

# REGIONAL COASTAL RESILIENCE ASSESSMENTS: Methodology and Data Report

2020

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*IMPORTANT INFORMATION/DISCLAIMER: This report describes the methods associated with the Regional Coastal Resilience Assessments, which can be used to identify places on the landscape for resilience-building efforts and conservation actions through understanding coastal flood threats, the exposure of populations and infrastructure have to those threats, and the presence of suitable fish and wildlife habitat. As with all remotely sensed or publicly available data, all features should be verified with a site visit, as the locations of suitable landscapes or areas containing flood threats and community assets are approximate. The data, maps, and analysis provided should be used only as a screening-level resource to support management decisions. This report should be used strictly as a planning reference tool and not for permitting or other legal purposes.*

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*Suggested Citation: Dobson, J.G., Johnson, I.P., Rhodes, K.A., Lussier, B.C., and Byler, K.A. (2020) Regional Coastal Resilience Assessments: Methodology and Data Report. UNC Asheville National Environmental Modeling and Analysis Center, Asheville, NC. Prepared for the National Fish and Wildlife Foundation. Available online: <https://www.nfwf.org/programs/national-coastal-resilience-fund/regional-coastal-resilience-assessment>.*

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# ACKNOWLEDGEMENTS

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## Funders

The Regional Coastal Resilience Assessments were commissioned by the National Fish and Wildlife Foundation (NFWF) and funded by, and conducted in partnership with, the National Oceanic and Atmospheric Administration (NOAA).

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We would also like to thank the following individuals for providing valuable input, data, technical expertise, and other support: Jose Rivera, Ernesto Diaz, Julio Morell, Marlon Hibbert, Hilary Lohmann, Chris George, Rob Ferguson, Iván Llerandi-Román, Janice Castro, Tony Benavente, Gus Kaipat, Manny Pangelinan, Kodep Ogumoro-Uludong, Erin Derrington, Robbie Greene, Fiona Langenberger, Tammy Summers, Bradley Eichelberger, Jean Tanimoto, Luna Kekoa, Victoria Keener, Melissa Iwamoto, Justine Nihipali, Sheldon Plentovich, Erica Towle, Shay Viehman, Sarah Groves, Thomas Oliver, Kaylyn McCoy, Kristen Kaufman, Leslie Henderson, Aurora Justiniano-Santos, Hideyo Hattori, Bernardo Vargas-Ángel, Lima Fiatoa, Gina Faiga-Naseri, Kelley Anderson Tagarino, Maria Vaofanua, Chris Swenson, Marie Auyong, Celine Cruz, Paul Santos, Diane Vice, Thomas Flores, Romina King, Vangie Lujan, Edwin Reyes, and Toni Mizerek.

In addition, we thank Mandy Chesnutt, Anthony Chatwin, Amanda Bassow, Jay Jensen, Christina Kakoyannis, Suzanne Sessine, Chris Doley, Kara Meckley, Tisa Shostik, Adam Stein, Janine Harris, Gib Owen, Sheri Moore, Christian Manolo, Patrick Crist, Rickie White, Pete Cutter, and Cameron Scott.

\* Contractor with Lynker Technologies

## ABSTRACT

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The National Fish and Wildlife Foundation (NFWF) and the National Oceanic and Atmospheric Administration (NOAA) are committed to supporting programs and projects that improve community resilience by reducing communities' vulnerability to coastal storms, sea level rise, and flooding by strengthening natural ecosystems and the fish and wildlife habitat they provide. The Regional Coastal Resilience Assessments seek to identify undeveloped, natural areas and habitat cores that, through the implementation of nature-based solutions, have the potential to build human community resilience while supporting fish and wildlife habitat and species. In 2019, Regional Assessments for the U.S. Atlantic, Gulf of Mexico, and Pacific coastlines used a standardized methodology to combine information about flooding threats, human community assets, and fish and wildlife species to identify Resilience Hubs. The analysis is being expanded to include Regional Assessments for Hawai'i, Alaska, the Great Lakes, and all U.S. territories. Owing to the uniqueness of each region, the methods continue to be refined and enhanced. This document describes the most up-to-date methods as applied to Puerto Rico, the U.S. Virgin Islands, the Northern Mariana Islands, Hawai'i, Guam, and American Samoa. As additional Regional Assessments are completed, this document may be updated accordingly.

# INTRODUCTION

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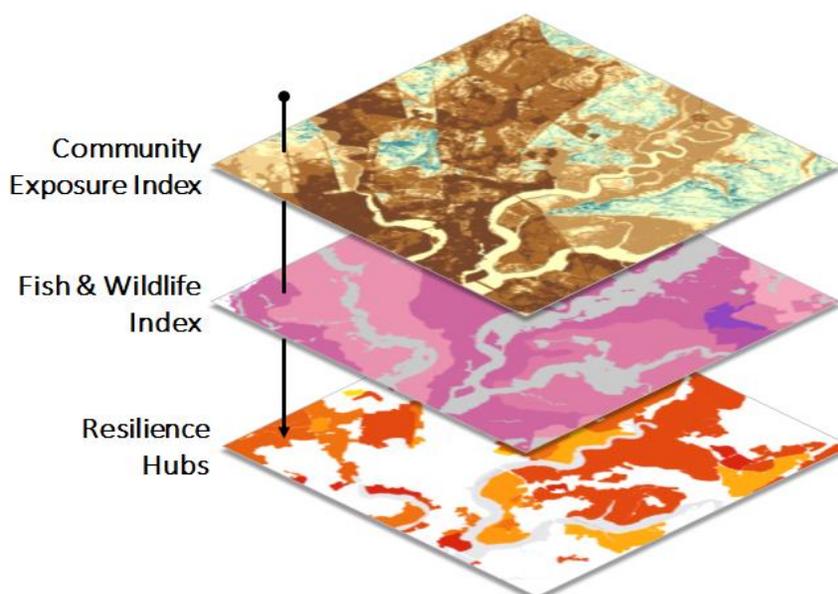
## 1.1 Background

Coastal communities throughout the United States face serious current and future threats from natural events, which are predicted to intensify over the short and long term. Dynamic processes such as erosion, storm surge flooding, and river runoff exacerbate the threat from sea level rise. Intense hurricanes and extreme flooding have the potential for devastating both human communities and fish and wildlife.

In partnership with the National Oceanic and Atmospheric Administration (NOAA), the National Fish and Wildlife Foundation (NFWF) is committed to supporting programs and projects that improve community resilience by reducing communities' vulnerability to coastal storms, sea level rise, and flooding while strengthening natural ecosystems and the fish and wildlife habitat they provide.

In response to growing coastal flooding threats, NFWF commissioned University of North Carolina (UNC) Asheville's National Environmental Modeling and Analysis Center (NEMAC) to develop an assessment to identify coastal areas that may be ideal for the implementation of nature-based solutions that build both human community resilience and fish and wildlife habitat. The resulting Regional Coastal Resilience Assessments (referred to from here forward as the Regional Assessments or Assessments) aim to identify and rank open space areas and habitat cores where targeted investments can implement resilience-building projects before devastating events occur and impact surrounding communities.

The Regional Assessments combine land use, protected areas, human community assets, flooding threats, and fish and wildlife resource spatial data to identify and rank Resilience Hubs (Figure 1). Resilience Hubs are large areas of natural, open space or habitat where, if investments are made in conservation or restoration, there is potential for improved human community resilience and benefits to fish and wildlife habitats and species.



*Figure 1. A conceptual model showing the separate, but interrelated components of the Regional Coastal Resilience Assessments.*

## 1.2 Overview of the Regional Coastal Resilience Assessments

Through a partnership among NEMAC, NOAA, and NFWF (the Project Team), the Regional Coastal Resilience Assessments seek to evaluate regional resilience for *all* U.S. coastlines. In 2019, the Project Team completed Regional Assessments for the U.S. Atlantic, Gulf of Mexico, and Pacific coastlines (Figure 2). In this initial phase, the Project Team worked with technical advisors to develop an overarching structure and methodology, which is described in detail in the regional report for the oceanic coastlines of the continental U.S. (CONUS) (Dobson et al. 2019). This methodology has served as a basis for subsequent Regional Assessments in Alaska, Hawai'i, Puerto Rico, the U.S. Virgin Islands (USVI), the Commonwealth of the Northern Mariana Islands (CNMI), Guam, American Samoa, and the U.S. Great Lakes (Figure 2). As Assessments in these new regions began, the Project Team identified numerous regional differences, from variable data availability to the presence of new habitat types to threats not prevalent along the CONUS coastlines. Through consultation with regional experts, the Project Team identified and developed new methods to improve model accuracy and support standardization across regions.

This document outlines the foundational methods developed for the CONUS Regional Assessments, but also incorporates refinements and enhancements developed for the other regions. In some cases, the changes are minor (e.g., the Community Exposure Index). In other cases, the methods described here vary significantly from those used in CONUS (e.g., Fish and Wildlife Index). As a result, readers interested in the complete methods for CONUS should review the regional report for the U.S. Atlantic, Gulf of Mexico, and Pacific coastlines (Dobson et al. 2019). Those interested in the enhanced methodology applied (or to be applied where practicable) for all other regions should refer to the details provided in this document. As additional Regional Assessments are completed, the Project Team may update this Methodology and Data Report accordingly.



*Figure 2. The geographic extent of the Regional Coastal Resilience Assessments in dark gray. The methods used to create the Assessments for the continental U.S. Atlantic, Gulf of Mexico, and Pacific coastlines are available in a separate report (Dobson et al. 2019); this document describes the overarching methods as applied to, or expected to be applied to, all remaining regions. All Regional Assessments will be completed by 2021. Map not shown to scale.*

### 1.3 Methods Overview

The foundation of the Regional Coastal Resilience Assessments is based on the coastal vulnerability research outlined in Gornitz et al. (1994). In 2011, the New Jersey Office of Coastal Management and Department of Environmental Protection adapted that research to assess existing and future hazard vulnerabilities on a local scale (NJ-DEP 2011). This research was integral to structuring the inputs and methodology of this analysis.

The Regional Assessments use a Geographic Information System (GIS)-based approach to model landscape characteristics and their potential impacts. From a modeling standpoint, the Regional Assessments consists of three separate but interrelated analyses: (1) the Community Exposure Index, (2) the Fish and Wildlife Index, and (3) the Resilience Hubs. These three components make these Assessments unique, as they look at resilience potential through the lens of both human and wildlife communities. Specifically, the Community Exposure Index can guide land use and hazard mitigation planners in identifying potential development constraints and improve the understanding of potential risks to critical infrastructure and populations. The Fish and Wildlife Index can inform where on the landscape habitats and species of conservation concern occur. The Resilience Hubs then identify open spaces and habitat suitable for the implementation of projects that are expected to build a community's resilience to flooding events while also benefiting fish and wildlife.

While both the Gornitz et al. (1994) and the New Jersey research (NJ-DEP 2011) focus on determining the magnitude of flood hazards on the landscape, the Assessments focus on the exposure of community assets to flood threats. For example, the model shows communities as highly exposed if they are densely populated, have high social vulnerability, and have dense pockets of critical facilities and/or infrastructure that also overlap with numerous flooding threats.

In addition to mapping human assets and flooding threats across the landscape to determine exposure, wildlife resources were also identified. Multiple datasets highlighting threatened and endangered species designated under the Endangered Species Act, as well as species of greatest conservation need identified in territorial or State Wildlife Action Plans<sup>1</sup> and their habitats were incorporated into two Indices: the Marine Index and the Terrestrial Index. Many species are vulnerable to flood-related stressors such as sea level rise, storm surge, and coastal habitat loss (Powell et al. 2017; Thorne et al. 2018; von Holle et al. 2019). For example, flooding can impact water quality, which can have negative outcomes for sensitive populations of aquatic species (Georgakakos et al. 2014). Flooding can also upset ground-nesting birds, sea turtles, and other species vulnerable to coastal inundation. However, neither the Community Exposure Index nor the Resilience Hubs are used to assess the exposure of fish and wildlife habitat or species to flooding threats and should only be used to help identify areas of highly exposed human assets that coincide with the location of fish and wildlife assets.

The overarching goal of the Regional Assessments is to identify Resilience Hubs, which help to identify where natural, open space or habitats on the landscape are most suitable for resilience-building and conservation or restoration efforts that can help communities prepare for potentially adverse impacts to infrastructure and communities, while also improving the habitats of fish and wildlife species. These Hubs are determined first by the identification of undeveloped, natural landscapes or habitat cores, and then by the ranked combined averages of the Community Exposure and Fish and Wildlife Indices (Figure 3).

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<sup>1</sup> State Wildlife Action Plans are available on the Association of Fish and Wildlife Agency website: [https://docs.google.com/document/d/1B-W237P77DvGkLolo7rpewfzwZ\\_1sccobfzSwqPIOk/edit#](https://docs.google.com/document/d/1B-W237P77DvGkLolo7rpewfzwZ_1sccobfzSwqPIOk/edit#).



*Figure 3. Viewing open spaces through the lenses of human community exposure and fish and wildlife assets to identify Resilience Hubs that may be well suited for resilience-building projects. This is a conceptual framework of the overall objective of the Regional Assessments, not the actual process of developing the Community Exposure and Fish and Wildlife Indices or the Resilience Hubs.*

This document summarizes the most up-to-date inputs and methods used to create the Community Exposure Index, Fish and Wildlife Index, and Resilience Hubs. (Previously developed methods applied only to the continental U.S. are available in a separate report (Dobson et al. 2019) for reasons described above.) The [Appendix](#) provides additional details that can be used to replicate all or parts of the analysis.

### **1.3.1 Geographic Scope**

The Regional Coastal Resilience Assessments are unique in that they not only take into account the immediate coastline, but also focus on inland areas that can often directly contribute to coastal flood-related issues. For instance, intense rain and riverine flooding that drains directly to the coast can exacerbate coastal flooding. The boundary of the Regional Assessments follow the U.S. Environmental Protection Agency’s (EPA) designated coastal watersheds, which are hydrologic unit code eight (HUC-8)<sup>2</sup> watersheds that drain directly to the ocean or watersheds that are tidally influenced or particularly low lying. Watershed boundaries are represented using a hierarchical system of nesting hydrologic units at various scales, each with an assigned HUC (Figure 2). The HUC-8 scale is the sub-basin level, analogous to medium-sized river basins. For the island regions of Puerto Rico, U.S. Virgin Islands, Hawai’i, the Commonwealth Northern Mariana Islands, Guam, and American Samoa, the HUC-8 watersheds cover each island entirely and thus the Assessments include the entire area of each populated island.

### **1.3.2 Data Collection**

The Regional Coastal Resilience Assessments relied heavily on the availability of public data from federal agencies at a national scale. For CONUS, all data used were at a national scale with a 30-meter resolution (Dobson et al. 2019). These public data were mostly discovered through the literature and internet searches. For other regions, the Assessments utilized many local datasets that were identified through local Advisory Committees, stakeholder workshops, and interactions and communication with other technical experts.

<sup>2</sup> According to the Environmental Protection Agency’s Coastal Wetlands Initiative: <https://www.epa.gov/wetlands/coastal-wetlands>.

There were several factors that precluded the use of certain data, e.g., if data were only available for a portion of the region or lacked supporting metadata or other documentation. In some Regional Assessments, new spatial data were created by NEMAC where datasets were unavailable. Specifically, NEMAC digitized some critical infrastructure data (i.e., additional heliports, marinas, ferry terminals) used to create the Community Asset Index. In addition, NEMAC utilized the Green Infrastructure methodology (Firehock & Walker 2019) and developed the Blue Infrastructure methods (described below) to identify habitat cores used to create Resilience Hubs.

This report describes the full range of data used across all Regional Assessments. Each Regional Assessment report includes additional details about regionally specific data (Dobson et al. 2019; Dobson et al. 2020a-d; Dobson et al. 2021a-b).

