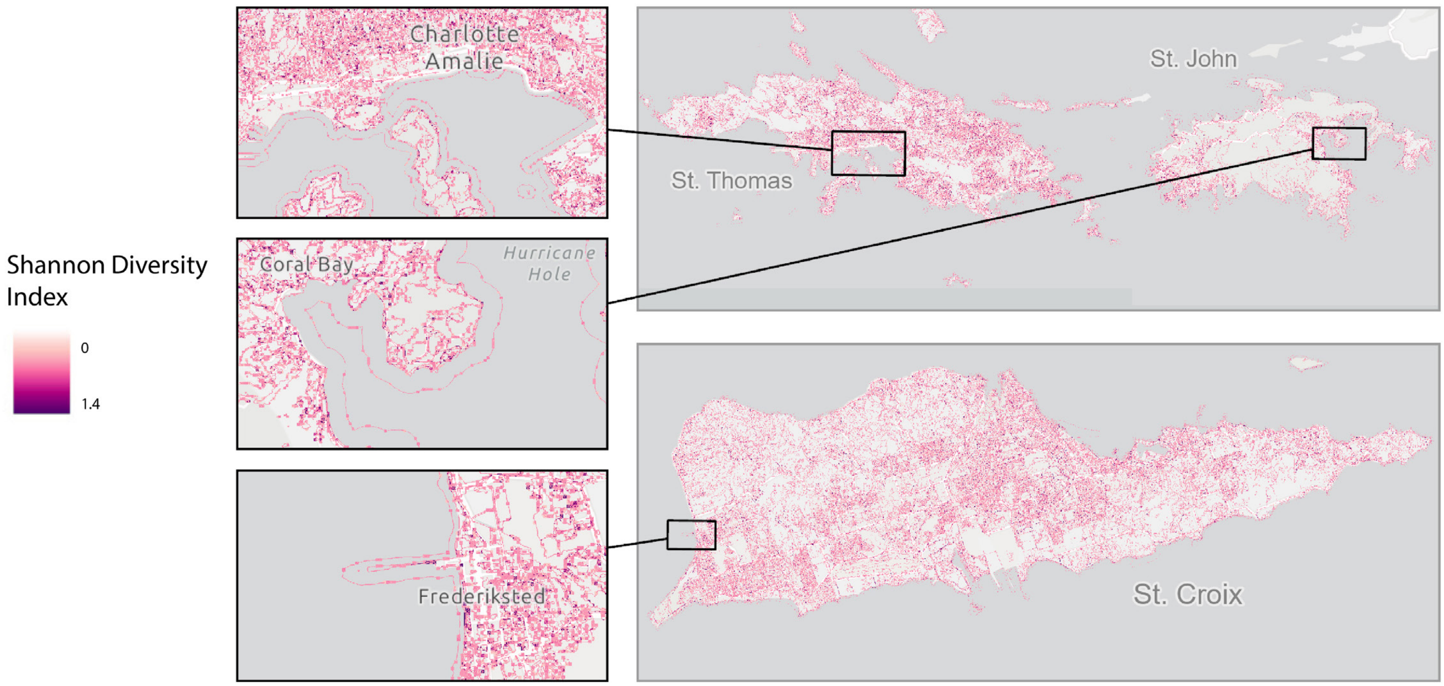

Figure 37. Shannon (land use) diversity index raster data.

Building density was determined by examining building footprint data (USVI Hazard Mitigation and Resilience Plan, 2023b) and calculating the total count of building footprints per estate (Figure 36). Since higher building densities often contribute to increased walkability (Carr et al., 2010), higher density scores correspond to higher walkability.

Sidewalk presence was calculated by summing the total length of sidewalks per estate (Figure 36), using data from the USVI Department of Public Works (USVI Hazard Mitigation and Resilience Plan, 2023b). Since the presence of sidewalks increases the safety and comfort of walking (Suarez-Balcazar et al., 2020), higher sidewalk scores correspond to higher walkability.

To determine road quality, the research team calculated the total length of roads per estate and the total length of fatigued roads per estate, divided the latter values by the former, and then inverted the scores to estimate a fatigued road percentage per estate (Figure 36). Roads were considered fatigued for this analysis if they were coded as high-high or high-med fatigue level within the USVI Department of Public Works dataset (2021). Since higher road quality supports higher walkability (Reisi et al., 2019), higher road quality scores correspond to higher walkability.

Finally, public transportation access was determined by calculating the total count of Virgin Islands Public Transit System stops within each estate (Figure 36). The Virgin Islands Public Transit System is designed to promote public transit in the territory and includes amenities such as bus stops and other public transit options (USVI Department of Public Works, 2023). Since increased access to public transportation supports higher walkability (Carr et al., 2010), higher public transportation access scores correspond to higher walkability.

All seven walkability indicators summarized in Figure 36 were renormalized to 0 to 1 using a min-max scaling approach (preserving the inverted scores for road slope and road quality) and then combined into an additive index (Figure 38). The final potential walkability index portrays relative walkability across the territory but, due to limited data availability, omits safety concerns for issues like crime and neighborhood disorder. Because much of the territory's terrain is mountainous, a medium walkability score might still lean towards un-walkable, but this is a relative index.

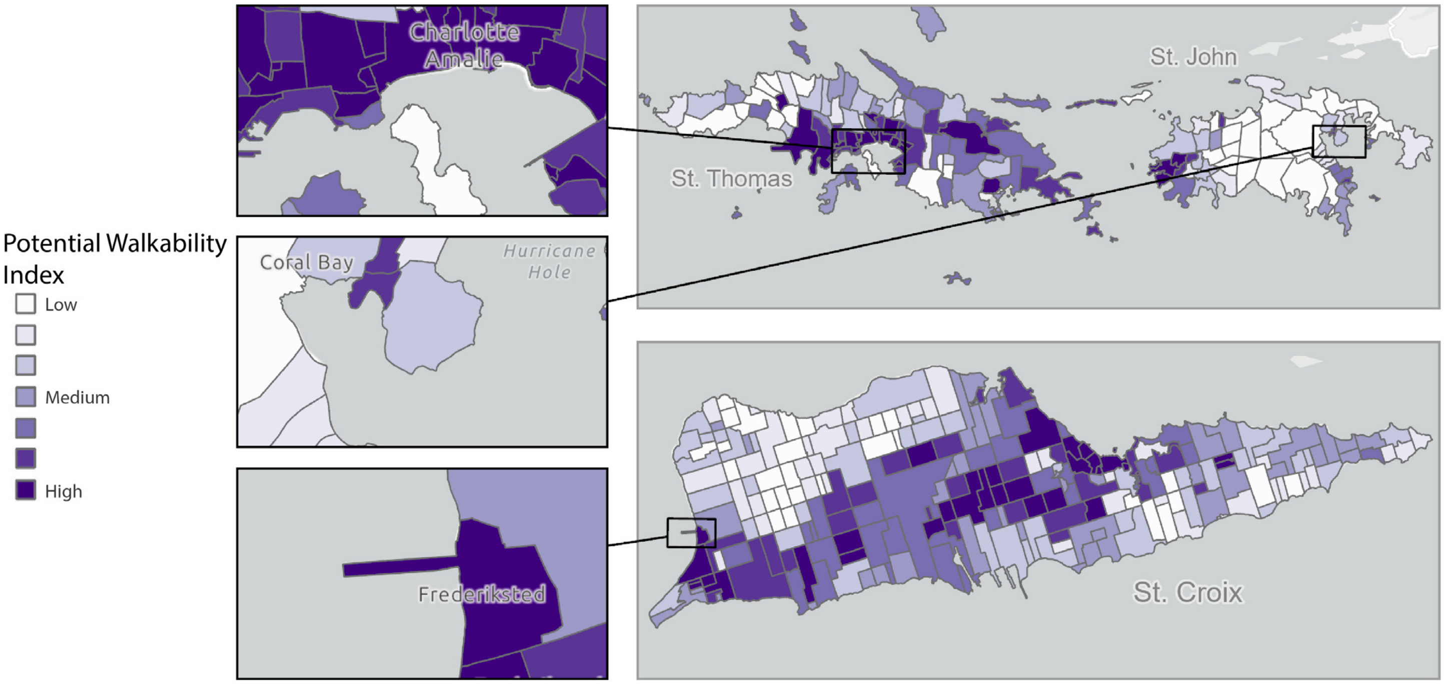

Figure 38. Final potential walkability index.

Bay in USVI. Credit: Seann Regan (CSS Inc./NOAA NCCOS)

3. Assessing Risk & Co-Occurrence

After creating individual profiles, the research team assessed risk by intersecting selected assessment components through bivariate choropleth mapping. This mapping technique depicts two variables at once, and areas of overlap within each map show co-occurrence of the two components, often communicating relative risk. These maps can help prioritize actions and aid in decision making when considering particular aspects of vulnerability, exposure, hazard, and risk.

All estate scores from each component within Section 2 were transformed to a 1 to 3 scale, using a discrete scaling system for each estate, and scores were broken into three categories of low, medium, and high based upon a quantile distribution of normalized values (see Figure 3). Because estates with limited population were suppressed within the social vulnerability index, bivariate maps that include this index were restricted to only the 311 estates with social vulnerability scores (Figure 4) and matching estate names. To achieve these estate restrictions, excluded estates were removed, and index values were recalculated to reflect the restricted universe of data. Implementing this approach may cause estates with the same component to have slightly different index scores when the component is displayed within the bivariate maps. For example, every estate has a compounded flood hazard index score and a structural vulnerability score, so if these two indices were intersected in a bivariate map, all estates would have values. However, if either of these indices were intersected with social vulnerability, their index scores would be recalculated to the restricted number of estates available for social vulnerability. Similarly, bivariate maps that include the nearshore environment protection benefits index were restricted to only coast-adjacent estates, using the same index recalculation approach described above.

Figure 39 displays the legend for how to read each of the resulting bivariate choropleth maps. As one component's scores increase from left to right (in blue), another component's scores increase from bottom to top (in pink). Each corner of the matrix represents a different extreme in terms of variable scoring. Dark blue estates on each map indicate areas of higher co-occurrence (e.g., risk), while light gray estates indicate lower co-occurrence. Magenta and teal estates indicate areas with disparate scores (high for one component but low for the other).

All maps in this section are available as full-page graphics in Appendix D: Mapbook. Across this assessment, there are numerous potential map combinations; however, the research team prioritized the bivariate map combinations identified during the March 2024 partner and stakeholder workshops (see Section 1.4 and Appendix B). They have been organized into four categories: co-vulnerabilities, risk in relation to flood hazard, benthic environment interactions, and other important relationships.

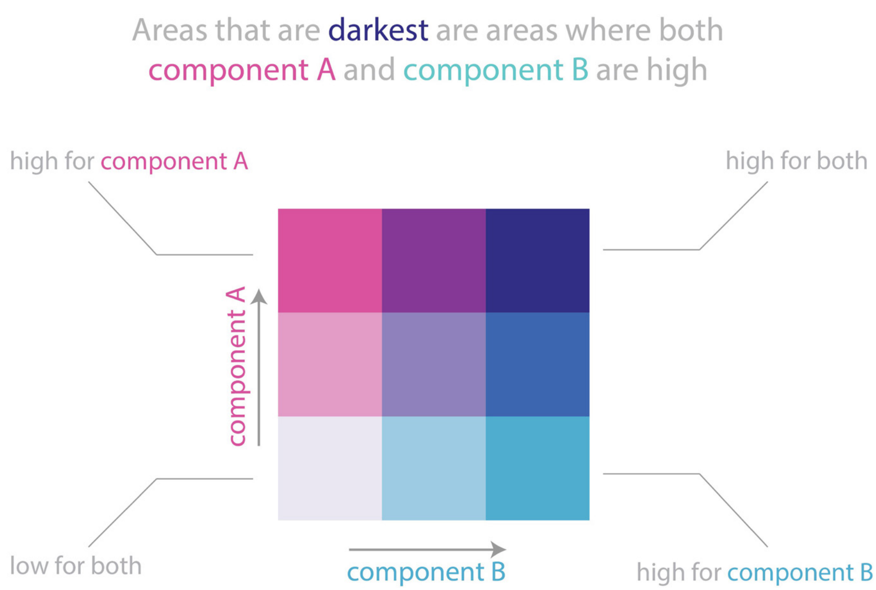

Figure 39. Bivariate choropleth map legend.

3.1 Co-Vulnerabilities

The maps in this subsection display two vulnerability or exposure indices to highlight areas of increased vulnerability related to social and structural systems. Figure 40 highlights areas across the territory that are most likely to experience both social vulnerability and structural vulnerability. It shows the combination of social and structural vulnerability (restricted to estates with sufficient population data); areas with no data or insufficient population data are displayed in white. There is higher co-vulnerability (dark blue estates) in southwestern to central St. Croix in areas from around Frederiksted, to around Christiansted. On St. Thomas, higher co-vulnerability is found from around the airport through Charlotte Amalie, with additional pockets in a few eastern estates. Areas of higher co-vulnerability on St. John are found from Cruz Bay, moving inland and then north to Dennis Bay, as well as fringing from Coral Bay down to Mandahl.

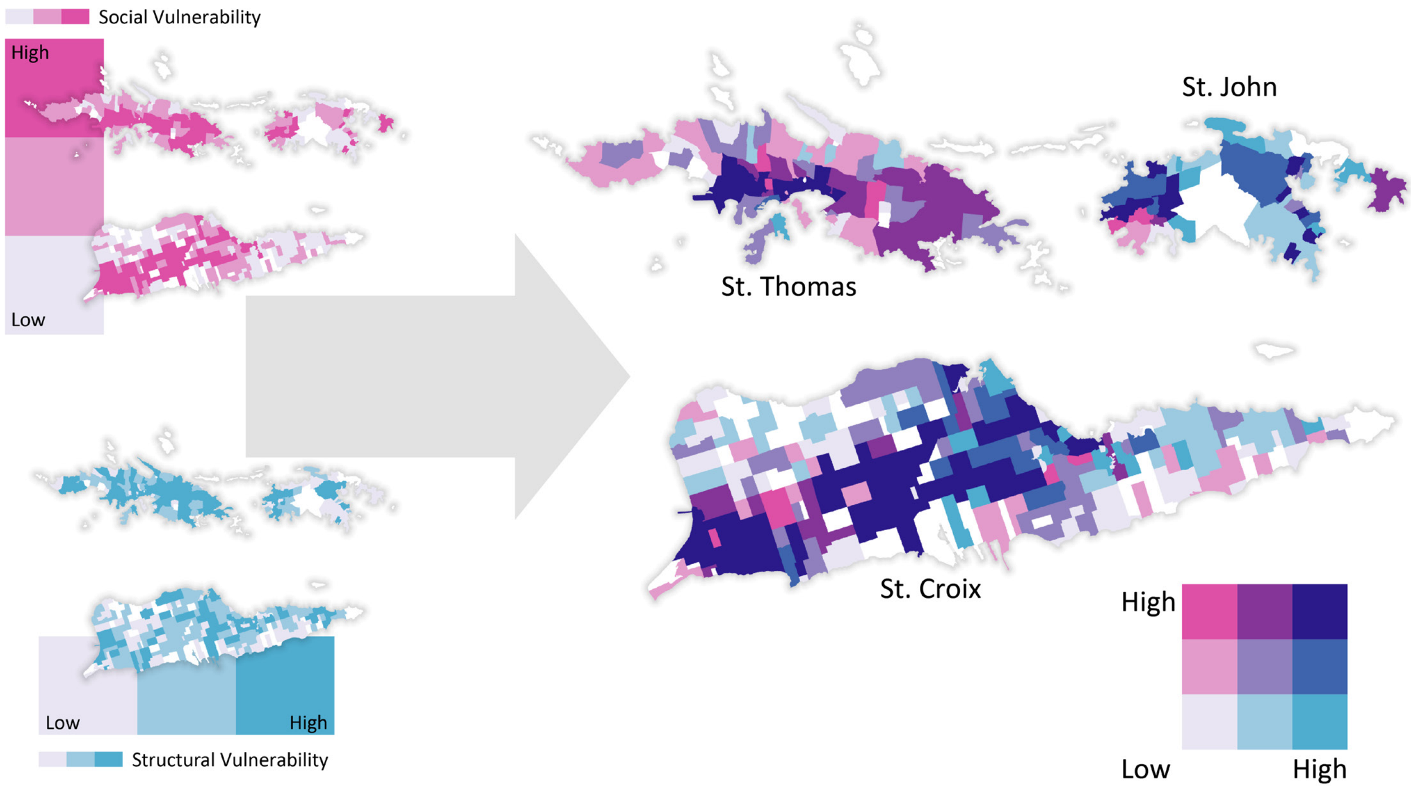

Figure 40. Social vulnerability in relation to structural vulnerability

Co-occurrence of multiple vulnerabilities may be problematic for the estates identified because the vulnerability of social and structural systems may compound, and this is amplified during and following a hazard event (Highfield et al., 2014). For example, an investigation of damage assessment reports following Hurricane Ike in Texas found that older homes in areas with higher proportions of minority populations were more likely to have experienced storm damage (Highfield et al., 2014), and another temporal study of the U.S. Gulf Coast found that more vulnerable populations were more likely to experience worsened structural damage (Logan and Xu, 2015). Since the damage caused to more-vulnerable housing structures is often greater than to less-vulnerable structures, this increased damage is also likely to place additional strain on socially vulnerable populations during storm recovery. In the identified estates, the reduction of structural vulnerability through improved plumbing and kitchen facilities both in the home and supporting infrastructure, for example, may also contribute to improvements in social vulnerability.

Figure 41 highlights areas with higher social vulnerability but also higher concentrations of critical infrastructure. It still shows social vulnerability but now intersected with structural exposure (again, restricted to estates with sufficient population data). Areas of high co-occurrence are now more concentrated on St. Thomas, from the airport through parts of Charlotte Amalie to Sapphire Beach and also south to Estate Bovoni. High co-occurrence areas on St. Croix and St. John are similar to those of Figure 40, but fewer. A reminder that while structural vulnerability incorporates indicators of vulnerable housing characteristics and vacancy, structural exposure instead incorporates presence and locations of communications, utilities, and transportation infrastructure. If an extreme hazard event were to occur in the highlighted estates and their communications, utilities, and transportation infrastructure were damaged, this would further stress already vulnerable populations. Importantly, much of the infrastructure included within the structural exposure index provides island- or territory-wide services. Loss, damage, or interruption to this infrastructure would likely extend beyond their identified estates.

Lastly, Figure 42 highlights areas with more critical infrastructure at potential risk of increased vulnerability. It shows the intersection of structural exposure with structural vulnerability (restricted to estates with sufficient population data), highlighting areas where critical infrastructure is more concentrated, but also where built structures are more vulnerable.

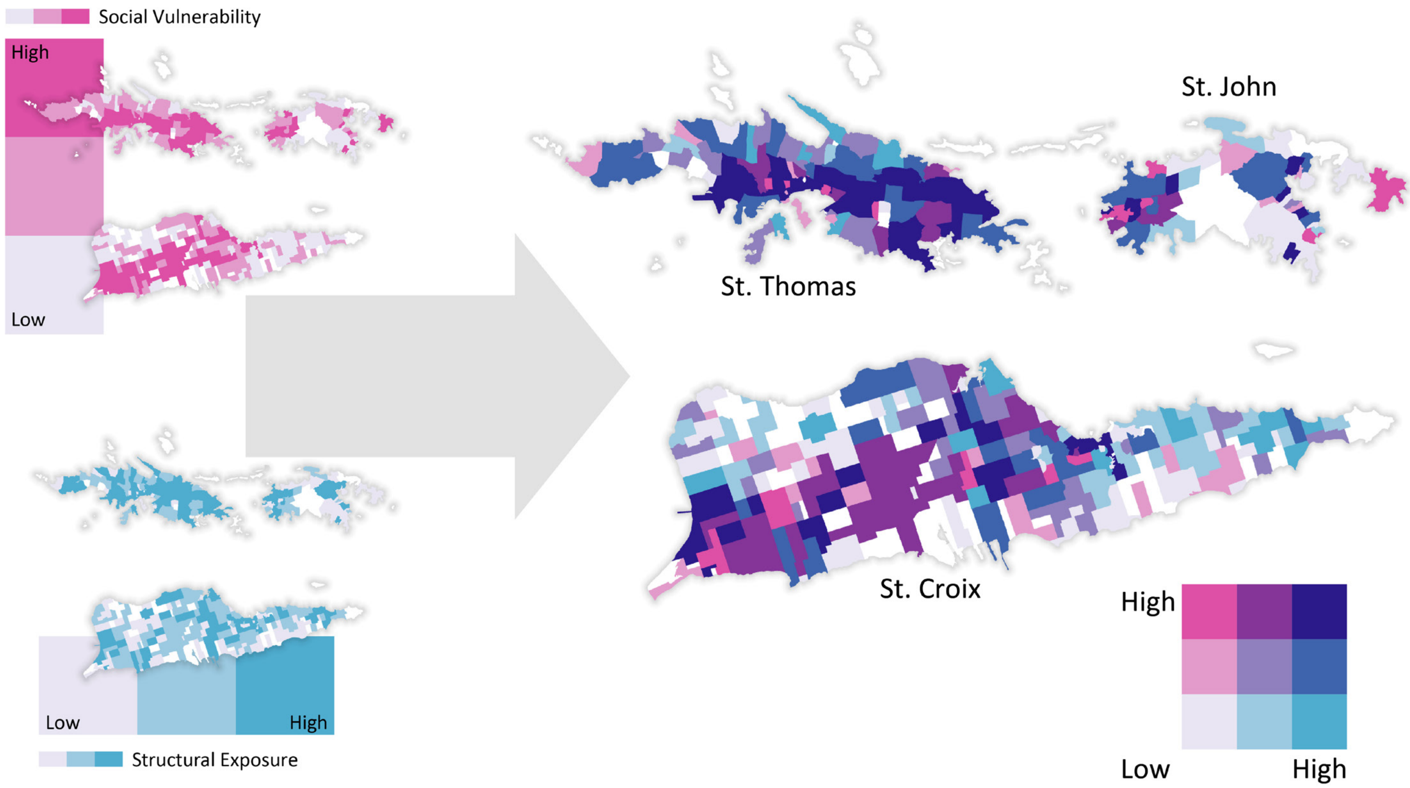

Figure 41. Social vulnerability in relation to structural exposure.

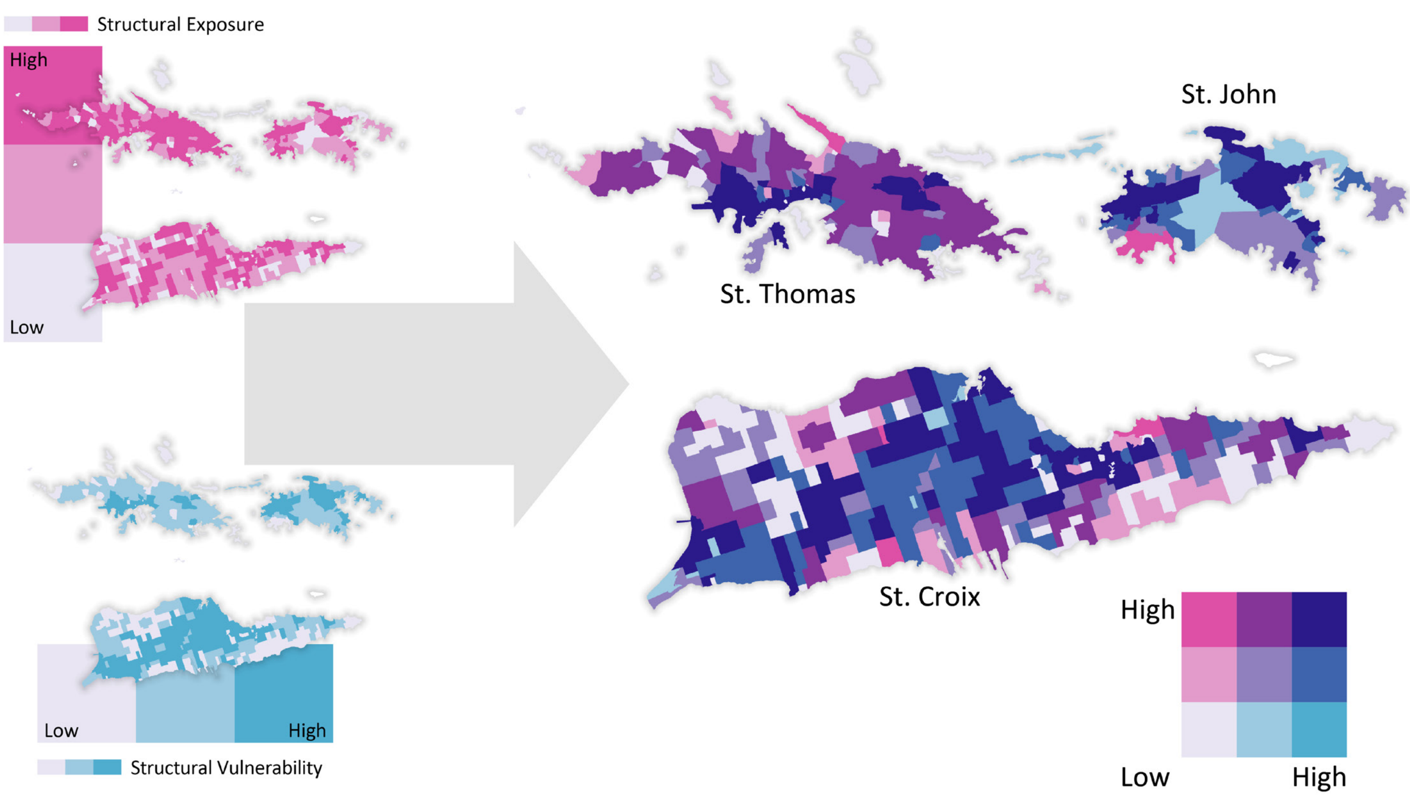

Figure 42. Structural exposure in relation to structural vulnerability

Here, there are relatively fewer areas of co-occurrence on St. Thomas when compared to the previous map, though areas from the airport through parts of Charlotte Amalie are still identified, as are pockets in the northeast and the addition of northern Water Island. Coral Bay, Annaberg, and Mary Point emerge as new areas of interest on St. John, as do areas around Teagues Bay, Clairemont, and Judith's Fancy on St. Croix. Though the indicators that inform these two indices are unique, it is possible that critical infrastructure in estates with high structural vulnerability may themselves be more vulnerable as well.

3.2 Risk in Relation to Flood Hazard

One of the primary goals of the present vulnerability assessment is to assess risk. Following NCCOS's framework approach, risk maps can be generated by intersecting vulnerability or exposure with hazard. Figure 43 highlights flood risk for vulnerable populations by showing social vulnerability intersected with compounded flood hazard (restricted to estates with sufficient population data). Dark blue estates correspond to areas where social vulnerability and flood hazard is higher, and where human populations might be at greater risk during a flooding event. On St. Croix, this risk is highest from Frederiksted and the southwestern coast eastward through the center of the island to areas around Christiansted. On St. Thomas, high-risk areas are identified in Charlotte Amalie and the eastern coast from Frydendal to Sapphire Beach and from Benner's Hill to Estate Bovoni. St. John is relatively least at-risk in this map, with the exception of Mandahl. Storm surge and flooding already pose safety concerns for at-risk populations, but intense rain events and underlying soil conditions can also trigger mudslides and other forms of gravity erosion (Xu et al., 2015). Identified areas of higher compounded flood hazard and social vulnerability might benefit from increased planning, mitigation, and communications efforts related to flood hazard to better prepare for and withstand impacts. For example, there were two fatalities on St. Thomas during Hurricane Maria caused by flood waters and a mudslide (Pasch et al., 2023), and maps like these can serve as a tool to start important conversations around flood hazard planning and informing community members and emergency response teams for future events. This action would support the goals of the territory's 2019 Hazard Mitigation Plan update (Virgin Islands Territorial Emergency Management Agency, 2019) and the current 2024 draft (USVI Hazard Mitigation and Resilience Plan, 2024).

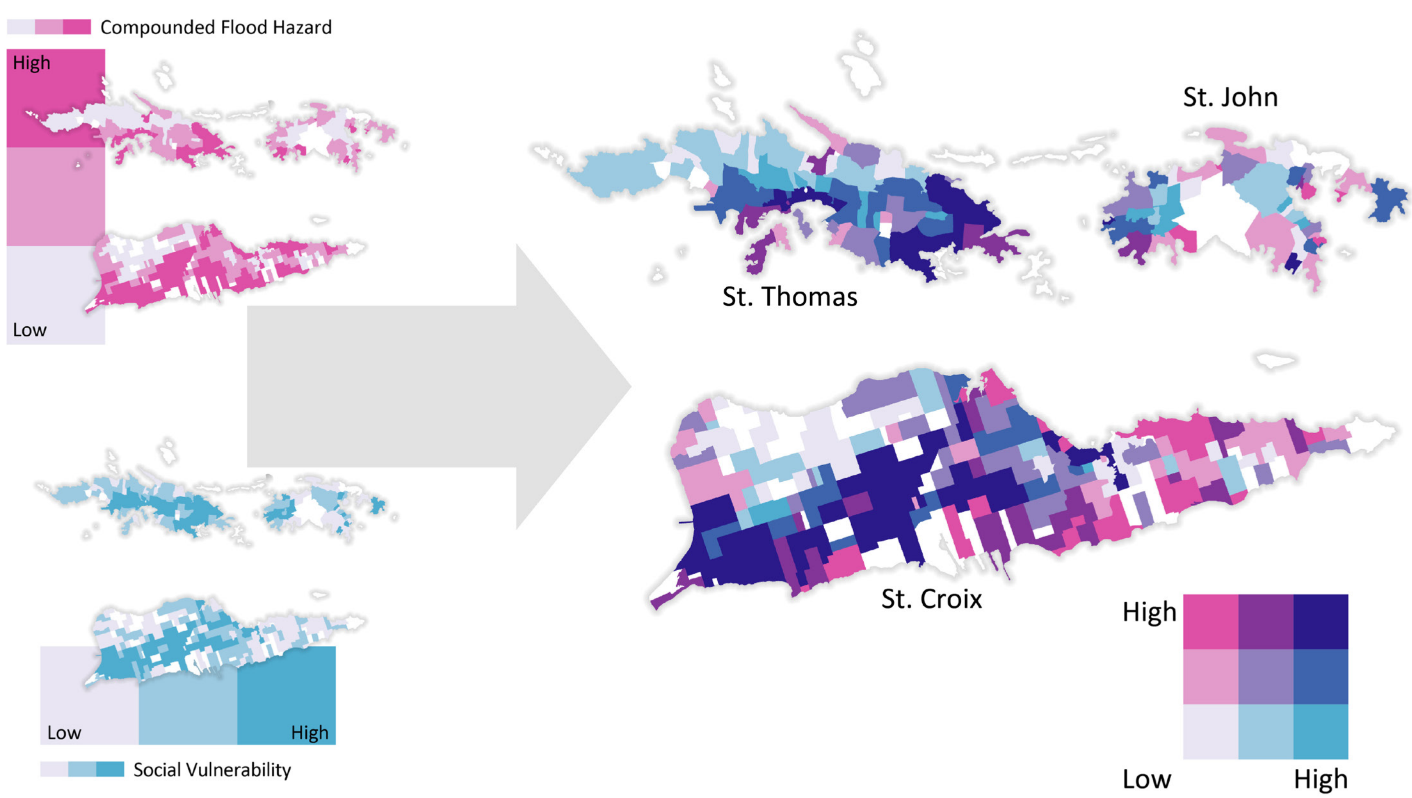

Figure 43. Compounded flood hazard in relation to social vulnerability.

Vulnerable structures may also be more easily impacted by flooding. Figure 44 shows areas of higher structural vulnerability with areas of higher compounded flood hazard. There are relatively more at-risk estates on St. Croix, following a similar pattern to previous maps from Frederiksted westward to Christiansted; however, the north-central shore, pockets of the northeastern shore, and parts of the south-central shore also emerge, including near the refinery. Areas of the airport through Charlotte Amalie, as well as Nadir and Frydendal are again identified on St. Thomas, in addition to the northern part of Water Island. St. John has relatively fewer at-risk areas, with pockets at Fish Bay, Mandahl, and Sabbat Point. These areas might benefit from prioritized infrastructure improvement projects to lessen their structural vulnerability as they are more likely to be impacted by compounded flood hazard.

Figure 45 shows not where structures or populations are vulnerable, but instead where critical infrastructure is located (exposure) related to compounded flood hazard. While there are some similarities to previous maps (e.g., the airport through Charlotte Amalie and Estate Bovoni on St. Thomas; Mandahl and Sabbat Point on St. John; Frederiksted, Christiansted, and Teagues Bay on St. Croix), some new at-risk areas emerge such as Red Hook on St. Thomas and Chocolate Hole on St. John. Higher-risk areas are somewhat scattered on St. Croix, with more estates identified along the northern shore east of Christiansted and also along parts of the southern shore. These areas might benefit from targeted flood mitigation infrastructure improvements to better protect the territory's critical infrastructure. Green infrastructure that encourages rapid water draining can support water management goals (Fletcher et al., 2014). Green infrastructure controls in more urban environments might include greening of roofs, porous pavement, vegetated swales, or bioretention cells (Mei et al., 2018). Improving the condition of natural infrastructure in more rural areas, such as through wetland and floodplain restoration, is also likely to reduce flooding locally as well as downstream from the improvement site (Suttles et al., 2021). While green infrastructure controls have been shown to reduce flooding risk, green infrastructure alone is unlikely to eliminate flooding (Mei et al., 2018). Since the identified estates hold higher quantities of critical infrastructure, hybrid gray-green infrastructure such as mangrove hybrid projects, tidal marsh hybrid projects, and other hybrid approaches might be considered (Waryszak et al., 2021). In the USVI, Guannel et al. (2023) summarized that the territory has relatively little hardened shoreline for protection against erosion or inundation, and most of what exists was built for transportation access.