## CREATING THE COMMUNITY EXPOSURE INDEX

The Community Exposure Index was created by combining the Threat Index and Community Asset Index, depicting the spatial distribution of the potential exposure of assets to flood threats (Figure 4). Inputs used to create the Threat and Community Asset Indices are, to the extent practicable, consistent among all regions.



Figure 4. Elements of the Threat and Community Asset Indices used to create the Community Exposure Index. Data inputs vary by region.

### 2.1 Threat Index

Flood-related datasets are used to help communities understand which flooding threats are potentially present in their area. While other threats may exist, for the purposes of this analysis only those threats relevant to flooding were included and potentially varied by region (Figure 5). Datasets range from periodic threats such as inundation from storm surge to landscape characteristics such as the presence of low-lying areas. The Assessments also incorporated regionally specific threats, such as geologic stressors that may impact a community’s ability to survive or recover from flood events (Shinkle & Dokka 2004). To determine the most suitable data inputs for this analysis, the foundational work from Gornitz et al. (1994) and the New Jersey Vulnerability Assessment and Mapping Protocol (NJ-DEP 2011) were considered, as well as data that were cited in other vulnerability assessments (Turner et al. 2003; Adger 2006).

Using an ordinal combination method, all inputs were ranked numerically from low to high, representing the risk—not the degree—of impact (MacDonald 2007; Gornitz et al. 1994; NJ-DEP 2011). Each ranked input is used to create the cumulative Threat Index (Ponce Manangan et al. 2014). The Threat Index is then reclassified into 10 classes using a percentile distribution. For a complete list of data used in the Threat Index, see [Appendix A.1](#). Detailed methodologies for each input are located in [Appendix B](#).

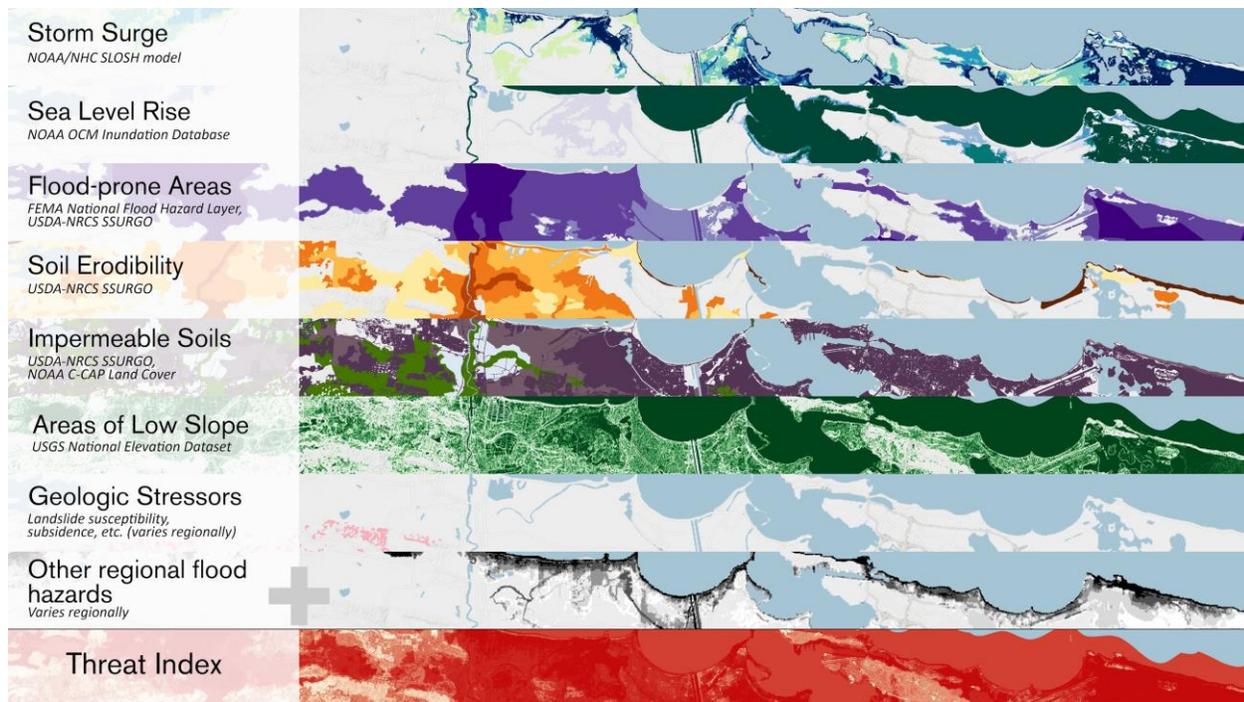


Figure 5. An example of all inputs (listed on the left) used to generate the resulting Threat Index. Darker colors in each input equate to higher rank values. The darkest red in the Threat Index is the highest value. Figure represents a generic region and is only intended to illustrate the methods and data used. Data inputs vary by region.

### Storm Surge

Surge from major storms is the greatest threat to life and property from a storm<sup>3</sup> and varies by region. The width and slope of the continental shelf plays an important role in this variation, where shallow slopes can potentially produce a greater storm surge than steep shelves<sup>4</sup>. To understand the potential inundation caused by storm surge, the Assessments used the National Hurricane Center’s Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model with the Mean Higher High Water surge scenario for each region where data were available. These threat data use a *likelihood* ranking where a one-foot surge is given a higher ranking than a five-foot surge. See [Appendix B.1](#) for more details.

### Sea Level Rise

Coastal decision-makers and wildlife managers often use NOAA’s modeled sea level rise scenarios to understand the potential impacts that a community may encounter, from the impacts on existing or proposed infrastructure or land use options to the decisions made in conservation efforts.

Sea level rise occurs at varying rates across all coastal areas considered in this analysis. The Assessments used scenarios for a one- to five-foot rise in relative sea level, where a one-foot projected rise carries a “very high” level of threat (5) and a five-foot rise carries the lowest threat (1). While seemingly backwards, this ranking captures the likelihood of each foot rise in sea level: a one-foot rise is more likely to occur than a five-foot rise scenario, hence a one-foot rise poses a more immediate threat. See [Appendix B.2](#) for more information.

<sup>3</sup> For details, see the National Weather Service, National Hurricane Preparedness website: <https://www.weather.gov/wrn/hurricane-preparedness>.

<sup>4</sup> For overview of storm surge, see the National Hurricane Center website: <https://www.nhc.noaa.gov/surge/>.

### ***Flood-Prone Areas***

Flood-prone areas identified in the Regional Assessments are a combination of the Federal Emergency Management Agency (FEMA) National Flood Hazard Layer (NFHL) and the USDA-NRCS Soil Survey Geographic Database (SSURGO). Whenever available, FEMA 100- and 500-year floodplains and the floodway were used because these data are the most accessible flood information available to municipal officials, non-government organizations, and communities. In areas where data were missing or unavailable, soils identified as having high to occasional inundation in a given year were included. More details about the creation of this input can be found in [Appendix B.3](#).

### ***Soil Erodibility***

Soil erosion resulting from flooding can drastically alter the landscape and impact both human communities and wildlife habitats. To assess the erodibility of soils throughout coastal watersheds, the USDA-NRCS SSURGO database K Factor (*kffact*) was used, which measures the susceptibility of soil particles to detachment by water. Soils high in clay have low K values because they resist detachment. Soils having high silt content are the most erodible of all soils, as they are easily detached and produce high rates of runoff (Renard et al. 2011).

Additionally, this input includes beaches and dunes—systems known to be dynamic by nature. Although these landforms are beneficial and can help buffer a community from flooding, the risk of erosion is relatively high (Gornitz et al. 1994). See [Appendix B.4.2](#) for details.

### ***Impermeable Soils***

The rate at which water flows through the soil or land influences the frequency and duration of time that lands are inundated. Slower rates of drainage can impede a community's ability to recover from a flood event since surfaces can remain flooded for longer periods of time. Where soils are impacted by development or infrastructure, they can also become impervious. To account for water retention rates in soils, data from USDA-NRCS SSURGO Natural Drainage Classes (*drclassdcd*) were used to classify a soil's ability to allow water to pool or drain (USDA 2018). To identify the impervious land cover in urban areas—areas often lacking in comprehensive soil data—impervious land cover classifications were incorporated with the NOAA Coastal Change Analysis Program land cover and included throughout the Assessment regions.

For a landscape to carry a “very high” ranking in the Regional Assessments, it must be a somewhat-to-very-poorly-drained soil type *and* contain an intensity of development. As a result of this multi-criteria ranking scheme, urban or semi-urban areas with both (1) soils that retain water, and (2) impervious surfaces where water may pool or runoff, received a higher rank value. See [Appendix B.4.1](#) for details on this input and its ranking.

### ***Areas of Low Slope***

As a terrain's slope decreases, more land areas become prone to pooling water that can lead to prolonged periods of inundation. This threat input was developed with consideration of the Brunn Rule, which states that every foot rise in water can result in a 100-foot loss of sandy beach (NJ-DEP 2011). In this case, a one percent or less slope is likely to be inundated with a one-foot rise in water, providing insight for low-lying coastal areas that are more susceptible to inundation and changing coastal conditions. More information is found in [Appendix B.5](#).

### ***Geologic Stressors***

Geologic stressors were used in the Regional Assessments to show potential additional threats to a landscape but are not intended to be interpreted as threats resulting directly from a severe storm or flood event. The geologic conditions of the landscape can exacerbate the level of threat represented by the other inputs. For example, sinking lands—or land subsidence—can increase the impacts caused by storm surge or sea level rise. Historic landslide occurrences can also increase the threat posed by highly erodible soils. As the causes of these geologic stressors vary greatly among regions, the Regional Assessments were individually constructed based on existing models (where available) to reflect the impact and severity of regional landslide occurrence, land subsidence, and other geologic stressors (Dobson et al. 2019; Dobson et al. 2020a-d). Details about the creation of this input are found in [Appendix B.6](#).

### ***Other Regional Flood Hazards***

Where appropriate, Regional Assessments also considered additional, regionally specific flood hazards. For instance, tsunamis pose a great flood risk to many coastal communities. Tsunamis can be generated when the sea floor abruptly deforms and vertically displaces the overlying water. In areas where there is onshore and underwater landslide activity, tsunamis can also be generated. See [Appendix B.7](#) for more details. For information about other regional flood hazards, see regional reports (Dobson et al. 2019; Dobson et al. 2020a-d).

## **2.2 Community Asset Index**

The Community Asset Index identifies human community assets that are important to help a community to respond to and recover from a flooding event. To allow consistency within a given region, all datasets used had spatial data available at a regional scale. The Community Asset Index was created using datasets that quantify the number of assets present—not their magnitude of vulnerability or susceptibility to flood threats. Datasets chosen focused on human community asset inputs such as population density and social vulnerability, as well as critical facilities and infrastructure that help communities respond to flood events, such as hospitals or police and fire stations (Figure 6). Where appropriate, additional types of infrastructure were included, such as communication infrastructure and cultural and historic sites. See [Appendix A.2](#) for a complete list of data sources and descriptions. The use of these data aims to facilitate more informed decision-making. As with the Threat Index, the Community Asset Index was ultimately reclassified into 10 classes using a percentile distribution. For more information on this classification process, see [Appendix C.5](#).

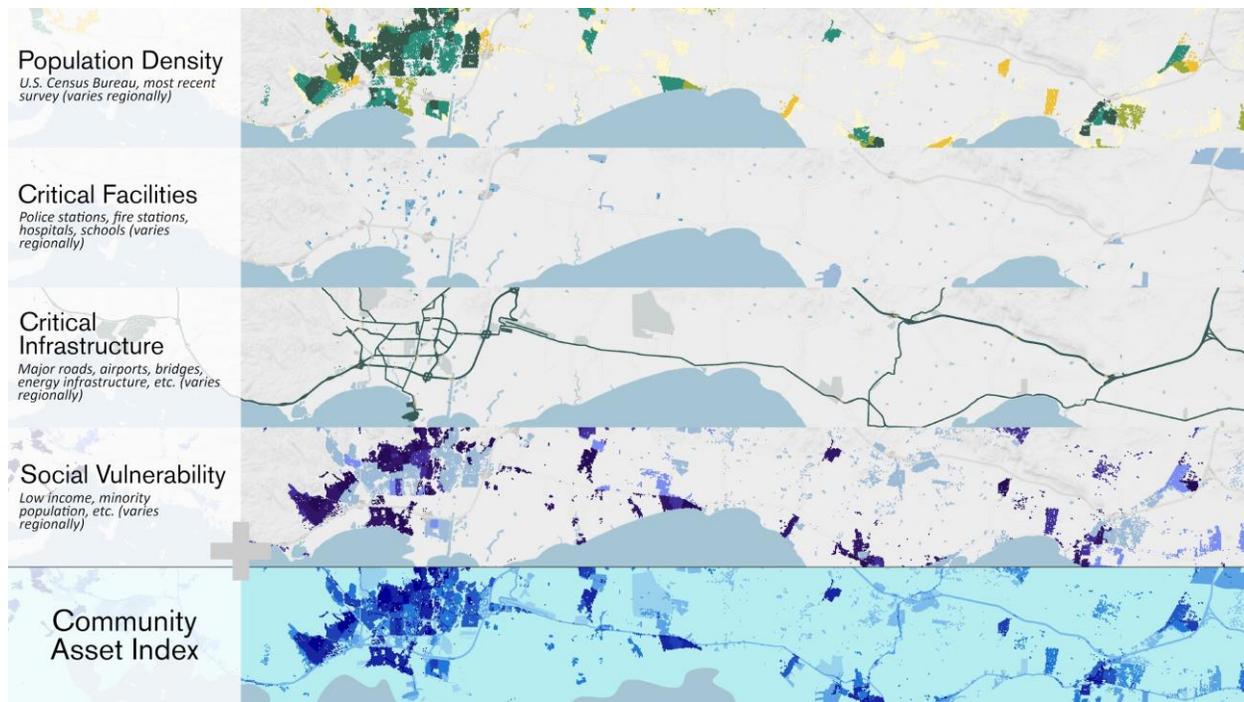


Figure 6. An example of all inputs (listed on left) used to generate the resulting Community Asset Index. A darker color for each input equates to a higher rank value. The darkest blue in the Community Asset Index is the highest value. Figure represents a generic region and is only intended to illustrate the methods and data used.

### **Population Density**

Population density is used to help identify densely populated areas throughout each regional study area that may ultimately require more resources to respond to a flood event. By identifying these areas in each Assessment, it is possible to locate projects that may help build adaptive capacity. See [Appendix C.1](#) for details on creating this input.

### **Critical Facilities**

Critical facilities used in the Regional Assessments include schools, hospitals, nursing homes, and fire and police stations identified using the USGS National Structures Dataset. Local data were substituted for the National Structures Dataset whenever possible; see regional reports for more information (Dobson et al. 2019; Dobson et al. 2020a-d; Dobson et al. 2021a-b). It is important to emphasize that these critical facilities provide important services that support the operation of other types of community infrastructure, such as residential, commercial, industrial, and public properties. These facilities are often prioritized in disaster planning since they may offer refuge to vulnerable populations. See [Appendix C.2](#) for more details on the creation of this input.

### **Critical Infrastructure**

The Regional Assessments included infrastructure that either helps communities immediately recover from devastating storm events or is considered a significant economic asset. The types of critical infrastructure included airport runways, dams, ports, refineries, hazardous chemical facilities, wastewater treatment facilities, power plants, and more. Relevant infrastructure types may vary by region; see each regional report for additional details (Dobson et al. 2019; Dobson et al. 2020a-d; Dobson et al. 2021a-b). In island regions, additional infrastructure types were considered such as marinas, ferry terminals and routes, communication infrastructure, and other types of infrastructure

necessary to support response and recovery in remote islands. Additionally, cultural and historic data were considered where available. See [Appendix C.3](#) to learn more about the various datasets and creation of this input.