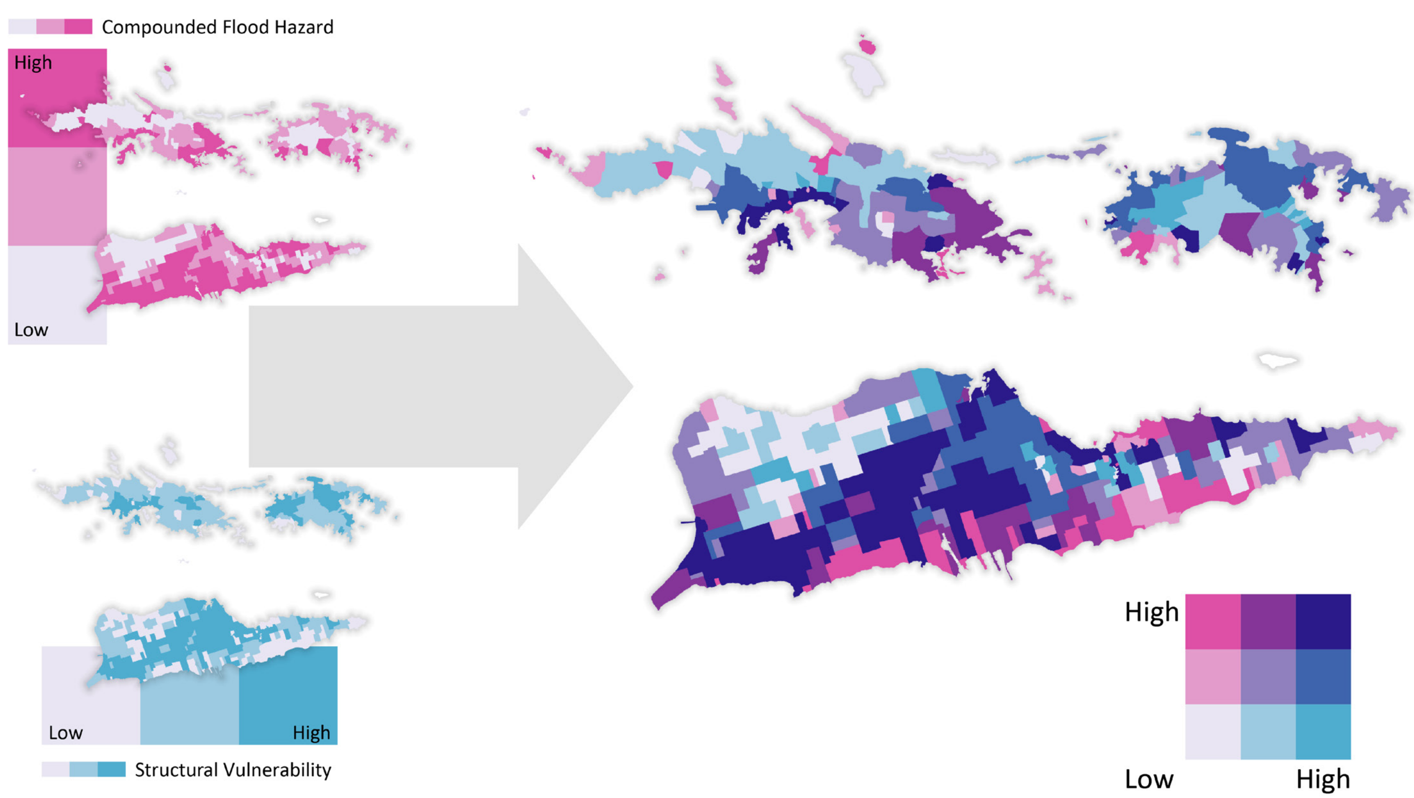

Figure 44. Compounded flood hazard in relation to structural vulnerability.

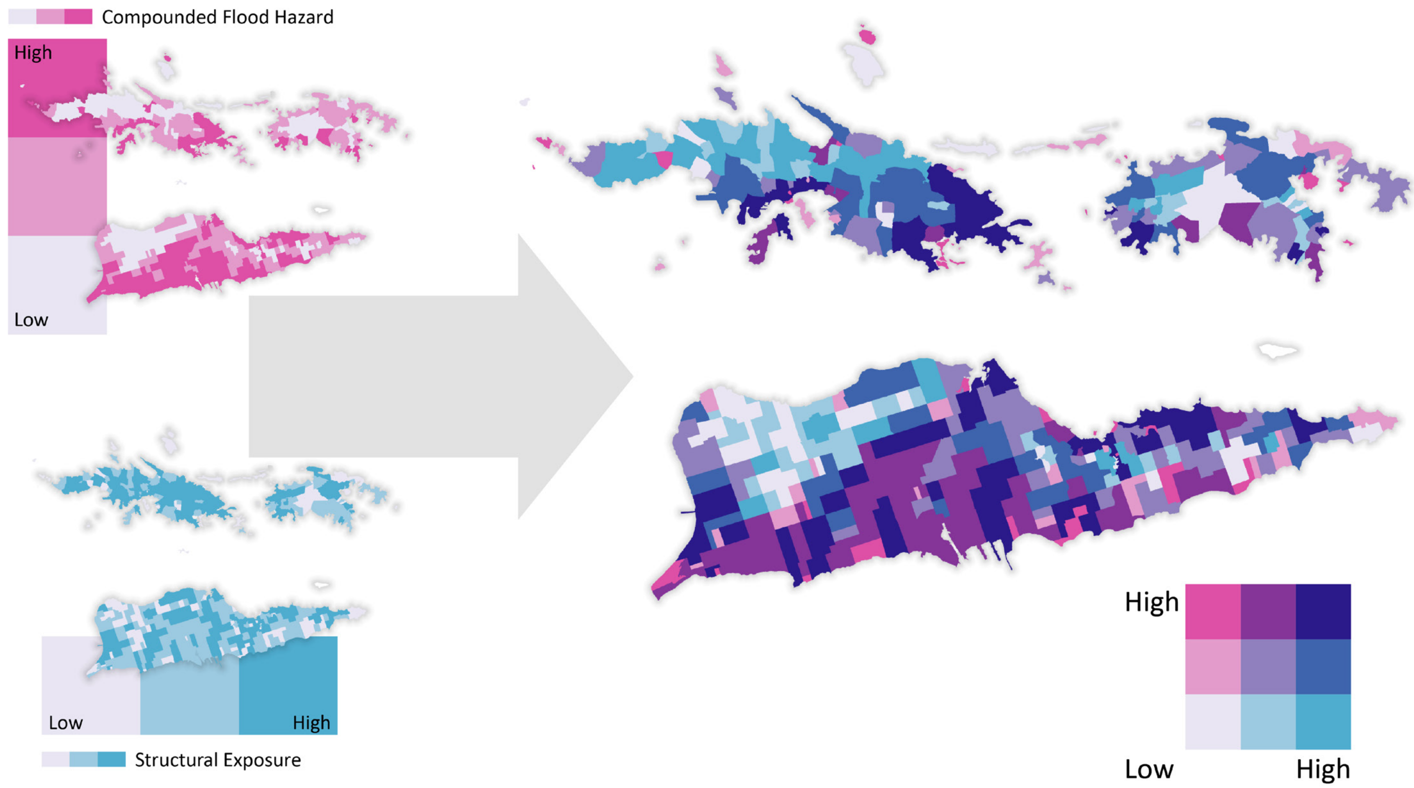

Figure 45. Compounded flood hazard in relation to structural exposure.

Figure 46 shows areas of higher waterborne toxins and contaminants compared with areas more at risk from compounded flood hazard. On St. Thomas, Magens Bay emerges as a higher-risk area, as well as the entire southeastern shore from Estate Bovoni through Red Hook and pockets from around the airport through Charlotte Amalie. On St. John, parts of the southern shore are identified from Chocolate Hole to Sabbat Point, as well Turner Point in the northeast. Central St. Croix is a general hotspot, reaching down to the southern coast around Canegarden Point and farther east to Great Pond. Parts of the northern coast from Salt River to Green Cay are also at greater risk of contaminant resuspension and movement by flooding events. Communities in these estates as well as downstream from these estates are at increased risk of contaminant releases during and after flood events. Studies have found relationships between flooding and gastrointestinal illness (Crespo et al., 2019; Wade et al., 2014). In Puerto Rico, researchers found increased concentrations of heavy metals and organic micropollutants in water samples following Hurricane Maria, as well as 13 micropollutants and pesticides that had been absent from pre-hurricane samples (Lin et al., 2020). The same study found higher pollutants and toxicity levels in water samples from northern Puerto Rico, where eight Superfund sites are located. Dark blue estates are therefore likely at increased risk from contaminant and toxin releases.

Figure 47 highlights areas with less onshore vegetation that are at risk of compounded flood hazard impacts by showing the relationship between the compounded flood hazard and inverted vegetation indices. The vegetation index was inverted so that dark blue estates have higher compounded flood hazard and lower vegetation values. Except for one estate around Frydendal on St. Thomas (and another smaller island to the north), all identified estates are throughout largely coastal areas of St. Croix, ranging from Salt River through Teagues Bay on the north shore, and from Frederiksted to the airport, and farther east to Spring Bay, with additional pockets of inland estates. Areas that are at greater risk of compounded flood hazard impacts but also have less onshore vegetation to help mitigate flooding extent or longevity are potentially at increased risk. In areas with critical built infrastructure or coastal communities, efforts might be made to restore or increase vegetation to improve flood-attenuating properties.

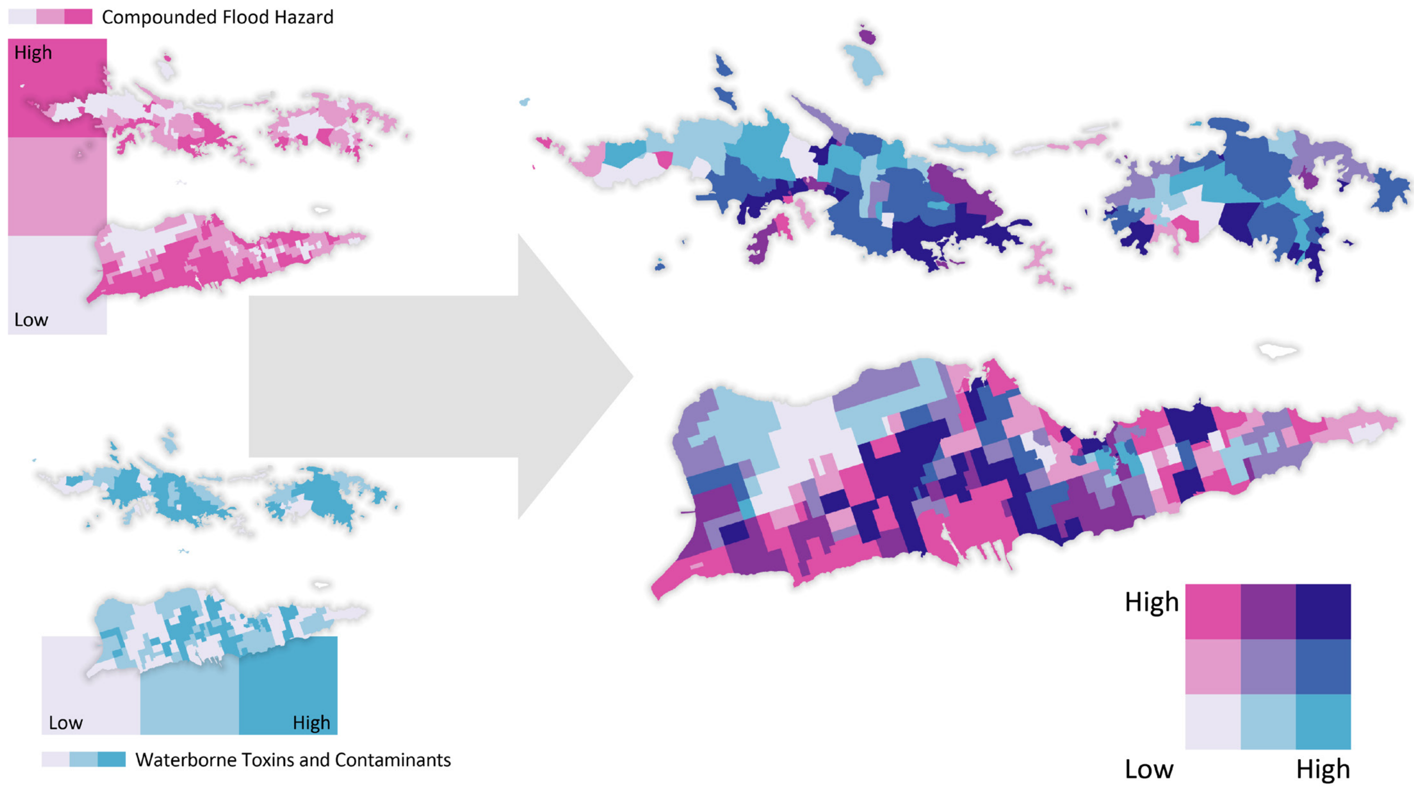

Figure 46. Compounded flood hazard in relation to waterborne toxins and contaminants.

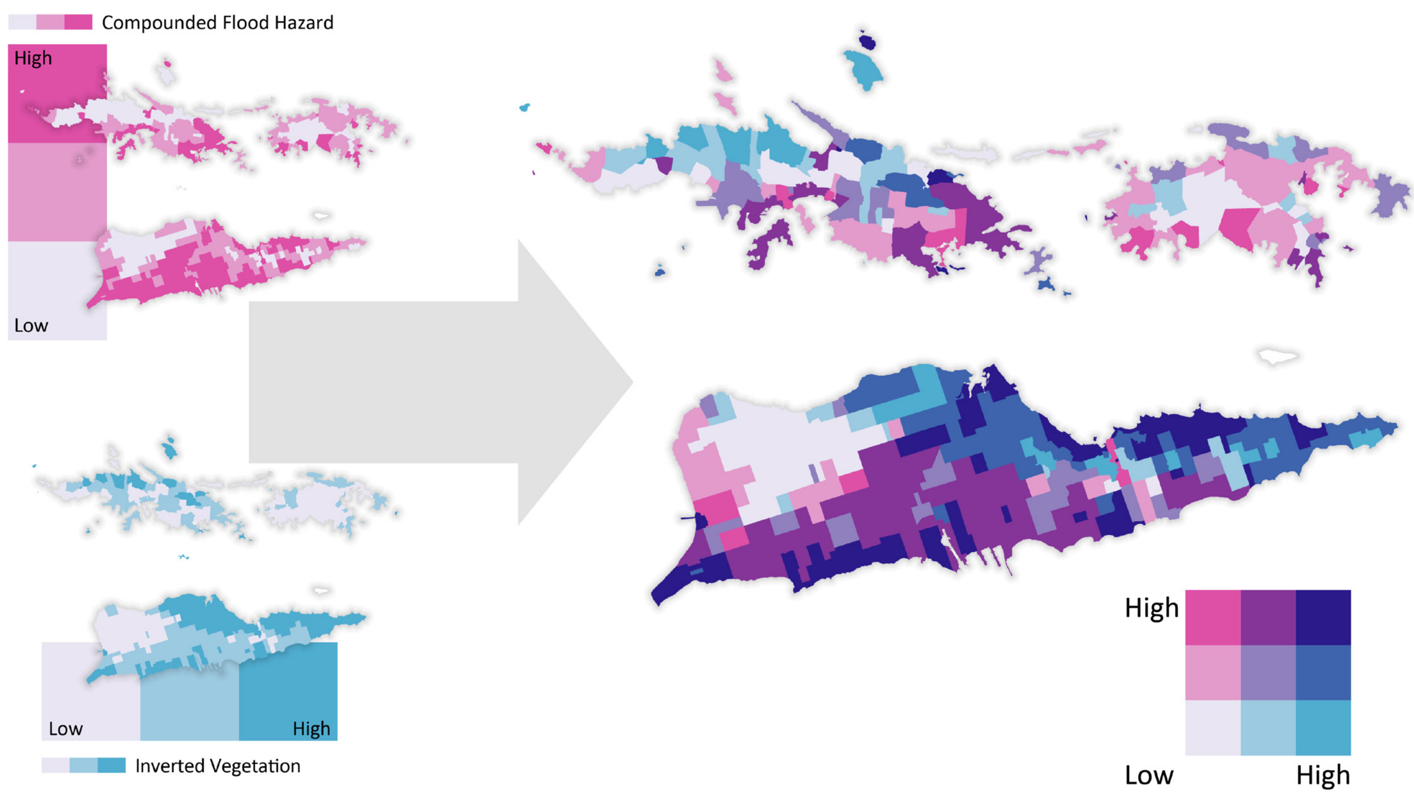

Figure 47. Compounded flood hazard in relation to inverted vegetation.

3.3 Nearshore Environment Interactions

Offshore and nearshore marine environments as well as their underlying sea floor bathymetry provide a level of natural protection to adjacent coastal communities and assets (Arkema et al., 2013; Barbier et al., 2011; Beck et al., 2018). This subsection of maps explores the relationships between the nearshore environment and other assessment components, highlighting the flood-mitigating properties of natural nearshore environments and their inherent protection benefits. First, Figure 48 highlights socially vulnerable populations closer to the shoreline with varying degrees of protection value from nearshore environment. It shows the relationship between the nearshore environment and social vulnerability indices (restricted to coast-adjacent estates with sufficient population data), where areas with higher social vulnerability and higher nearshore environment protection benefits are identified in dark blue. These estates are found mostly throughout south-central St. Thomas, central St. John including around Maho Bay and areas of Coral Bay through Mandahl, and Frederiksted on St. Croix. These pockets of more socially vulnerable populations closer to the shoreline receive relatively more protection value from nearshore environments; though, studies have shown that these benefits sharply decline as coastal storm intensity increases (Temmerman et al., 2023). This is true for all of the maps in this subsection.

Estates shown in bright pink, however, still have similar levels of social vulnerability but lower nearshore environment protection benefits, leaving these coastal populations potentially more at risk. These estates are found mostly in eastern St. Thomas, areas from Salt River through parts of Christiansted in northern St. Croix, as well as parts of St. Croix's southern shore, including Whites Bay, parts of the airport, and part of Great Pond Bay. These are areas where already higher social vulnerability might be exacerbated by lower likelihood of coastal protection and might be candidates for additional protections. As suggested in Section 3.2, coastal hybrid solutions that combine gray and green structures might be effective flood-mitigating strategies. Nature-based approaches often have lower implementation costs (Ferrario et al., 2014), support ecosystem functions, and have the capacity to self-build and self-repair (Ghiasian et al., 2021), but the integration of artificial structures as well encourages better protections as storm intensity increases. Natural solutions are recommended by both the territory's 2019 Hazard Mitigation Plan (Virgin Islands Territorial Emergency Management Agency, 2019) and the draft 2024 plan (USVI Hazard Mitigation and Resilience Plan, 2024).

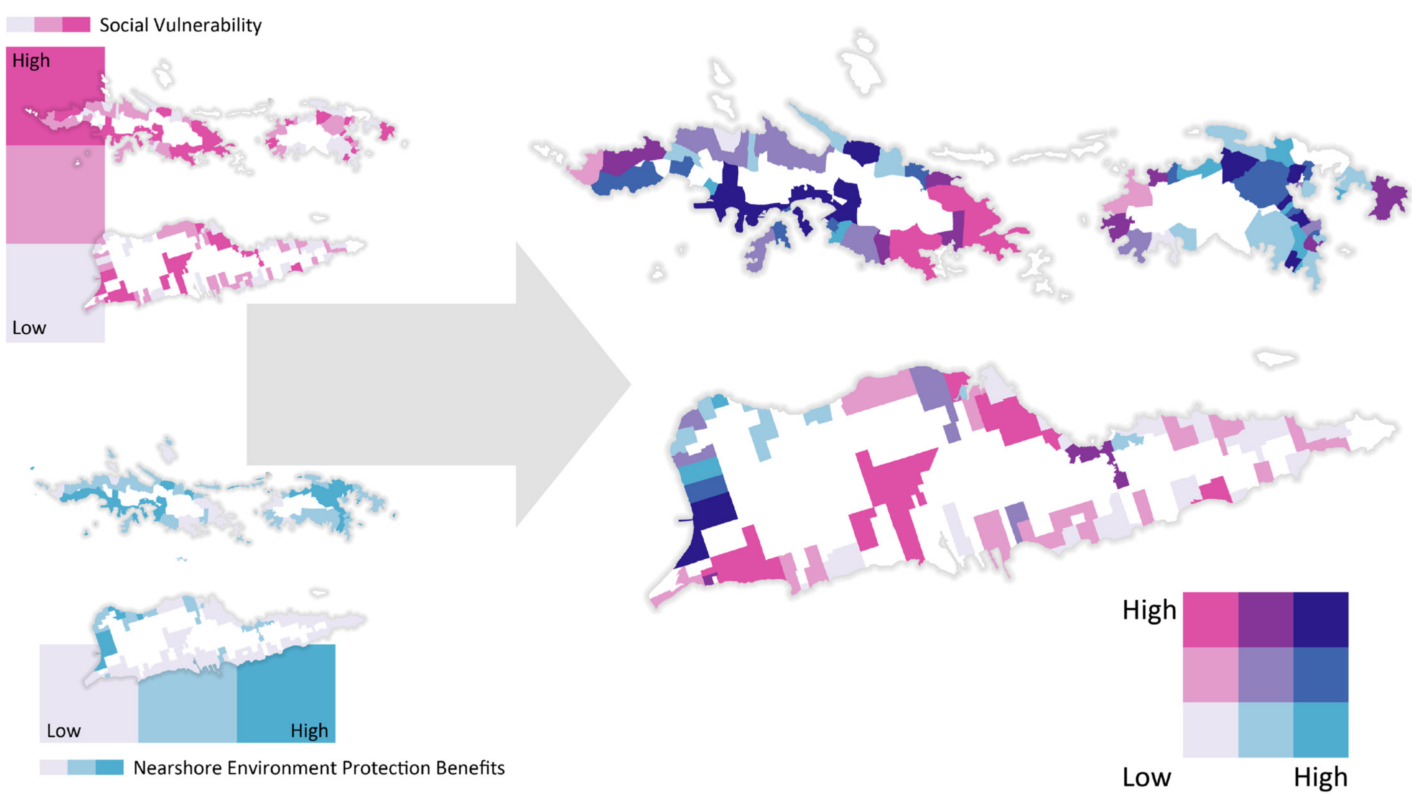

Figure 48. Nearshore environment protection benefits in relation to social vulnerability.

Figure 49 highlights areas where structures might be at increased risk from coastal storms since nearshore environments are less likely to offer as much protection. It shows the relationship between the nearshore environment and structural vulnerability indices (restricted to coast-adjacent estates), where areas with higher structural vulnerability and higher nearshore environment protection benefits are identified in dark blue. These estates are gathered largely throughout south-central St. Thomas, throughout central St. John, and around Frederiksted on St. Croix. The more vulnerable infrastructure identified in these estates is relatively more protected by nearshore environments. The estates shown in bright teal, however, still have the same relatively high structural vulnerability but lower nearshore environment protection benefits. These estates are found mostly throughout coastal St. Croix, from Baron Bluff through Christainsted, Carden, and Teagues Bay in the north, and from Whites Bay to parts of the airport, refinery, and Canegarden Point in the south. There are also identified areas in western St. John around Caneel Bay and Fish Bay. In response, these estates might be candidates for additional protections as discussed in the prior paragraph.

Figure 50 highlights areas with critical infrastructure that might potentially be at increased risk from coastal storms by showing the relationship between the nearshore environment and structural exposure indices (restricted to coast-adjacent estates), where areas with higher structural exposure and higher nearshore environment protection benefits are shown in dark blue. These estates are identified in similar areas to the previous map: largely throughout south-central St. Thomas but also in southwestern St. Thomas, throughout central St. John, and around Frederiksted on St. Croix. The infrastructure identified in these estates are relatively more protected by nearshore environments. The estates shown in bright teal, however, still have relatively high structural exposure, but lower nearshore environment protection benefits. These estates are found throughout St. Croix's northern and southern coasts, in eastern St. Thomas, and western St. John. These estates may also be candidates for additional protections.

Figure 51 highlights estates that are relatively more exposed and less likely to absorb flood waters due to less vegetation cover. It shows the relationship between the nearshore environment benefits and vegetation indices (restricted to coast-adjacent estates) so that areas of dark blue highlight estates with higher nearshore environment protection benefits and higher onshore vegetation values. Dark blue estates are found mostly scattered throughout south-central to southwest St. Thomas and are only in northwestern St. Croix around Mahogany Road and parts of Maroon Ridge. Central St. John is again identified as well as new areas from Brown Bay to Hermitage and Turner Point.

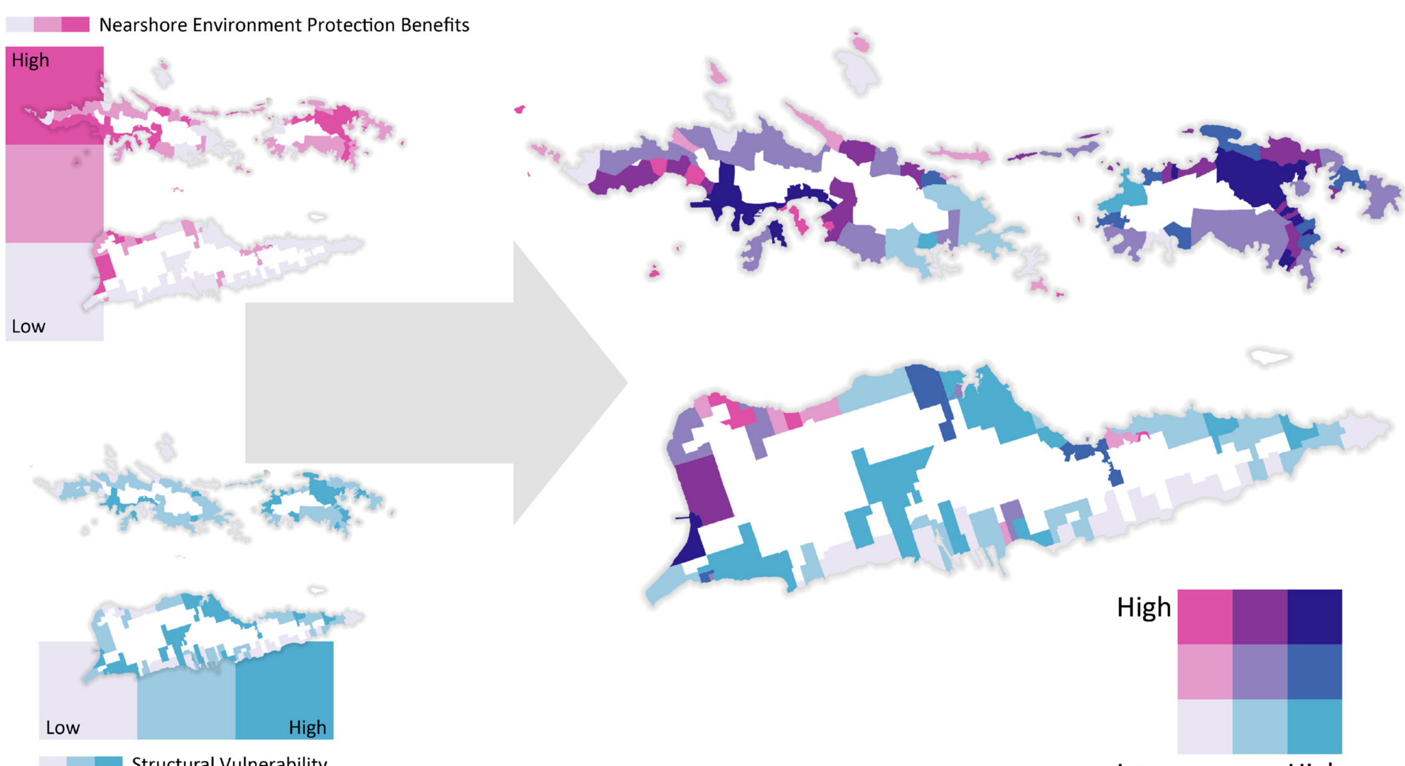

Figure 49. Nearshore environment protection benefits in relation to structural vulnerability.

These estates have higher natural infrastructure mitigation properties both from nearshore and onshore environments related to flooding. Conversely, coastal estates shown in gray are less protected from nearshore environments and have less onshore vegetation. These are found primarily along about half of St. Croix's shores, from north-central eastward as well as southwest. There is also a pocket in north-central St. Thomas around Neltjeberg Bay.

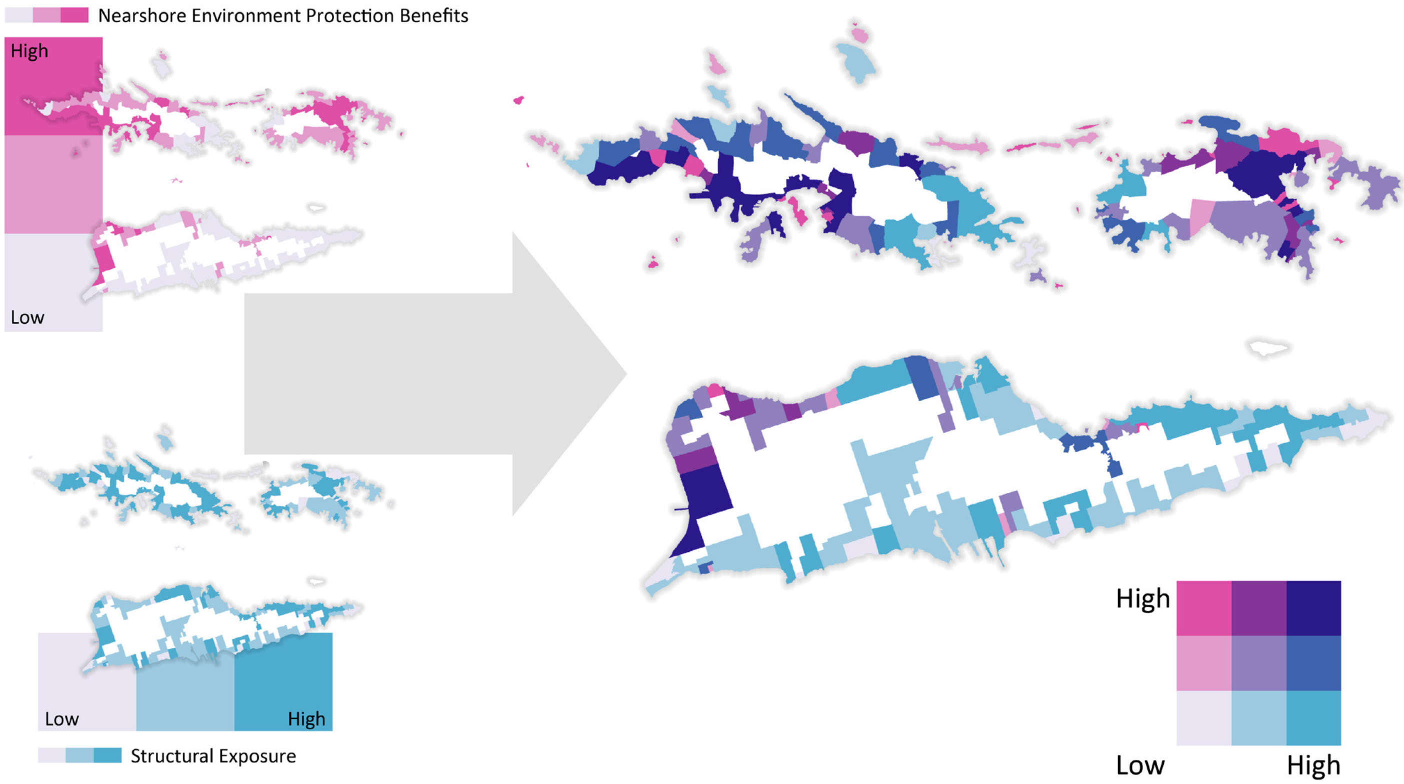

Figure 50. Nearshore environment protection benefits in relation to structural exposure.

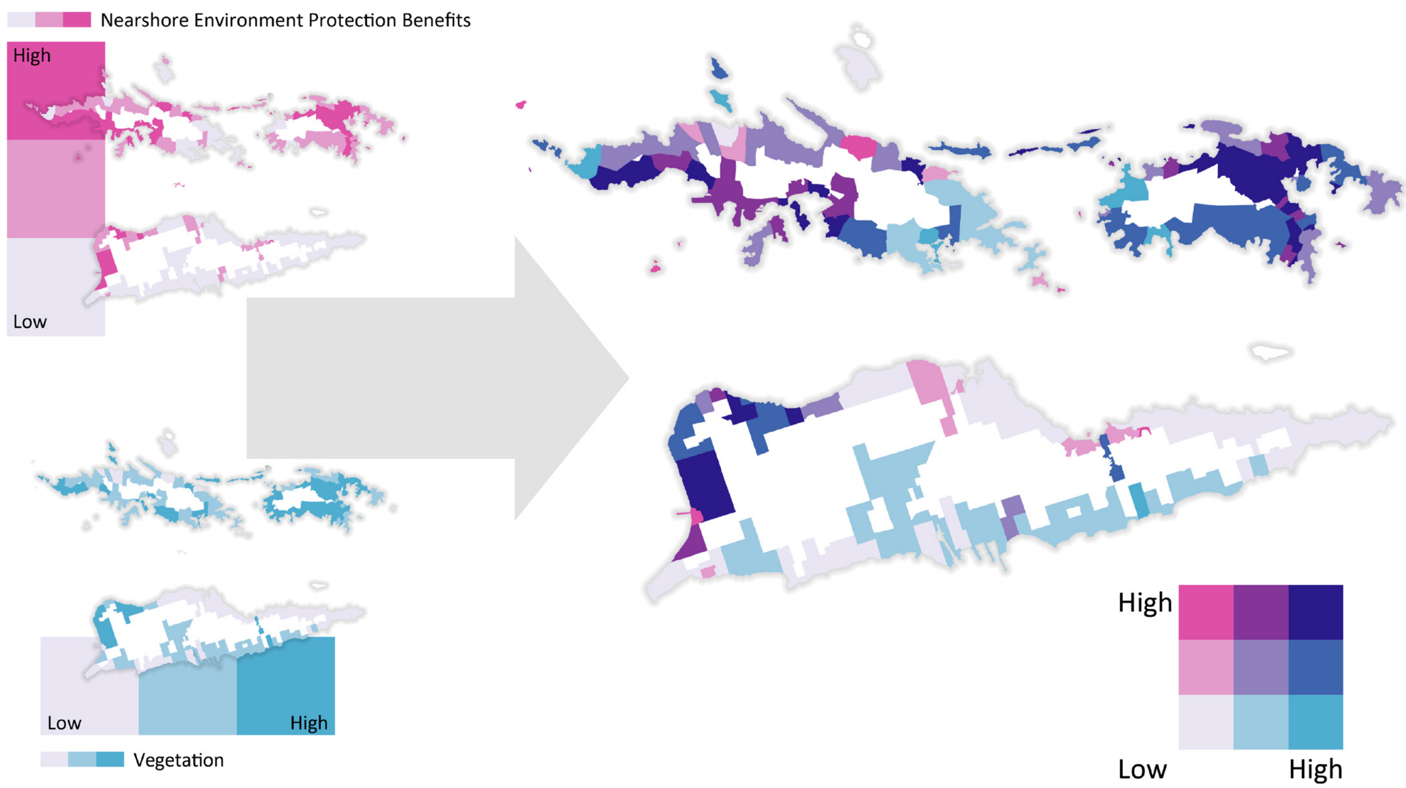

Figure 51. Nearshore environment protection benefits in relation to vegetation.

3.4 Other Important Relationships

Deteriorated infrastructure, USVI. Credit: Seann Regan (CSS Inc./NOAA NCCOS)

Other important interactions are discussed in this section. First, Figure 52 shows the interaction between social vulnerability and waterborne toxins and contaminants (restricted to estates with sufficient population data). Dark blue areas highlight estates likely to experience higher social vulnerability as well as higher potential for waterborne toxins and contaminants exposure. Areas of greatest interest on St. Thomas are around the airport through Charlotte Amalie, as well as eastern St. Thomas from Bovoni Estate to Secret Harbor Beach and north through Anna's Retreat. On St. John, Cruz Bay and East End are identified, as well as pockets from Carolina to Concordia. On St. Croix, dark blue estates are found mostly inland in south-central areas as well as part of Christiansted. Those most socially vulnerable have a history of disproportional toxin and contaminant exposure and health impacts (Fedinick et al., 2019; Heaney et al., 2011). A study that examined safe drinking water act violations across the U.S. found that 70% of health-based violations occurred in communities characterized by high social vulnerability (Scanlon et al., 2023). The study also found that recurrent violations were also associated with higher likelihood of social vulnerability. This has synergies with the present research team's finding of recurrent violations in the USVI (see Section 2.4). Safe drinking water is of critical importance in the territory, and despite the potential for waterborne toxins and contaminants to affect those more vulnerable in Figure 52, the input data exclude potential cistern contaminants due to limited data availability. Given complementary research that found contaminants in a majority of drinking water samples studied (Rao et al., 2022), the potential for waterborne toxins and contaminants is likely greater than the present assessment's findings. This is especially true when considering that exposure to waterborne toxins is not limited to drinking water but also occurs through recreational and agricultural activities. The USVI's water distribution systems are complex and at increased risk during and following hurricanes and other storm events, especially those that result in extended power outages (Klise et al., 2022). Though the territory's potable water systems could benefit from systematic upgrades, the identified dark blue estates might benefit from pilot initiatives to serve those most at risk and most vulnerable. This recommendation was also made by the territory's 2019 Hazard Mitigation Plan (Virgin Islands Territorial Emergency Management Agency, 2019).

Figure 53 shows social vulnerability intersected with walkability potential (restricted to estates with sufficient population data), where dark blue areas highlight estates with higher social vulnerability and higher potential for walkability. Key areas include the downtown bay areas of Charlotte Amalie and Benner on St. Thomas, Cruz Bay on St. John, and Christiansted and Frederiksted on St. Croix, as well as some other inland pockets. Despite the potential for better walkability and access to transit, a study investigating walkability of the 106 most populous metropolitan statistical areas in the U.S. found that populations with high social vulnerability that lived in more walkable neighborhoods were also more likely to experience higher levels of personal crime (Bereitschaft, 2023). Higher crime rates and sometimes only the perception of higher rates have been shown to reduce walkability (Hong and Chen, 2014; Rees-Punia et al., 2018). Since crime, safety, and resident perceptions of these metrics were omitted from the present assessment, the potential walkability shown is likely unrealistic in some areas. Future efforts could consider overlaying spatially explicit crime statistics on this map and/or recalculating the walkability index to incorporate these statistics for a more holistic understanding of walkability within the territory. In contrast, areas identified in bright pink have higher social vulnerability but lower walkability. On St. John, East End, Dennis Bay, south of Grunwald, north of Bethany, and south of Carolina are identified. Small pockets in Charlotte Amalie East and north of Lilliendahl are identified on St. Thomas, and there is a block of estates from Frederiks Haab to Hope on St. Croix, as well as one small estate near Frederiksted Southeast and another east of Fredensdal. These estates might be considered for future infrastructure projects that may increase walkability and positively impact social vulnerability.

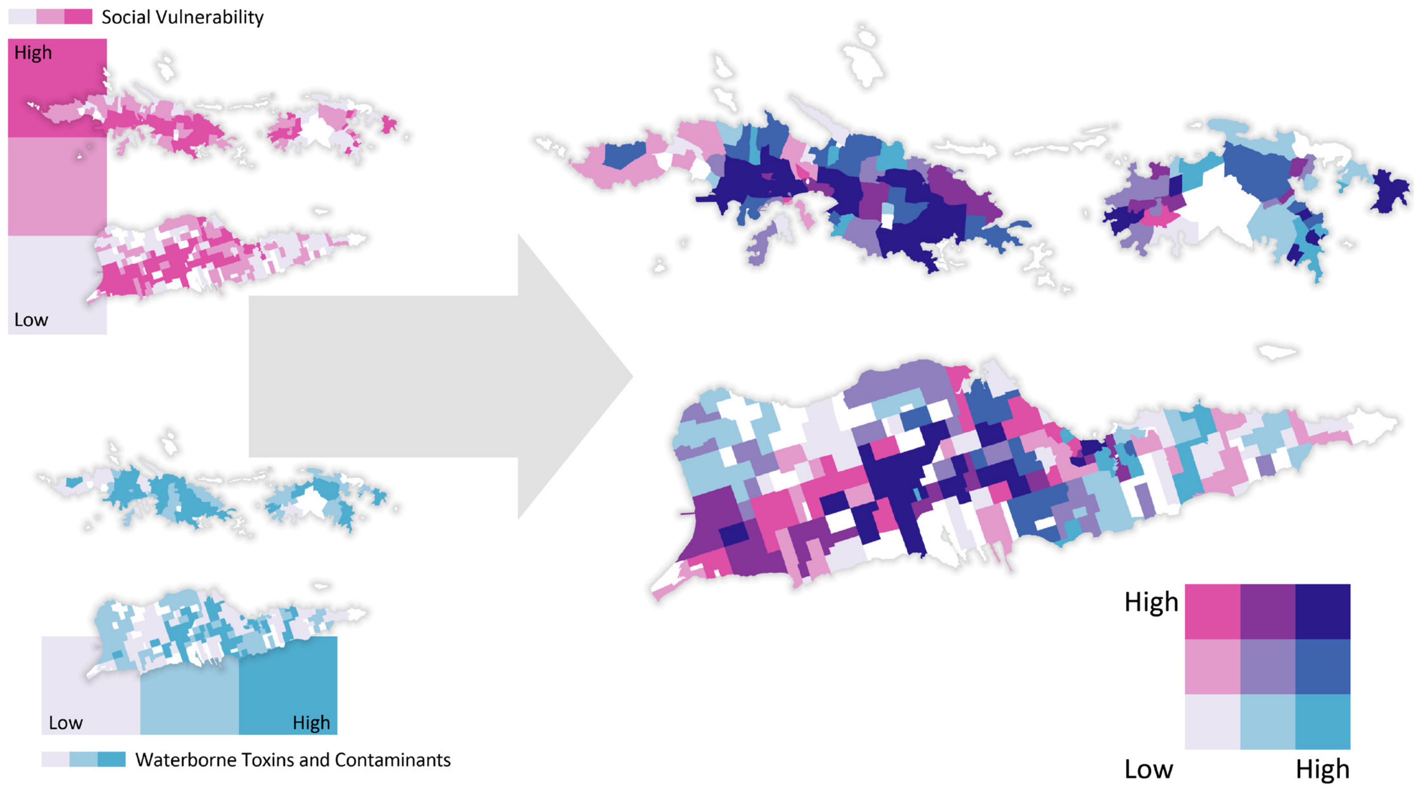

Figure 52. Social vulnerability in relation to waterborne toxins and contaminants.

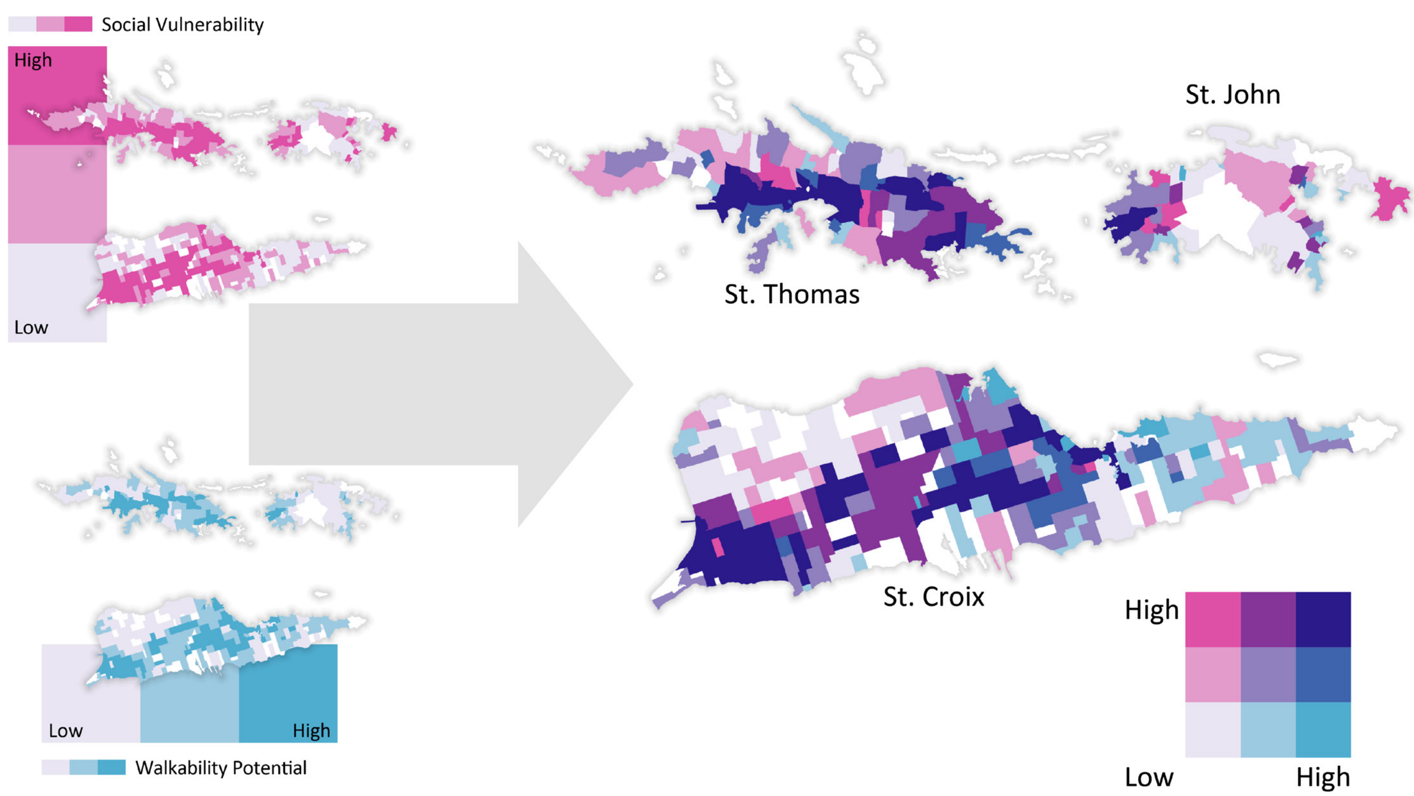

Figure 53. Social vulnerability in relation to walkability potential.

Lastly, Figure 54 shows potential walkability intersected with vegetation. The vegetation index was inverted so that dark blue areas identify estates that are more likely to have higher walkability, but lower vegetation. The majority of dark blue estates are found on St. Croix, loosely gathered from Judith's Fancy through Christiansted, from Altona Lagoon Park through Shoy's Beach, Grapetree, Whim, the Frederiksted Pier area, and some pockets throughout the central island. On St. Thomas, estates around Anna's Retreat, Mandahl, and Frydendal are identified, with no dark blue estates on St. John. As described in the paragraph above, higher walkability potential may not always equate to increased walkability in practice since safety and perceived safety data were unavailable for analysis. One approach to encourage actual walkability within the territory is to restore green space and vegetation to encourage walking through aesthetics, shading, and heat reduction (Tsai et al., 2019), and since the dark blue estates in Figure 54 have relatively less vegetation and already high walking potential, these areas might be socially ideal for restoration. This approach would be potentially less effective in bright pink estates such as in parts of downtown St. Thomas and St. John, because these estates are identified as already having relatively high vegetation as well as high walkability. In these areas, other social measures focused on improved amenities and safety might have a larger impact on residential walkability.

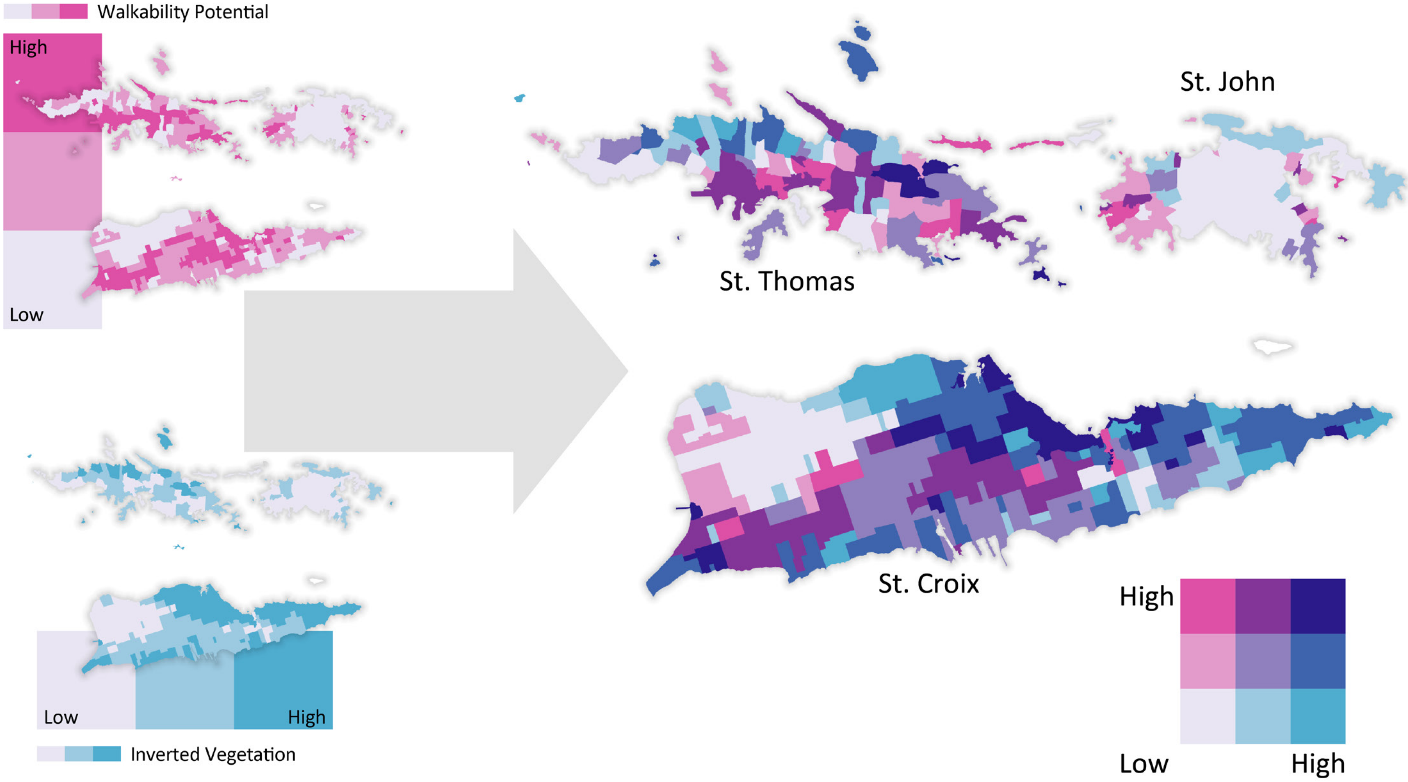

Figure 54. Walkability potential in relation to inverted vegetation.

Seaborne Seaplane Terminal and Wapa Powerplant, Christiansted Harbor, St. Croix. Credit: Chloe Fleming (CSS Inc./NOAA NCCOS)

4. Applications & Conclusions

This community vulnerability assessment strives to close gaps in USVI vulnerability research to support near-term and future planning efforts related to climate action and adaptation in the territory by providing an estate-level integration of vulnerability, exposure, hazard, and risk. In general, assessment maps highlight that USVI communities are at risk for flooding, toxins, and contaminants but that some estates have higher risk than others. Some of the territory's most socially vulnerable populations have increased risk of waterborne toxin and contaminant exposure, more vulnerable housing, and increased risk of flooding. Many of the territory's industrial and waste management sites are in coastal areas at risk of flooding, and adjacent and downstream communities should exercise increased caution when flood events occur. Much of the territory's critical infrastructure is in areas of high flood risk and overlaps with areas of increased structural vulnerability, including around Charlotte Amalie, Frederiksted, and Christiansted. Since most critical infrastructure services not only nearby areas but often the entire island, damage or loss of this infrastructure can have devastating effects on the territory.

Aerial photography from seaplane, USVI. Credit: Chloe Fleming (CSS Inc./NOAA NCCOS)

In response to these risks, preparation and action is encouraged. Assessment maps and data can be used by local governments, natural resource managers, community planners, and other partners to establish adaptation priority areas related to flood hazard, contaminants, and community use. Alongside other local datasets and technical expertise, the identified areas can then be further investigated for siting decisions and project planning. Maps and supporting data can be used for a variety of end goals. The assessment can support the first goal of the USVI's current draft Hazard Mitigation and Resilience Plan (USVI Hazard Mitigation and Resilience Plan, 2024, Ch. 7)(under public comment at the time of drafting) to "Manage natural hazard risk by applying risk reduction (mitigation) policies to prevent new risk, reduce existing risk, and adapt to the future risk associated with climate change by strengthening infrastructure, critical facilities, and lifelines" by providing technical support and project siting guidance. It can also inform future hazard mitigation plan updates and similar territorial planning documents, support parks and green-space projects within the USVI Department of Planning and Natural Resources' new Division of Territorial Parks and Protected Areas (Akin, 2023), inform natural resource planning and wildlife management, or support watershed management, stormwater control measures, or implementation of nature-based solutions.

This assessment can be used in a variety of ways. First, the bivariate maps provide visual summaries of relevant interactions among vulnerability, exposure, hazard, and risk. As suggested throughout Section 3, each bivariate map can suggest priority areas for unique action items related to the intersected indices. Potential future projects might include efforts to:

- Improve plumbing and kitchen facilities (both in the home and supporting infrastructure) in estates with higher structural vulnerability;
- Update or improve critical infrastructure in at-risk estates;
- Implement coastal gray-green hybrid solutions for improved flood mitigation for estates with reduced nearshore environment protection benefits or those at increased risk of flooding;
- Restore or increase onshore vegetation to improve natural flood attenuation in areas with limited vegetation;
- Systematically upgrade potable water systems through pilot initiatives to serve those most vulnerable and at risk;
- Increase greening efforts in areas with high potential walkability but lower vegetation to improve aesthetics, increase shading, and maximize heat reduction; and
- Increase walkability potential in areas of higher social vulnerability.

These potential efforts support the goals of the territory's 2019 Hazard Mitigation Plan (Virgin Islands Territorial Emergency Management Agency, 2019) and the 2024 draft update (USVI Hazard Mitigation and Resilience Plan, 2024), are mentioned explicitly as recommendations within one or both of these documents, and/or support overall well-being and quality of life in the USVI.


Seascape, USVI. Credit: Seann Regan (CSS Inc./NOAA NCCOS)

Bivariate maps can also help to inform or improve communications and outreach materials. For example, emergency response and planning teams might find certain maps useful in conveying areas of high avoidance to residents during disaster events, and other maps might support sheltering protocols or emergency triage maps for emergency response teams. Other maps might inform public awareness campaigns that communicate potential contaminant and toxin risk related to drinking water, swimming and wading, or subsistence seafood harvest, as well as circumstances that might cause risks to increase. The specific bivariate maps shown in section 3 were prioritized by local partners, and the potential management actions described address those specific interactions. To assess additional needs, other map intersections can be created from the available geodatabase.

Second, in addition to individual bivariate maps, some estates consistently emerged as high interest across bivariate maps. For instance, higher social vulnerability, structural vulnerability, and structural exposure all co-occur in areas around Cyril E. King Airport and parts of Charlotte Amalie on St. Thomas; southern Cruz Bay, northern Coral Bay, and around Carolina, Calabash Boom, and Mandahl on St. John; and parts of west-central St. Croix from around Plessen to Sunny Isle, as well as Frederiksted southeast and south of the pier, and parts of Christiansted. These areas of repeated co-occurrence not only suggest the need for adaptation action in the face of a changing climate but also present an opportunity to develop and implement innovative strategies that mitigate multiple concerns at once. For example, Estate Bovoni on St. Thomas has high co-occurrence of social vulnerability, structural exposure, waterborne toxins and contaminants, and compounded flood hazard, whereas Judith's Fancy on St. Croix has high co-occurrence of structural vulnerability, structural exposure, compounded flood hazard, walkability, and low vegetation. Flooding events in both examples have higher likelihoods of impacting critical infrastructure, but in Estate Bovoni, flooding might result in increased likelihood of waterborne toxin and contaminant release, while flooding in Judith's Fancy might interrupt resident walkability and overwhelm available vegetation. Solutions in each of these estates might be designed accordingly. Some of these consistently emerging estates might have larger implications. For instance, on St. Croix, the estates in the Annaberg area have high co-occurrence of social vulnerability, structural vulnerability, compounded flood hazard, waterborne toxins and contaminants, and low nearshore environment protection benefits. This area also contains the island's only landfill. If severely flooded, landfill toxins and contaminants have the potential to leach into water supplies, potentially putting already socially vulnerable communities at increased risk.

Third, though this assessment emphasizes the resulting bivariate maps, the individual assessment components may also be useful in certain management and planning contexts. Due to the complexity of the bivariate map legend, there is less resolution provided for each index scale (i.e., three groupings of low, medium, and high). The individual component scales shown in Section 2 are able to provide better resolution with up to seven groupings per scale. This allows users to separate relatively high index values from the highest index values for more nuanced prioritization and investigation. To further advance the capabilities of this assessment, each component index could be requantified from relative scales of low to high to set thresholds. For example, the final potential walkability index could be refined to walkable and non-walkable areas based on slope or another chosen constraint.

Fourth, the underlying component variables might also be integrated and assessed together. For example, if a planning department was considering installation of a new service tower, they could examine the communications infrastructure indicator or its variables and compare existing infrastructure with compounded flood hazard in low-lying areas or only stormwater flooding hazard in higher areas to consider future installment sites. This subset of potential sites could then be further evaluated by on-the-ground engineering specialists and other experts.

As a final product, this assessment can also be used to support grant applications by demonstrating need and advocating for climate action. The variety of assessment outputs allows for management action based on various time horizons, management needs, levels of political and public support, and availability of funding. The results provide opportunities for planners to make educated trade-offs when prioritizing resources for adaptation and mitigation action. Further, many of the findings in this report related to green infrastructure and stormwater management support existing recommendations found in the territory's Environmental Protection Handbook (Horsley Witten Group, 2022). This handbook and other territory policy documents can support next steps related to climate adaptation action.

4.1 Limitations and Future Research

This assessment faced limitations centered around data and metadata availability. For example, an extensive stormwater modeling study had been completed for the territory (RMSI, 2021), but the research team was unable to access the underlying data that contributed to this modeling effort. In another example, areas around the St. Croix refinery have high hazard but score low in waterborne toxins and contaminants, social vulnerability, and structural indices. This is largely due to limited data availability and how data are compiled and reported instead of suggesting that these areas have true low potential for waterborne toxins and contaminants. More research in refinery-adjacent communities could be beneficial. As with all NCCOS assessments and pursuant to NOAA's open science goals (NOAA, 2023), the research team used the best available data, and all assessment data are publicly available for sharing and replication. The USVI could benefit from initiatives to improve quality and access to data to better support local communities and future adaptation planning efforts.

In addition to the suggested potential applications provided earlier in Section 4, this assessment also joins the suite of available territory research (e.g., Guannel et al., 2022a; Mckayle et al., 2019) that provides foundations for additional research and analysis. The geophysical, ecological, and socioeconomic differences among the islands (described in Section 1.2) suggest some variation in each island's priorities. Future researchers could consider recalculating the relative index scores presented in this assessment by island. This effort would reprioritize estates within each island instead of across islands, and potentially highlight areas of need for island-level decision making. Another area of potential continued research is examining heat impacts. At the time of assessment scoping, there was insufficient in situ or on-the-ground data available to investigate this; however, the vegetation index may serve as an indirect proxy and would be a useful comparison if and when heat analysis is conducted.

Related to data restrictions, there are many potential analyses in the USVI that require additional data. For example, there was significant interest in household hazardous waste and electronic waste during assessment scoping. These topics are discussed in Section 2.4, but future research might consider household inventories or resident surveys to measure the extent of this issue and inform future solutions. The territory might also consider systematic monitoring of private cisterns for potential contaminants or developing a territory-led beached sargassum citizen science or webcam-recorded database. Other primary data collections could monitor the status and health of ghuts across the islands to better understand water flow and areas prone to blockage and discarded waste.

Downtown Christiansted, St. Croix. Credit: Seann Regan (CSS Inc./ NOAA NCCOS)

Applications & Conclusions

As datasets become available, the incorporation of projected datasets, such as land use change and population change data would provide additional insights related to projected sea level rise impacts for aid in future scenario planning. The continuation of research in the USVI will continue to enhance the information available for decision makers and planners. Without the science needed to create and implement climate adaptation action, USVI communities are at risk.

This community vulnerability assessment is the first implemented under NCCOS's new programmatic research approach and the fifth assessment overall. This assessment benefited from improvements and advancements learned from past assessments. First, this assessment maintains use of NCCOS's flexible and stakeholder-influenced assessment methodology, where the assessment components and their sub-indices and variables are constructed based on the best available scientific methodologies as well as partner priorities and local needs. This is the first time an NCCOS assessment has included waterborne toxins and contaminants or walkability indices. Second, the research team continued the practice of iterative partner and stakeholder feedback. This was critical within the present assessment as multiple component methodologies were significantly revisited following review sessions, especially the nearshore environment protection benefits and vegetation indices. Consulting with local experts was also imperative in using appropriate and accurate terminology for many of the component names. These review and revision processes emphasize the importance of local partnership, collaboration, and consultation. Lastly, while this assessment constitutes the first iteration under the NCCOS programmatic research approach, there are lessons to be learned with each new assessment, and the research team will apply these lessons to future assessments when feasible.

From an NCCOS programmatic perspective, future research might also consider additional methods of spatial refinement and downscaling of social and other datasets. Though the NCCOS research team did not conduct the social vulnerability research within the present assessment, the use of census geographies as the limiting unit of analysis is not new. To date, NCCOS has conducted assessments at the Census Block, Block Group, Zip Code Tabulation Area, and now at the Estate. Appropriate downscaling of social data and its inherent personally identifiable information concerns and the desire for consistency among assessment component indices has resulted in the above unit of analysis decisions; however, future assessments might consider other approaches such as dasymetric analysis using land cover and other spatial data to help determine where populations are distributed within census geographies and allow for more refined assessments.

The USVI integrated community vulnerability assessment and supporting complementary research provides meaningful information to better protect, advance, and manage climate change impacts within the territory's local communities.

St. Thomas sunset. Credit: Seann Regan (CSS, Inc./NOAA NCCOS)

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Appendices

Appendix A: May 2023 Workshop Summary

USVI Community Vulnerability Assessment: Stakeholder Workshop Summary

May 17th and 18th, 2023

NOAA's National Centers for Coastal Ocean Science (NCCOS) held three stakeholder workshop meetings on May 17th and 18th, 2023 to inform the project scope for the present assessment. These sessions (A-C) were designed to facilitate small-group conversations and provide all interested parties a voice in the research process. Note: Cells highlighted green indicate higher final rankings for all tables in this appendix.

Workshop Key Findings

Structural vulnerability and exposure – Stakeholders prioritized critical infrastructure, wastewater systems, road systems, and waste management (i.e., landfills). They highlighted the need to include nature-based flood mitigation infrastructure like coral reefs and breakwaters as an expanded category of critical infrastructure. Other emphasized components of critical infrastructure included utilities/power, telecommunications (buried vs. elevated), ocean access (marinas/boat ramps), drinking water (public and private, including cisterns), and port infrastructure.

Flood hazard – Stakeholders generally prioritized higher-strength storm surges (specifically, hurricane Categories 3 and 5), sea level rise, and stormwater flooding as key concerns within the territory.

Place-based analysis topics – While many topics were discussed, stakeholders prioritized toxin and contaminant concerns, green-space analysis and access, and an overall transportation assessment. Participants brainstormed a long list of toxins and contaminants such as vessels, household hazardous materials, medical waste, electronics waste, aging systems, landfills, industrial areas, sargassum, and contaminants to ocean water, drinking water, and soil. Green spaces were emphasized for their importance for well-being and food security; drainage, water absorption, and erosion-prevention benefits; heat impacts reduction; and alignment with complementary territorial research. A transportation assessment was strongly suggested due to overall transportation and access issues within the territory, safety and quality-of-life concerns, and additional stressors during disaster scenarios.

Workshop Goals and Tools

The goals of the workshops were to 1) provide overviews of NCCOS's programmatic portfolio approach and the USVI assessment, 2) gather feedback from stakeholders to better understand territorial needs, 3) gather input that can be used to modify and improve the existing project scope, and 4) share next steps and project trajectory.

The workshops utilized polling, ranking exercises, and facilitated discussion to better understand territory needs related to social and structural vulnerability, flood hazard, and additional place-based analysis topics. They also incorporated discussions of local data and leveraging opportunities within the territory.

Detailed Workshop Summary

I. Social Vulnerability

In support of project partners' plan to update the territory's social vulnerability index, additional complementary data outside of the CDC framework is being considered for further analysis within the following categories, dependent on partner and stakeholder priority and data availability. Participant prioritization of these topics is shown in Table A1.

Table A1. Participant prioritization of social vulnerability categories.

Items	Rankings: Session A	Rankings: Session B	Rankings: Session C	Total
Inflation/cost of living	5	1	5	11
Job security	0	1	0	1
Reliance on ecosystems	5	4	1	10

Additional Insights:

- The rankings were fairly split between inflation/cost of living and reliance on ecosystems. Session A had a friendly debate over the interconnectedness of these two concepts where "everything depends on the ecosystem," but "money is needed to [improve/restore them]."

II. Structural Vulnerability and Exposure

A planned structural vulnerability to flooding index (with some exposure overlap) will have the following categories considered, again dependent on partner and stakeholder priority and data availability. Participants were first asked if anything was missing from this list and then to rank their top three elements of structural vulnerability. Findings are shown below in Table A2, with items added by participants denoted with an asterisk.

Table A2. Participant prioritization of structural vulnerability and exposure elements. Items added by participants denoted with an asterisk.