### ***Social Vulnerability***

Social vulnerability varies regionally, especially in coastal areas where there are often large socioeconomic disparities (Moser et al. 2014). This input is meant to identify areas in a community where an individual's ability to respond to and cope with the effects of threats might be more or less difficult as compared to other areas in the same community. Disadvantaged households are typically found in areas of higher risk, leaving them vulnerable to flooding, disease, and other chronic stressors (Adger 2006). Therefore, the input considers two demographic criteria: percent minority and percent low income in each census block group (EPA 2016). The CONUS Regional Assessments were modeled in such a way that each region could be compared against one another (Dobson et al. 2019). As such, a percentile distribution was used to identify the 85th, 90th, and 95th percentile classes for the social vulnerability input. In contrast, non-continental regions are not directly comparable and thus the social vulnerability was ranked from very low to very high using a distribution specific to each region. For more details on the creation of this input, see [Appendix C.4](#).

## **2.3 Community Exposure Index**

To create the Community Exposure Index, the Threat and Community Asset Indices were each given a value of 1 to 10 to indicate a low-to-high presence of threats or assets, respectively. Combination methods traditionally result in the summation of inputs to create a final land suitability index; however, the Regional Assessments aim to understand exposure—the relationship between potential threats and the presence of community assets. Therefore, a multiplication function was used to understand this relationship. Areas with the highest prevalence of threats and the highest presence of community assets were calculated as having the highest levels of exposure. See [Appendix D](#) for a detailed description of the methodology used to calculate the Community Exposure Index.

## CREATING THE FISH AND WILDLIFE INDEX

The Fish and Wildlife Index, which consists of Marine and Terrestrial components, provides a greater understanding of important habitats and wildlife resources to aid in the identification of areas where implementing nature-based solutions may support coastal resilience and ecosystem benefits (Figure 7). This Index attempts to identify areas on the landscape where terrestrial, aquatic, and marine species and their habitats are located. For these Assessments, only those species of conservation concern with federal-, state-, or territorial-level protection status and/or those included in wildlife action plans were considered. It is important to note that the Fish and Wildlife Index presented here uses a significantly different methodology than that used in the CONUS Regional Assessments. The reasons for this reflect the adaptive and flexible approach embraced by the Assessments. While complete details of the Fish and Wildlife Index methodology used for CONUS are available (Dobson et al. 2019), there are several key differences. First, the data used to generate the Index in the CONUS were not available in all regions, which resulted in the development of revised and enhanced methods that could be applied consistently across all regions. Second, in CONUS the Index focused principally on terrestrial and freshwater resources, with limited data on marine species and ecosystems. The enhanced methodology described here includes a broader suite of species and habitats. It also includes freshwater species and habitats within the Terrestrial Index, allowing the Marine Index to focus on nearshore habitats.

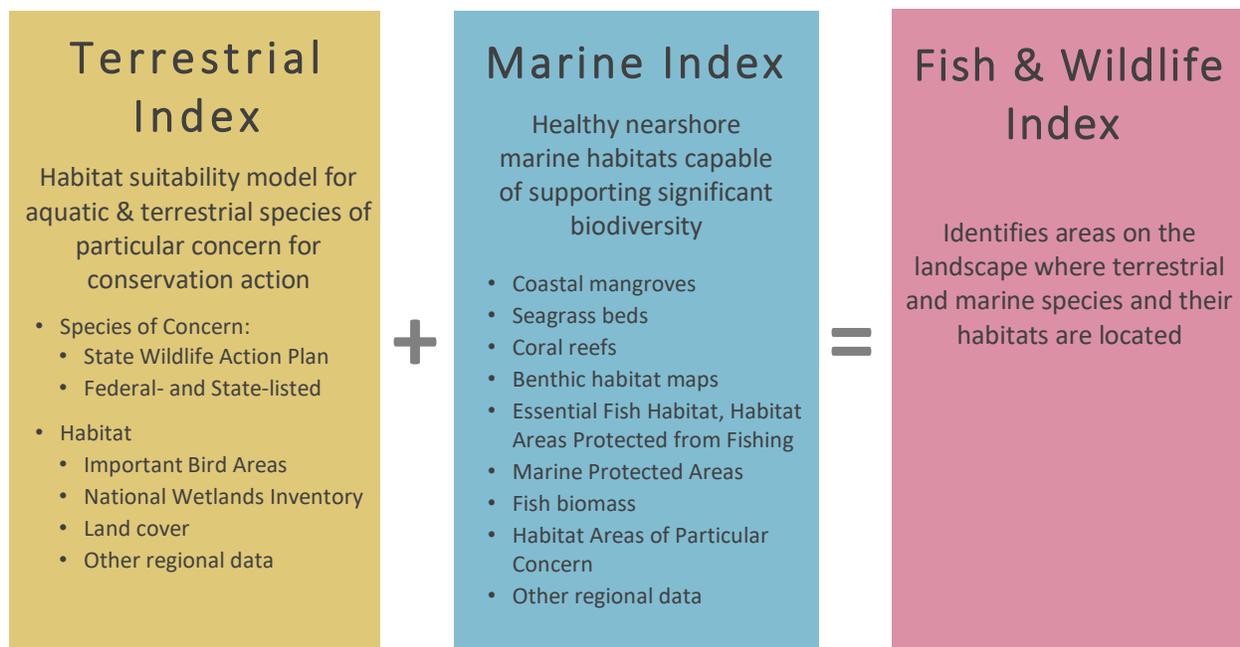


Figure 7. Elements of the Terrestrial and Marine Indices used to create the Fish and Wildlife Index. Data inputs vary by region.

For the terrestrial environment, the revised methodology described herein attempts to identify *primary*, *secondary*, and *tertiary* habitat by the common habitat preferences and threats associated with the following taxonomic groups: birds, reptiles, amphibians, freshwater fishes, invertebrates, and mammals. These taxonomic groups are based on species identified through each region's territorial or State

Wildlife Action Plan and available data using the IUCN Red List of Threatened Species database<sup>5</sup> and Habitat Classification Scheme<sup>6</sup>. Primary, secondary, and tertiary habitats were identified using available land cover and other habitat-related datasets. Detailed information about exact species and datasets used for each region can be found in the regional reports (Dobson et al. 2019; Dobson et al. 2020a-d; Dobson et al. 2021a-b) and [Appendix A.3](#).

In the marine environment, the revised methodology aimed to identify nearshore marine habitat types that support significant biodiversity, such as coral reefs, seagrass beds, and coastal wetlands such as mangroves, where applicable. The Terrestrial and Marine Indices combine to create the Fish and Wildlife Index (Figure 8).

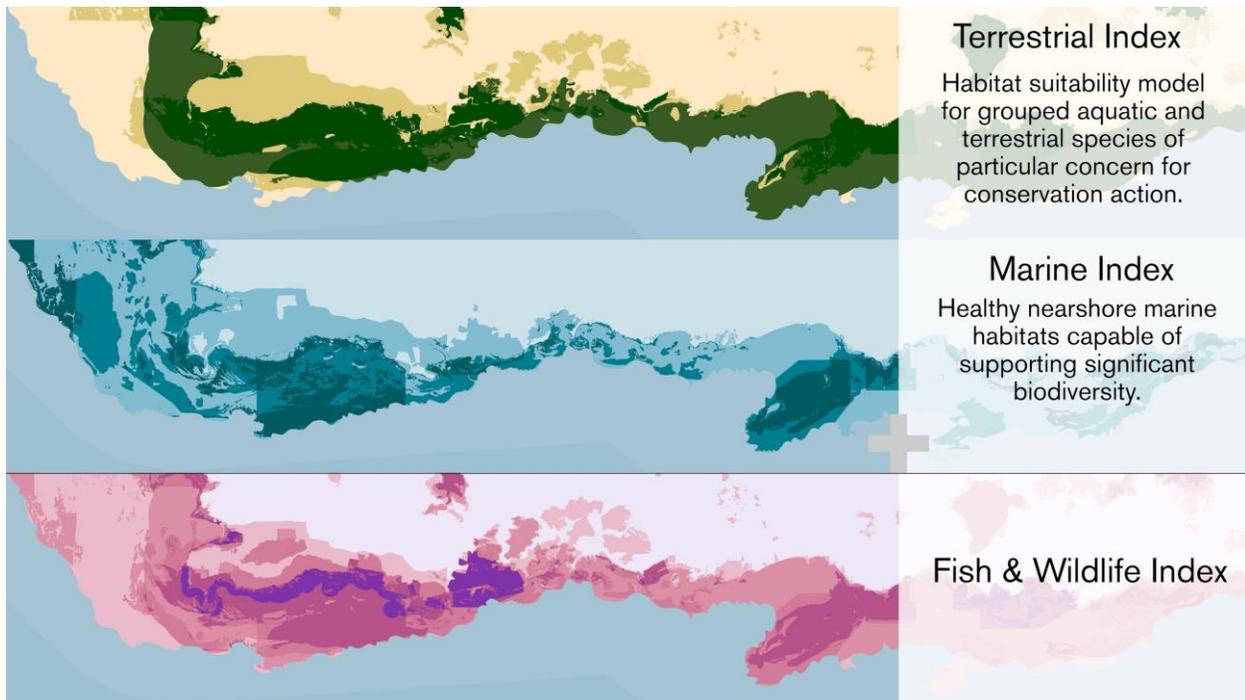


Figure 8. An example of the Terrestrial and Marine Indices used to create the Fish and Wildlife Index, with their various inputs listed. Figure represents a generic region and is only intended to illustrate the methods and data used.

### 3.1 Terrestrial Index

The Terrestrial Index aims to identify suitable habitats for species of greatest conservation concern. Wildlife modeling has consistently been challenged by limited species occurrence data (Rondini et al. 2011). Unlike approaches that rely on uneven data availability, a habitat suitability approach provides the opportunity to model groups of species at a consistent regional scale, regardless of geography. Habitat suitability modeling has been successfully applied in many settings (Araújo & Guisan 2006). Based on the methods outlined by Rondini et al. (2011), three levels of habitat suitability, described below, were modeled. In this work, Rondini et al. (2011) suggest that the proportion of actual suitable habitat within a defined occurrence range for a species is variable, but suitability models can enhance the resolution of the analysis.

<sup>5</sup> See <https://www.iucnredlist.org/>.

<sup>6</sup> IUCN Habitat Classification Scheme, Version 3.1 available at: <https://www.iucnredlist.org/resources/habitat-classification-scheme>

Except for the CONUS Regional Assessments (Dobson et al. 2019), all species considered in the Regional Assessments were either identified as species of conservation concern in territorial or State Wildlife Action Plans (SWAP) or under the U.S. Endangered Species Act (see Dobson et al. 2020a-d; Dobson et al. 2021a-b). All species of conservation concern were then compiled into taxonomic groups: birds, reptiles, amphibians, freshwater fishes, invertebrates, and mammals. The variation in groupings by region depended heavily on each region's Wildlife Action Plan. In some cases, groupings were broad. For example, 'birds' may encompass seabirds, land birds, and migratory birds that were listed in Wildlife Action Plans, regardless of whether they use terrestrial or marine habitat. Finally, using the IUCN Habitat Classification Scheme<sup>7</sup> and various habitat-related datasets, habitat preferences were identified for each taxonomic group. Based on those habitat preferences, three levels of habitat suitability were modeled.

1. *Primary habitat* represents preferred habitat where the species is known to occur. Using these guidelines, all designated critical habitat for species listed under the Endangered Species Act, as well as habitats identified as important for threatened and endangered species, was considered primary habitat for that species' taxonomic group.
2. *Secondary habitat* represents areas where the species can be found but would be unlikely to persist in the absence of primary habitat. Secondary habitat also coincides with protected areas that are managed for biodiversity, potentially increasing the probability of species utilization.
3. *Tertiary habitat* includes areas that meet the preferences of the taxonomic group and spatially proximate to either primary or secondary habitat, meaning the species may utilize that habitat patch, but is unlikely to thrive in that habitat alone.

In addition to modeling habitat suitability, the Index also included BirdLife International Important Bird Areas (IBAs) and all designated terrestrial protected areas managed for biodiversity. These additional datasets help to identify areas that support habitat conservation through acquisitions or easements or by encouraging the voluntary adoption of best management practices<sup>8</sup>. This information is combined with habitat suitability to create the Terrestrial Index. See [Appendix A.3](#) for a complete list of datasets used and [Appendix E.1](#) for more details on the creation of this Index.

### 3.2 Marine Index

The Marine Index aims to identify healthy marine habitats that can support significant biodiversity to a 30-meter depth contour or boundary. This depth boundary was selected for the Fish and Wildlife Index to incorporate the majority of shallow water coral reef habitat. Unlike the Terrestrial Index, the Marine Index is not driven by the habitat preferences of individual species, but rather the presence of habitats that support high levels of biodiversity including many marine species of conservation concern. For tropical regions, biodiverse habitat types considered in the Marine Index included coral reefs, seagrass beds, and coastal wetlands such as mangroves, where applicable. As methods are applied to more temperate or polar regions, additional habitat types will be considered. While other marine habitat types may support significant biodiversity, the Regional Assessments focused on those habitat types where restoration and resilience projects may offer the multiple benefits of ecosystem enhancement, species richness, and coastal protection.

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<sup>7</sup> Available at <https://www.iucnredlist.org/resources/habitat-classification-scheme>.

<sup>8</sup> Visit National Audubon Society (<https://www.audubon.org/important-bird-areas>) or BirdLife International (<https://www.birdlife.org/worldwide/programme-additional-info/important-bird-and-biodiversity-areas-ibas>) for additional information about Important Bird Areas.

The Marine Index includes several distinct data sets to identify the presence of important habitat. In tropical regions, benthic habitat maps were used to delineate the extent of coral and seagrass habitat (where available). Where applicable, the extent of current mangrove habitat was gathered from the Global Mangrove Watch (Bunting et al. 2018) or local data sources. Finally, the Marine Index accounted for the presence of Critical Habitat for species listed under the U.S. Endangered Species Act, areas designated as Essential Fish Habitat (EFH), Habitat Areas of Particular Concern (HAPC), and Marine Protected Areas, where applicable. These datasets are combined to create a composite index of marine habitats. Note that regional differences were considered, such as differences in data availability or relevance. EFH is identified for species managed in Fishery Management Plans under the Magnuson-Stevens Fishery Conservation and Management Act and represents the habitat necessary for federally managed fishes to complete their life cycles. HAPCs are considered a high priority for EFH conservation because they provide important ecological functions and are particularly vulnerable to degradation<sup>9</sup>.

The Marine Index primarily considers the presence and extent of important habitat types. However, wherever possible, data related to habitat condition were also incorporated into the analysis, under the assumption that habitats in better condition can support more species and offer greater coastal protection benefits. For example, in the case of coral reef habitat, NOAA's Coral Reef Conservation Program regularly surveys coral reefs found in all U.S. jurisdictions to monitor a suite of metrics including live coral cover and reef fish biomass. Due to the spatial and temporal coverage of those data, it was possible to use live coral cover to represent habitat condition, where reefs with high coral cover received a higher value in the Marine Index. Coral reef habitat, specifically live coral cover, is correlated with reef fish diversity (Komyakova et al. 2013) and wave attenuation (Storlazzi et al. 2019).

See [Appendix A.3](#) for a complete list of datasets used and [Appendix E.2](#) for more details on the creation of this Index. As with the Terrestrial Index, datasets and wildlife needs vary regionally; refer to regional reports for detailed information specific to each region (Dobson et al. 2019; Dobson et al. 2020a-d; Dobson et al. 2021a-b).

### 3.3 Fish and Wildlife Index

To identify areas likely to support a high number of priority species and habitats, the Terrestrial and Marine Indices are summed to create one combined Fish and Wildlife Index. By combining these two indices, it creates a continuous index between the two environments that helps to identify areas where implementing a resilience or restoration project would likely benefit fish and wildlife communities. See [Appendix E.3](#) for more details on the creation of this combined Fish and Wildlife Index.