	Rankings			
Items	Session A	Session B	Session C	Total
Road systems	1	3	5	9
Building infrastructure	1	3	0	4
Impervious surfaces	0	2	0	2
Drainage system (guts)	2	1	3	6
Sidewalks	0	0	0	0
Critical infrastructure (e.g., hospitals, schools)	8	2	7	17
Wastewater systems	2	7	4	13
Solar panel distribution	0	0	0	0
*Nature-based drainage solutions (breakwaters, etc.) OR *Nature-based critical infrastructure (coral reefs)	7	4	n/a	11
*Personal cisterns	2	1	n/a	3
*Waste management (landfills)	3	n/a	3	6
*Utilities	2	n/a	n/a	2
*Potable public water systems	2	n/a	n/a	2

Additional Insights:

- Critical infrastructure, and what was or should be included as critical infrastructure, was a key topic across all sessions. There was emphasis on the inclusion of telecommunications and utility/power infrastructure (buried or above ground) and boat launches, marinas, and port facilities. Two of the sessions also highlighted the need to showcase natural flood attenuation infrastructure such as coral reefs as "critical" for analysis and final products.
- There was a focus on healthy and clean water, both public and private, as this is a concern now and into the future. Corrosion, salt-water intrusion, contamination, desalination process concerns, and lack of cistern regulations were all listed as threats to clean water supply. The water supply conversations were often linked to wastewater and broader waste management system vulnerabilities.
- Participants commented on the interconnectedness of these categories.
- Participants discussed why some of the categories were left with no votes and suggested that this was due to overlap in some of the broader categories (e.g., sidewalks could be nested within road systems or critical infrastructure) or overall impact (e.g., solar panel access is a lower priority to other more pressing needs).
- Session B participants noted that there may be differences among sessions, as off-island agency priorities may differ from local government priorities.
- Session A participants held a brief discussion on farm infrastructure, where it was decided that the underlying infrastructure to support farms (e.g., roadways, water supply) were more important to include (also, that farming concerns applied primarily to St. Croix).
- The issue of sidewalks reappeared in the place-based analysis section (see below).

Flood Hazard

It is planned that a suite of priority flood hazards will be investigated and then intersected with vulnerability to assess risk. Partners have suggested four areas to include: stormwater flooding hazard from extreme rainfall events, sea level rise flooding, hurricane storm surge, and high tide flooding.

Sea Level Rise

Per partner request, 2050 projection estimates are planned to be used with 1–2 ft of sea level rise (SLR). Participant feedback is summarized below.

- Session B participants suggested a multiagency set of SLR projections to consider.
- Session C participants had some concerns over planning for such a high level (1–2 ft) of SLR as that may put many communities underwater, and they recommended exploring or documenting the tipping point.

Hurricane Storm Surge

Participant prioritization of hurricane categories is shown below in Table A3.

Table A3. Participant prioritization of hurricane strengths.

Items	Rankings Session A	Session B	Session C	Total
Category 1	1	1	0	2
Category 2	0	2	0	2
Category 3	3	1	1	5
Category 4	0	0	0	0
Category 5	4	1	2	7

Additional Insights:

- There was an overall split between planning for lower- and higher-category storms. Session B participants felt that more frequent but less intense storms have had much more devastating impacts on island communities than on the mainland, and that Category 1 and 2 hurricanes are becoming more frequent with less time in between storms to recover. Conversely, Sessions A and C felt the opposite: that it would be better to prepare for the worst since they've been experiencing more and more high-strength storms, and preparations for the higher-category storms will also prepare for lower-category storms. This argues that more investments now will result in better preparation and decrease the need for repetitive investments after the fact.

Hazard Prioritization

Partners have stressed the importance of compounded flooding within the territory. The impacts of simultaneous flooding scenarios will be investigated, and participants were asked which of the following hazards they would eliminate, if needed. Results are shown below in Table A4.

Table A4. Participant prioritization of flood related categories.

Items	Rankings (for removal) Session A	Session B	Session C	Total
Stormwater (precipitation)	1	1	0	2
Sea level rise projections	1	3	3	7
Hurricane storm surge	0	1	0	1
High tide flooding	6	0	2	8

Additional insights:

- All sessions felt that SLR was closely related to one or more of the other hazards.
- Session A participants noted that the tide differential in the USVI is minimal, so while high tide flooding increases flood risk, SLR is likely to have a bigger impact. Conversely, Session B participants felt that the focus should be on managing hazards occurring here and now before shifting focus to future concerns. Session C participants were divided between these perspectives.

III. Additional Place-Based Analysis Topics

The project team currently has capacity to analyze two additional place-based topics related to vulnerability planning in the territory. While those choices may be limited by data availability and feasibility concerns, participants were first asked if anything key was missing from the list below and then asked to rank their top two choices. Findings are shown below in Table A5, with items added by participants denoted with an asterisk.

Table A5. Participant prioritization of additional place-based analysis topics. Items added by participants denoted with an asterisk.

Items	Rankings Session A	 Session B	 Session C	Total
Green-space index and access	4	4	4	12
Urban heat index	0	2	0	2
Beach access	0	0	2	2
Toxins and contaminants	7	5	6	18
Traffic congestion	0	0	0	0
*Impacts of sargassum on boat and fishing traffic	n/a	3	n/a	3
*Transportation assessment	8	n/a	n/a	8

Additional Insights:

- There was substantial interest in toxins and contaminants across all sessions. Since this category is broad, these are some of the suggested areas of investigation:
  - Displaced/sunken vessels with hazardous substances aboard
  - Household hazardous materials (better disposal options to avoid stockpiling)
  - Medical waste
  - Electronics waste
  - System leaks aboard vessels
  - Landfill seepage and wastewater leakage from septic systems, treatment plants, etc.
  - Industrial contaminants, to include the St. Croix refinery
  - Drinking water contaminants
  - Sargassum toxins
  - Ocean water contaminants and runoff
  - Soil contaminants
- There was consistent interest in green-space analysis. Session A participants shared news of an upcoming territory parks effort, so there might be good traction for this now. There was also emphasis on green space for food security and the importance of overall well-being. Participants of sessions B and C noted that a focus on green space would also capture drainage, water absorption, and erosion-prevention benefits. Session C participants highlighted the inverse relationship between green space and urban heat concerns.
- Session A participants reflected on the overall transportation and access issues in the USVI, both within this activity and in the earlier structural vulnerability activity. There was emphasis on how the USVI "is not walkable" (distances plus safety) and how this is impacting current accessibility and quality of life, but also how this is worsened during disaster scenarios. The importance of a transportation vulnerability assessment is high.
- Session B participants mentioned the current issues with sargassum and its impacts on tourism, water quality, shipping/boat access, access to fishing grounds, and well-being impacts from toxins/smell. Within the scope of this assessment, it was included as a possibility as related to shipping/boat access and fishing grounds access.

Participants Summary

Participants were invited to the workshop sessions based on interest, availability, and expertise within the USVI. The following Table A6 summarizes overall workshop participation across all sessions.

Table A6. Workshop participation summary by session, organization, and number of participants.

Workshop Session	Organization	Number of Participants
Session A	Virgin Islands Department of Planning and Natural Resources – Coastal Zone Management	1
	Virgin Islands Department of Planning and Natural Resources – Division of Fish and Wildlife	2
	Virgin Islands Lieutenant Governor's Office	1
	Virgin Islands National Park Service	3
	U.S. Environmental Protection Agency, Region 2	3
	Total	**10** (38%)
Session B	U.S. Fish and Wildlife Service (Southeast Conservation Adaptation Strategy)	2
	U.S. Geological Survey (Southeast Climate Adaptation Science Center)	1
	National Sea Grant	2
	Caribbean Integrated Ocean Observing System (CARICOOS)	1
	NOAA Office for Coastal Management – Southeast and Caribbean Regional Team	2
	Total	**8** (31%)
Session C	NOAA National Centers for Coastal Ocean Science	1
	NOAA Coral Reef Conservation Program	2
	NOAA Fisheries – Southeast Fisheries Science Center	3
	NOAA Fisheries – Southeast Regional Office	1
	U.S. Environmental Protection Agency, Region 2	1
	Total	8 (31%)
TOTAL		**26** (100%)

Appendix B: March 2024 Workshop Summary

USVI Community Vulnerability Assessment: Components and Prioritization Workshop Summary

March 5th and 8th, 2024

NOAA's National Centers for Coastal Ocean Science (NCCOS) held two stakeholder workshop meetings on March 5th and 8th, 2024, to continue informing the present assessment. These sessions (A and B) were designed to facilitate small-group conversations and provide all interested parties a voice in the research process. Note: Cells highlighted green indicate higher final rankings for all tables in this appendix.

Workshop Key Findings

Preliminary assessment component feedback – Participants communicated the need for clear legends and accompanying narratives for each index component map. The relative nature is helpful, but identifying threshold values or expanding the upper bounds of the index scores (i.e., extending from five to six or seven categories) would be helpful.

Mapping prioritization – While each index component is useful as a stand-alone resource, participants identified 16 priority map combinations. Common threads included social vulnerability, compounded flooding, and coastal protection.

Story map messaging – Participants identified six components or component combinations to incorporate within the ERSI StoryMap, focused largely on social vulnerability, compounded flooding, and coastal protection. The story map messaging will likely aid resource and land-planning management agencies but should also serve as outreach and education material for a wider end-user population.

Workshop Goals and Tools

The goals of the workshops were to 1) present preliminary assessment components and gather feedback for improvement, 2) prioritize index combination preferences for risk assessment, and 3) prioritize story map messaging. The workshop meetings also provided overviews of NCCOS's programmatic portfolio approach and the USVI assessment and shared next steps and project trajectory. The workshops utilized matching exercises, facilitated discussion, and Google Jamboard sticky notes.

Detailed Workshop Summary

I. Preliminary Assessment Component Feedback

Drafts of each of the individual assessment components were presented. Preliminary components: 1) were presented as estate-level aggregations to allow for eventual intersection with other components, 2) communicated relative (high to low) likelihood of hazard/vulnerability/occurrence across the territory, 3) used publicly available and shareable data in support of NOAA's open science standards, and 4) used diverse indicators and input variables, despite only showing the final indices.

A.1 Overall Insights

- Be cognizant of showing maps without descriptive narrative to avoid misleading and misinterpretation of results.
- Be clear in how scale breaks were determined for all indices.
- Consider expanding beyond five scale categories or other visualization methods to avoid conflating index values and masking key takeaways.
- Messaging is critical in communicating what these indices show and what they do not show.

A.2 Compounded Flood Hazard Index

- Hull Bay might not pass the gut check since there are compounded flooding issues there, so raster to estate and composite index calculations need to be confirmed.
- Be clear with legends and scale used.

A.3 Structural Exposure Index

- Discussion on relative scale vs. potential for thresholds.
- Utility in providing underlying data inputs as well as composite so end users know what is driving exposure scores in each estate. Consider having raster/point data map followed by composite index estate maps.
- Suggestion of breaking into more than five categories to highlight estates of highest exposure.
- Suggestion to revisit scale breaks and use statistical break quantiles to avoid conflating higher exposure levels and masking the bigger story.
- Be clear in how the breaks were determined for this and other indices.

A.4 Structural Vulnerability Index

- Include descriptive accompanying narrative on vacancy index because this could tell two different stories: 1) that vacancy data on St. John is driven by part-time residents and this could mask those living full time or 2) that vacancy data are true to the housing crisis where off-islanders have homes that aren't cared for and prevent islanders from accessing/renting/buying.
  - Be clear about vacancy data and what the categories of residential, commercial, and other mean and how they're gathered (e.g., based on USPS records? Are historic properties included?).

A.5 Coastal Protection Index

- Underlying habitat categories (four) need to be better visualized with an updated legend.
- Confirm accuracy of habitat data around St. John.
- Consider incorporating National Coral Reef Monitoring Program gridded system to update benthic data to a more accurate state, and consider incorporating resilient reef data to address questions of reef degradation.
- Be clearer in the underlying reef and habitat classifications, depth threshold, etc.

A.6 Social Vulnerability Index

- Lots of interest in incorporating this University of the Virgin Islands – Department of Planning and Natural Resources dataset.

A.7 Walkability Index

- Really important to communicate that this is the potential for walkable areas based largely on physical data, but excludes most social data (i.e., safety). This isn't "actual" or "realized" walkability, but a map of walkability potential or perhaps of where walkability improvement projects could be prioritized.
- Define walkability as everyday walkable access vs. recreational/exercise access, and note that this does not incorporate compliance with the Americans with Disabilities Act.
- Consider rescaling the index since the majority of the islands aren't walkable. For example, consider incorporating a threshold of what is realistically walkable and showing the relative walkability from there.
- Check on Sandy Point; it's showing as very walkable, but it's a giant beach without shade.

A.8 Vegetation Index

- Parks point data are likely not helpful to overlay since these are recreational parks, basketball. courts, etc., and are outdated. Consider incorporating other parks data or omitting from visuals.
- Check on the northwest corner of St. Croix from Hamm's Bluff to Carambola since that's relatively green; perhaps there are high reflectance values due to the type of vegetation and slope?

A.9 Waterborne Toxins and Contaminants Index

- Consider expanding the scale categories as the top category seems to be lumping areas of high toxins/contaminants with areas that should be relatively less. Perhaps a six or seven point scale.

II. Index Pairing Preferences

Participants were asked to choose only their top two pairing preferences for each index component. Summary tables for each component are provided below in Table B1 through B8.

Table B1. Participant prioritization of preferred compounded flooding index pairings.

COMPOUNDED FLOODING should be paired with:	Rankings Session A	Session B	TOTAL
Social vulnerability	3	5	8
Structural exposure	0	1	1
Structural vulnerability	2	2	4
Coastal Protection	4	5	9
Walkability	0	0	0
Vegetation	0	0	0
Toxins and contaminants	0	3	3

Table B2. Participant prioritization of preferred social vulnerability index pairings.

SOCIAL VULNERABILITY should be paired with:	Rankings Session A	Session B	TOTAL
Compounded flooding	3	0	3
Structural exposure	1	2	3
Structural vulnerability	1	5	6
Coastal Protection	0	5	5
Walkability	0	1	1
Vegetation	0	0	0
Toxins and contaminants	3	3	6

Table B3. Participant prioritization of preferred structural exposure index pairings.

STRUCTURAL EXPOSURE should be paired with:	Rankings Session A	Session B	TOTAL
Compounded flooding	3	4	7
Social vulnerability	1	6	7
Structural vulnerability	2	2	4
Coastal Protection	4	3	7
Walkability	0	0	0
Vegetation	0	0	0
Toxins and contaminants	0	1	1

Table B4. Participant prioritization of preferred structural vulnerability index pairings.

STRUCTURAL VULNERABILITY should be paired with:	Rankings Session A	Session B	TOTAL
Compounded flooding	4	4	8
Social vulnerability	1	5	6
Structural exposure	4	1	5
Coastal Protection	1	6	7
Walkability	0	0	0
Vegetation	0	0	0
Toxins and contaminants	0	0	0

Table B5. Participant prioritization of preferred coastal protection index pairings.

COASTAL PROTECTION should be paired with:	Rankings Session A	Session B	TOTAL
Compounded flooding	3	7	10
Social vulnerability	2	3	5
Structural exposure	0	2	2
Structural vulnerability	2	2	4
Walkability	0	0	0
Vegetation	1	2	3
Toxins and contaminants	0	0	0

Table B6. Participant prioritization of preferred walkability index pairings.

WALKABILITY should be paired with:	Rankings Session A	Session B	TOTAL
Compounded flooding	1	0	1
Social vulnerability	2	7	9
Structural exposure	0	0	0
Structural vulnerability	2	0	2
Coastal Protection	0	0	0
Vegetation	1	7	8
Toxins and contaminants	0	0	0

Table B7. Participant prioritization of preferred vegetation index pairings.

VEGETATION should be paired with:	Rankings Session A	Session B	TOTAL
Compounded flooding	1	5	6
Social vulnerability	0	3	3
Structural exposure	1	2	3
Structural vulnerability	0	0	0
Coastal Protection	4	5	9
Walkability	0	1	1
Toxins and contaminants	2	0	2

Table B8. Participant prioritization of preferred toxins and contaminants index pairings.

TOXINS AND CONTAMINANTS should be paired with:	Rankings Session A	Session B	TOTAL
Compounded flooding	5	4	9
Social vulnerability	4	8	12
Structural exposure	0	3	3
Structural vulnerability	0	1	1
Coastal Protection	0	0	0
Walkability	0	0	0
Vegetation	0	0	0

Additional Insights:

In summary, consider prioritizing the following map combinations:

- Social vulnerability with
  - Compounded flooding
  - Structural vulnerability
  - Structural exposure
  - Coastal protection
  - Walkability
  - Toxins and contaminants
- Compounded flooding with
  - Coastal protection
  - Structural exposure
  - Structural vulnerability
  - Toxins and contaminants
  - Vegetation
- Coastal protection with
  - Structural exposure
  - Structural vulnerability
  - Vegetation
  - Vegetation with walkability
  - Structural vulnerability with structural exposure

III. Story Map Question Prompts

Lastly, a series of question prompts were asked to inform development of the online ESRI StoryMap. The questions and key takeaways are summarized below. Each item was suggested only once unless accompanied by a parenthetical number.

C.1 If you had to choose only one, what is the most important component or combination to highlight in the story map?

- Emphasis on social vulnerability, overall
- Social vulnerability and structural vulnerability (2)
- Social vulnerability and coastal protection (3) or vegetation
- Compounded flooding and social vulnerability
- Compounded flooding and coastal protection
- Coastal protection as a stand-alone

C.2 We are considering the use of call-out boxes to zoom in on areas of interest. If you could only pick two areas of interest on St Thomas and St John, what would you pick?

- Charlotte Amalie/Frenchtown (4)
  - Including the watershed, Bovoni, and possibly St. Thomas East End Reserves
- Estate Bovoni and Nadir area (3)
  - Encompassing St. Thomas East End Reserves and Coral Bay, if possible
  - East End
- Coral Bay, St. John (2)
- Cruz Bay Quarter
- North shore of St. John

C.3 Now, which two areas would you pick for St. Croix?

- Frederiksted (7)
- Christiansted (5)
- Areas adjacent to the refinery/south shore (4)
    - And/or surrounding Krause Lagoon
- Somewhere relatively protected like the west end of Maroon Ridge

C.4 What lessons or insights do you hope readers or viewers will take away from the story map?

- Help decide where investments should be made (2).
- Identify areas that require management action to increase climate resilience.
- Identify where infrastructure may need to be moved or modified, and highlight the importance of these indices being incorporated into future infrastructure planning processes.
- Highlight how much of the islands' critical infrastructure and most vulnerable communities are at highest risk of flooding.
- Highlight how social vulnerability is the most important driver of many of these indices.
- Provide emphasis on connections and seeing connections among social vulnerability, flooding, green space, etc., and how interlinked these components are.
- Public service announcement–related general population outreach:
    - Identify areas of likely flooding to stay away from during emergency flooding scenarios (2).
    - Highlight that there is hope for action to minimize vulnerability and risk and that working together can accomplish more than can be done individually.

C.5 Who do you see as the story map's primary audience? Which user groups do you think will use the story map most? Or which user groups do you plan to share it with?

User groups seemed to fit within two general categories: planning and policy needs, and outreach and education needs. There's overlap between these categories, but they've been summarized as such below:

- Planning and policy
    - Territorial and federal government officials and agencies (5)
        - Including resource managers (2) and land management officials
    - Non-governmental organizations (2)
    - Scientists (2)
    - National leadership to include the U.S. Congress
- Outreach and education
    - USVI population (3)
    - Community advocacy groups (2)
    - Local schools

C.6 Do you have any other feedback you'd like to share on the assessment components or product development?

- Provide access to geodatabase that created the indices, and be clear in how categories (scale breaks) are defined
- Emphasis on scales for visualization of the maps
- Question: How has this project intersected with the USVI Hazard Mitigation Plan that is currently still in development?
- Praise

Participants Summary

Participants were invited to the workshop sessions based on interest, availability, and expertise within the USVI. The following Table B9 summarizes overall workshop participation across all sessions.

Table B9. Workshop participation summary by session, organization, and number of participants.

Workshop Session	Organization	Number of Participants
Session A	NOAA Fisheries Southeast Fisheries Science Center	2
	Virgin Islands National Park Service	3
	U.S. Environmental Protection Agency, Region 2	1
	University of the Virgin Islands	2
	Virgin Islands Department of Public Works	1
	Coral Reef Watch	1
	U.S. Geological Survey (Southeast Climate Adaptation Science Center)	1
	Total	**11 (52%)**
Session B	University of the Virgin Islands	1
	NOAA National Centers for Coastal Ocean Science	1
	NOAA Office for Coastal Management – Southeast and Caribbean Regional Team	1
	NOAA Coral Reef Conservation Program	1
	U.S. Environmental Protection Agency, Region 2	2
	Virgin Islands Department of Planning and Natural Resources – Division of Fish and Wildlife	1
	U.S. Fish and Wildlife (Southeast Conservation Adaptation Strategy)	1
	National Park Service, South Atlantic and Caribbean	1
	Virgin Islands Department of Planning and Natural Resources – Division of Territorial Parks and Protected Areas	1
	Total	**10 (48%)**
TOTAL		**21 (100%)**

Appendix C: Data Sources

Table C1. Data sources for structural vulnerability.

	Variable	Resolution	Year	Source	Notes
Communications Infrastructure	Cell service towers	point	2023	(U.S. Department of Homeland Security, 2023)	N/A
	Land mobile broadcast towers	point	2023	(U.S. Department of Homeland Security, 2023)	N/A
	Internet service access	polygon (estate)	2020	(U.S. Census Bureau, 2023g)	N/A
	Radio broadcast transmission towers	point	2023	(U.S. Department of Homeland Security, 2023)	N/A
	Microwave service towers	point	2023	(U.S. Department of Homeland Security, 2023)	N/A
	TV station transmitters	point	2023	(U.S. Department of Homeland Security, 2023)	N/A
Utilities Infrastructure	Public drinking water supply facilities	point	2023	EPA water treatment facilities (Environmental Protection Agency, 2023b)	Combined datasets; date excluded from second dataset metadata
			n.d.	Water standpipes, public water tanks, public water pumps, groundwater wells, bottlers (USVI Hazard Mitigation and Resilience Plan, 2023b)	
	Power generating facilities	point	n.d.	(USVI Hazard Mitigation and Resilience Plan, 2023b)	Included electrical substations and energy facilities; date excluded from metadata
	Wastewater treatment facilities	point	n.d.	(USVI Hazard Mitigation and Resilience Plan, 2023b)	Included transfer points and pump stations; date excluded from metadata
	Waste management (landfills and bin sites)	point	n.d.	(USVI Hazard Mitigation and Resilience Plan, 2023b)	Included landfills and bin sites; date excluded from metadata
Transportation Infrastructure	Airports	point	2023	(U.S. Department of Homeland Security, 2023)	Site_type = A
	Helicopter transport	point	2023	(U.S. Department of Homeland Security, 2023)	Site_type = H
	Seaplanes	point	2023	(U.S. Department of Homeland Security, 2023)	Site_type = C
	Roadway bridge structural and functional assessment rating	point	2020	(Federal Highway Administration, 2023)	N/A
	Roadway bridge structures	point	2020	(Federal Highway Administration, 2023)	N/A
	Total miles of urban and rural arterial roads	line	n.d.	(USVI Hazard Mitigation and Resilience Plan, 2023b)	Date excluded from metadata
	Boat ramps, marinas, ports	point	2023	Marinas, anchorage sites (VInow, n.d.)	Listed marinas and anchorage sites were manually confirmed against Google Earth (2023) and georeferenced within an internal geodatabase; the two datasets were then combined
			2023	Docks (U.S. Department of Transportation, 2023)	

Table C2. Data sources for structural exposure.

	Variable	Resolution	Year	Source	Notes
Housing Characteristics	Home overcrowding	estate	2020	(U.S. Census Bureau, 2023b)	N/A
	Homes with inadequate plumbing and kitchen facilities	estate	2020	Plumbing facilities (U.S. Census Bureau, 2023e)	Combined datasets
				Kitchen facilities (U.S. Census Bureau, 2023f)	
	Median age of residential housing	estate	2020	(U.S. Census Bureau, 2023d)	N/A
	Homes per square mile	estate	2020	(U.S. Census Bureau, 2023a)	N/A
	Non-permanent or mobile residential structures (excluding vans, campers, etc.)	estate	2020	(U.S. Census Bureau, 2023c)	N/A
	Median housing value	estate	2020	(U.S. Census Bureau, 2023h)	N/A
Vacant Structures	Vacant structures that are not identified as business or residential	tract	2020	(U.S. Department of Housing and Urban Development, 2020)	Excludes no-stat addresses
	Vacant business structures	tract	2020	(U.S. Department of Housing and Urban Development, 2020)	Excludes no-stat addresses
	Vacant residential structures	tract	2020	(U.S. Department of Housing and Urban Development, 2020)	Excludes no-stat addresses

Table C3. Data sources for flood hazards.

	Variable	Resolution	Year	Source	Notes
Sea Level Rise	Sea level rise projection of 2 ft	1-m raster		(NOAA Office for Coastal Management, 2024)	2-ft sea level rise projection was used as the closest estimate to the desired model of 1.61 ft
Storm Surge	Category 3 hurricane storm surge	1-m raster	2018	(NOAA National Hurricane Center, n.d.-b)	N/A
	Category 5 hurricane storm surge	1-m raster	2018	(NOAA National Hurricane Center, n.d.-b)	N/A
Stormwater Flooding	Flow accumulation	10-m Raster	2010	(NOAA National Geophysical Data Center, 2010)	Derived from elevation data; Resampled to 30 m for analysis
	Rainfall intensity	1-m raster	n.d.	(USVI Hazard Mitigation and Resilience Plan, 2023a)	Dewberry (100-year rainfall data); date excluded from metadata
	Hydrologic soil groups	polygon	2003	(National Resources Conservation Service Soil Survey Staff, 2023)	Individual soil surveys merged; Reclassified according to hydrologic soil group; Converted to 30-m raster for analysis
	Land use–land cover	30-m raster	2012	(NOAA Office for Coastal Management, 2015)	Reclassified according to land cover type propensity to inundation
	Slope	10-m raster	2010	(NOAA National Geophysical Data Center, 2010)	Derived from elevation data from the U.S. Geological Survey's 10-m National Elevation Dataset (NED); Resampled to 30 m for analysis
	Elevation	10-m raster	2016	(NOAA National Geophysical Data Center, 2010)	Derived from elevation data from the U.S. Geological Survey's 10-m National Elevation Dataset (NED); Resampled to 30 m for analysis
	Density of drainage network	polyline	2010	(USGS National Hydrography, 2010)	Line density calculated and clipped to the USVI region; 30-m raster used for analysis

Table C4. Data sources for waterborne toxins and contaminants.

	Variable	Resolution	Year	Source	Notes
Waterborne Toxins and Contaminants Index	Bin sites	point	n.d.	(USVI Hazard Mitigation and Resilience Plan, 2023b)	Volume calculated from attributes; date excluded from metadata
	Landfills	point	n.d.	(USVI Hazard Mitigation and Resilience Plan, 2023b)	Date excluded from metadata
	Drinking water contaminants: Percentage of water sources that are within 0.25 mi of FRS water related sites	point and polygon	2023	(Environmental Protection Agency Facility Registry Service, 2023)	N/A
	Wastewater	point	n.d.	(USVI Hazard Mitigation and Resilience Plan, 2023b)	Date excluded from metadata
	Water sources: standpipes, public water tanks, public water pumps, groundwater wells, bottlers	point	n.d.	(USVI Hazard Mitigation and Resilience Plan 2023)	Joined SDWIS data to point data by water source ID #; date excluded from first dataset metadata
		N/A	2022	Safe Drinking Water Information System (SDWIS) Federal Reporting Services (Environmental Protection Agency, 2022, 2024c)	
	Industrial zones per USVI Department of Planning and Natural Resources	polygon	2022	(ArcGIS Living Atlas, 2024)	N/A
	Electronic waste	N/A	2022	U.S. Trade with Puerto Rico and U.S. Possessions, 2022, p. 345 (U.S. Census Bureau, 2023i)	NOT included in final index
	Sargassum	N/A	2022	(Sargassum Monitoring, 2023)	NOT included in final index
			2024	(NOAA ERDDAP, 2024)	
	Offshore sediment monitoring	N/A	2014	(Whitall et al., 2014)	NOT included in final index

Appendix D: Mapbook

The mapbook appended in the pages that follow is a standalone product included in this report supplemental material.

Mapbook

2024

Mapbook Appendix
Community Vulnerability Assessment in the United States Virgin Islands

NCCOS NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE

SCIENCE SERVING COASTAL COMMUNITIES

TABLE OF CONTENTS

Cover photo:
Whale Point, St. Croix, USVI. Credit: Seann Regan, CSS Inc./NOAA NCCOS

1 Introduction

Coastal populations, including those in the United States Virgin Islands (USVI), are exposed to various climate hazards such as erosion, flooding, heavy rains, high temperatures, and strong winds. However, the impact of these hazards is unevenly distributed. Structural social inequalities contribute to varying degrees of vulnerability and exposure, with marginalized and underserved communities often facing greater challenges in preparing for and recovering from natural hazard events.

This mapbook is an appendix to a larger report that provides an overview of a community vulnerability assessment conducted in the USVI. For access to the full report, please see the project page at the end of this mapbook. This assessment marks the first implementation under the National Centers for Coastal Ocean Science (NCCOS) new research portfolio and is the fifth assessment overall by NCCOS. It involved developing indicators for vulnerability, exposure, and hazard, and integrating these indicators to produce detailed maps of risk and co-occurrence. This mapbook relies on various data collected from secondary sources throughout the USVI. For a full list of data sources, spatial resolutions, and notes for all analyses used within this assessment, see Appendix C: Data Sources.

Hams Bluff lighthouse, St. Croix, USVI
Credit: Seann Regan, CSS Inc./NOAA NCCOS

NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE

Glossary of terms used in this mapbook

Vulnerability: The propensity or predisposition of assets to be adversely affected by hazards (U.S. Climate Resilience Toolkit).

Exposure: The presence of people, assets, and ecosystems in places where they could be adversely affected by hazards (U.S. Climate Resilience Toolkit).

Hazard: An event or condition that may cause injury, illness, or death to people or damage to assets (U.S. Climate Resilience Toolkit), including loss of property, infrastructure, livelihoods, service provision, ecosystems and environmental resources (IPCC AR6).

Risk: The potential for negative consequences where something of value is at stake. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard (U.S. Climate Resilience Toolkit).

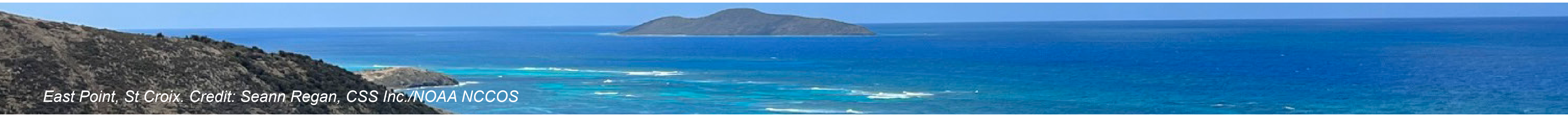
Underserved Communities: Populations sharing a particular characteristic, as well as geographic communities, that have been systematically denied a full opportunity to participate in aspects of economic, social, and civic life (E.O. 13985, Sec. 2; NCCOS).

Assessment Component (Component): Each analytical category within this assessment.

Index: The final culmination of each assessment component or sub-component.

Indicator: One of multiple concepts that contributes to an index.

For a full glossary of terms used please see our programmatic glossary at:
https://cdn.coastalscience.noaa.gov/projects-attachments/480/Vulnerability-Assessment-Portfolio-Glossary.pdf

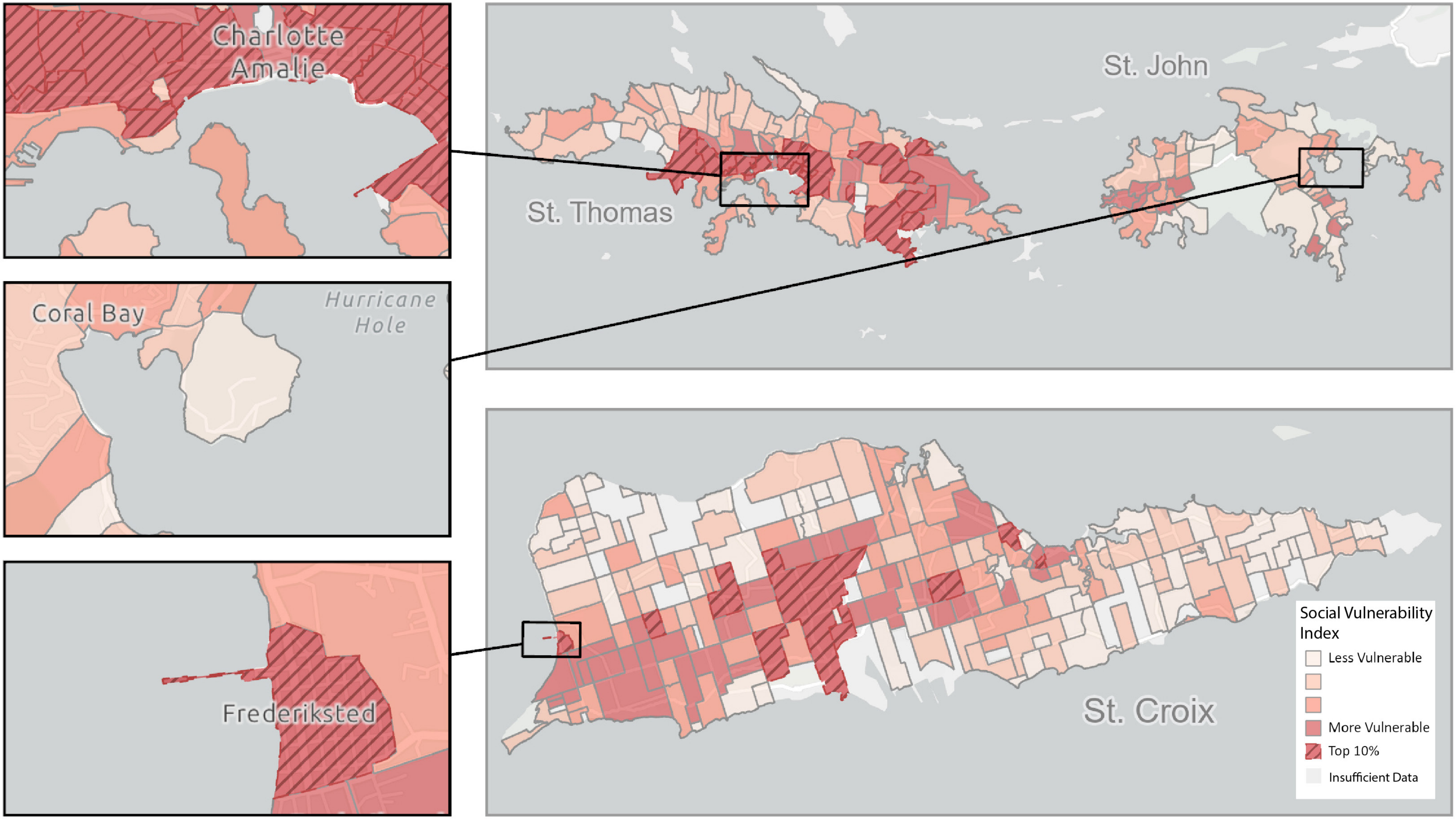


East Point, St Croix. Credit: Seann Regan, CSS Inc./NOAA NCCOS

2 Vulnerability and exposure

The maps in this section display aspects of vulnerability and exposure in the USVI. Themes include social vulnerability, structural exposure (communications, utilities, and transportation infrastructure), structural vulnerability (housing characteristics and vacancy), as well as wave orbital velocity and nearshore environment protection benefits.