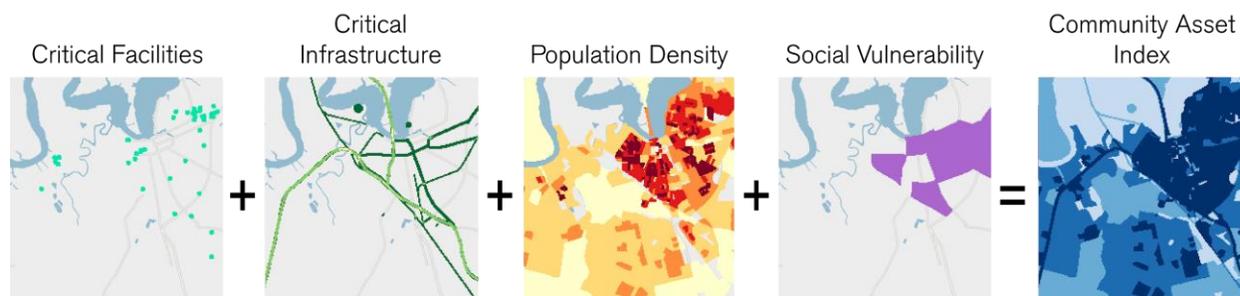
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<sup>9</sup> For details about Habitat Areas of Particular Concern, visit NOAA Fisheries website at: <https://www.fisheries.noaa.gov/southeast/habitat-conservation/habitat-areas-particular-concern-within-essential-fish-habitat>.

## OVERVIEW OF THE RASTER ANALYSIS

The calculation methods used to complete the Community Exposure and Fish and Wildlife Indices have their foundations in land suitability modeling and were conducted following a geospatial vulnerability methodology (Gornitz et al. 1994). To calculate cumulative values of certain environmental characteristics (e.g., landscape characteristics susceptible to flood-related threats) and relevant social and human community assets, a raster-based analysis was used to identify where these inputs overlap and how they sum based on input intensity or presence.

Each data input for the Threat and Community Asset Indices and the Marine and Terrestrial Indices were rasterized, with each cell ranked in order of increasing exposure, number of assets, or presence. Raster resolution was dependent on available data in each region, but typically ranged from 30 meters in CONUS to 3 to 10 meters in the island regions; see regional reports for details (Dobson et al. 2019; Dobson et al. 2020a-d; Dobson et al. 2021a-b). The input rasters were combined, adding the ranked data in each cell to show the intensity of all flood threats, community assets, or wildlife assets on the landscape. For example, Figure 9 shows the four inputs to the Community Asset Index. Darker colors are higher ranking values; when following the figure from left to right, patterns resembling those seen in the Community Asset Index can be identified in the individual inputs. See [Appendix B.8](#) for more details.



*Figure 9. Example of the inputs to and results of the Community Asset Index. From left to right, higher values in the inputs can be identified by darker colors. These patterns can be seen in the resulting Community Asset Index on the far right.*

## CREATING THE RESILIENCE HUBS

Resilience Hubs are areas of natural, undeveloped space that attempt to identify where open spaces or habitats are most suitable for resilience-building conservation or restoration efforts that can help prepare for potential, adverse impacts to infrastructure and communities, while also improving the habitats of fish and wildlife species. Therefore, Resilience Hubs represent open spaces and habitats that have a high potential to provide benefit to both human communities and fish and wildlife. Accounting for natural spaces on both inland areas and in the nearshore marine environment, Resilience Hubs are formed based upon undeveloped landscapes and habitat types and create two outputs: Green Habitat Cores (inland) and Blue Habitat Cores (marine)(Figure 10).

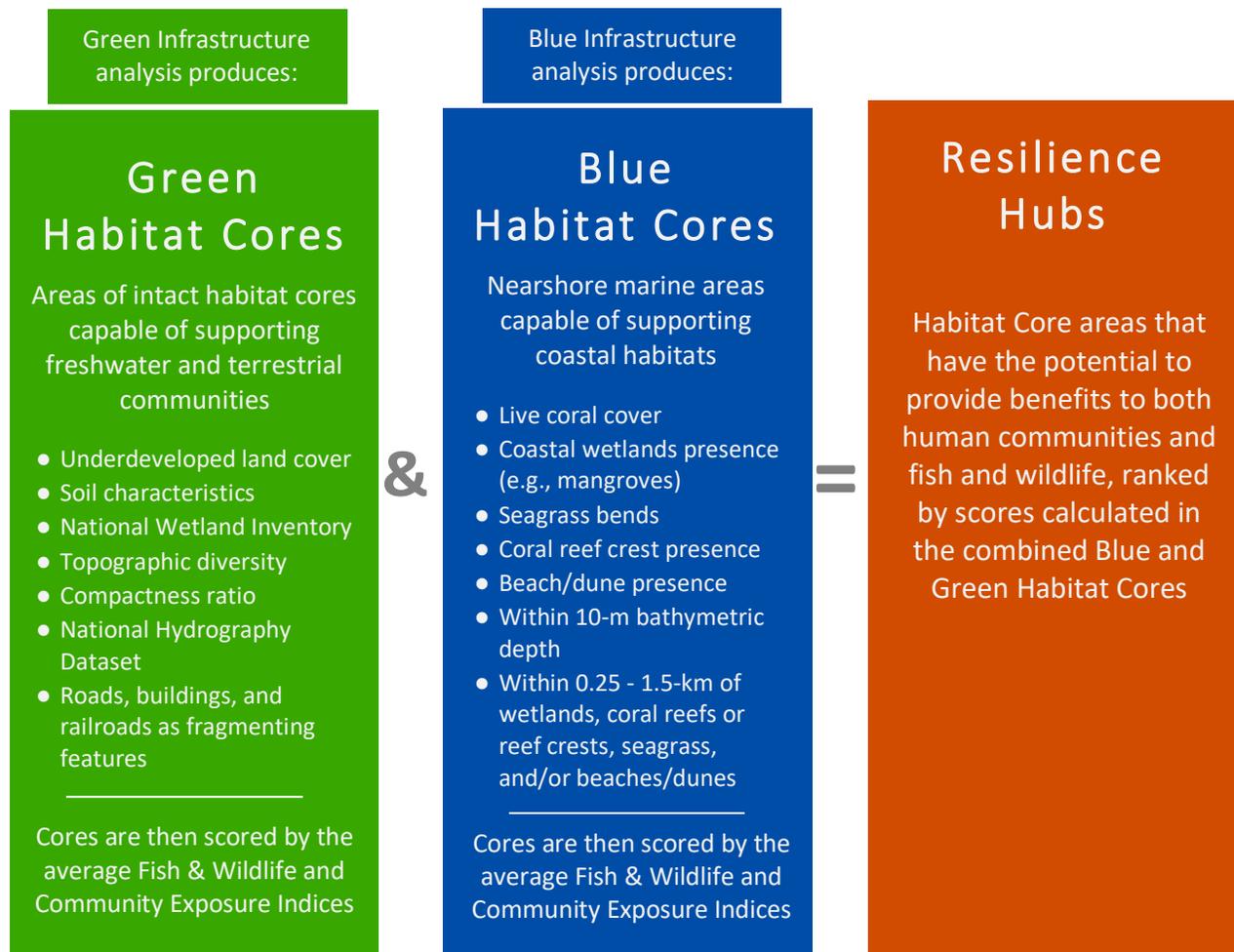


Figure 10. Example of the Green and Blue Habitat Core outputs used to create the Resilience Hubs. Data inputs vary by region.

While the criteria differ between the Green and Blue Habitat Cores, both models rank Resilience Hubs according to the combined average values of the Community Exposure Index and the Fish and Wildlife Index. The methods for developing Resilience Hubs described below vary from those used in the CONUS but represent important improvements in the accuracy and comparability of results across regions. Refer to regional reports for detailed information specific to each region (Dobson et al. 2019; Dobson et

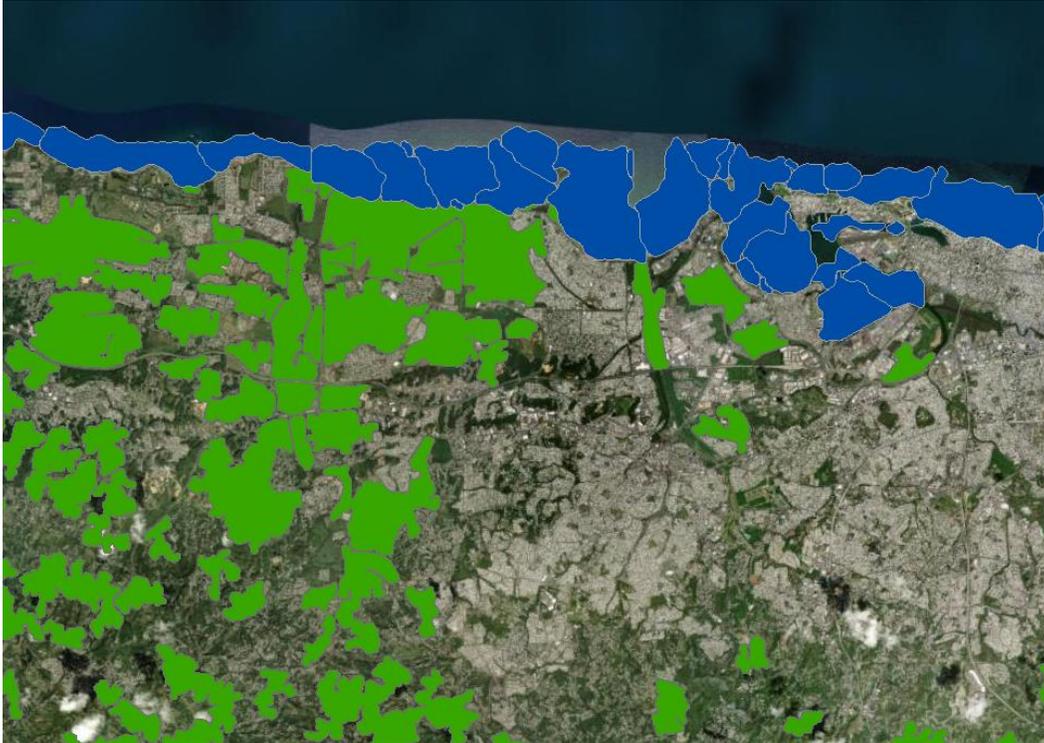
al. 2020a-d; Dobson et al. 2021a-b). To show variation within Resilience Hubs, the Habitat Cores were further subdivided and scored at a finer 4-hectare (10-acre) hexagon grid (Figures 11-13). For details, see [Appendix F](#).



*Figure 11. An initial step in creating the Green and Blue Habitat Cores. Note the Green Habitat Cores include both terrestrial and freshwater aquatic areas. The Blue Habitat Cores include estuarine, beach and dune, mangrove, and nearshore marine areas less than 10 meters in depth but have not yet been grouped into Cores.*



*Figure 12. Green and Blue Habitat Cores converted to 4-hectare (10-acre) hexagons. Along with each Habitat Core, each hexagon is ranked to show variation within Resilience Hubs.*



*Figure 13. Green and Blue Habitat Cores. The Blue Habitat Cores are grouped by bathymetric basin. The Green and Blue Cores are then ranked to become Resilience Hubs.*

## 5.1 Green Infrastructure

The Green Infrastructure<sup>10</sup> analysis used in the Regional Assessments builds upon methodology developed by the Green Infrastructure Center for the continental United States (Firehock & Walker 2019). The Green Infrastructure methods accomplish several key goals needed to develop Resilience Hubs: (1) establish criteria by which usable, open, and natural landscapes are clearly identified; (2) form contiguous, connected cores of habitats based upon landscape characteristics; (3) eliminate unsuitable, undeveloped areas not detectable by land cover alone; (4) prevent contiguous, open areas that are extremely large; and (5) allow consistent application of methods to any region using commonly-accessible datasets. By following the Green Infrastructure analysis, the resulting Green Habitat Cores have a geometry and size that approximates the scale of resilience-building efforts.

Esri—in partnership with the National Geographic Society and the Green Infrastructure Center—has developed a suite of tools and data to assist communities in protecting natural open spaces, watersheds, wildlife habitats, parks, and other open landscapes of ecological, cultural, and scenic importance. The resulting national dataset depicts “intact habitat cores,” or every natural area 40.5 hectares (100 acres) or greater, regardless of ownership or preservation status. The dataset is intended to guide local, regional, and urban planners in identifying important places to conserve prior to planning development projects. The dataset also helps to prioritize which landscapes to protect and connect—such as natural systems that mitigate flooding, provide recreation opportunities, and benefit air and water quality (Firehock & Walker 2019).

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<sup>10</sup> Note that Green Infrastructure analysis—as it is referred to in the Regional Assessments—pertains to a specific methodology and is not intended to represent other local planning and management projects.

Based on the methodology developed by the Green Infrastructure Center, a habitat core is defined as: “An area or patch of relatively intact habitat that is sufficiently large to support more than one individual of a species” (Firehock and Walker 2019). Habitat cores are non-developed areas that are at least 40.5 hectares (100 acres) in size, at least 200 meters wide, and that do not contain “fragmenting” elements (such as paved surfaces or agricultural areas that can interrupt the movement of species). These connected features form habitat cores of natural, open spaces based on several landscape characteristics that make the Green Infrastructure integral to the Regional Assessments. While the standard Esri-based methodology uses this size threshold to create habitat cores in the contiguous U.S., a smaller area threshold of approximately 4.04 hectares (10 acres) was used in Guam and American Samoa to better capture natural areas on these islands (see Dobson et al. 2021a-b for details).

The habitat cores are formed with consideration of the following characteristics: patch thickness, a compactness ratio, topographic diversity, percent wetlands cover, and stream density. The datasets used to create the habitat cores include: USGS National Hydrology Dataset, USGS NHDPlusV2, USDA SSURGO soils survey, National Wetlands Inventory, US Census Bureau’s TigerLine Roads and Railroads, the USGS National Elevation Dataset, the 2011 National Land Cover Dataset (or later, where available), and NOAA’s Coastal Change Analysis Program (C-CAP) land cover (Firehock and Walker 2019). Additional information on these datasets can be found in [Appendix A.4](#).

Following this analysis, open-space landscapes are identified and developed into inland Green Habitat Cores (Figure 11). The resulting core features were then converted into a finer resolution 4-hectare (10-acre) hexagonal grid (Figure 12). The hexagonal grid helps to highlight variation within habitat cores to facilitate fine-scale decision-making.

In summary, the Green Infrastructure approach—used to determine both Green Habitat Cores and subsequent hexagons—identifies contiguous natural landscapes composed of similar landscape characteristics. Lands identified have the potential to be of higher ecological integrity and thus may offer improved potential for both human and fish and wildlife benefits. This allows for a more accurate determination of the boundaries of natural landscapes when forming and ranking the Resilience Hubs. See [Appendix F](#) for more details.

## 5.2 Blue Infrastructure

Recognizing the prominence of valuable coastal and nearshore marine habitats, particularly in tropical regions, the Project Team developed a Blue Infrastructure<sup>11</sup> analysis. Nearshore marine habitats not only support significant biodiversity but are also important features that can protect human communities and infrastructure. Marine environments are typically undeveloped “open spaces” that lack features such as roads that fragment terrestrial environments. Due to this, determining Blue Habitat Cores in a marine environment required a different approach. For the purposes of the Regional Assessments, habitat cores were created based on a hexagonal grid of all marine areas within a 10-meter depth boundary. Unlike the Fish and Wildlife Index, only habitats less than or equal to 10 meters in depth were considered in the Blue Infrastructure analysis since nature-based solutions are more likely to provide coastal protection when implemented in shallow water habitats.

This 4-hectare (10-acre) hexagonal grid was developed not only to establish Blue Habitat Cores, but to also allow for a finer resolution analysis, which also facilitates grouping hexagons based upon

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<sup>11</sup> Note that Blue Infrastructure analysis—as it is referred to in the Regional Assessments—pertains to a specific methodology and is not intended to represent other local planning and management projects.

bathymetric watershed basins (Figure 13). Groupings of hexagons by bathymetric basin form the geometry of the resulting Blue Habitat Cores.

The Blue Infrastructure analysis considered coastal and marine areas less than 10 meters in depth with the presence of habitats that can potentially provide protection to exposed nearby communities. In tropical regions, the Assessments considered seagrass beds, coral reefs, beaches/dunes, and coastal wetlands such as mangroves (where applicable), all of which are coastal habitats known to provide coastal protection benefits (Ondiviela et al. 2014; Guannel et al. 2016; Storlazzi et al. 2019). As methods are applied to more temperate or polar regions, additional habitat types that may offer coastal protection benefits will be considered.

The data used to create Blue Habitat Cores following the Blue Infrastructure analysis included: NOAA National Centers for Coastal Ocean Science Benthic Habitat Maps (seagrass), NOAA National Coral Reef Monitoring Program (corals), Global Mangrove Watch and NOAA C-CAP land cover (mangroves), and NOAA C-CAP land cover (beaches/dunes), and NCEI's U.S. Coastal Relief Model (bathymetry). Additional information on these datasets can be found in the [Appendix A.4](#).

The Blue Infrastructure approach—in determining both Blue Habitat Cores and the hexagons that define them—identifies nearshore Blue Habitat Cores that contain nearshore and coastal habitat types. These delineated boundaries are then used to determine the potential protection to nearby communities and benefits to fish and wildlife species when ranking Blue Habitat Cores to become Resilience Hubs. See [Appendix F](#) for more details.

### 5.3 Combining Habitat Cores and Ranking Resilience Hubs

To capture the potential impact that the Green and Blue Habitat Cores may have on reducing the effects of coastal flooding to nearby community assets while also benefiting wildlife, the Habitat Cores were scored using the average values of the Community Exposure and Fish and Wildlife Indices to determine the rankings of Resilience Hubs.

#### *Scoring Green Habitat Cores*

Using a zonal statistics geoprocessing technique common to many GIS analyses, average values from the Community Exposure Index were calculated for each Green Habitat Core, including the surrounding areas within one kilometer of each Core; a 0.25km buffer was used Guam and American Samoa (see Dobson et al. 2021a-b for details). Incorporating the buffer area outside the Core was necessary because Habitat Cores are natural, open landscapes containing few to no exposed community assets. The buffer was determined in consultation with technical experts. Next, the average Fish and Wildlife Index value was calculated for each Core without applying the buffer. The average Community Exposure and Fish and Wildlife Index values were then multiplied to produce a score for each Core.

This calculation is more simply summarized by the following expression:

$$\text{(average Fish and Wildlife Index value * average Community Exposure Index value) = Green Habitat Core score}$$

Using a geometric interval distribution, the values were then classified into a 10-class ranking scale. This 1-10 ranking results in the final Resilience Hub rank for each Green Habitat Core. The scores of each hexagon contained within every inland habitat core were determined by the same expression described above and ranked by the same distribution of values.

In Guam and American Samoa, an additional distance and density factors were applied to the Green Habitat Cores to prioritize those open, natural landscapes nearest dense community assets (see Dobson et al. 2021a-b for details).

### ***Scoring Blue Habitat Cores***

Following the Blue Infrastructure analysis, a depth factor score and habitat factor score were generated for all nearshore areas less than 10 meters in depth. The depth factor represents the average depth of each Resilience Hub: Hubs with average depths of 0 to 3 meters received a factor of 3; 3 to 5 meters received a factor of 2; 5 to 10 meters received a factor of 1. This distribution of depths and the factors applied were determined in consultation with technical experts to place priority on shallow marine environments expected to have greater potential to protect coastal assets.

The habitat factor is the result of an expression that accounts for the sum of averages among the priority habitat designations within each Blue Habitat Core (e.g., in tropical climates coral reefs, seagrass beds, beaches/dunes, and wetlands such as mangroves, where applicable). This sum of habitat averages for each core was then added to the product of the depth factor multiplied by the number of habitat types present within 1.5 kilometer (Guannel et al. 2016) of each Blue Habitat Core (a 0.25km distance was used in Guam and American Samoa).

The full expression varies slightly by region but generally follows:

$$\text{(average coral presence by rank) + (average beach/dune presence by rank) + (average seagrass presence by rank) + (average wetland/mangrove presence by rank)) + (depth factor * number of habitats present within 1.5km) = habitat factor}$$

Next, the resulting habitat factor was multiplied by the average Community Exposure and Fish and Wildlife Index values for each Core. This calculation is more simply summarized by the following expression:

$$\text{(average Fish and Wildlife Index value * average Community Exposure Index value) * habitat factor = final Resilience Hub score}$$

Similar to the Green Habitat Cores, the Blue Habitat Core score values were classified into a 10-class scale using a geometric interval distribution. This 1-10 rank then becomes the final Resilience Hub rank for each Core. Accordingly, the scores of each hexagon contained within every Blue Habitat Core were determined by the same expression described above and ranked by the same distribution of values. This distribution was chosen to highlight variability among higher-ranking Hubs; however, other distributions are possible and would certainly change the final Hub rankings.

### ***Ranked Resilience Hubs***

The ranked Blue Habitat Cores and ranked Green Habitat Cores were then combined into a single dataset, resulting in the final Resilience Hubs. When considering the Resilience Hubs that result from these Assessments, the following will generally be true:

- (1) Hubs that are not near significant densities of exposed assets will receive lower average Community Exposure Index values, whereas those near more exposed assets will receive higher values;
- (2) Hubs not containing fish and wildlife assets will receive lower average Fish and Wildlife Index values, whereas those near more fish and wildlife assets will receive higher fish and wildlife values; and

- (3) Hubs with the highest Community Exposure Index and Fish and Wildlife Index values will receive a higher ranking.

Ranking the Hubs consistently within and across regions produces comparable products throughout the U.S., which can aid in prioritization of open landscapes with the potential to engage in conservation and restoration efforts. However, it is important to note that Hub values should not be compared between distinct regions and should only be used to make comparisons within a given region. Additionally, Hub rankings may not reflect local landscape characteristics, land ownership, local hazards, societal concerns, or local policy near a given Hub.

As noted above, every habitat core feature was converted into a finer-resolution 4-hectare (10-acre) hexagonal grid. As a result, each hexagon receives its own individual ranking, allowing for a fine-scale view of areas within any given Resilience Hub. When considered in combination with the Resilience Hubs, the hexagons can help identify areas that may be ideal for resilience-building efforts that achieve dual human community and fish and wildlife benefits. See [Appendix F.8](#) for more details on combining Green and Blue Habitat Cores to create Resilience Hubs.

## CONCLUSION

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As coastal and inland communities throughout the United States deal with current and future flooding threats from natural events, tools such as the Regional Coastal Resilience Assessments can help decision-makers and other stakeholders make data-driven decisions about how to identify and prioritize areas for resilience-focused and nature-based restoration projects. These Assessments provide a resource for stakeholders including community planners, conservation specialists, funding applicants, and others to help make informed decisions about the ability of restoration, conservation, or resilience projects to achieve dual benefits for both human and fish and wildlife community resilience. However, it is not intended to be a comprehensive list of all potential variables of impact or exposure nor is it inclusive of all habitat and species. Users should not use the Regional Assessments, which focus on exposure, to determine vulnerability and risk.

Interested stakeholders and decision-makers can access an online interface to interact with key Assessment data, including input data and final models for the Community Exposure Index, Fish and Wildlife Index, and the Resilience Hubs. The Coastal Resilience Evaluation and Siting Tool (CREST) was developed as an accompanying GIS-based web tool to view, interact with, and download Assessment results (available at [resilientcoasts.org](https://resilientcoasts.org)). CREST helps users make informed decisions about proposed project sites and other key questions about how to build resilience within their community. It also allows users full access to data from each Regional Assessment so they may incorporate these data into their own GIS applications or other planning processes. Additionally, CREST provides access to the Assessment results even if the user does not have a GIS background or access to GIS software.

The Regional Coastal Resilience Assessments were developed through an iterative process supported by substantial guidance from technical and regional experts. As the Regional Assessments advanced from the CONUS to additional regions, the Project Team identified numerous regional differences, from variable data availability to the presence of new habitat types and threats not prevalent in CONUS. Through consultation with regional experts, the team identified and developed new methods to improve model accuracy and support standardization across regions. These updates now serve as a basis for Regional Assessments in Alaska, Hawai'i, Puerto Rico, U.S. Virgin Islands (USVI), Commonwealth of the Northern Mariana Islands (CNMI), Guam, American Samoa, and the U.S. Great Lakes. As new Regional Assessments for each region are completed, the Project Team may update this document to reflect any additional updates or changes. The application and continued development of the Regional Assessments will assist NFWF and others in the implementation of nature-based solutions that build community resilience to flooding threats while benefiting fish and wildlife populations nationwide.

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# APPENDIX

## A. Data Summary

Below is a summary of common datasets used in the Regional Coastal Resilience Assessments. Note that final data and inputs used may differ by region since an effort was made to use locally available datasets whenever possible. Each regional report includes a separate list of dataset used in that region to highlight these differences (Dobson et al. 2019; Dobson et al. 2020a-d; Dobson et al. 2021a-b).

### A.1 Threat Index

Layer Name	Dataset and Source	Description
Flood-prone Areas	FEMA National Flood Hazard Layers, USDA-NRCS SSURGO (2.2 or later)	Floodway, 100-year, 500-year; occasional and frequently flooded soils
Sea Level Rise	NOAA Office for Coastal Management Sea Level Rise Inundation Database (2015 or later)	1 - 5 feet (0.3 - 1.5 meters) above mean higher high water scenarios. Data do not include natural processes
Storm Surge	NOAA/NHC Sea, Lake, and Overland Surge from Hurricanes (SLOSH) model (2014 or later)	Tens of thousands of climatology-based hypothetical tropical cyclones are simulated in each SLOSH basin, and the potential storm surges for Categories 1 - 5
Areas of Low Slope	USGS National Elevation Dataset (most recent available)	Used to generate percent rise across the region
Soil Erodibility	USDA-NRCS SSURGO (2.2 or later)	Data attribute <i>kffact</i> is used to identify soils with high potential for erosion
Impervious Surfaces	USDA-NRCS SSURGO (2.2 or later), NOAA Coastal Change Analysis Program Landcover (most recent available)	Data attribute <i>drclassdcd</i> and developed land cover classes used to identify areas with poor drainage potential
Geologic Stressors	USGS Landslide Susceptibility (most recent available) and regionally available subsidence mapping	Highlights areas that are most susceptible or have high incidence to landslides, subsidence, or other stressors
Tsunami Inundation	Variable by region.	Accounts for seismically active areas that might be susceptible to flood inundation from tsunamis.

## A.2 Community Asset Index

Layer Name	Dataset and Source	Description
Population Density	U.S. Census Bureau (2010 or later)	Calculates density by available census geography
Social Vulnerability	U.S. EPA Environmental Justice Screening and Mapping tool (2016 or later)	Uses demographic indicators to identify disadvantaged populations
Critical Facilities	USGS National Structures Dataset (2015 or later)	Fire stations, police stations, hospitals, schools, and government buildings
Parcels	Most recently available local data	Used for infrastructure and facility locations
Building Footprints	Most recently available local data	Used for infrastructure and facility locations and identifying populated areas

### Critical Infrastructure (*Various inputs, see below*)

<i>Primary roads</i>	<i>National Highway Planning Network: National Transportation Atlas Database (v.11.09 or later)</i>	<i>Comprehensive database of major highway systems in the U.S.</i>
<i>Bridges</i>	<i>Federal Highway Administration: National Bridge Inventory (v.7 or later)</i>	<i>Database of bridges located on public roads and publicly-accessible bridges on Federal lands</i>
<i>Airport runways</i>	<i>National Transportation Atlas Database: Airport Runways (2015 or later)</i>	<i>Runways in the U.S. and its territories; derived from the FAA's National Airspace System Resource Aeronautical Data Product</i>
<i>Ports</i>	<i>USDOT/Bureau of Transportation Statistics' National Transportation Atlas Database (2015 or later)</i>	<i>Small ports and the top 150 major ports in the U.S. for import and export activity</i>
<i>Power Plants</i>	<i>U.S. Energy Information Administration: EIA-860, Annual Electric Generator Report; EIA-860M, Monthly Update to the Annual Electric Generator Report; EIA-923, Power Plant Operations Report (2016 or later)</i>	<i>All plants that are operating, on standby, or short- or long-term out of service with a combined nameplate capacity of 1 MW or more</i>
<i>Wastewater treatment facilities</i>	<i>USGS National Structures Dataset (2015 or later)</i>	<i>Wastewater Treatment Facilities</i>
<i>Railroads</i>	<i>USDOT/Bureau of Transportation Statistics' National Transportation Atlas Database (2015 or later)</i>	<i>Comprehensive database of the rail system covering all 50 states, the District of Columbia, U.S. Territories - wherever relevant</i>
<i>Major dams</i>	<i>USDOT/Bureau of Labor Statistics' National Transportation Atlas Database (2015 or later)</i>	<i>Dams 50ft or more in height or with a normal storage capacity of 5,000 acre-feet or more, or with a maximum storage capacity of 25,000 acre-feet or more; extracted from the USACE National Inventory of Dams</i>
<i>Petroleum terminals</i>	<i>U.S. Energy Information Administration: EIA-</i>	<i>All operable bulk petroleum product terminals</i>

<b>Layer Name</b>	<b>Dataset and Source</b>	<b>Description</b>
<i>and refineries</i>	<i>815, Monthly Bulk Terminal and Blender Report; EIA-820 Refinery Capacity Report (2015 or later)</i>	<i>within a total bulk shell storage capacity of 50,000 barrels or more, and/or ability to receive volumes from tanker, barge, or pipeline</i>
<i>Natural gas terminals and processing plants</i>	<i>U.S. Energy Information Administration, Federal Energy Regulatory Commission, and U.S. Dept. of Transportation; EIA-757, Natural Gas Processing Plant Survey (2015 or later)</i>	<i>LNG import/export terminals in the U.S., defined as terminals capable of liquefaction of natural gas for transport or receipt and regasification of LNG for use as natural gas; locations of processing plants based on approximate centroids</i>
<i>Hazardous Sites</i>	<i>U.S. EPA Facility Registry Service (2016 or later)</i>	<i>Large Quantity Generators and Superfund National Priority List Sites</i>
<i>Cultural and Historic Assets</i>	<i>Varies regionally</i>	<i>Identifies sites and buildings that have significant cultural and historic value</i>

### A.3 Fish and Wildlife Index

#### Terrestrial Index

Layer Name	Dataset and Source	Description
Species of Greatest Conservation Need	USGS, State Wildlife Action Plans by region via the USGS Compiled List of Species of Concern	Species most in need of conservation action in that state or territory
Important Bird Areas	Audubon, BirdLife International (most recent available)	Sites that provide essential habitat for one or more bird species
Land cover	NOAA Coastal Change Analysis Program (C-CAP)	Land cover classification data used to identify habitat equivalencies
Hydrography	USGS National Hydrography Dataset	Identifies permanent and intermittent rivers, lakes, and streams; used to identify habitat equivalencies
Wetland Habitats	U.S. Fish and Wildlife Service National Wetlands Inventory	Inventory of wetland types used to identify habitat equivalencies
Critical Habitat Designations	NOAA, U.S. Fish and Wildlife Service	Habitats designated under the Endangered Species Act for Threatened and Endangered Species
Protected Areas Managed for Biodiversity	USGS Protected Areas Database of the U.S. with a GAP Status of 1 or 2	Areas protected by federal, state, or local authority and managed for biodiversity
Threatened and Endangered Species: Environmental Sensitivity Index	NOAA Office of Response and Restoration	Species' habitats for which the federal and state status is threatened or endangered
Habitat Classification Scheme	IUCN Red List of Threatened Species	Defines standard terms used to describe the major habitat(s) in which taxa occur. Used to identify habitat equivalencies
Other Regional Data	Locally-derived habitat or species data	Additional sources of habitat, species, and/or protected and managed areas; varies regionally