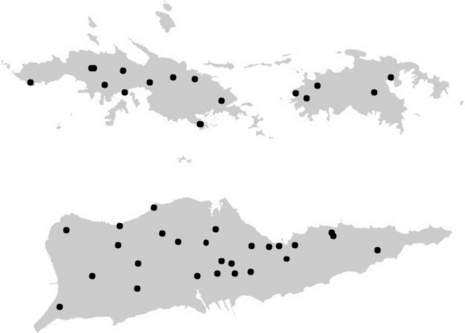
Caribbean architecture, St. Thomas , USVI. Credit: Seann Regan, CSS Inc./NOAA NCCOS



Final social vulnerability index. This social vulnerability index was developed by partners using the Centers for Disease Control and Prevention Social Vulnerability Index methodology. It includes indicators such as poverty, unemployment, per capita income, educational attainment, age, race, English proficiency, and access to transportation. The index excludes estates with insufficient population data (shown in light gray).

Final structural exposure index. This final index highlights areas of greater resilience-supporting infrastructure that may be at risk of damage or loss if impacted by a hazard event. It combines three sub-indices: communications, transportation, and utilities infrastructure

Number of cell service towers

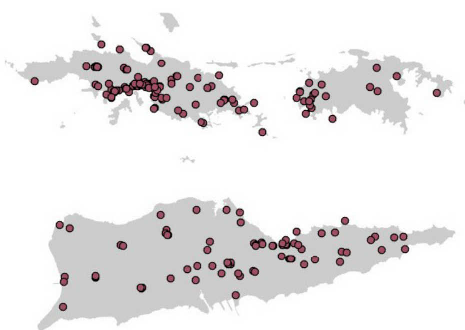


Number of radio broadcast transmission towers

Number of paging transmission towers

Number of TV station transmitters

Number of microwave service towers



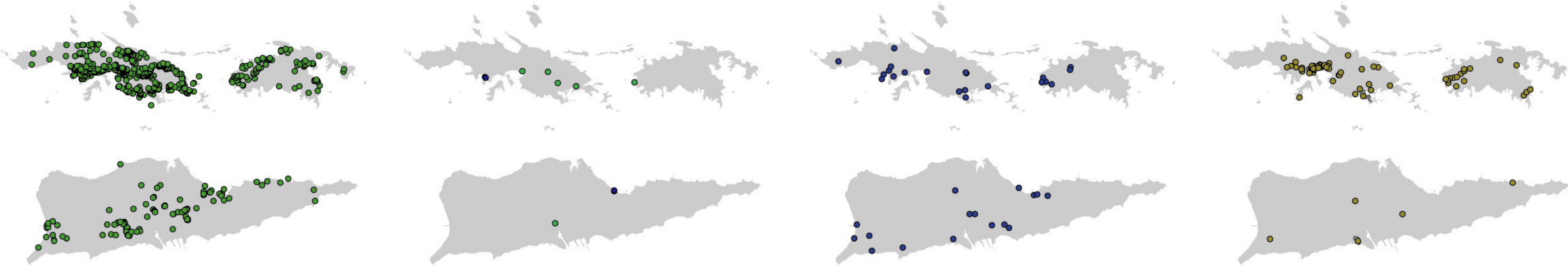
Number of land mobile broadcast towers

Number of radio broadcast transmission towers

Indicators within the communications infrastructure index. There are seven indicators used in the communications infrastructure index (next page). They include cell service towers, land mobile broadcast towers, internet service access, paging transmission towers, radio broadcast transmission towers, microwave service towers, and TV station transmitters.

Communications infrastructure index. This index highlights the infrastructure needed to support communication activities within a community. It includes seven indicators: cell service towers, land mobile broadcast towers, internet service access, paging transmission towers, radio broadcast transmission towers, microwave service towers, and TV station transmitters. Estates with higher values have more critical communications infrastructure and increased exposure potential.

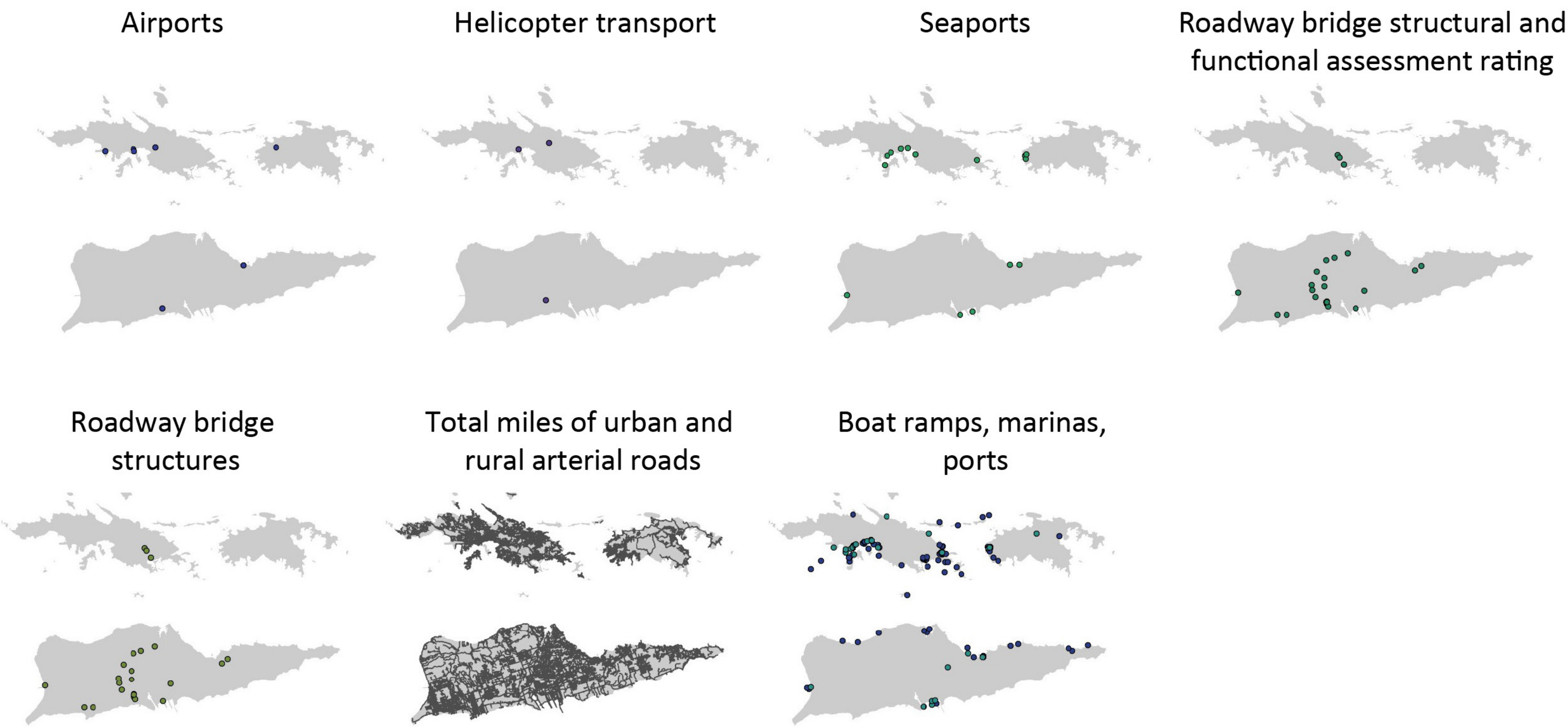
Public drinking water supply facilities | Power generating facilities | Wastewater treatment facilities | Waster management (landfills and bin sites)



Indicators within the utilities infrastructure index. There are four indicators used in the utilities infrastructure index (next page). They include public drinking water supply facilities, power generating facilities, wastewater treatment facilities, and waste management sites (landfills and bin sites).

Harbor flooding, St.Thomas, USVI.
Credit: Seann Regan, CSS Inc./NOAA NCCOS

Utilities infrastructure index. This index highlights the infrastructure needed to manage critical utilities within a community. It includes four indicators: public drinking water supply facilities, power generating facilities, wastewater treatment facilities, and waste management sites (landfills and bin sites). Estates with higher values have more critical utilities infrastructure and increased exposure potential.

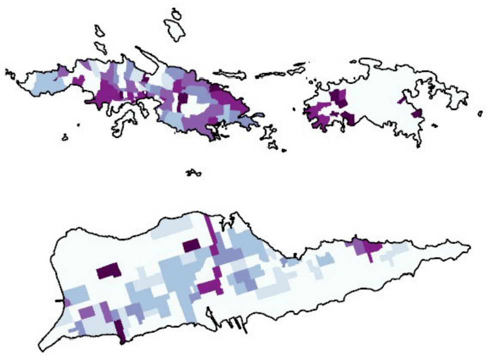


Indicators within the transportation infrastructure index. There are five indicators used in the transportation infrastructure index (next page). They include air access points (including airports, helicopter transport, and seaplanes), bridge structures, bridge structural and functional assessment ratings, miles of urban and rural roads, and ocean access points (including boat ramps, marinas, ports, and ferry terminals).

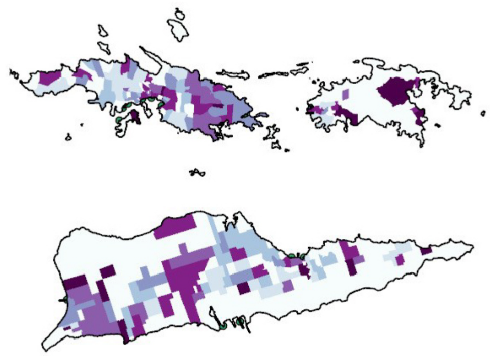
Transportation infrastructure index. This index highlights resources that support the flow of people, goods, and services. It includes five indicators: air access points (including airports, helicopter transport, and seaplanes), bridge structures, bridge structural and functional assessment ratings, miles of urban and rural roads, and ocean access points (including boat ramps, marinas, ports, and ferry terminals). Estates with higher values have more critical transportation infrastructure and increased exposure potential.

Final structural vulnerability index. This final index highlights the vulnerability of built structures. It combines two sub-indices: housing characteristics and vacant structures.

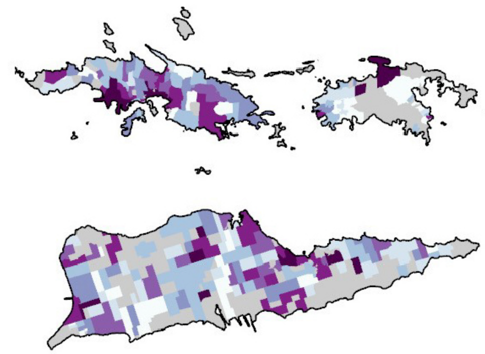
Home overcrowding



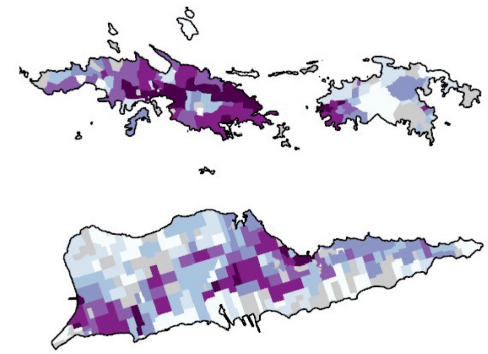
Homes with inadequate plumbing and kitchen facilities



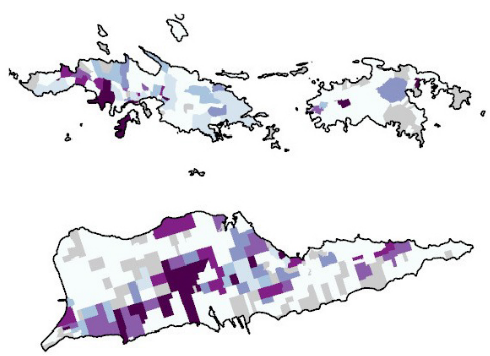
Median age of residential housing



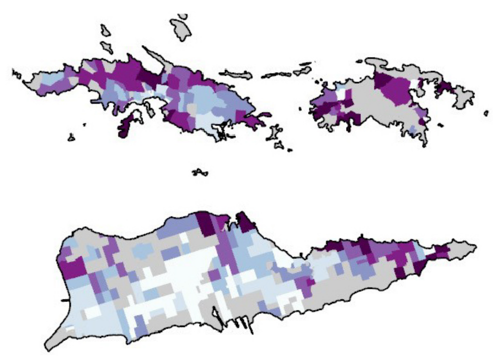
Homes per square mile



Non-permanent or mobile residential structures

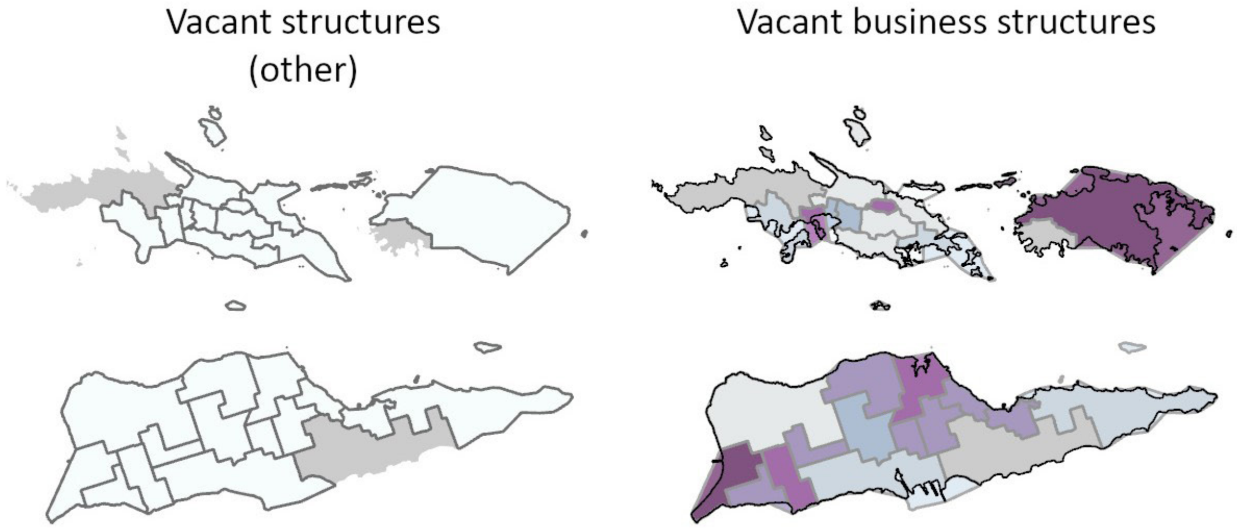


Median housing value



Indicators within the housing characteristics index. There are six indicators used in the housing characteristics index (next page). They include home overcrowding, homes with inadequate plumbing and kitchen facilities, median age of residential housing, homes per square mile, non-permanent or mobile residential structures, and median housing value.

Housing characteristics index. This index highlights housing features that contribute to structural vulnerability. It includes six indicators: home overcrowding, homes with inadequate plumbing and kitchen facilities, median age of residential housing, homes per square mile, non-permanent or mobile residential structures, and median housing value. Estates with higher values have more likelihood of increased structural vulnerability.



Indicators within the vacant structures index. There are three indicators used in the vacant structures index (next page). They include vacant residential structures, vacant business structures, and vacant "other" structures.

Damaged buildings on St. Croix, USVI.
Credit: Seann Regan, CSS Inc./NOAA NCCOS

Vacant structures index. This index highlights vacant structures that are typically more likely to be at risk of hazard impacts and may also increase hazard for the surrounding community. It includes three vacancy indicators: vacant residential structures, vacant business structures, and vacant "other" structures. Estates with higher values have higher vacancy and likely more structural vulnerability.

Input data (orbital velocity) to capture nearshore environment impacts. The research team consulted with NCCOS colleagues to estimate bottom orbital wave velocity values for the territory's benthic environment. Areas of increased orbital velocity values have increased wave action.

Final nearshore environment protection benefits index. This index shows the relative impact of nearshore coastal environments on coastal estates. Bottom orbital wave velocity values were assigned to each estate. Estates with higher index values indicate lower orbital velocity and greater nearshore environment protection benefits for coastal areas.

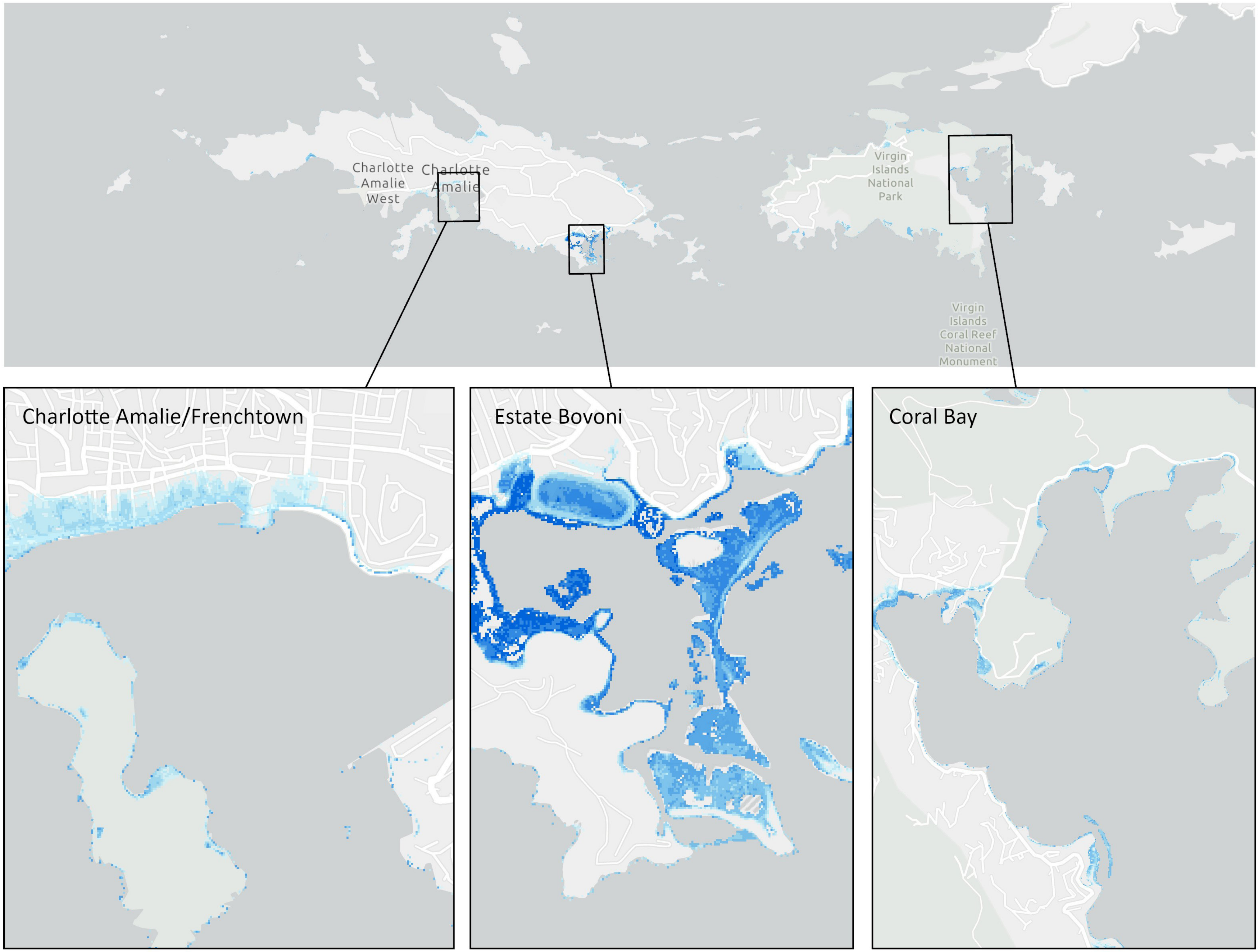
3 Flood hazards

The maps in this section display data from four categories of flood hazard: sea level rise inundation, storm surge from a Category 3 and Category 5 hurricane, stormwater flooding from precipitation, and a measure of compounded flooding.

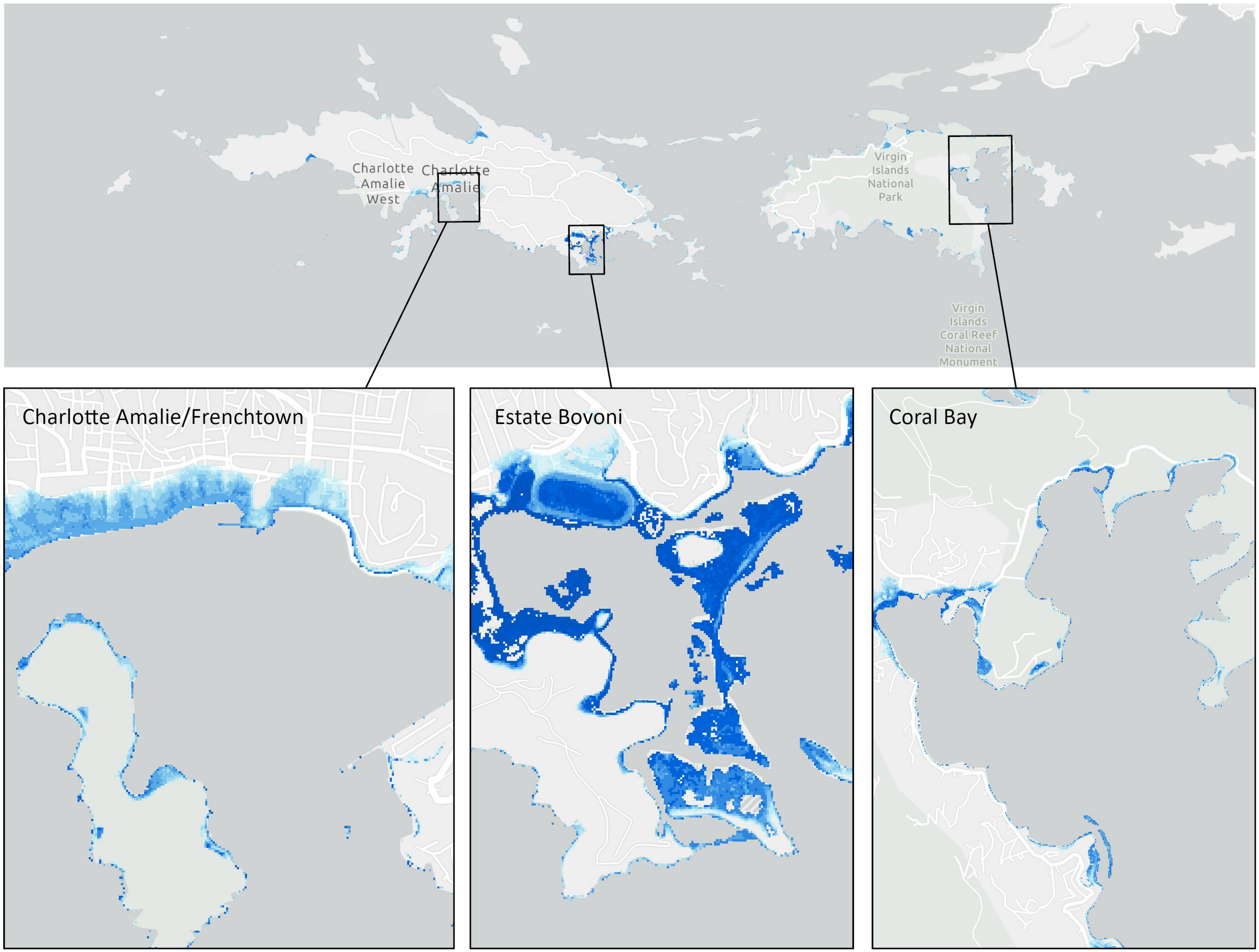
Water runoff, St. Thomas, USVI.
Credit: Seann Regan, CSS Inc./NOAA NCCOS

Projected 2 ft of sea level rise. NOAA's Sea Level Rise data projects sea level rise estimates of 1.61 ft for Lime Tree Bay (St. Croix) and 1.64 ft for Charlotte Amalie (St. Thomas) by year 2060. This map shows 2 ft of sea level rise with an amplified line thickness to better visualize the data.

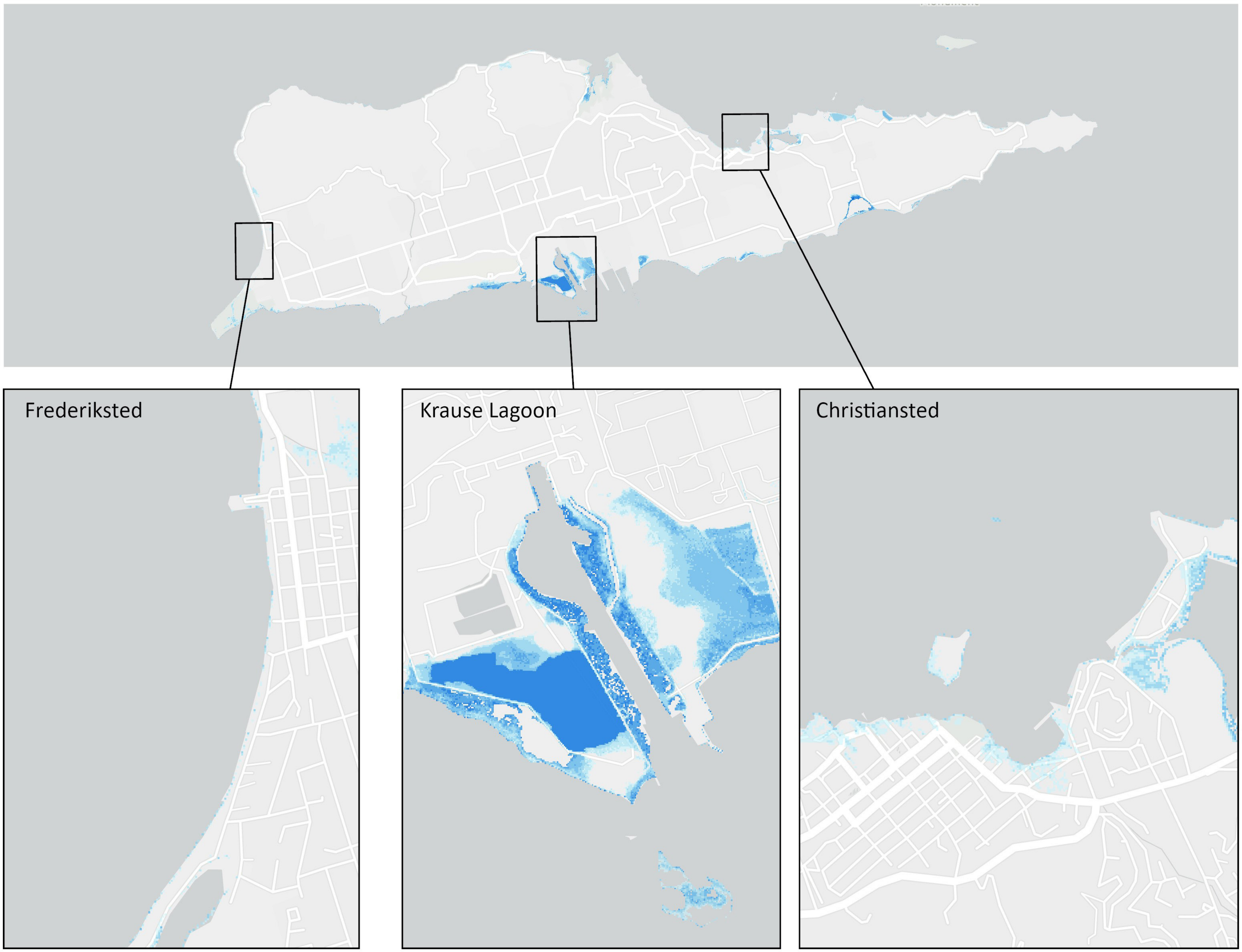
Projected Category 3 storm surge for St. Thomas and St. John. These maps show projected storm surge inundation levels for St. Thomas and St. John under a Category 3 hurricane.



Projected Category 5 storm surge for St. Thomas and St. John. These maps show projected storm surge inundation levels for St. Thomas and St. John under a Category 5 hurricane.



Projected Category 3 storm surge for St. Croix. These maps show projected storm surge inundation levels for St. Croix under a Category 3 hurricane.