## Marine Index

Layer Name	Dataset and Source	Description
Essential Fish Habitat, Essential Fish Habitat Areas Protected from Fishing, Habitat Areas of Particular Concern	NOAA National Marine Fisheries Service	EFH are sites designated under the Magnuson-Stevens Fishery Conservation and Management Act, defined as waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity. HAPCs are defined as subsets of EFH that exhibit one or more of the following traits: rare, stressed by development, provide important ecological functions for federally managed species, or are especially vulnerable to anthropogenic degradation (NOAA Fisheries "Habitat Areas of Particular Concern within Essential Fish Habitat").
Critical Habitat Designations	NOAA/U.S. Fish & Wildlife Service	Habitats designated under the Endangered Species Act for Threatened and Endangered Species
Seagrass Cover	NOAA National Centers for Coastal Ocean Science Benthic Habitat Maps	Mapped seagrass cover from the most recently available Benthic Habitat Maps
Coral Cover	NOAA National Coral Reef Monitoring Program	Stratified random sample surveys of coral cover used to identify healthy corals
Reef Fish Biomass	NOAA National Coral Reef Monitoring Program: Reef Fish Monitoring	Data on the number and size of reef fishes within sample units at the lowest feasible taxonomic resolution (typically species level)
Mangrove	Global Mangrove Watch, NOAA C-CAP Landcover	Either the presence of mangrove using available land cover or growth, lost, or maintained mangrove forests over time
Marine Protected Areas	USGS Protected Areas Database	Areas of the ocean set aside for long-term conservation aims
Other Regional Data	Locally-derived habitat or species data	Additional sources of habitat, species, and/or protected and managed areas; varies regionally

## A.4 Resilience Hubs

### Green Habitat Cores

Layer Name	Dataset and Source	Description
C-CAP Land Cover Atlas	NOAA Office for Coastal Management (latest available data used)	Nationally standardized, raster-based inventory of land cover for the coastal areas of the U.S. Data derived through the Coastal Change Analysis Program from the analysis of multiple dates of remotely sensed imagery
National Wetlands Inventory	NOAA/U.S. Fish & Wildlife Service	Provides detailed information on the abundance, characteristics, and distribution of U.S. wetlands
National Hydrography Dataset	U.S. Geological Survey (USGS) 1:24,000	The NHD is a comprehensive set of digital spatial data that contains information about surface water features such as lakes, ponds, streams, rivers, springs, wells, and HUC watershed boundaries
National Elevation Dataset	U.S. Geological Survey (USGS), EROS Data Center	7.5-minute seamless mosaic of elevation data for the U.S.
SSURGO Soils Survey	USDA, NRCS	Provides soil geographic data developed to represent soil properties and characteristics
Roads polyline	OpenStreetMap (latest data available)	OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations, and much more, all over the world.
Railroads polyline	OpenStreetMap (latest data available)	OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations, and much more, all over the world.

## Blue Habitat Cores

Layer Name	Dataset and Source	Description
C-CAP land cover	NOAA Office for Coastal Management (latest available data used)	Nationally standardized, raster-based inventory of land cover for the coastal areas of the U.S. Data derived through the Coastal Change Analysis Program from the analysis of multiple dates of remotely sensed imagery
Critical Habitat Designations	NOAA/U.S. Fish & Wildlife Service	Habitats designated under the Endangered Species Act for Threatened and Endangered Species
Seagrass Cover	NOAA National Centers for Coastal Ocean Science Benthic Habitat Maps	Mapped seagrass cover from the most recently available Benthic Habitat Maps
Coral Cover Surveys	NOAA National Coral Reef Monitoring Program (2014, 2016)	Stratified random sample surveys of coral cover used to identify healthy corals
Benthic Habitat Maps	NOAA National Centers for Coastal Ocean Science (2015)	Benthic/seafloor habitat maps to help coastal managers assess, protect, and preserve the condition of coastal ocean ecosystems
Global Mangrove Watch	UNEP and others (2010/2016)	Either the presence of mangrove using available land cover or growth, lost, or maintained mangrove forests over time
Bathymetry	NCEI's U.S. Coastal Relief Model	Integrates offshore bathymetry with land topography into a seamless representation of the coast

## B. Detailed Methodology: Threat Index

### B.1 Create the Storm Surge Input

- A. Import each SLOSH model raster and reclassify inundation values for each storm category.
  - a. Spatial Analyst Tools > Reclass > Reclassify
    - i. Reclassify values 1 - 99 according to the table below. Making them the same value is important for later steps.
    - ii. Complete this step for Categories 1-5.
- B. Vectorize each reclassified raster.
  - a. Conversion Tools > From Raster > Raster to Polygon
    - i. Value Field: Value
    - ii. Uncheck 'simplify polygons'
  - b. Repeat for all storm categories (there should be a total of 5 vectors when this step is complete)
- C. Add a rank field to each storm category vector and populate.
  - a. Right click layer in Table of Contents > Attribute Table > Add Field: "Rank", Field Type: Short Integer
  - b. If each layer was given the correct value for each storm surge category in step A., populate the rank field according to gridcode field.
    - i. Right click Rank field > Field Calculator > Rank = [gridcode]
- D. Merge storm categories together in ascending rank value order. The order is important for the rasterize step ahead.
  - a. Geoprocessing > Merge
    - i. Add each layer to the tool dialogue in ascending order:
      1. Category 5 (rank = 1)
      2. Category 4 (rank = 2)
      3. Category 3 (rank = 3).... And so on.
- E. Clip the merged vector categories to the region.
  - a. Geoprocessing > Clip
    - i. Input: Merged storm categories
    - ii. Clip features: regional extent
- F. Merge clipped storm categories to the regional extent. This is important for the rasterizing process.
  - a. Geoprocessing > Merge (add each layer to the tool dialogue in ascending rank order: regional extent, merged storm categories)
- G. Rasterize the merged vectors
  - a. Conversion Tools > To Raster > Polygon to Raster
    - i. Input Feature: Merged region and storm category vector
    - ii. Value Field: Rank
    - iii. Cell assignment type: Maximum Area
    - iv. Priority Field: Rank
    - v. *varies by region*
- H. Shift the raster input
  - a. Data Management Tools > Projections and Transformations > Raster > Shift
    - i. Shift X & Y Coordinates by: 1 (each)
    - ii. Input Snap Raster: *varies by region*

Storm Surge	Rank Type	Rank Value
No inundation / No data	None	0
Inundation during a Category 5 storm	Very low	1
Inundation during a Category 4 storm	Low	2
Inundation during a Category 3 storm	Moderate	3
Inundation during a Category 2 storm	High	4
Inundation during a Category 1 storm	Very high	5

*If a surge category is not available for the area of interest, follow the same ranking scheme shown here and ignore the missing value.*

## **B.2 Create the Sea Level Rise Input**

- A. Merge and clip each foot of sea level rise inundation to the watershed boundary.
  - a. Geoprocessing > Merge
    - i. Input features: all 1-foot projections; all 2-foot projections (repeat for all 1-5-foot levels of inundation, creating a total of 5 Sea Level Rise vectors)
  - b. Geoprocessing > Clip
    - i. Input features: merged inundation vector
    - ii. Clip features: watershed boundary
    - iii. Repeat for all levels of inundation, creating a total of 5 *clipped* Sea Level Rise inundation layers.
- B. Create a “Rank” attribute in each Sea Level Rise layer
  - a. Right click layer in attribute table > open attribute table
  - b. Add field “Rank”; field type: Short Integer
  - c. Right click the Rank field and use Field Calculator to add values according to the table below
- C. Merge the individual sea level rise inundation vectors in ascending Rank value order to create one complete vector containing all levels of sea level rise.
  - a. Geoprocessing > Merge
- D. Expand resulting features to cover the entire regional area before rasterizing to ensure the data is continuous across the entire watershed region. This step is essential for the final raster calculations in the Assessment.
  - a. Merge Sea Level Rise vector output with the watershed region.
    - i. Geoprocessing > Merge
- E. Make sure values outside of any Sea Level Rise inundation scenarios within the watershed region are a value of 0 in the Rank attribute field. If they are NULL, change them to 0.
- F. Convert merged SLR vector to raster:
  - a. Conversion Tools > To Raster > Polygon to Raster
    - i. Value Field: Rank
    - ii. Cell assignment type: Maximum Area
    - iii. Priority field: Rank
    - iv. Cell size: *varies by region*

- G. Shift the raster input
  - a. Data Management Tools > Projections and Transformations > Raster > Shift
    - i. Shift X & Y Coordinates by: 1 (each)
    - ii. Input Snap Raster: *varies by region*

Sea Level Rise	Rank Type	Rank Value
No inundation / No data	None	0
Inundation during 5ft SLR	Very low	1
Inundation during 4ft SLR	Low	2
Inundation during 3ft SLR	Moderate	3
Inundation during 2ft SLR	High	4
Inundation during 1ft SLR	Very high	5

### B.3 Create the Flood-Prone Areas Input

- A. Import the **S\_Fld\_Haz\_Ar** polygons for each county in the region. Rename and reproject the polygons one at a time to continue with the following steps.
  - a. Right click layer in Table of Contents > Data > Export Data
    - i. Set the coordinate system to the same as the data frame and change the output location and name to something unique. To complete step B., each polygon must have a unique name.
- B. Merge all county-level FEMA data into one regional vector.
  - a. Geoprocessing > Merge
- C. Several different layers will be extracted from the FEMA data as separate layers. Use the following queries to select by attributes and export the data to create these vector layers. Right click the layer in the Table of Contents after each selection > Data > Export
  - a. Right click layer in Table of Contents > Attribute Table > Select by Attributes.
    - i. To extract and export the floodway use the query: `FLD_ZONE = 'AE' AND ZONE_SUBTY = 'FLOODWAY'`
    - ii. To extract and export the 100-year floodplain: `FLD_ZONE = 'A' OR FLD_ZONE = 'AE'`
    - iii. To extract and export the 500-year floodplain: `FLD_ZONE = 'X' AND ZONE_SUBTY = '0.2 PCT ANNUAL CHANCE FLOOD HAZARD'`
- D. Rank each new layer according to the table below. For each layer:
  - a. Open Attribute Table > Add Field > "Rank", field type: Short Integer
  - b. Right click field "Rank" > Field Calculator
- E. Merge these ranked FEMA layers together
  - a. Geoprocessing > Merge
    - i. Data will need to be merged in ascending order based on rank value: 500-year (rank 3), 100-year (rank 4), Floodway (rank 5)
- F. Create feature of Flood-Prone soils. Again, multiple inputs will be extracted from the SSURGO data. Use the following queries to select and export the data.
  - a. Select by attributes (2 separate queries) and export the selected features:
    - i. `WHERE flodfreqmax = frequent OR flodfreqmax = very frequent`

1. Right click layer in Table of Contents > Export Data
- ii. WHERE flodfreqmax = occasional
  1. Right click layer in Table of Contents > Export Data
- b. Erase from the soils data those areas already covered by FEMA data extracted in above steps
  - i. Analysis Tools > Overlay > Erase
    1. Input Features: Soils data
    2. Erase Features: FEMA data
- c. Add Rank value to attribute table for soil layers “frequent/very frequent” and “occasional”
  - i. Right click each layer in Table of Contents > Attribute Table
    1. Add Field > Name: Rank > Type: Short Integer
    2. Rank each layer according to the Flood-Prone Areas table below using the Field Calculator.
- G. Merge ranked SSURGO inputs together
  - a. Geoprocessing > Merge
    - i. Data need to be entered in ascending order based on rank value: occasionally flooded input (rank 1), frequently flooded input (rank 2)
- H. Merge ranked SSURGO and FEMA inputs together
  - a. Geoprocessing > Merge
    - i. Data need to be entered in ascending rank value: merged SSURGO inputs, merged FEMA inputs.
- I. Merge the vector with the region to ensure there are values of 0.
  - a. Geoprocessing > Merge
- J. Use the Polygon to Raster tool to create a raster of the data.
  - a. Conversion Tools > To Raster > Polygon to Raster
    - i. Value field: Rank
    - ii. Cell Assignment: Maximum Area
    - iii. Priority Field: Rank
    - iv. Cell size: *varies by region*
- K. Shift raster output
  - a. Data and Management Tools > Projections and Transformations > Raster > Shift
    - i. Input: Flood-prone Areas raster
    - ii. Shift X & Y Coordinates by: 1 (each)
    - iii. Snap to: *varies by region*

Flood-Prone Areas	Rank Type	Rank Value
Outside of floodplain and non-flood-prone soils	None	0
Occasionally flooded soils outside the flood zone	Very low	1
Frequently flooded soils outside the flood zone	Low	2
500-year floodplain (X500)	Moderate	3
100-year floodplain (A, AE)	High	4
Floodway (V & VE)	Very High	5

### B.4 Prepare the Soils Data

Before using the NRCS-USDA SSURGO Soil data in the Assessments, the data will need to be prepared. This needs to be completed *once* for all inputs that require the use of soils data. The following are the steps to complete this preparation:

1. Prepare SSURGO soils data for each county to be used in ArcMap.
  - a. Open the Microsoft Access file in the soils folder.
  - b. An Import SSURGO notification will open. Copy the file path in Windows Explorer where the tabular data is stored and paste it into the notification window. This will link the tabular soils data to the spatial soils data. Close Access once complete.

Table Used	Represents
drclassdcd	The natural drainage condition of the soil refers to the frequency and duration of wet periods. This column displays the dominant drainage class for the map unit, based on the composition percentage of each map unit component.
geomdesc	A narrative description of the geomorphic setting of a component. The description may incorporate multiple geomorphic features as well as their relationship to each other. The individual parts of the description are recorded in the Component Geomorphic Description table.
muname	Correlated name of the mapunit (recommended name or field name for surveys in progress).
kffact	An erodibility factor which quantifies the susceptibility of soil particles to detachment by water
mukey	A non-connotative string of characters used to uniquely identify a record in the Mapunit table.
chkey	A non-connotative string of characters used to uniquely identify a record in the Horizon table
mukey	A non-connotative string of characters used to uniquely identify a record in the Mapunit table.
cokey	A non-connotative string of characters used to uniquely identify a record in the Component table.

2. Join the SSURGO tabular data to soil polygons in ArcMap:
  - a. Add the following data from the Catalog to the map document:
    - i. The polygon **“soilmu...”** from the spatial folder
    - ii. The tables **“mapunit,” “muaggatt,” “component,” “chorizon,”** and **“chaashto”** from the **“soildb...”** geodatabase
  - b. Join the tables to the polygon (*NOTE: these steps must be completed in the following order*):
    - i. Join the SSURGO soils layer **“soilmu...”** to the **“mapunit”** table.

1. Right click "soilmu..." in the Table of Contents > Joins and Relates > Join...
  - a. Table (step 2): mapunit
  - b. Field (step 1 & 3): **mukey**
- ii. Join the SSURGO soils layer "**soilmu...**" to the "**muaggat**" table.
  1. Right click "soilmu..." in the Table of Contents > Joins and Relates > Join...
    - a. Table (step 2): muaggat
    - b. Field (step 1 & 3): **mukey**
- iii. Join the table "**component**" to the table "**chorizon**" (*table to table join*).
  1. Right click the table "**component**" > Joins and Relates > Join...
    - a. Table (step 2): chorizon
    - b. Field (step 1 & 3): **cokey**
- iv. Join the SSURGO soils layer "**soilmu...**" to the joined table "**component:chorizon**"
  1. Right click "soilmu..." in the Table of Contents > Joins and Relates > Join...
    - a. Table (step 2): component:chorizon (it will display "component")
    - b. Field (step 1 & 3): **mukey**
  2. NOTE: Perform this join *from the spatial soils layer!* If the join is done from "chorizon:component," the table will not successfully join data to the spatial layer.
- v. Join the SSURGO soils layer "**soilmu...**" to the table "**chaashto**"
  1. Right click "soilmu..." in the Table of Contents > Joins and Relates > Join...
    - a. Table (step 2): chaasto
    - b. Field (step 1 & 3): **chkey**
- vi. Save these joins by exporting the soil polygon layers with all of the joined tables as a new shapefile.
  1. Right click layer in Table of Contents > Data > Export Data
  2. Add the new layer to the map when prompted.
3. Complete this step for every polygon/county in the area of interest.
4. After SSURGO data has been linked to spatial data for the entire regional extent, merge all counties together and clip the merged vector to the watershed region.
  - a. Geoprocessing > Merge
  - b. Geoprocessing > Clip

#### **B.4.1 Create the Impermeable Soils Input**

- A. In the attribute table of the soil vector, add field "**Drainage\_rank**"
  - a. Right click layer in the Table of Contents > Attribute Table > Add Field
    - i. Field type: Short Integer
- B. Begin adding the rank values to the appropriate soil drainage classification in the new field "Drainage\_rank"
  - a. In the attribute table choose "Select by Attribute" Field: drclassdcd
    - i. Query: Drclassdcd = "well drained"
    - ii. In Attribute Table > Show selected records
    - iii. Right click field "Drainage\_rank" > Field Calculator > "Drainage\_rank" = 1

- iv. Repeat for all rank values according to the table below.

Soil Drainage	Rank Type	Rank Value
Null	None	0
Well-drained	Very low	1
Moderately well-drained	Low	2
Somewhat poorly drained	Moderate	3
Poorly drained	High	4
Very poorly drained	Very high	5

**Note:** “Excessively drained” and “Somewhat excessively drained” are not vulnerable to extended inundation and not considered in this analysis, and should carry a value of 0. “Subaqueous” soils should carry a value of 5 where applicable. For a detailed list on the descriptions of these soil classifications, see the end of section C.4.2 contained in this report.

- C. Merge the ranked vector to the watershed region and change any NULL values to 0.
  - a. Geoprocessing > Merge
  - b. Attribute Table Options > Select by Attributes
    - i. Query: “Drainage\_rank IS NULL”
    - ii. In Attribute Table > Show selected records > Right click “Drainage\_rank” > Field Calculator > Drainage\_rank = 0
- D. Convert the vector layer to a raster:
  - a. Conversion Tools > To Raster > Polygon to Raster
    - i. Value field: Drainage\_rank
    - ii. Cell assignment type: Maximum area
    - iii. Priority field: Drainage\_rank
    - iv. Cellsize: *varies by region*
- E. Shift the raster to properly align cells
  - a. Data and Management Tools > Projections and Transformations > Raster > Shift
    - i. Input: Drainage\_rank raster
    - ii. Shift X & Y Coordinates by: 1 (each)
    - iii. Snap to: *raster varies by region*
- F. Clip the land cover raster to the region
  - a. Data Management Toolbox > Raster > Raster Processing > Clip
    - i. Check “Use Input Features for Clipping Geometry”
    - ii. NoData Value: 255
- G. Reclassify the clipped land cover as appropriate, some datasets and regions will have more specific classes for development intensity. A general rule should be the higher the development intensity, the higher the rank value. If there is only one intensity provided, it gets the highest rank value (see table below). Make all other land class values 0.
  - a. Spatial Analyst Toolbox > Reclass > Reclassify
    - i. Choose Unique Values and rank accordingly:

Rank Type	Rank Value
Low Intensity Development	3
Medium Intensity Development	4
High Intensity Development, Impervious Surface	5

- H. Add the reclassified development raster to the soil drainage raster
- a. Spatial Analyst Toolbox > Map Algebra > Raster Calculator
- I. Use the following distribution to reclassify the sum of development and soil drainage:

Rank Values	Rank Type	Final Rank Value
0	None	0
1	Well-drained soils	1
2	Moderately well-drained soils	2
3	Somewhat poorly drained soils; Low intensity development	3
4	Poorly drained soils; Medium intensity development; Low intensity development <b>AND</b> well-drained soils	4
5 -10	Very poorly drained soils; High intensity development; Medium intensity development <b>AND</b> well-drained soils; Low intensity development <b>AND</b> moderately well-drained soils; Low intensity development <b>AND</b> somewhat poorly drained soils; Medium intensity development <b>AND</b> moderately well-drained soils; High intensity development <b>AND</b> well-drained soils; High intensity development <b>AND</b> moderately well-drained soils; Medium intensity development <b>AND</b> somewhat poorly drained soils; Low intensity development <b>AND</b> poorly drained soils; High intensity development <b>AND</b> somewhat poorly drained soils; Medium intensity development <b>AND</b> poorly drained soils; Low intensity development <b>AND</b> very poorly drained soils; High intensity development <b>AND</b> poorly drained soils; Medium intensity development <b>AND</b> very poorly drained soils; High intensity development <b>AND</b> very poorly drained soils -- Impervious surface; Impervious surface <b>AND</b> well-drained soils; Impervious surface <b>AND</b> moderately well-drained soils; Impervious surface <b>AND</b> somewhat poorly drained soils; Impervious surface <b>AND</b> poorly drained soils; Impervious surface <b>AND</b> very poorly drained soils;	5

## USDA-NRCS SSURGO Soils: Descriptions Soil Drainage Classes

*From the NRCS Survey Manual (USDA Natural Resources Conservation Services)*

**Well drained:** Water is removed from the soil readily but not rapidly. Internal free water occurrence commonly is deep or very deep; annual duration is not specified.

**Moderately well drained:** Water is removed from the soil somewhat slowly during some periods of the year. Internal free water occurrence commonly is moderately deep and transitory through permanent.

**Somewhat poorly drained:** Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. The occurrence of internal free water commonly is shallow to moderately deep and transitory to permanent. The soils commonly have one or more of the following characteristics: low or very low saturated hydraulic conductivity, a high water table, additional water from seepage, or nearly continuous rainfall.

**Poorly drained:** Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or remains wet for long periods. The occurrence of internal free water is shallow or very shallow and common or persistent. Free water is commonly at or near the surface long enough during the growing season so that most mesophytic crops cannot be grown, unless the soil is artificially drained.

**Very poorly drained:** Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. The occurrence of internal free water is very shallow and persistent or permanent. Unless the soil is artificially drained, most mesophytic crops cannot be grown. The soils are commonly level or depressed and frequently ponded.

### ***B.4.2 Create the Soil Erodibility Input***

#### **Prepare a beaches/dunes data input to be included in Erodible Soils input:**

- A. Prepare the NHD dataset for use, if necessary.
  - a. If the area of interest is multi-state and NHD was downloaded by state, merge each state's "NHD Area" vector with one another to create one vector.
- B. If no other regional data is available, use land cover data to identify beaches and/or dunes
  - a. Clip the land cover to the region
    - i. Data Management Tools > Raster > Clip
  - b. Reclassify the clipped land cover for the class(es) that represent beach and dune systems. This may vary depending on the land cover dataset, use imagery to determine the most suitable class or classes.
    - i. Spatial Analyst Tools > Reclass > Reclassify
      1. Make the class(es) representing Beach and Dune systems a value of 1
      2. Change all other values to "NoData"
      3. check "Change missing values to NoData"
  - c. Change the reclassified raster to a vector.
    - i. Conversion Tools > From Raster > Raster to Polygon
      1. Uncheck simplify polygons
  - d. Select by Location where the Beach/Dune vector is within 50 meters of the NHD (*this distance will vary by region, especially in island environments*). This will help exclude any unnecessary areas of the region.
    - i. Export the selection as a new vector
      1. Right click layer in the Table of Contents > Data > Export Data

- e. Start an edit session with the coastal Barren Land vector and remove any unnecessary data.
  - i. Right click layer in Table of Contents > Edit Features > Start Editing
  - ii. Use the aerial imagery basemap at various extents to edit the vector (imagery may change between years and months, revealing slight differences in coast lines, because of shifting coastlines, this product will be “close enough” to exact beaches that it could be used to identify sandy areas).
  - iii. When complete, save the edits and exit the edit session. This is the final land cover product for the Beaches and Dunes dataset.
    - 1. From Editor Toolbar > Editor > Save Edits; Editor > Stop Editing
- C. Use the USDA-NRCS SSURGO soils data to supplement the land cover.
  - a. For steps on how to create and use the SSURGO dataset, see *Prepare Soils Data* in Appendix C.4.1.
  - b. After preparing the SSURGO data for use, examine the fields “geomdesc” and “muname”.
    - i. Desired descriptions may vary based on region and should be carefully examined with aerial imagery in order to select the correct descriptions. A sample of descriptions used in each region is found in the table below.
  - c. Create a new field in the attribute table to separate the desired descriptions
    - i. Add field: “Beaches”, field type: short integer
    - ii. Select by attributes: desired descriptions from the fields “geomdesc” and “muname”.
    - iii. Show only selected records > right click field “beaches” > field calculator > beaches = 5. All other entries will receive a value of 0.
  - d. Select by attributes where “Beaches” = 5, export selected features to a new layer.
    - i. Right click layer in Table of Contents > Data > Export Data
  - e. Select by Location where the SSURGO beaches, exported above, are within 100 meters of the NHD. This will help exclude any unnecessary areas of the region.
    - i. Export the selection as a new vector
      - 1. Right click layer in Table of Contents > Data > Export Data
  - f. Start an edit session with the coastal SSURGO beaches and remove any unnecessary data.
    - i. Right click layer in Table of Contents > Edit Features > Start Editing
    - ii. Use the aerial imagery basemap at various extents to edit the vector (imagery may change between years and months, revealing slight differences in coast lines, because of shifting coastlines, this product will be “close enough” to exact beaches that it could be used to identify sandy areas).
    - iii. When complete, save the edits and exit the edit session. This is the final SSURGO product for the Beaches and Dunes dataset.
      - 1. From Editor Toolbar > Editor > Save Edits; Editor > Stop Editing
- D. Merge the two beaches datasets (land cover and SSURGO) together.
  - a. Geoprocessing Tools > Merge
- E. Add a Rank field
  - a. Open Attribute Table > Add Field “Erosion\_Rank”, Short Integer
  - b. Right click “Erosion\_Rank” field > Field Calculator > Erosion\_Rank = 5

**Rank the Soils data for Erodible Soils:**

- A. In the attribute table of the regional soils vector add field “**Erosion\_rank**”
  - a. Right click layer in the Table of Contents > Attribute Table > Add Field
    - i. Field type: Short Integer
- B. Begin adding the rank values to the appropriate soil erosion classification in the new field “Erosion\_rank”
  - a. Attribute Table options > Select by Attributes
    - i. Example query:  $kfact \leq '.10'$ ;  $kfact \geq '.15'$  AND  $kfact \leq '.17'$ ; etc.
    - ii. In Attribute Table > Show selected records
    - iii. Right click field “Erosion\_rank” > Field Calculator > “Erosion\_rank” = 1
    - iv. Repeat for all values according to the Soil Erodibility table below.
- C. Merge Beaches and Dunes data input to the ranked Soils dataset
  - a. Geoprocessing > Merge
- D. Merge the final vector with the region
  - a. Geoprocessing > Merge
- E. Convert the vector layer to a raster:
  - a. Conversion Tools > To Raster > Polygon to Raster
    - i. Value field: Erosion\_rank
    - ii. Cell assignment type: Maximum area
    - iii. Priority field: Erosion\_rank
    - iv. Cellsize: *varies by region*
- F. Shift each raster to properly align cells
  - a. Data and Management Tools > Projections and Transformations > Raster > Shift
    - i. Input: Erosion\_rank raster
    - ii. Shift X & Y Coordinates by: 1 (each)
    - iii. Snap to: *varies by region*

Soil Erodibility	Rank Type	Rank Value
Null	None	0
$\leq .10$ Kfact	Very low	1
.15 and .17 Kfact	Low	2
.20 – .28 Kfact	Moderate	3
.32 and .37 Kfact	High	4
$\geq .43$ Kfact	Very high	5

**B.5 Create the Areas of Low Slope Input**

- A. Import all the NED tiles to cover the region and create a mosaic
- B. Create a Raster Mosaic
  - a. Data Management Tools > Raster > Raster Dataset > Mosaic
    - i. Enter all of the tiles as inputs except one, this will be the target tile that all of the other tiles are “merged” to. *NOTE:* make a copy of this tile before merging all other tiles to it.
    - ii. Accept all default settings since none of the tiles are overlapping

- C. *If necessary*, resample the DEM to the regional modeling resolution
  - a. Data Management Tools > Raster > Raster Processing > Resample
- D. Use the Raster Clip tool to clip the raster mosaic to the region
  - a. Data management tools > Raster > Raster Processing > Clip
- E. Create a slope raster from the clipped raster using the Slope Tool
  - a. Spatial Analyst Tools > Surface > Slope
    - i. Output Measurement: Percent rise
- F. Reclassify the Slope raster to a ranked output
  - a. Spatial Analyst Tools > Reclass > Reclassify
    - i. Choose the Percent Rise raster as the input raster
    - ii. Create a distribution with corresponding rank values according to the table below.
- G. Shift the raster
  - a. Data and Management Tools > Projections and Transformations > Raster > Shift
  - b. Shift X & Y Coordinates by: 1 (each)
  - c. Snap to: *varies by region*

Slope (%)	Rank Type	Rank Value
> 2.00	None	0
1.00 – 2.00	Very low	1
.75 – 1.00	Low	2
.50 – .75	Moderate	3
.25 – .50	High	4
< .25	Very high	5

## B.6 Create the Geologic Stressors Input

### Prepare Landslide Susceptibility data input

- A. Import the vector data layer, clip it to the region, and set the output coordinates to the correct projection.
  - a. Geoprocessing Tools > Clip
- B. Open the Attribute table and add a new field
  - a. Name: Rank
  - b. Type: Short
- C. Select by attributes to isolate and rank the designated class types according to the Landslide Risk table below. Example:
  - a. Select by Attributes: POT\_RISK = 'No Data' OR POT\_Risk = 'Low Incidence'
  - b. Show only selected records. Right click Rank field > Field Calculator:
    - i. Rank = 0
  - c. Repeat for all landslide potentials and apply the rank values according to table below
- D. Merge ranked vector with the region
  - a. Geoprocessing Tools > Merge

Landslide Potential	Rank Type	Rank Value
No Data, Low incidence	None	0
High Susceptibility, Moderate Incidence	Moderate	1
High Incidence	High	2

### Prepare Subsidence data input

Due to the different regional causes of land subsidence and the lack of a cohesive, national dataset, regional analyses of known and prominent land subsidence occurrence were used to construct the subsidence featured in Regional Assessments (Dobson et al. 2019; Dobson et al. 2020a-d; Dobson et al. 2021a-b). The data was obtained from the following studies and/or reports:

- A. After obtaining the relevant subsidence data, add a field for ranking the values according to the level of impact the subsidence has on the local or regional area. For the Assessments, three categories Low, Medium, and High (ranked 1, 2, and 3, respectively) were used to represent subsidence impact. Ensure that the values chosen to represent regional impact correspond and are scaled to all other regional inputs.
- B. Merge all regions of subsidence vectors
- C. Merge output with the regional extent that includes all regions

### Combine Land Subsidence and Landslide Susceptibility data:

- A. Merge the vectors of the subsidence and landslide data into one vector.
- B. Rasterize the merged output to create the combined raster input.
  - a. Conversion Tools > To Raster > Polygon to Raster
    - i. Value field: RANK
    - ii. Cell assignment type: Maximum area
    - iii. Priority field: RANK
    - iv. Cell size: 30
- C. Shift output to the NLCD 2011 raster
  - a. Data and Management Tools > Projections and Transformations > Raster > Shift
    - i. Input: Beaches and Dunes raster
    - ii. Shift X & Y Coordinates by: 1 (each)
    - iii. Snap to: NLCD 2011

## B.7 Create the Tsunami Input

### Prepare tsunami data input

- A. Import the raster data layer, clip it to the region, and set the output coordinates to the correct projection.
  - a. Geoprocessing Tools > Clip
- B. Merge ranked vector with the region
  - a. Geoprocessing Tools > Merge
- C. Open the Attribute table and add a new field
  - a. Name: Rank
  - b. Type: Short

- D. Distribute the values of the tsunami raster into 5 groups based upon depth value using a quantile classification. This distribution of values will indicate the rank value. Areas with no data from the merge with the region should receive a value of 0
- E. Rasterize on the Rank field

Inundation Potential	Rank Type	Rank Value
0 to -0.30 meters	Lowest	1
-0.31 to -0.60 meters	Low	2
-0.61 to -1.00 meters	Moderate	3
-1.01 to -1.81 meters	High	4
-1.82 to -15.90 meters	Highest	5
No Data	None	0

### B.8 Combining the Threat Input Variables

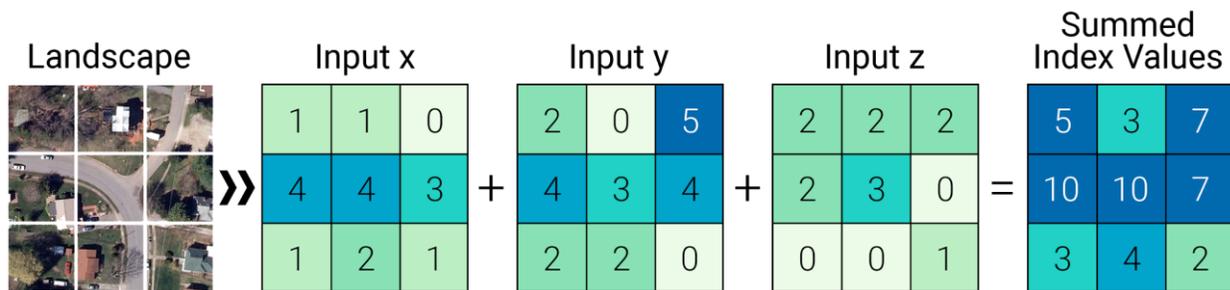


Figure B.1. Illustration of the raster calculation concept used for the Threat and Community Asset Indices.