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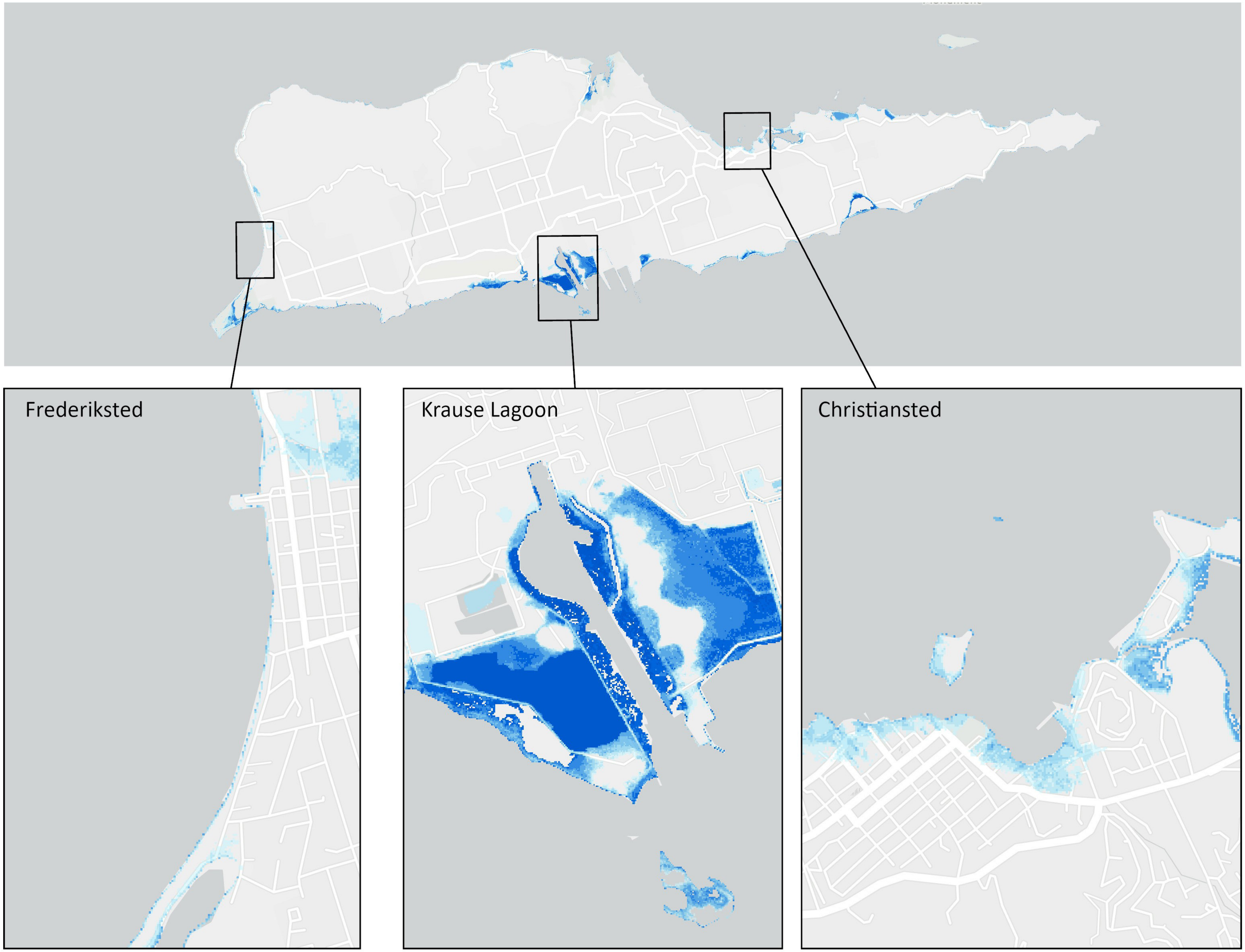
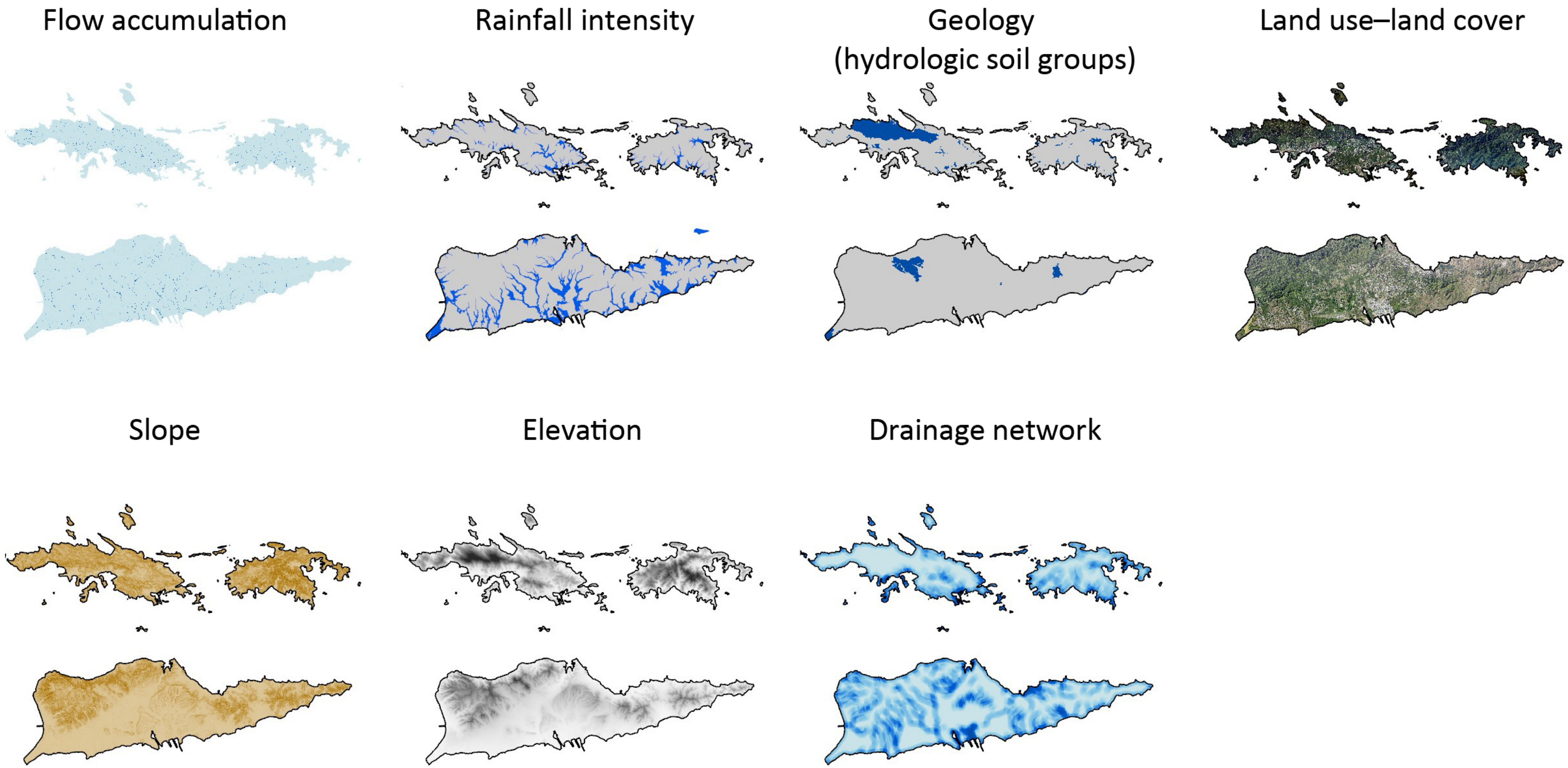
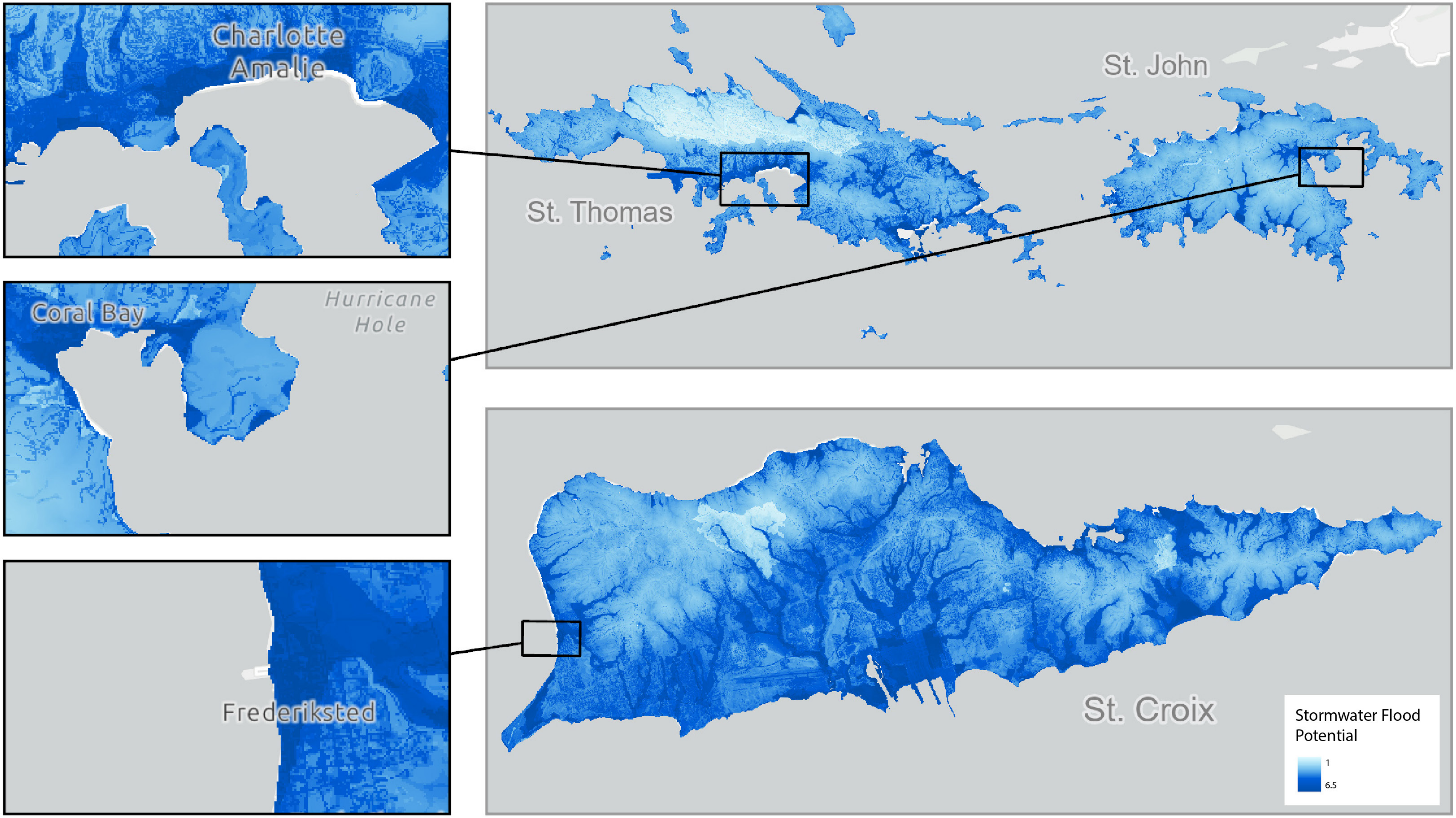
Projected Category 5 storm surge for St. Croix. These maps show projected storm surge inundation levels for St. Croix under a Category 5 hurricane.

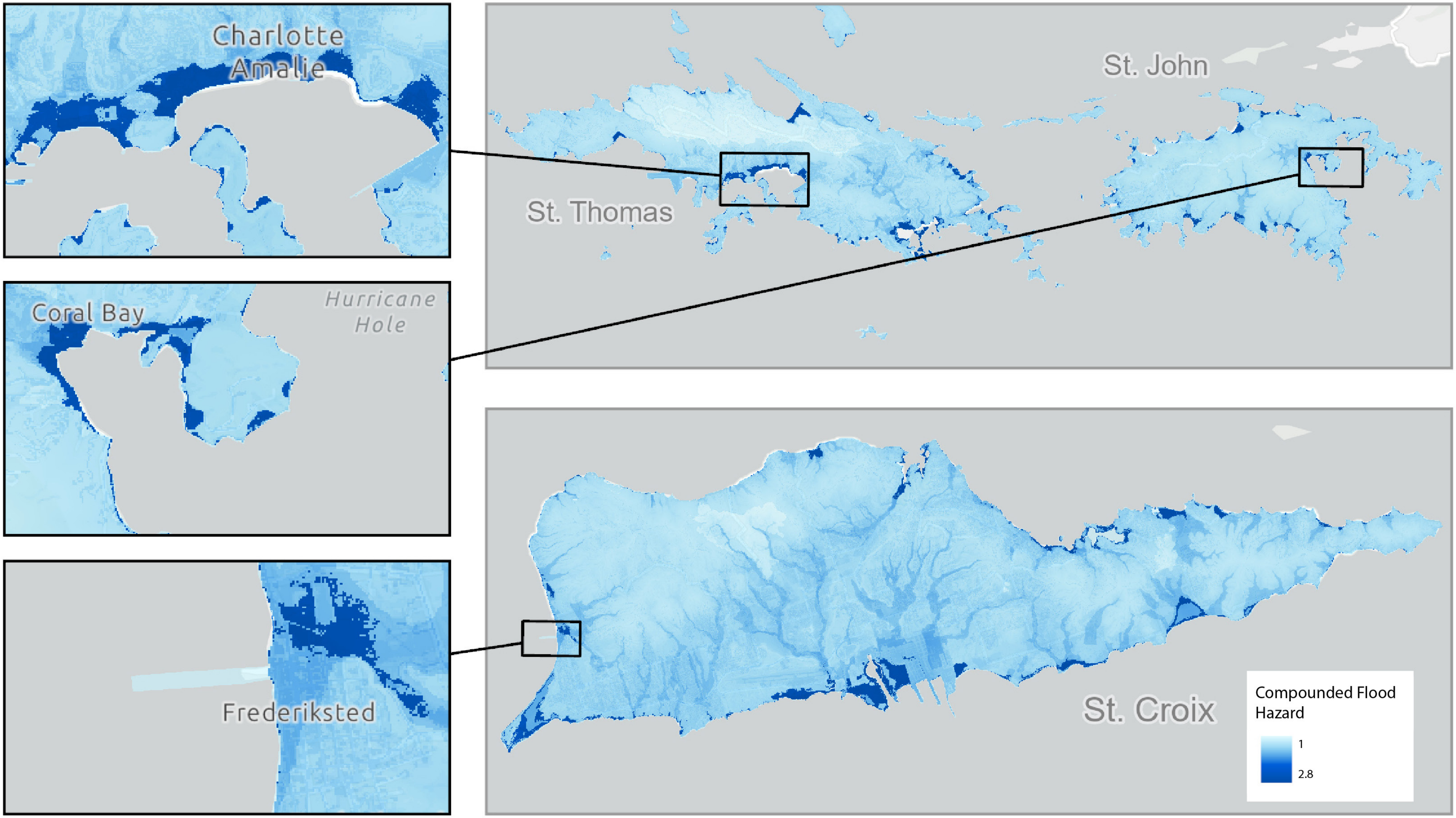




Indicators within the stormwater flooding hazard index. There are seven indicators used in the stormwater flooding index. They include flow accumulation, rainfall intensity, hydrologic soil groups, land use, slope, elevation, and distance from the drainage network.



Final stormwater flooding hazard index. This index (FIGUSED) highlights areas that have higher likelihood of flooding from stormwater and precipitation events. It includes seven indicators: flow accumulation, rainfall intensity, hydrologic soil groups, land use, slope, elevation, and distance from the drainage network.



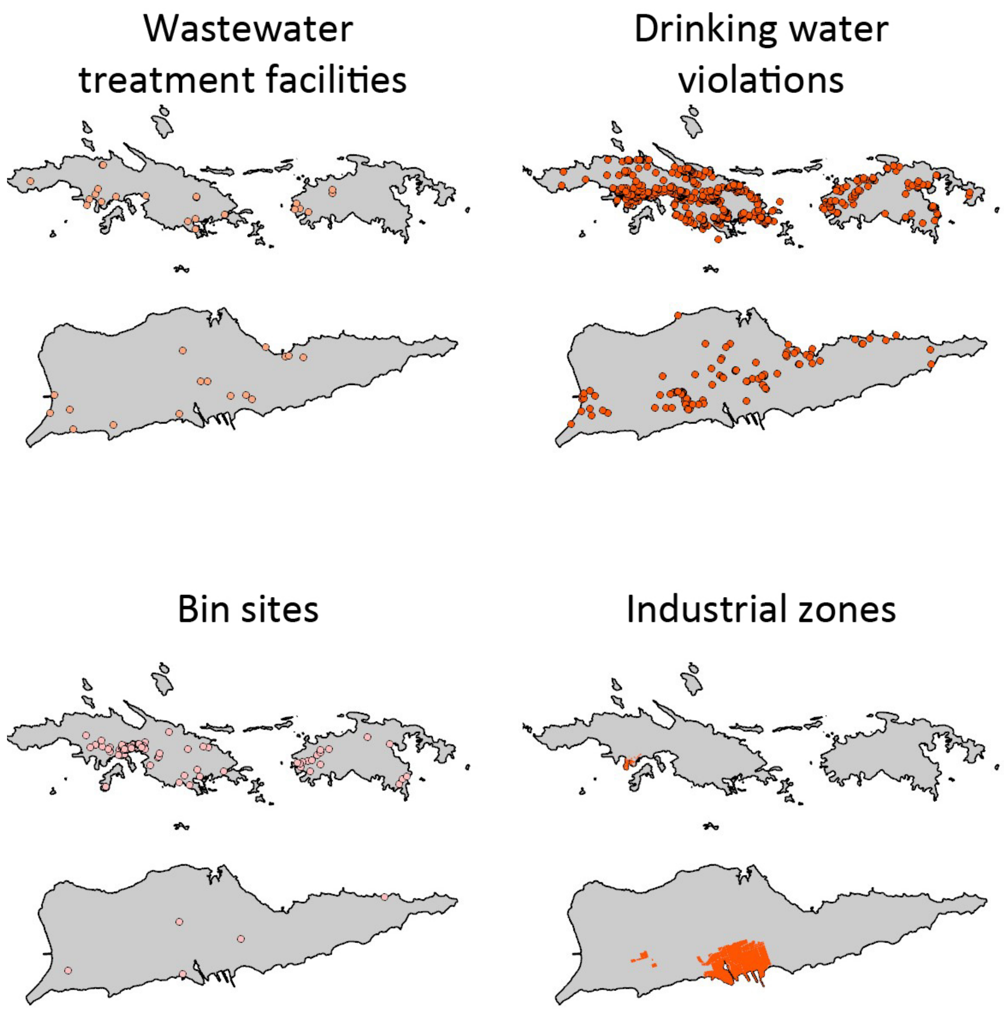
Compounded flooding scenario. Compound flooding captures the potential inundation of simultaneous flooding or consecutive hazard events. This map shows projected-high compounded flooding at projected sea level (2 ft) with stormwater flooding potential and Category 5 storm surge.

Final compounded flooding index. This index highlights the potential inundation of compounded current day stormwater flooding potential and Category 5 storm surge at projected sea level (2 ft). This approximates simultaneous flooding or consecutive hazard events, but does not incorporate compounded hydrological or sediment transfer modeling. Estates with higher values have higher likelihood of compounded flooding hazard potential.

4 Place-based assessment components

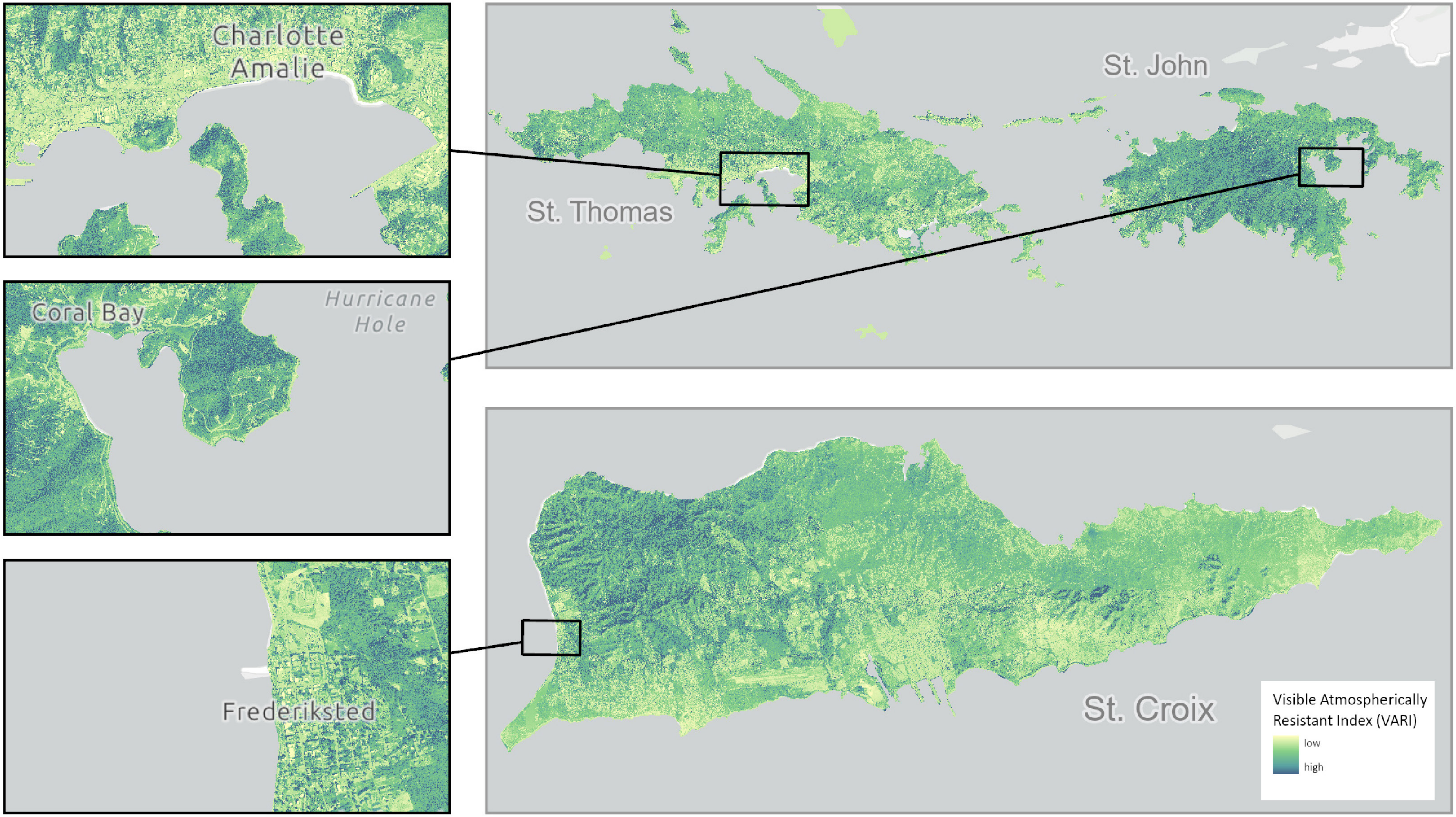
The maps in this section display information that builds upon additional needs identified in the territory, existing research, partner and stakeholder feedback, and data feasibility checks. This assessment identified components of vegetation, waterborne toxins and contaminants, and walkability.

Small dinghy on St. Croix, USVI.
Credit: Seann Regan, CSS Inc./NOAA NCCOS



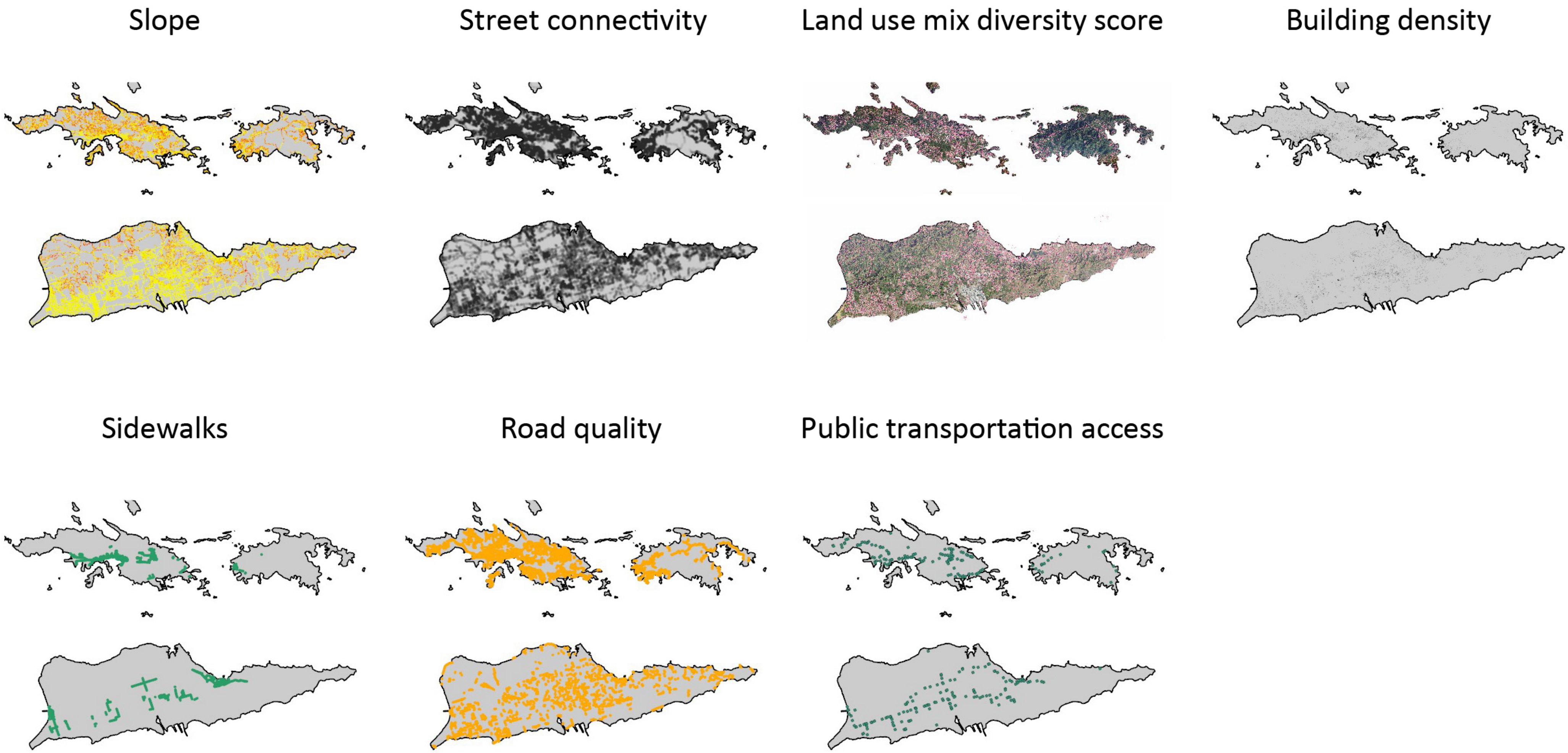
Indicators within the waterborne toxins and contaminants index. There are six indicators used in the waterborne toxins and contaminants index (next page). They include wastewater stations, drinking water violations, discharge facilities, landfills, bin sites, and industrial zones.

Final waterborne toxins and contaminants index. This index highlights the likelihood of potential waterborne toxins and contaminants in groundwater, drinking water, and flood waters. It includes six indicators: wastewater stations, drinking water violations, discharge facilities, landfills, bin sites, and industrial zones. Estates with higher values have higher potential for waterborne toxins and contaminants.



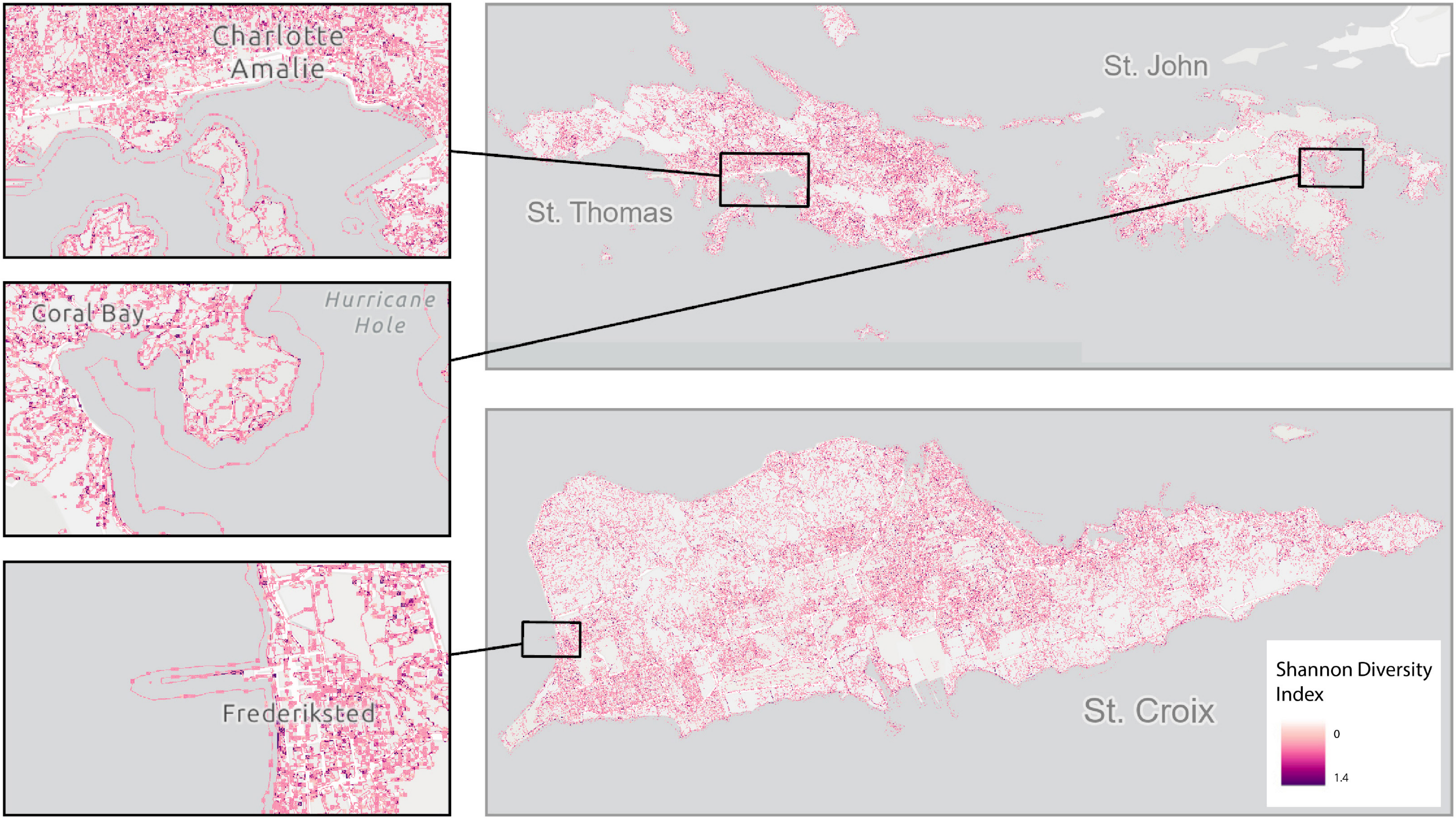
Visible atmospherically resistant index raster data. This maps shows vegetation within the visible portion of the light spectrum from aerial imagery, while minimizing illumination and shadowing impacts. It uses a visible atmospherically resistant index (VARI) calculation.

Final vegetation index. This index highlights relative vegetation. Input data from the VARI were aggregated to estates using the mean value per estate. Estates with higher values have more vegetation.



Indicators within the potential walkability index. There are seven indicators used in the potential walkability index. They include road slope, street connectivity, land use mix, building density, sidewalk presence, road quality, and public transportation access. This index reflects amenity-based walkability from the behavioral health literature as this type of walkability has been shown to influence everyday walking potential.

Elevation data by roadways. This map shows a higher resolution version of roadways by their relative elevation. This information was used to generate road slope, one of the indicators used in the potential walkability index.

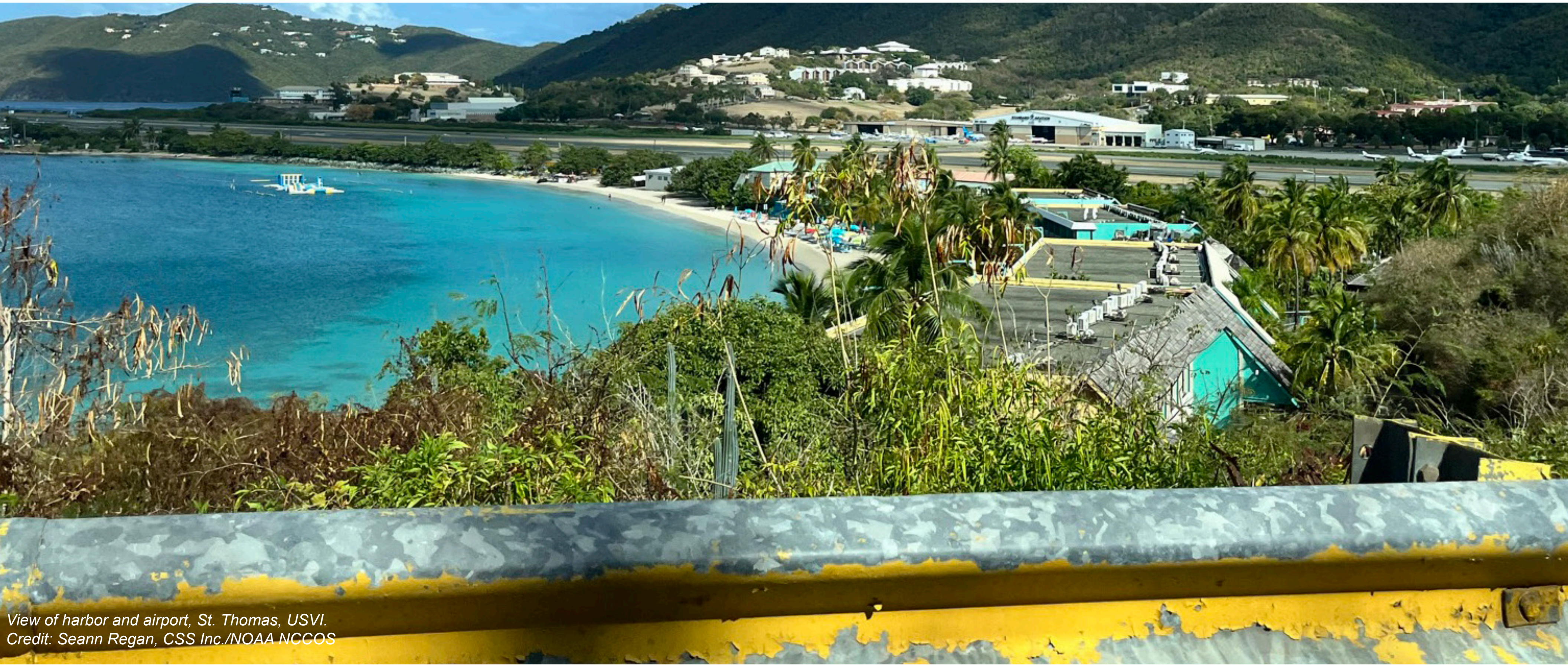


Shannon (land use) diversity index raster data. This maps shows a higher resolution version of land diversity using Shannon diversity index. This information was used to generate land use mix, one of the indicators used in the potential walkability index.

Final potential walkability index. This index highlights potential walkability. It includes seven indicators: road slope, street connectivity, land use mix, building density, sidewalk presence, road quality, and public transportation access. It does not include safety or additional amenities data due to data limitations. Estates with higher values have higher potential walkability, relative to other estates. Note that because much of the territory's terrain is mountainous, a medium walkability score might still lean towards less walkable.

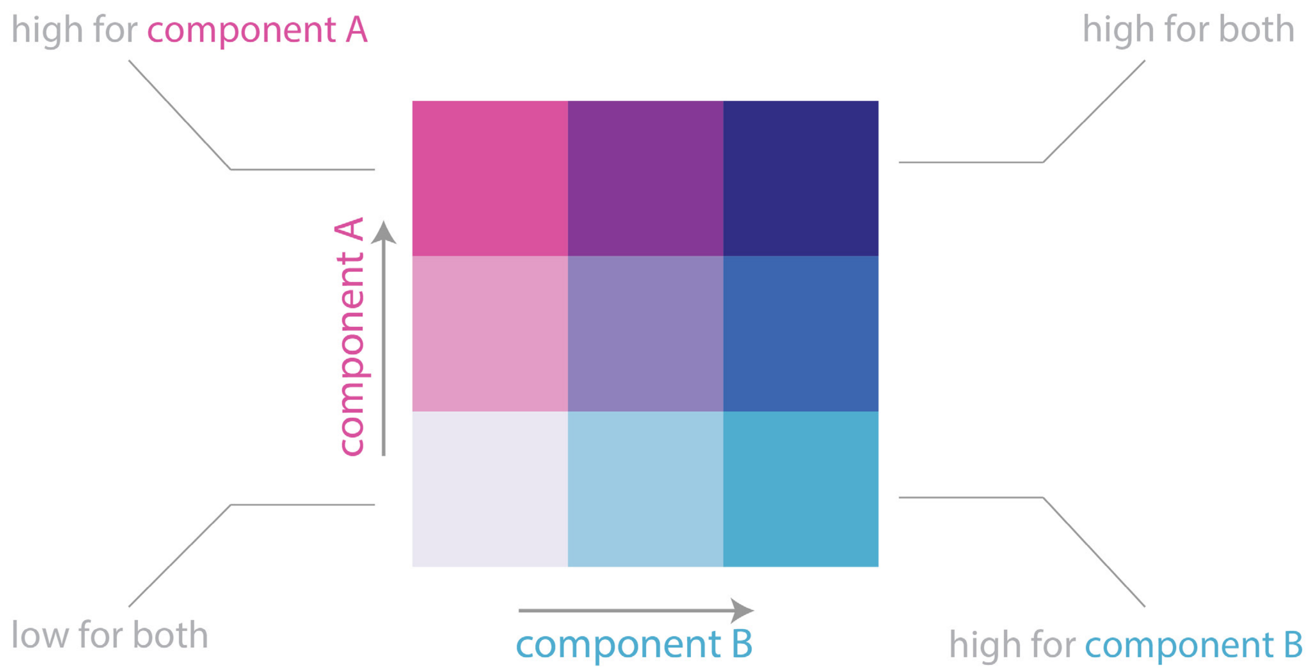
5 Assessing risk and co-occurrence

The maps in this section display areas of risk and co-occurrence. They're organized by theme: co-vulnerabilities, flood risk, nearshore environment interactions, and other key interactions.

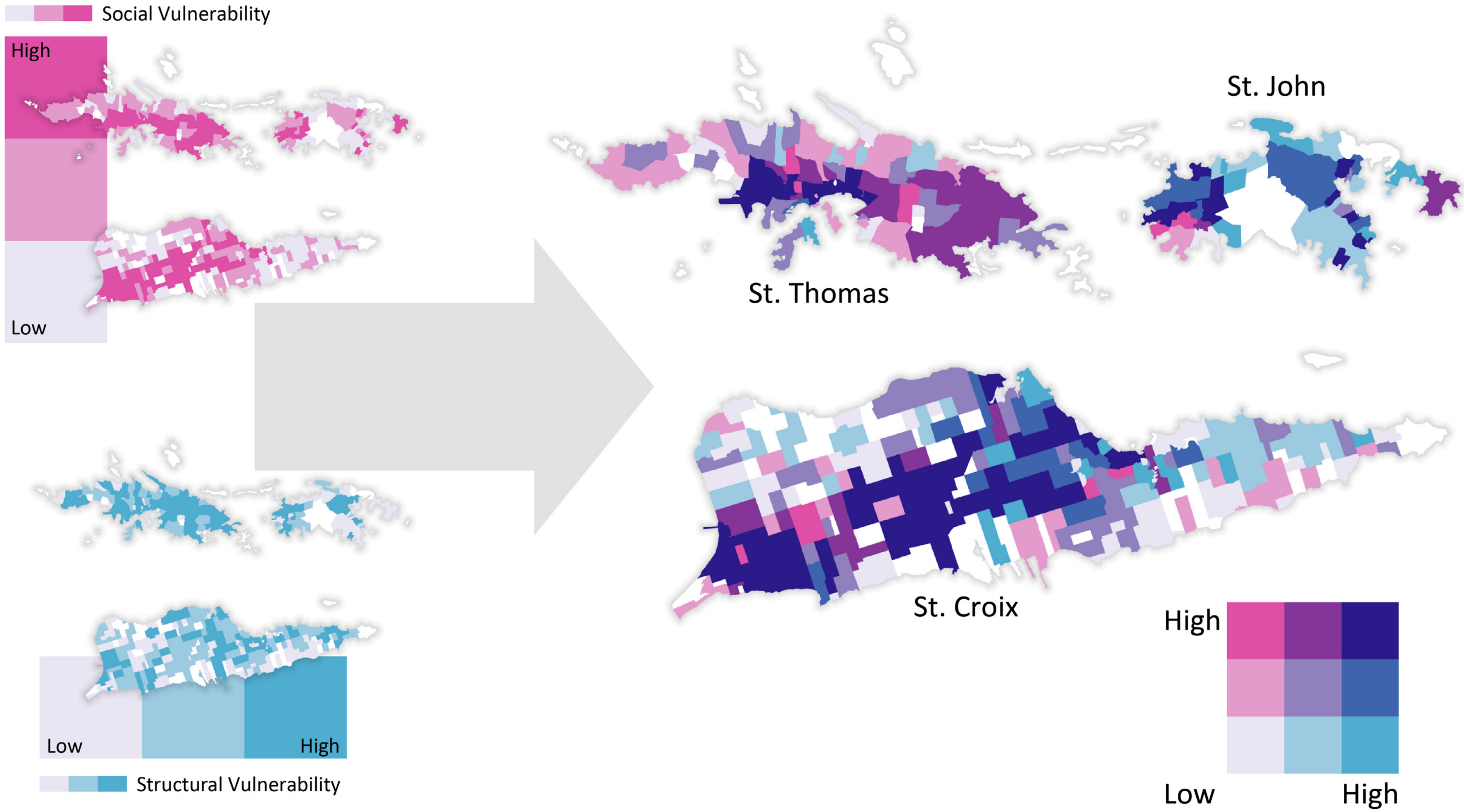


View of harbor and airport, St. Thomas, USVI.
Credit: Seann Regan, CSS Inc./NOAA NCCOS

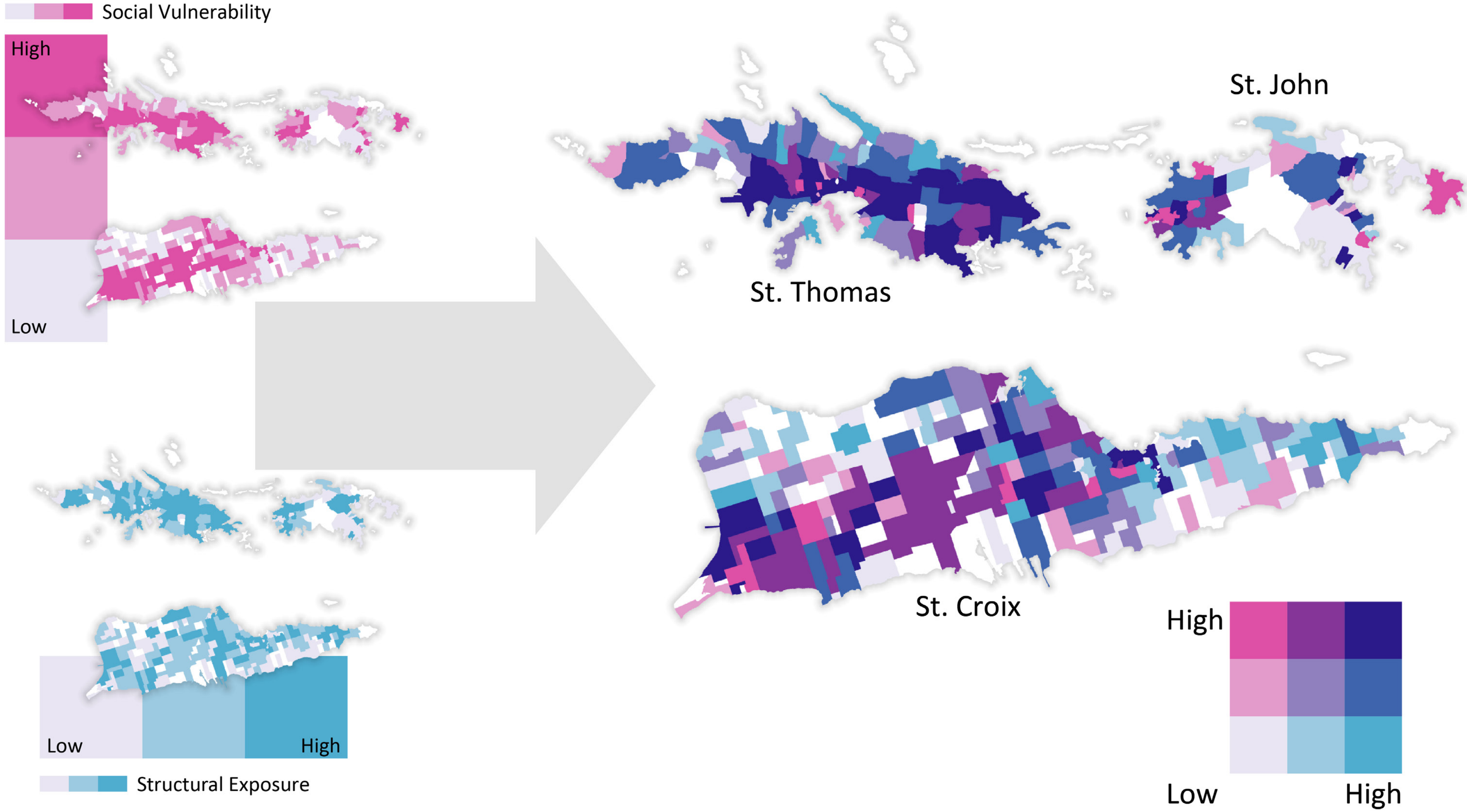
Areas that are darkest are areas where both component A and component B are high



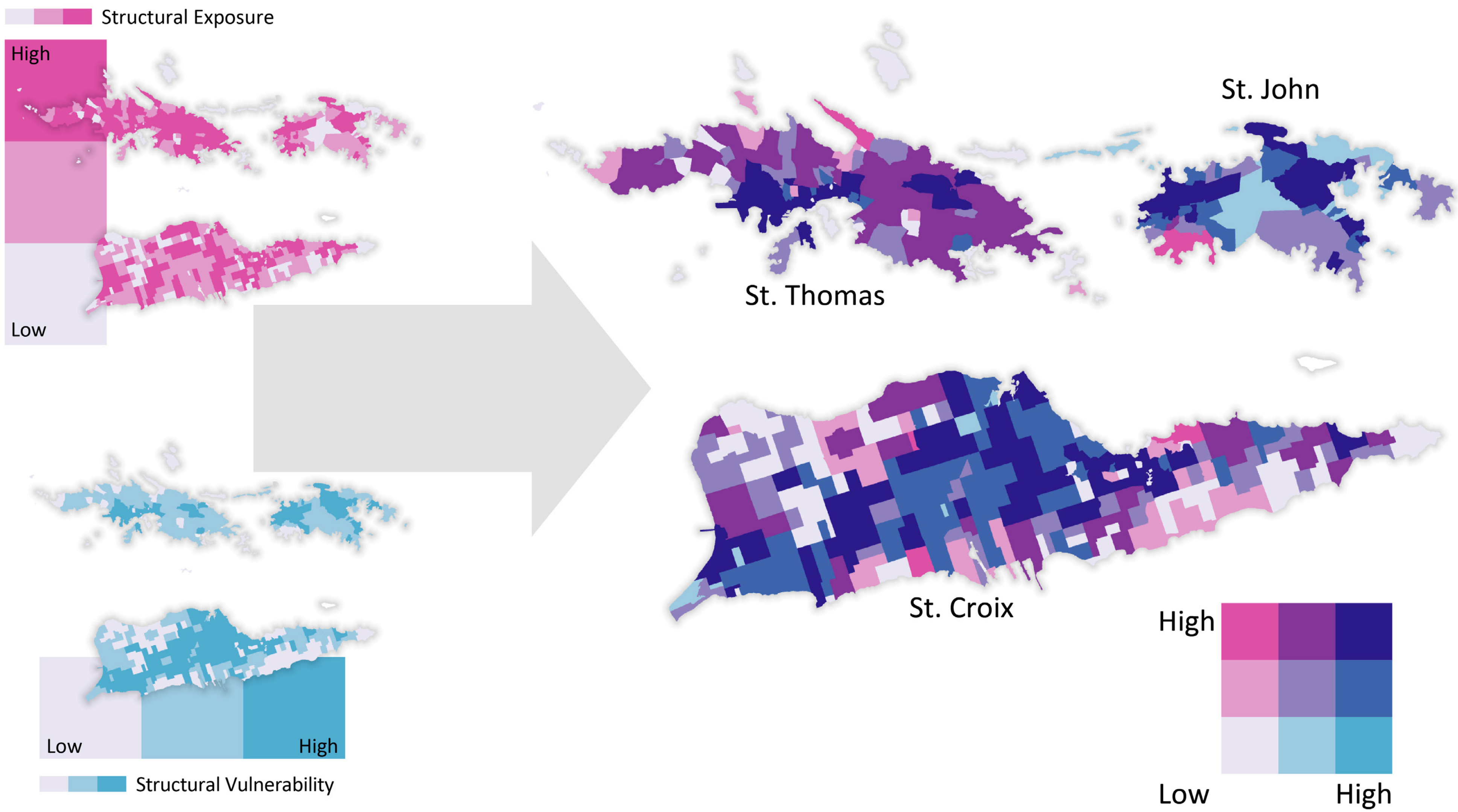
Bivariate map legend. This legend shows how to read the following bivariate maps. Bivariate maps use a mapping technique to depict two variables at once. This allows each map to show co-occurrence of the two chosen components. As one component's scores increase from left to right (in blue), another component's scores increase from bottom to top (in pink). Each corner of the matrix represents a different extreme. Dark blue areas have higher co-occurrence, while light gray areas have lower co-occurrence. Magenta and teal areas have disparate scores (high for one component but low for the other). These maps can help prioritize actions and aid in decision making when considering particular aspects of vulnerability, exposure, hazard, and risk.



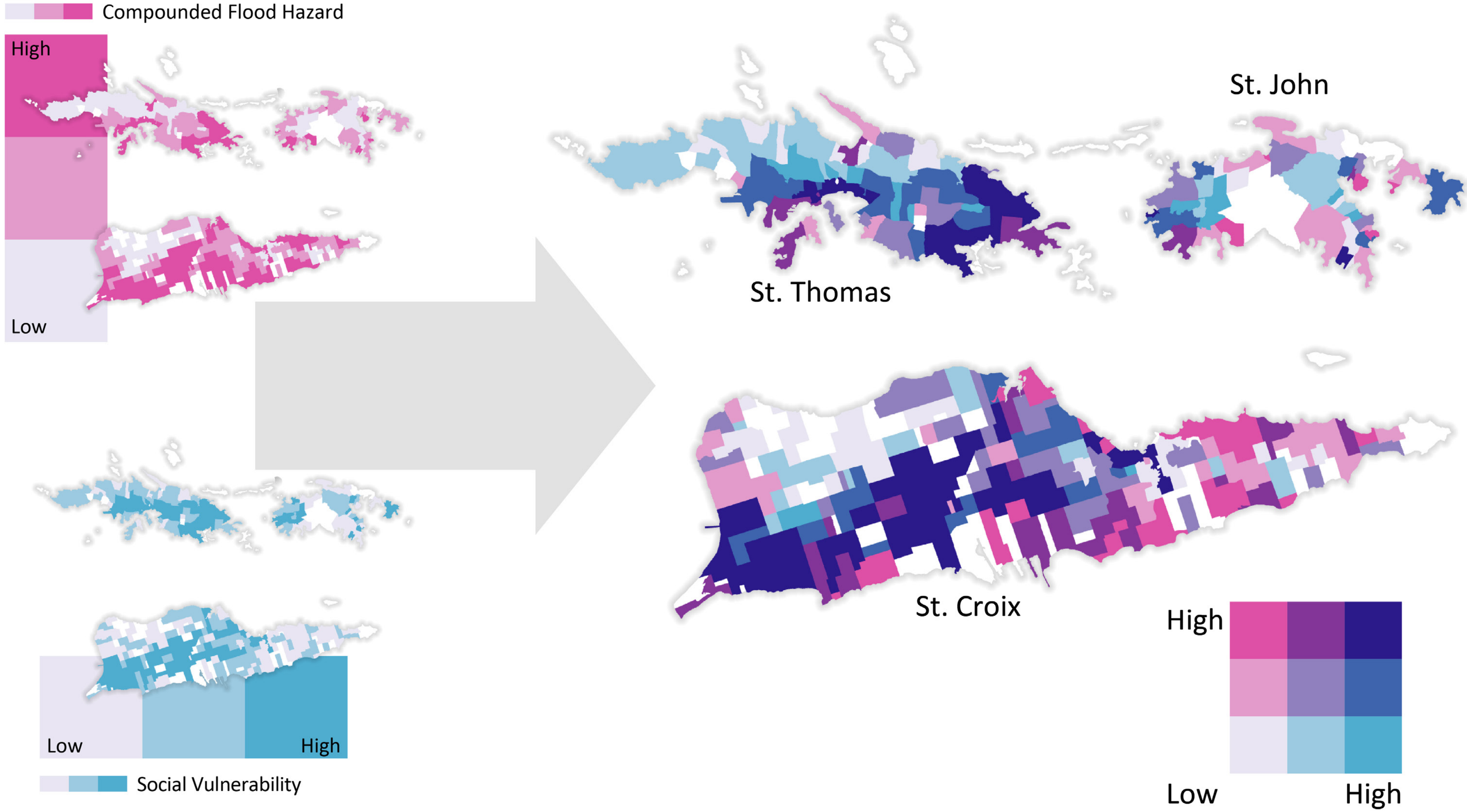
Social vulnerability and structural vulnerability. This map shows the relationship between social and structural vulnerability (restricted to estates with sufficient population data). Estates with potentially higher social and structural vulnerability are shown in dark blue. Both populations and structures might be more at risk in these areas.



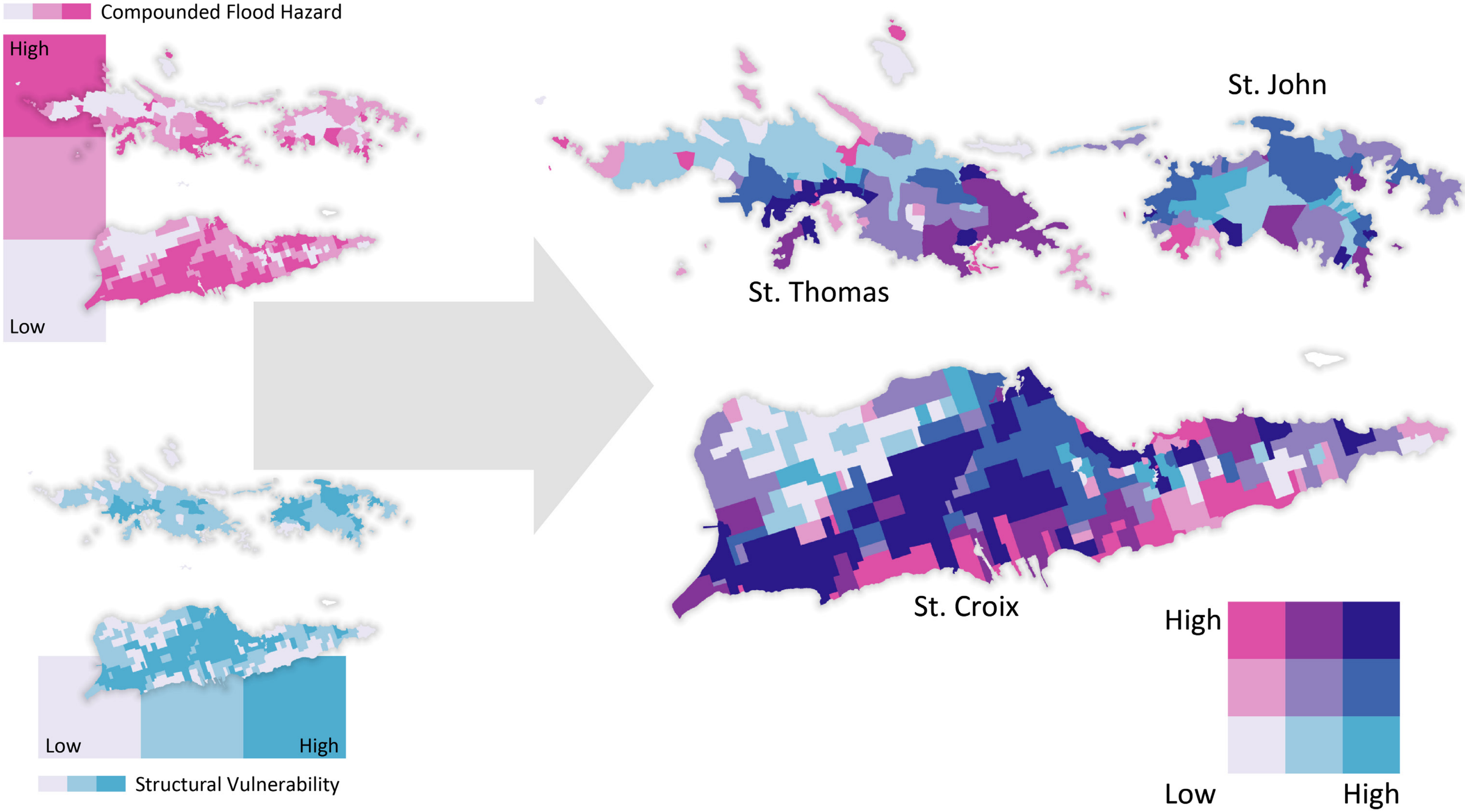
Social vulnerability and structural exposure. This map shows the relationship between social vulnerability and structural exposure (restricted to estates with sufficient population data). Estates with potentially higher social vulnerability and higher structural exposure are shown in dark blue. These areas have higher social vulnerability and also higher concentrations of critical infrastructure.



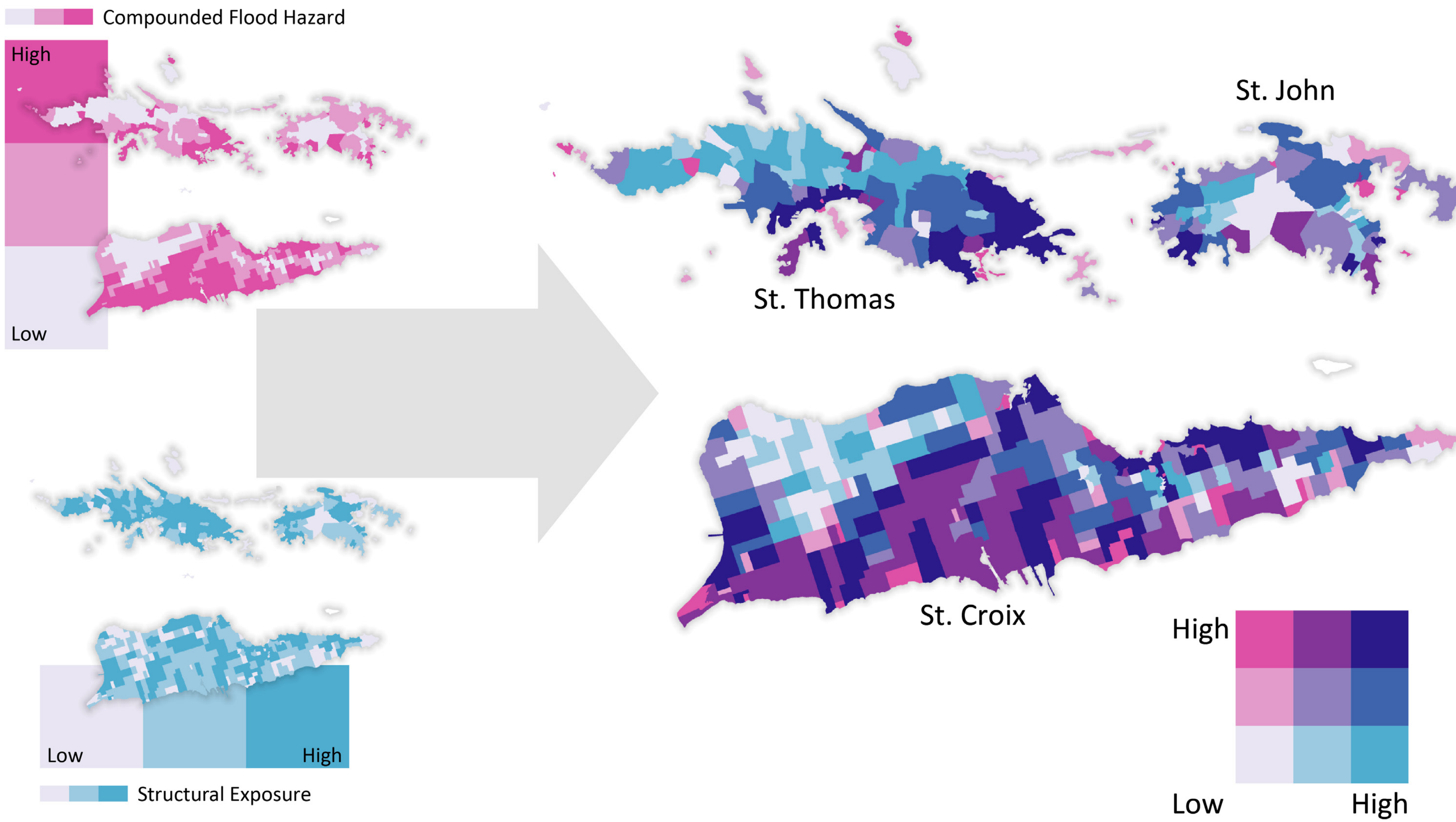
Structural exposure and structural vulnerability. This map shows the relationship between structural exposure and structural vulnerability. Estates with higher structural exposure and higher structural vulnerability are shown in dark blue. These areas have higher concentrations of critical infrastructure and also higher structural vulnerability.



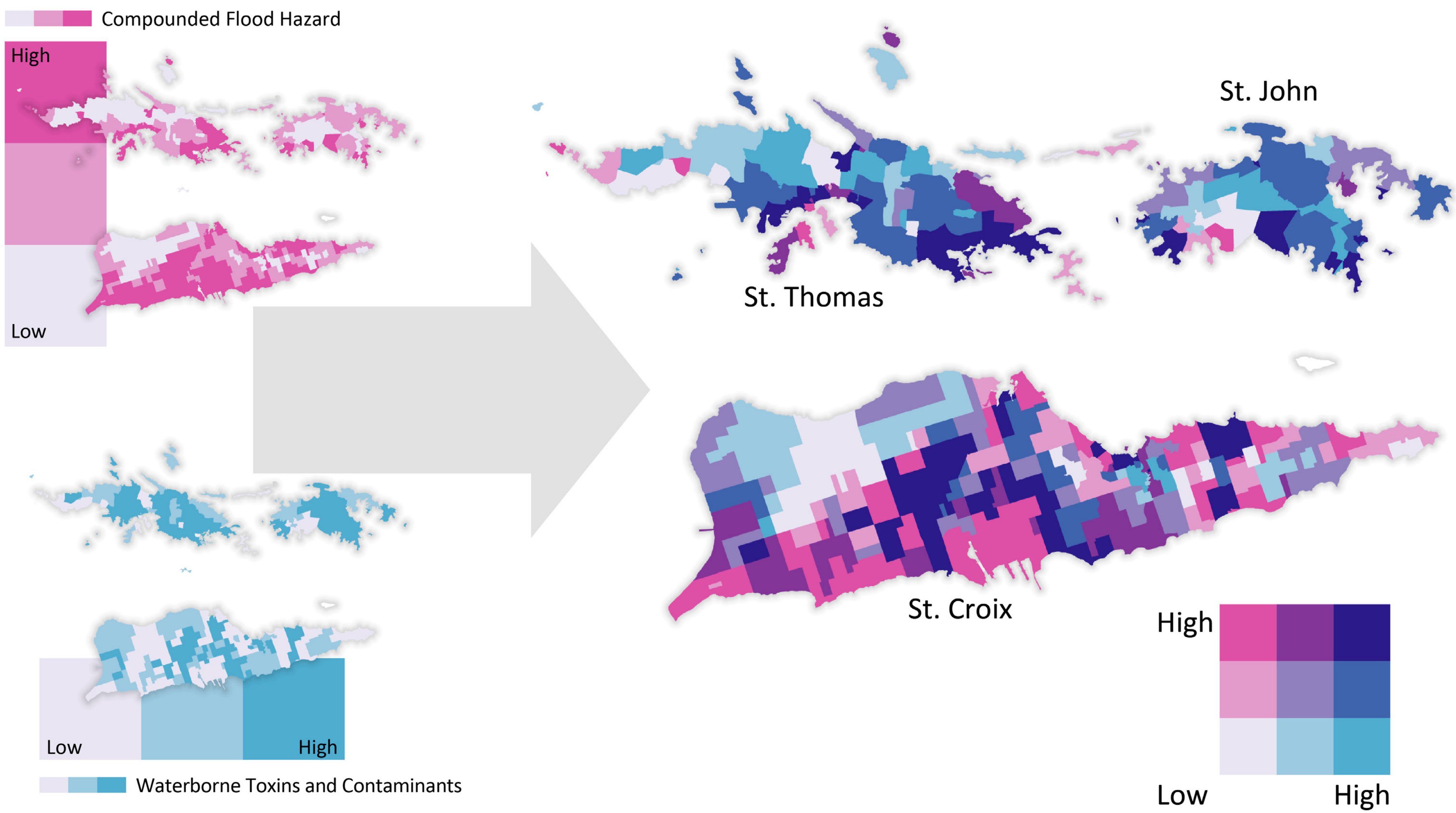
Compounded flood hazard and social vulnerability. This map shows the relationship between compounded flood hazard and social vulnerability. Estates with higher compounded flood hazard and higher social vulnerability are shown in dark blue. Populations in these areas are more likely to have higher flood hazard risk.



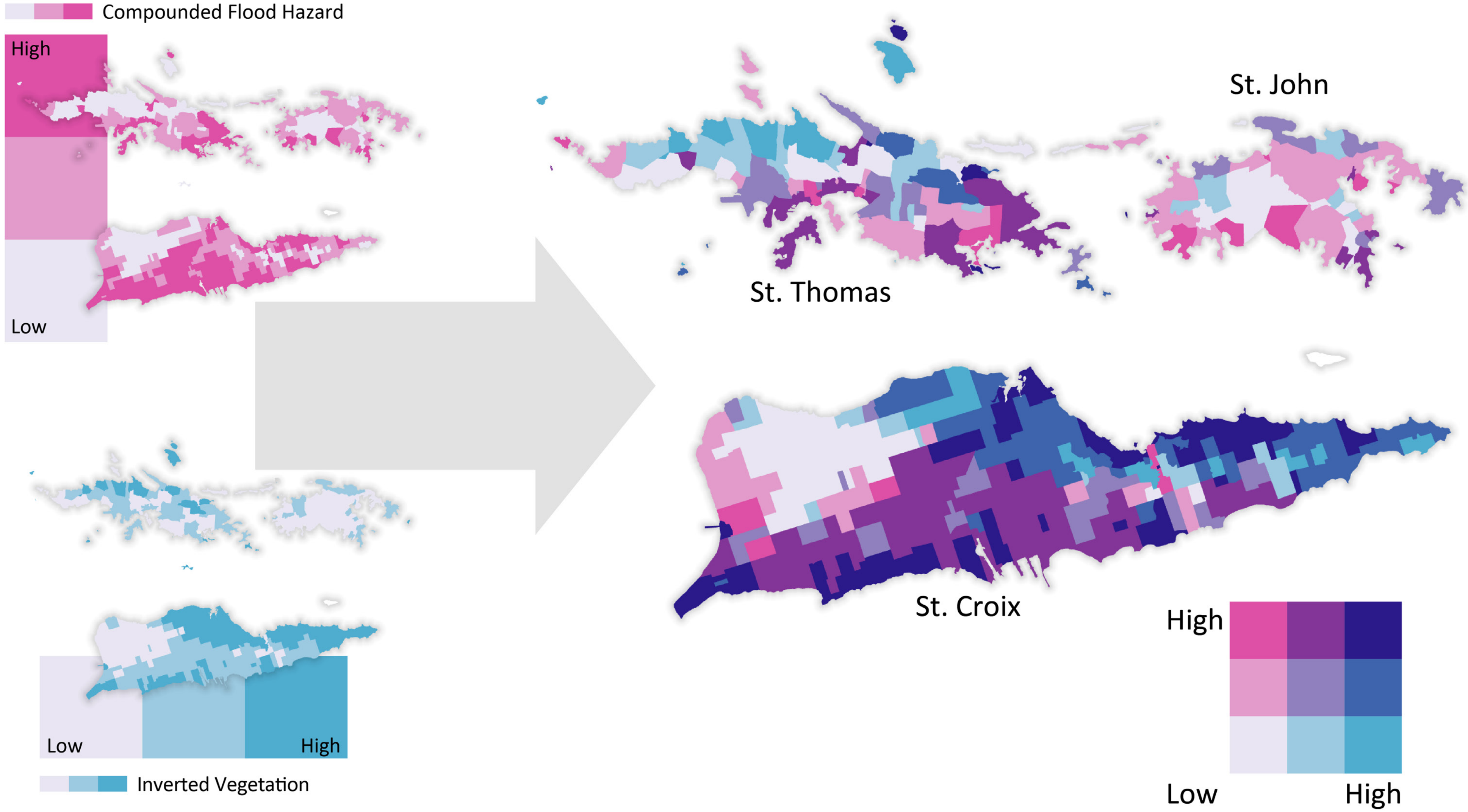
Compounded flood hazard and structural vulnerability. This map shows the relationship between compounded flood hazard and structural vulnerability. Estates with higher compounded flood hazard and higher structural vulnerability are shown in dark blue. Structures in these areas are more likely to have higher flood hazard risk.



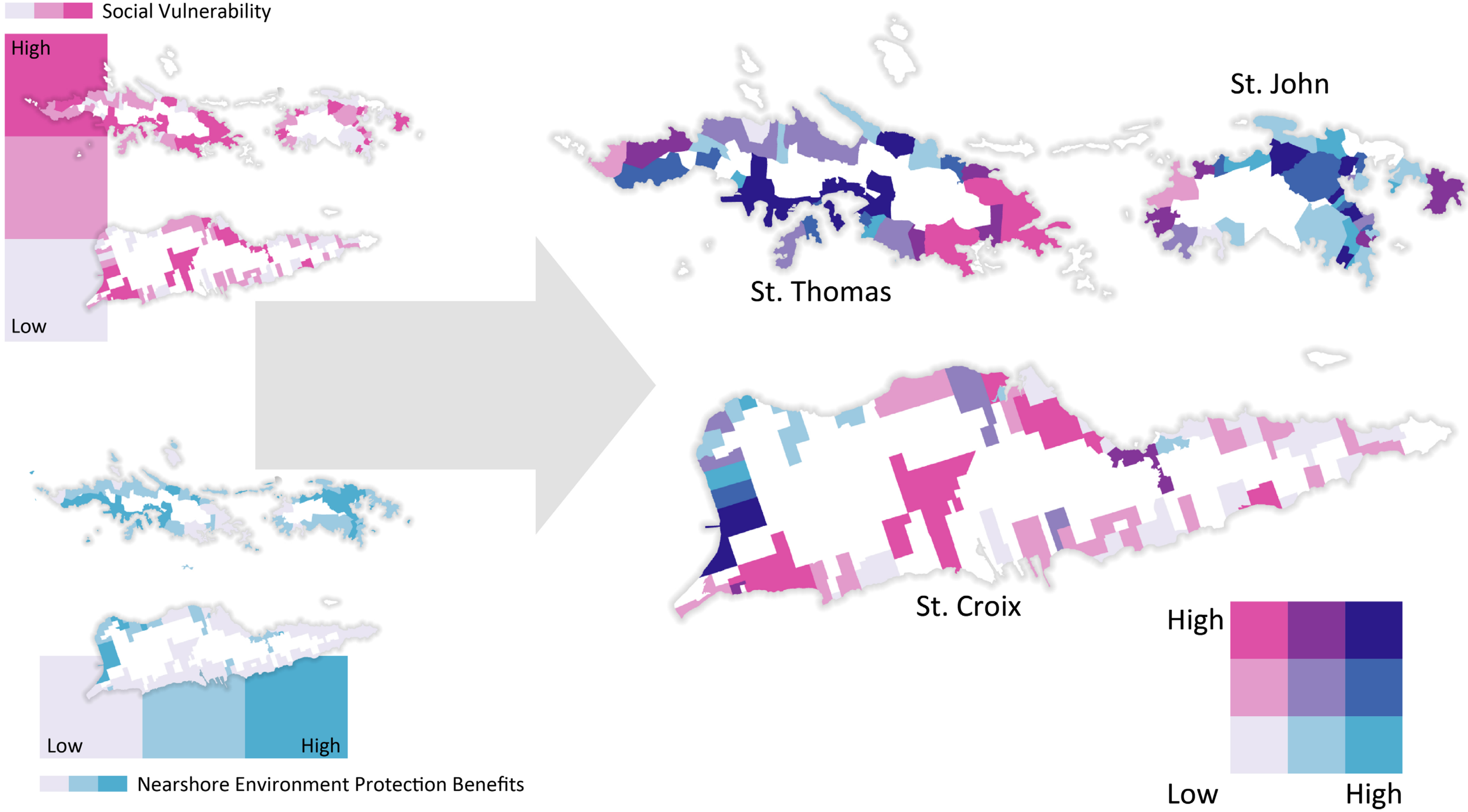
Compounded flood hazard and structural exposure. This map shows the relationship between compounded flood hazard and structural exposure. Estates with higher compounded flood hazard and higher concentrations of critical infrastructure are shown in dark blue. Structures in these areas are more likely to be exposed to flood waters. This could have implications beyond the identified estates since much of this critical infrastructure serves larger geographies within the territory.



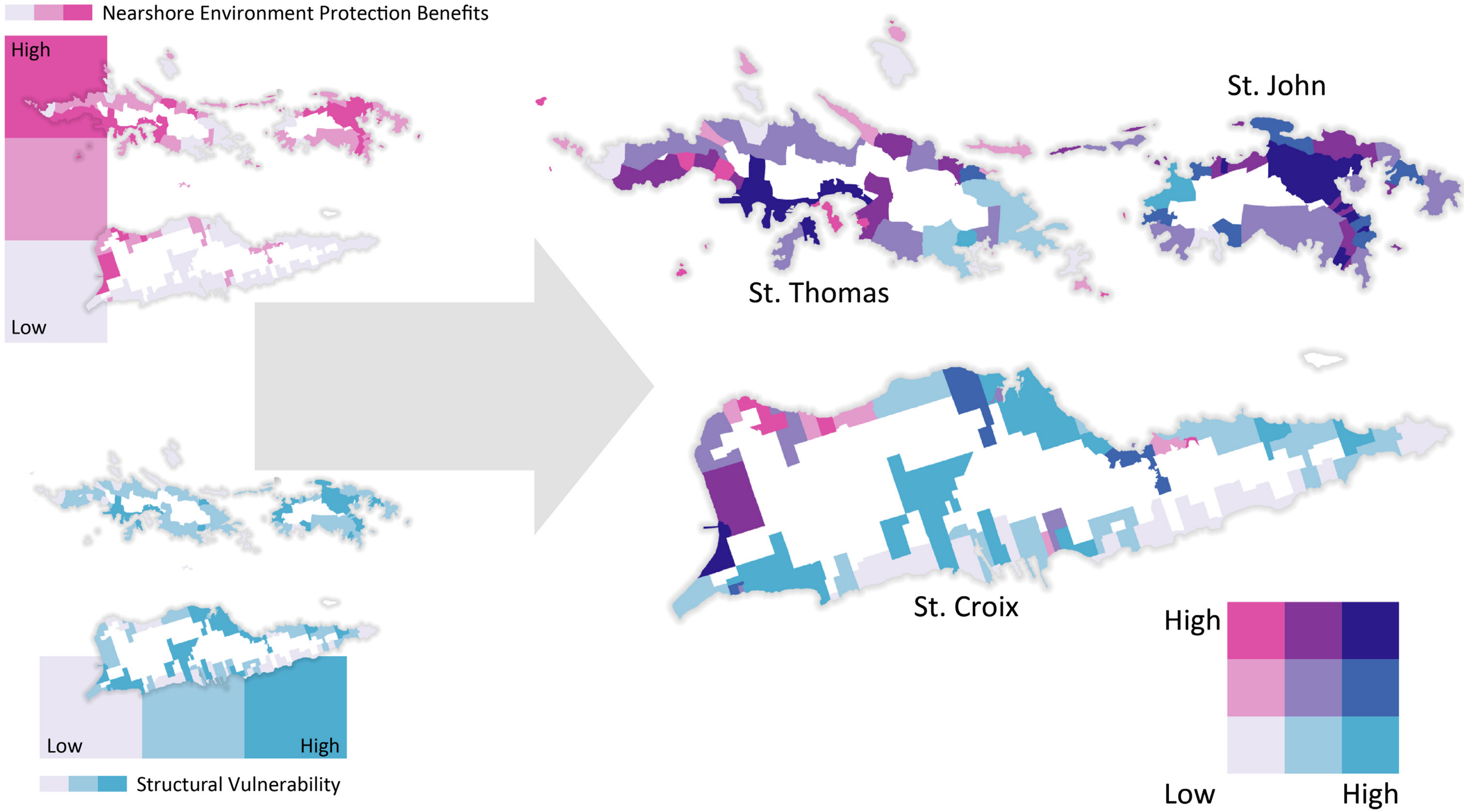
Compounded flood hazard and waterborne toxins and contaminants. This map shows the relationship between compounded flood hazard and waterborne toxins and contaminants. Estates with higher compounded flood hazard and higher potential for waterborne toxins and contaminants are shown in dark blue. Communities in these estates as well as downstream from these estates are at increased risk of contaminant releases during and after flood events.



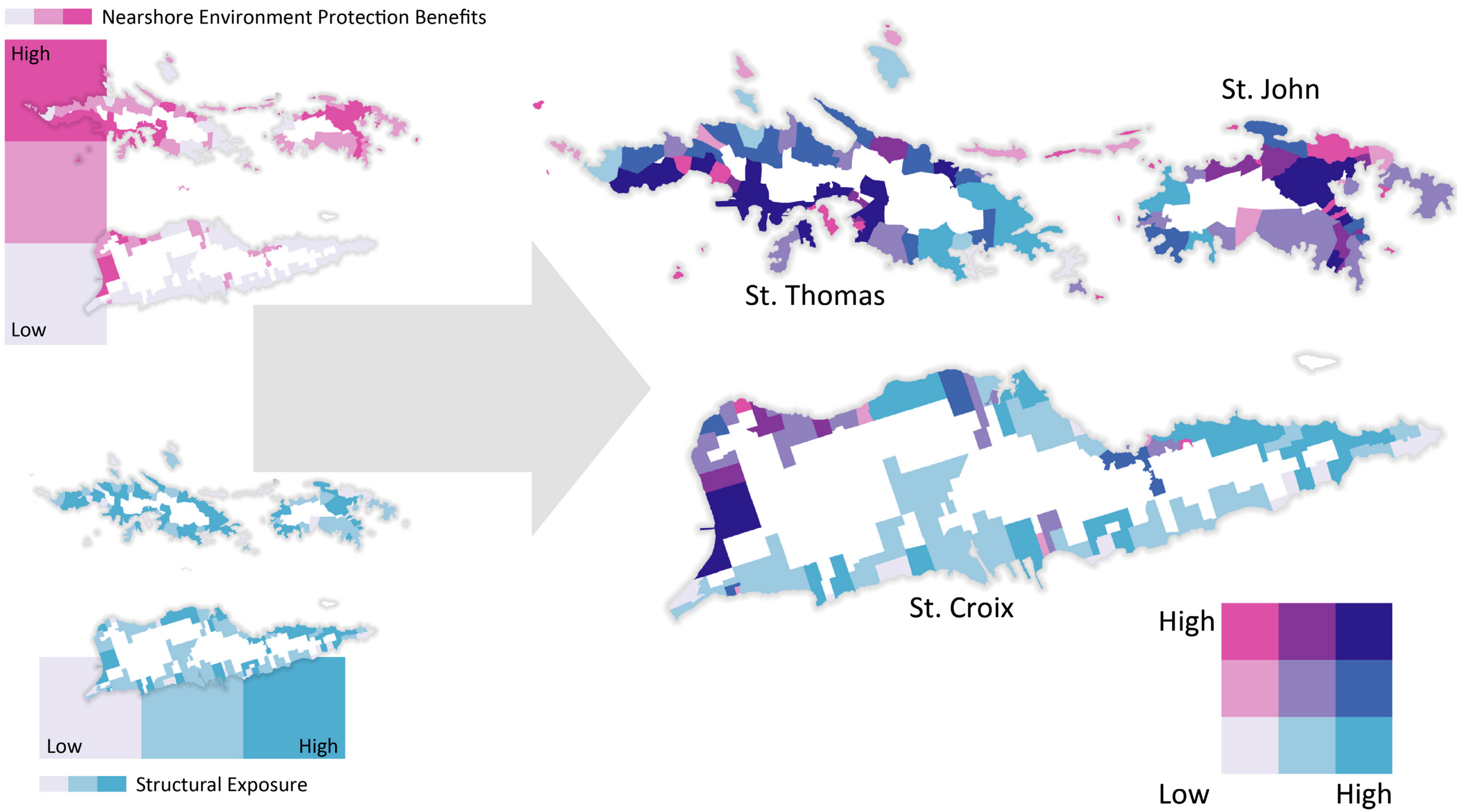
Compounded flood hazard and vegetation. This map shows the relationship between compounded flood hazard and vegetation. Estates with higher compounded flood hazard but lower vegetation are shown in dark blue. These estates have less onshore vegetation to help mitigate the impacts of flooding, despite being at greater likelihood of compounded flood hazard.



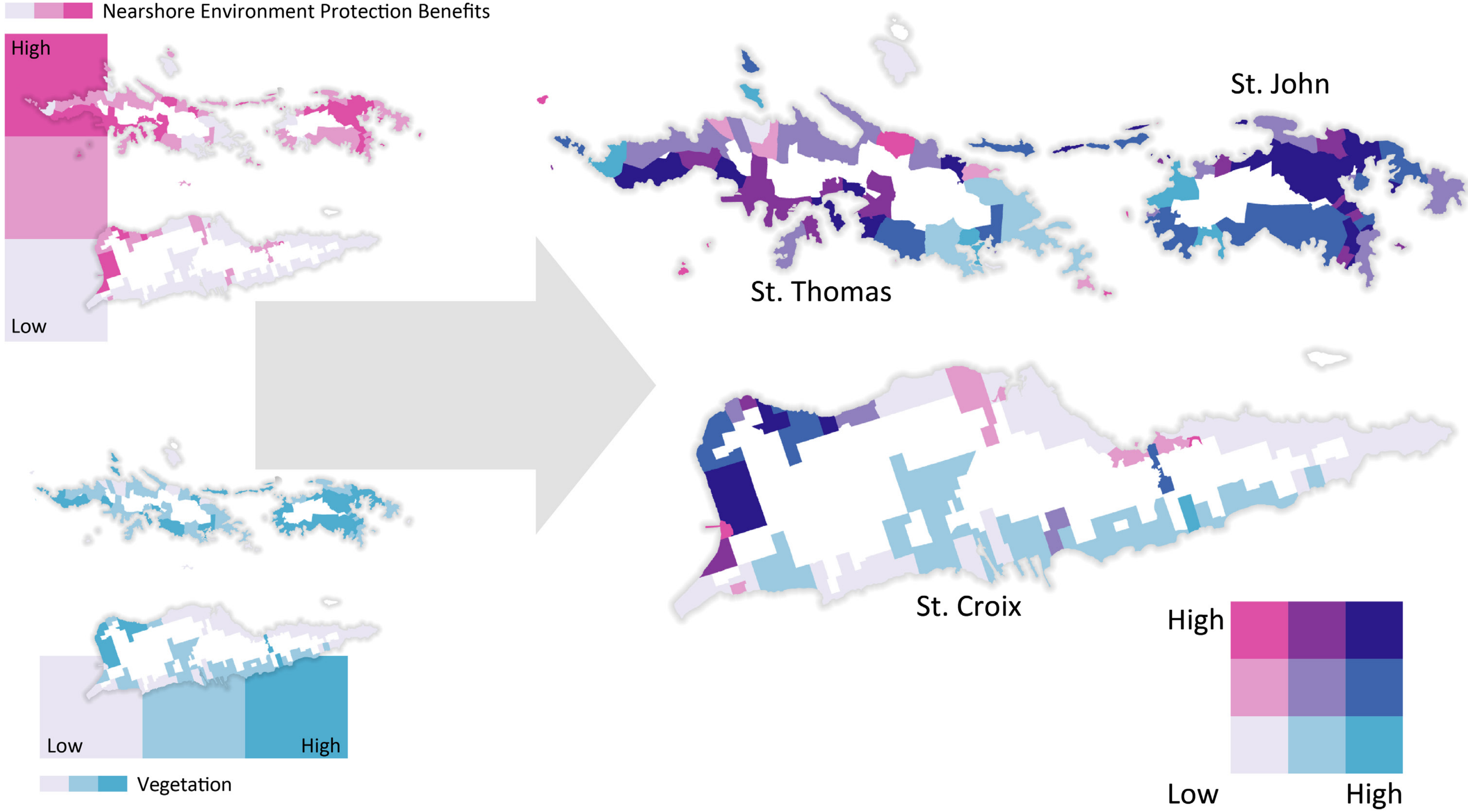
Nearshore environment protection benefits and social vulnerability. This map shows the relationship between nearshore environments and social vulnerability. Estates with higher nearshore environment protection benefits and higher social vulnerability are shown in dark blue. The socially vulnerable coastal populations in these estates are most likely to benefit from nearshore environment protections. Estates shown in bright pink, however, still have higher social vulnerability but lower nearshore environment protection benefits. The socially vulnerable coastal populations in these estates are least likely to receive nearshore environment protections.



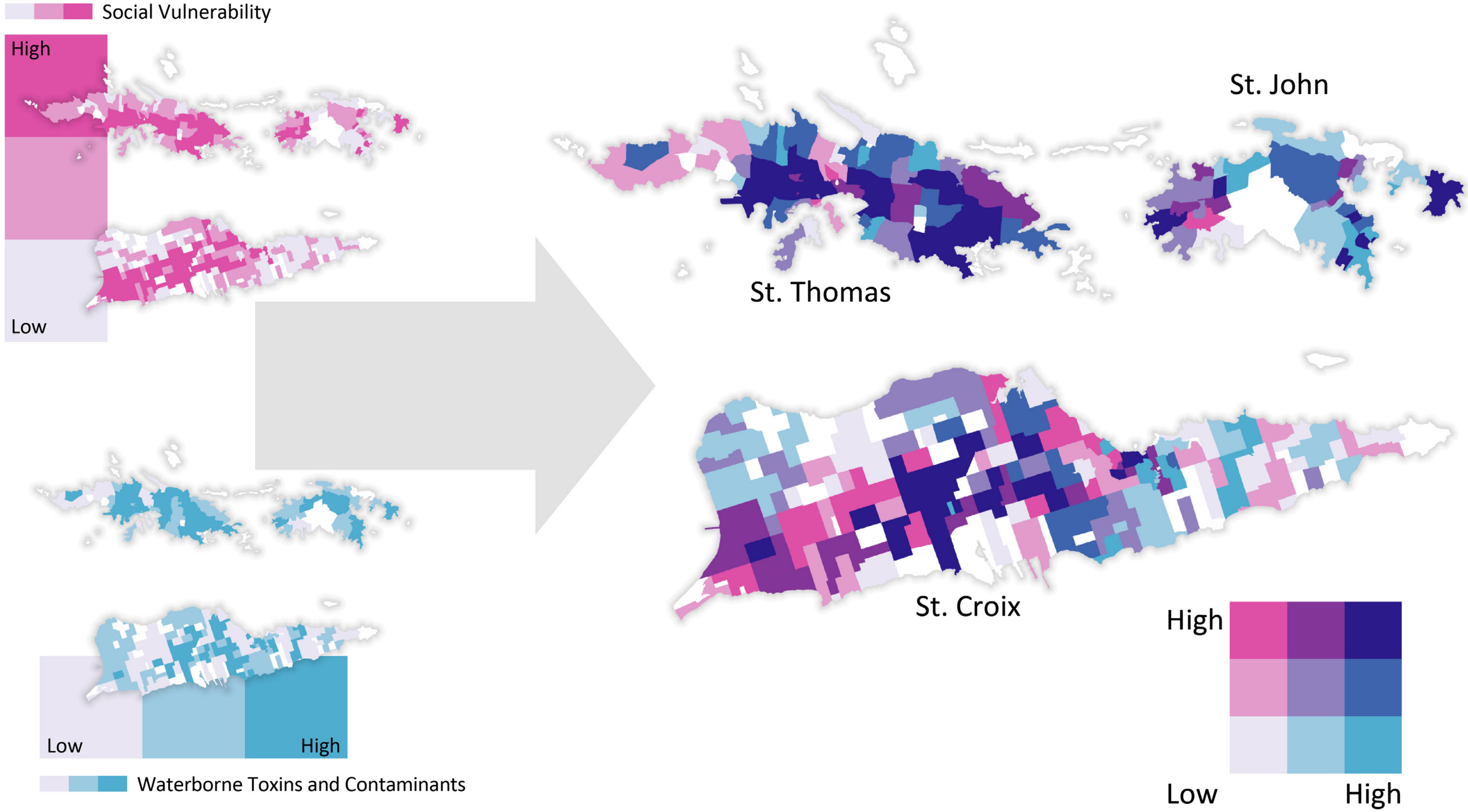
Nearshore environment protection benefits and structural vulnerability. This map shows the relationship between nearshore environments and structural vulnerability. Estates with higher nearshore environment protection benefits and higher structural vulnerability are shown in dark blue. Vulnerable coastal structures in these estates are most likely to benefit from nearshore environment protections. Estates shown in bright teal, however, still have higher structural vulnerability but lower nearshore environment protection benefits. Vulnerable coastal structures in these estates are least likely to receive nearshore environment protections.



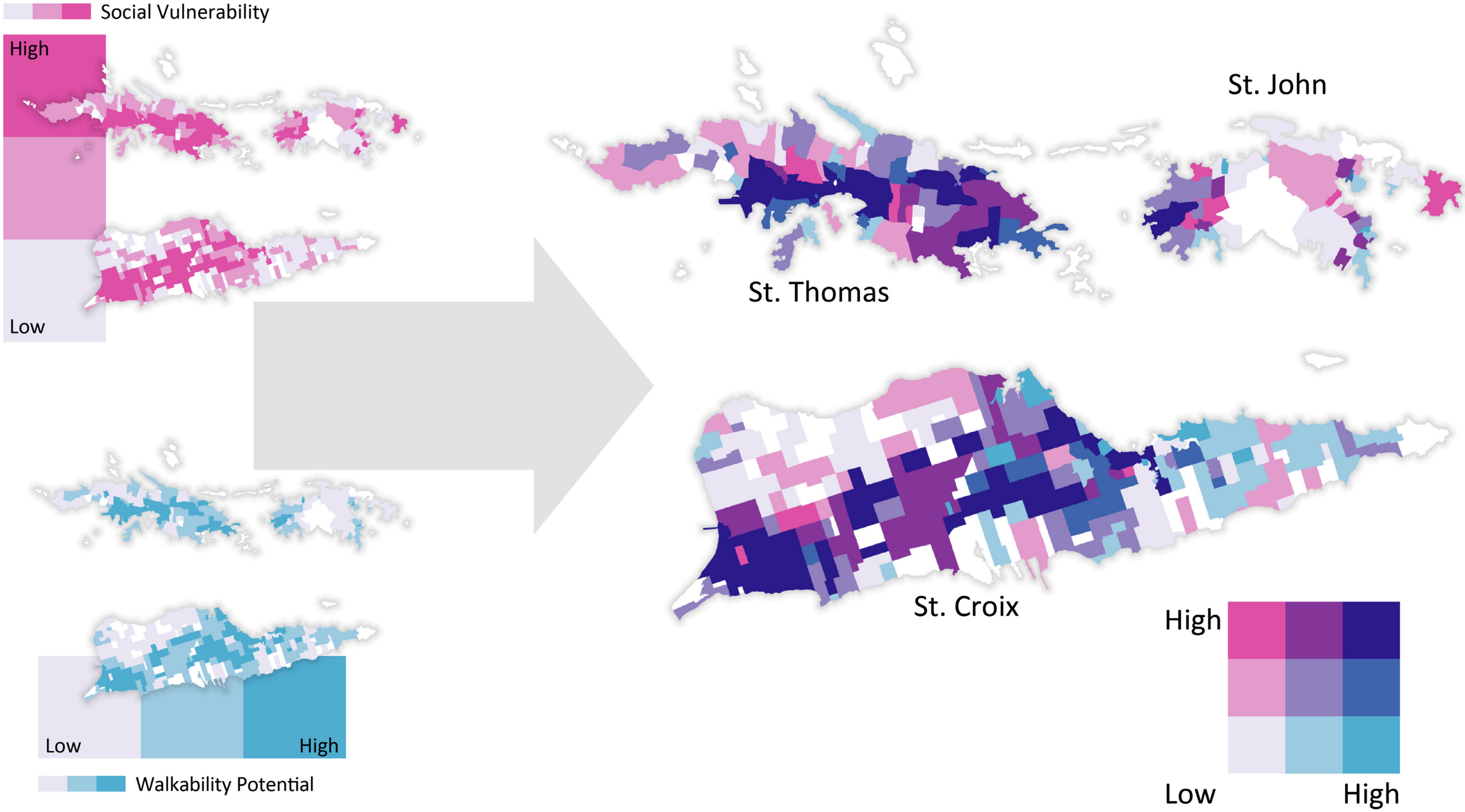
Nearshore environment protection benefits and structural exposure. This map shows the relationship between nearshore environments and structural exposure. Estates with higher nearshore environment protection benefits and higher structural exposure are shown in dark blue. Coastal critical infrastructure in these estates is most likely to benefit from nearshore environment protections. Estates shown in bright teal, however, still have higher structural exposure but lower nearshore environment protection benefits. Coastal critical infrastructure in these estates is least likely to receive nearshore environment protections.



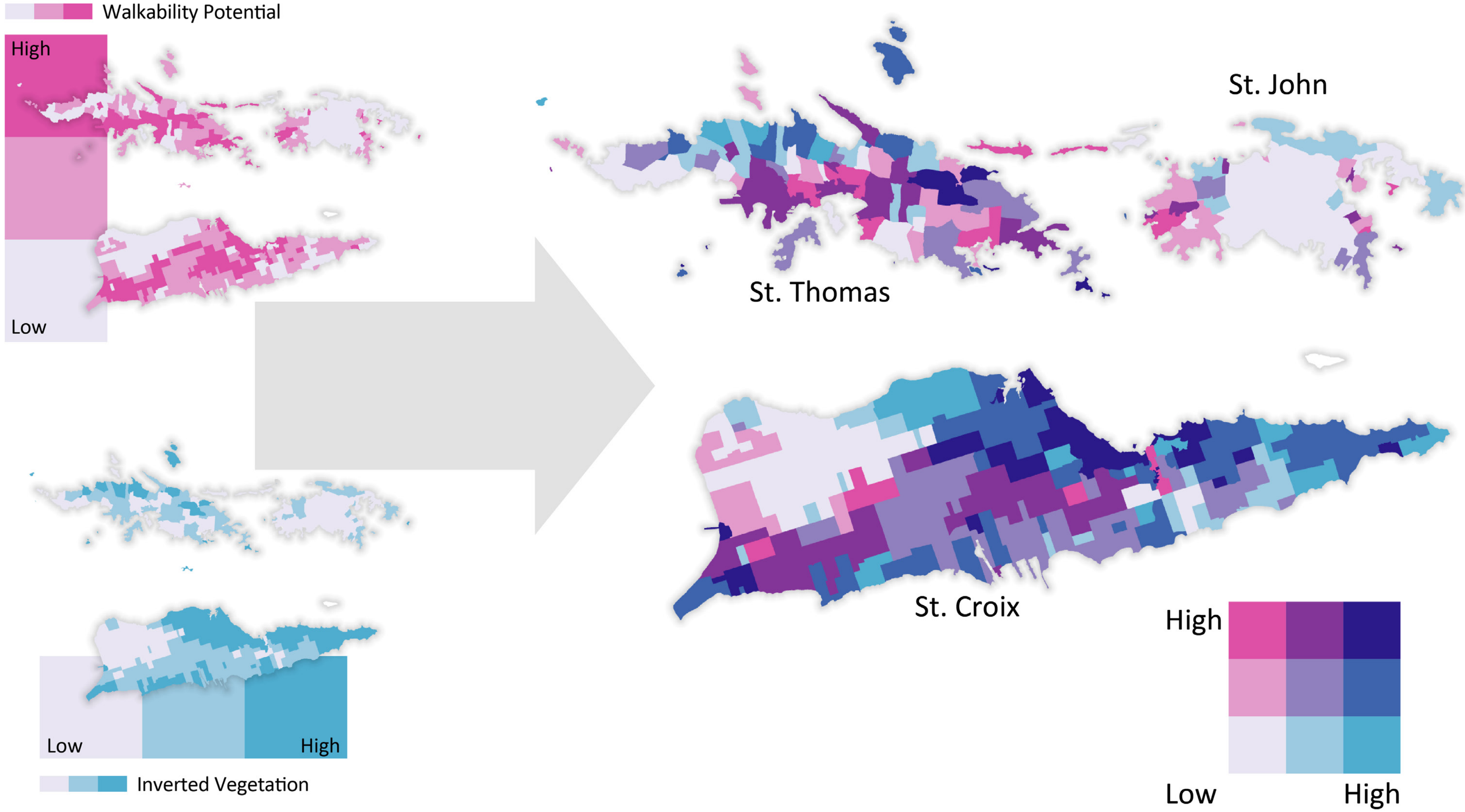
Nearshore environment protection benefits and vegetation. This map shows the relationship between nearshore environments and vegetation. Estates with higher nearshore environment protection benefits and higher vegetation are shown in dark blue. These estates have higher natural infrastructure flood mitigation properties both from nearshore and onshore environments. Estates shown in pale gray, however, are less protected from nearshore environments and have less onshore vegetation. These estates have fewer natural infrastructure flood mitigation properties.



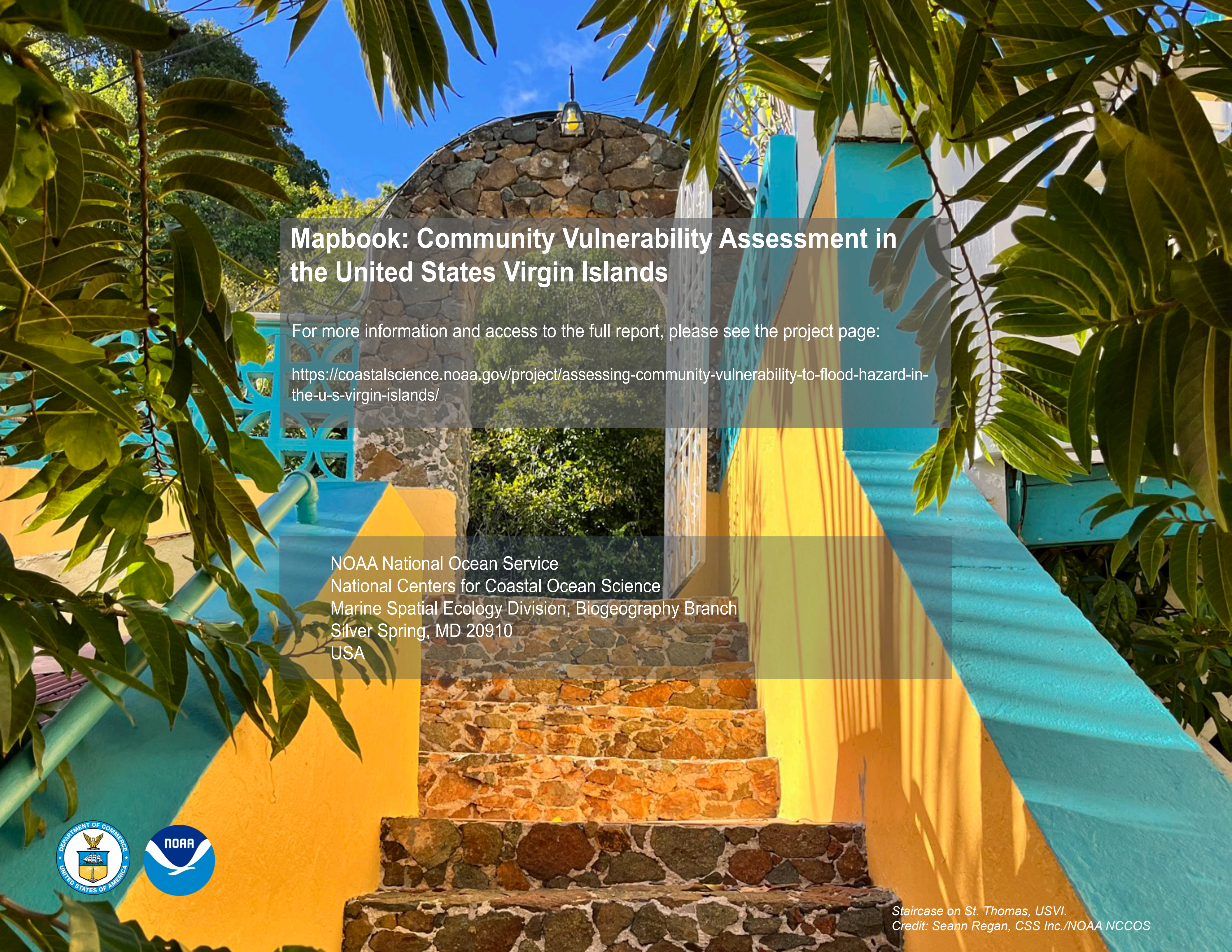
Social vulnerability and waterborne toxins and contaminants. This map shows the relationship between social vulnerability and waterborne toxins and contaminants. Estates with potentially higher social vulnerability and increased potential for waterborne toxins and contaminants are shown in dark blue. Populations in these estates have higher risk for toxin and contaminant exposure and related health impacts.



Social vulnerability and walkability potential. This map shows the relationship between social vulnerability and potential walkability. Estates with potentially higher social vulnerability and higher walkability potential are shown in dark blue. Socially vulnerable populations in these estates may have better access to walkable lifestyles. Estates shown in bright pink, however, have higher social vulnerability but lower walkability potential. Socially vulnerable populations in these estates have less access to walkable lifestyles.



Walkability potential and inverted vegetation. This map shows the relationship between potential walkability and vegetation. Estates with higher potential walkability but lower vegetation are shown in dark blue. These estates might benefit from vegetation restoration projects to encourage more walkable lifestyles.



Mapbook: Community Vulnerability Assessment in the United States Virgin Islands

For more information and access to the full report, please see the project page:

https://coastalscience.noaa.gov/project/assessing-community-vulnerability-to-flood-hazard-in-the-u-s-virgin-islands/

NOAA National Ocean Service
National Centers for Coastal Ocean Science
Marine Spatial Ecology Division, Biogeography Branch
Silver Spring, MD 20910
USA

Staircase on St. Thomas, USVI.
Credit: Seann Regan, CSS Inc./NOAA NCCOS

U.S. Department of Commerce

Gina M. Raimondo, *Secretary*

National Oceanic and Atmospheric Administration

Richard Spinrad, *Under Secretary for Oceans and Atmosphere*

National Ocean Service

Nicole LeBoeuf, *Assistant Administrator for National Ocean Service*

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