To complete the Threat Index, an ordinal combination method was used where cell values were added together and then classified into ten groups to create a raster that can be used for the Exposure Index calculation. Classification was done by performing a percentile distribution of all values. See each regional section for the 10-class distribution of the Threat Index that was used for the Exposure Index calculation. These values were then arranged in tiers ranging from “low” to “high” hazard designations. The higher the ranking, the higher the potential for the landscape to be impacted by a flood-related hazard.

## C. Detailed Methodology: Community Asset Index

**Important note regarding point datasets used for Community Asset Index inputs:** Point data are often placed in inaccurate locations. This is especially an issue in the Critical Infrastructure and Critical Facilities datasets. Careful attention to the locations of these points will be required. Beyond the filtering used in the attribute table, the locations of points will need to be adjusted using an edit session before rasterizing and including data in the Asset Index.

### C.1 Create the Population Density Input

- A. Join the regional geography dataset and the table containing the population data.
  - a. Add the table to the map. Be sure to identify which field is the total population per census geography.
  - b. Join the table to the vector:
    - i. Right click vector in the Table of Contents > Joins and Relates > Join...
      1. Table (step 2): *choose the table containing the population data*
      2. Field in the layer to join on (step 1): Geoid\_data
      3. Field in the table to join on (step 3): GEOID
  - c. Export the feature to save the join:
    - i. Right click layer in Table of Contents > Data > Export Data. When prompted, add the new layer to the map.
- B. Add a field to the attribute table and calculate area per census geography
  - a. Open Attribute Table > Add Field > Name: area\_km, Type: Float
  - b. Right click field 'area\_km' > Calculate Geometry > Units: square kilometers
- C. Add a field to the attribute table and calculate population density per block group
  - a. Open Attribute Table > Add Field > Name: popdens, Type: Float
  - b. Right click field 'popdens' > Field Calculator > popdens = 'total population' / 'area\_km'
- D. Using the building footprints for the region, create centroids to represent areas where people live
  - a. Data management tools > Features > Feature to Point
    - i. Leave "inside" unchecked (uses the representative center of an input feature as its output point location)
- E. Spatial Join the Population Density data to the building points
  - a. Analysis toolbox > Overlay toolset > Spatial Join
    - i. Target Features: building points
    - ii. Join Features: Population density
    - iii. Join operation: one to one
    - iv. Check: Keep all target features
- F. Create Hexagons for the region
  - a. Data Management toolbox > Sampling toolset > Generate Tessellation (Data Management)
    - i. Extent: *set to regional boundary*
    - ii. Shape type: Hexagon
    - iii. Size: 2500 square meters (*note: this size may differ across regions*)
    - iv. Spatial reference: *varies by region*
  - b. The output generated will cover the entire regional extent, including areas in the ocean or that are not in the region. For the next step, there are two options before proceeding:
    - i. Select by location where hexagons intersect the regional boundary

1. *Option 1*: export the selected features to a new feature class
  2. *Option 2*: with the features selected, run the tool in the next step. The output of that tool will only include the selected features.
- G. Summarize the population density building points on the hexagons
- a. Analysis toolbox > Statistics toolset > Summarize Within
    - i. Input polygons: hexagons (from either option in the step above)
    - ii. Input summary features: population density building points
    - iii. *Uncheck* keep all input polygons
    - iv. Summary field: population density
    - v. Statistic: mean
- H. Distribute the averaged population density in a way that best represents the data
- a. Exclude values and classify the data
    - i. Right click layer in the Table of Contents > Properties > Symbology > Quantities (Graduated colors) > Classify... > Exclusion...
      1. "Mean Pop Density" = 00
    - ii. Continue to distribute the remainder of the data, checking the map to determine the best breaks
- I. Rank the data according to the chosen class distribution
- a. Right click layer in Table of Contents > Attribute Table
    - i. Add Field > Name: Rank; Type: Short Integer
  - b. Using Select by Attributes, give each class a rank
    - i. Where *Mean Population Density* <= [lower distribution value] AND *Mean Population Density* >= [upper distribution value]
    - ii. Show selected records
    - iii. Right click field Rank > Field Calculator > Rank = 1-5 (reference the table below)
    - iv. Repeat for all classes
- J. Merge ranked Population Density vector to the region to ensure values of 0 exist where there is no population data. *This is an important step for rasterizing the vector.*
- a. Geoprocessing > Merge
- K. Rasterize the vector
- a. Conversion Tools > To Raster > Polygon to Raster
    - i. Value Field: rank
    - ii. Cell assignment: Maximum Area
    - iii. Priority Field: Rank
    - iv. Cellsize: *varies by region*
- L. Shift raster
- a. Data Management > Projections and Transformations > Raster > Shift
    - i. Shift X & Y coordinates by: 1 (each)
    - ii. Input snap raster: *varies by region*

## C.2 Create the Critical Facilities Input

Critical Facilities are considered schools, emergency response and law enforcement, health and medical, and government and military buildings. Locally available data should be used whenever applicable, however the USGS National Structures Dataset codes are listed in the table below.

FType	Description
730	Education
740	Emergency Response and Law Enforcement
800	Health and Medical
830	Government and Military*

- A. Clip data and reproject, as needed, including building footprints and parcel data
  - a. Geoprocessing > Clip
- B. If using the USGS National Structures Dataset, select all critical facilities of interest (see table above)
  - a. Right click layer in the Table of Contents > attribute table > Select by attributes: "FType" = *National Structures Code*
  - b. Export selected critical facilities as its own feature
    - i. Right click layer in Table of Contents > Data > Export Data
  - c. Other queries can be used to remove unnecessary records: correctional facilities, prisons, detention centers and juvenile detention centers, beauty schools, cosmetology schools
    - i. Begin an edit session. *NOTE:* after edits are made AND saved to the dataset, they are permanent. A suggestion is to make a copy of the data to avoid errors.
      1. Right click layer in the Table of Contents > Edit Features > Start Editing.
    - ii. Open the attribute table and Select by Attributes
      1. Enter the query:
        - a. "Name" LIKE '% Prison%'.
      2. Show only selected records
      3. Delete the records using the highlighted "X" at the top of the attribute table. *NOTE:* this step cannot be undone
      4. Repeat queries until all undesirable records are removed
    - iii. Save the edits in the Editor Toolbar and stop the edit session when finished
      1. From Editor Toolbar > Editor > Save Edits; Editor > Stop Editing
- C. Any data will need to be verified against aerial imagery for accuracy. Additionally, it is important to ensure that any point data is completely within at least one building footprint for the facility and the footprint(s) is/are completely within a parcel. Use an edit session to adjust data as needed. Follow steps above for beginning and ending an edit session.
- D. Select building footprints and parcels that represent the facilities.
  - a. Select by location where facility points intersect the footprints.
    - i. Export to a new feature class
      1. Right click footprint layer > Export Data
    - ii. Repeat for all facilities
  - b. Select by location where footprints intersect the parcels.
    - i. Export to a new feature class
      1. Right click parcel layer > Export Data

- ii. Repeat for all facilities
- E. Add Rank fields to building footprints and parcels
  - a. Right click layer in the Table of Contents > Attribute Table > Add field > Field name: "Rank", field type: Short Integer
  - b. Rank parcels and footprints according to the table below:

Facility Feature Type	Rank
Parcel	3
Footprint	5

- F. Expand resulting feature to cover entire watershed region to create values of 0 where there are no critical facilities on the landscape.
  - a. Merge facility feature classes with the regional boundary in the following order: boundary, parcel, footprint
    - i. Geoprocessing > Merge
- G. Convert merged layer from vector to raster:
  - a. Conversion Tools > To Raster > Polygon to Raster
  - b. Value Field: Rank
  - c. Cell assignment type: Maximum Area
  - d. Priority field: Rank
  - e. Cellsize: *varies by region*
- H. Shift raster
  - a. Data Management > Projections and Transformations > Raster > Shift
  - b. Shift X & Y coordinates by: 1 (each)
  - c. Input snap raster: *varies by region*

### C.3 Create the Critical Infrastructure Input

Use locally available data and inputs whenever possible.

#### Create the Bridges Dataset:

- A. Clip all required data to region
  - a. Geoprocessing > Clip
- B. Remove ferry routes from the roads dataset.
  - a. Right click layer in Table of Contents > Edit Features > Start Editing
  - b. Right click layer in Table of Contents > Attribute Table > Options > Select by Attributes
    - i. "Road\_class" = 8
    - ii. With features selected, choose the glowing "X" in the toolbar at the top of the Attribute Table.
  - c. From Editor Toolbar > Editor > Save Edits; Editor > Stop Editing
- C. Remove irrelevant bridges from the NBI
  - a. Right click layer in Table of Contents > Edit Features > Start Editing
  - b. Right click layer in Table of Contents > Attribute Table > Options > Select by Attributes
    - i. "ITEM71" = N
    - ii. With features selected, choose the glowing "X" in the toolbar at the top of the Attribute Table.
  - c. From Editor Toolbar > Editor > Save Edits; Editor > Stop Editing

- D. Snap bridge points to the roadways polyline dataset. This ensures that bridge point locations rest on a roadway polyline.
  - a. Editing Tools > Snap
    - i. Input Features: Bridges
    - ii. Snap Environment: Roadways
    - iii. Type: EDGE
    - iv. Distance: 10 meters
      - 1. There will be bridge point locations that are farther than 10 meters from a roadway. Use 10 meters as a starting point and adjust the distance incrementally until all bridge points are snapped. Incremental increases ensure the bridge point will be snapped to roadway polyline
- E. Import USGS National Hydrography Dataset for the region and merge
  - a. Import FlowLine, FlowArea, and Waterbody features
  - b. Buffer FlowLine feature to 1m to convert it from a polyline to a polygon
    - i. Geoprocessing > Buffer
  - c. Remove unnecessary features from the buffered FlowLine polygon
    - i. Right click layer in the Table of Contents > Edit Features > Start Editing
    - ii. Right click layer in the Table of Contents > Attribute Table > Options > Select by Attributes
      - 1. Where FTYPE = 428 (pipeline) OR FTYPE = 420 (underground conduit)
      - 2. With features selected, choose the glowing "X" in the toolbar at the top of the Attribute Table.
    - iii. From Editor Toolbar > Editor > Save Edits; Editor > Stop Editing
  - d. Merge the three NHD features into one layer
    - i. Geoprocessing > Merge
- F. There are many bridges that go over railways, roadways, or other obstacles. Select bridge points only relevant to this analysis; bridges that go over bodies of water.
  - a. Select by location:
    - i. Select features from: snapped bridges
    - ii. Source layer: merged NHD polygon
    - iii. Check "Apply search distance," and enter 100 meters
  - b. Export selected bridge points as a new feature
    - i. Right click layer in Table of Contents > Data > Export Data
- G. Use the bridge length attribute, "ITEM49," to buffer new bridge point locations
  - a. Add a field in the attribute table that will be the value that is buffered to approximate bridge length.
    - i. Right click layer in Table of Contents > Attribute Table > Options > Add Field
      - 1. Field Name: BLength, Field Type: Float
  - b. Right click field BLength > Field Calculator:  $BLength = ([ITEM49]/2)+40$ 
    - i. The bridge length divided by two is used because a buffer extending outward from the bridge's midpoint will reach the surveyed bridge length. The additional 40 meters is to compensate for the area of a bridge that connects with the roadway. This section of a bridge is also highly susceptible to flooding. This chosen value was determined suitable for this Assessment.
  - c. Geoprocessing > Buffer
    - i. Distance: Field: BLength
    - ii. Method: Planar
    - iii. Dissolve Type: None

- H. Select roads that intersect waterways and the buffered bridge output from G.
  - a. Select by location > Target layer: roads; Source layer: merged NHD; Spatial selection method: intersect the source layer feature
  - b. Select by location > Selection method: select from the currently selected features in: Target layer: roads > Source layer: buffered bridge output from G.
  - c. Export selected roadways as a new feature
    - i. Right click layer in Table of Contents > Data > Export Data
- I. Intersect the bridges buffered by length output from step G with the roads dataset from step H to isolate roadways that are bridges and remove slivers of roadway that are not actual bridge decks and bridge approaches
  - a. Geoprocessing > Intersect
    - i. Input Features: Buffered bridges (G) and roads
    - ii. Output Feature Class: G\_roads\_Intersect
  - b. Geoprocessing > Intersect
    - i. Input Features: G\_roads\_Intersect and roads (H)
    - ii. Output Feature Class: GH\_roads\_Intersect
  - c. Select by Location:
    - i. Target Layer: GH\_roads\_Intersect
    - ii. Source Layer: Bridge point dataset
    - iii. Selection Method: Intersect the source layer feature
  - d. Export the resulting bridge polyline features as a new dataset
    - i. Right click layer in Table of Contents > Data > Export Data
- J. Join the data from the bridge dataset (NBI) to the bridge polyline (output I)
  - a. Analysis Tools > Overlay > Spatial Join
    - i. Target features: Bridge polylines (I)
    - ii. Join Features: snapped bridges buffered by length (G)
- K. Use the bridge width field, "ITEM52," and buffer bridge polylines to get approximate surveyed bridge width in meters
  - a. Change any NULL or values of 0 in field "ITEM52" to 12 (12 meters is the average bridge width used in this analysis)
    - i. Right click layer in Table of Contents > Attribute Table > Select by Attributes:
      - 1. "ITEM52" = '0' OR "ITEM52" IS NULL
    - ii. Show only selected records in Table > Right click field ITEM52 > Field Calculator:
 

```
ITEM52 = 12
```
    - iii. Clear selected records
  - b. Geoprocessing > Buffer
    - i. Output Features: Bwidth\_buffer
    - ii. Distance: Field: ITEM52
    - iii. Method: Planar
    - iv. Dissolve Type: None
- L. There may now be slivers of bridge/roadways that aren't actually bridges. Go through the resulting bridges and perform a manual QC clean up. Dissolve bridge polygons and spatial join with the snapped bridge dataset for additional cleanup. The spatial join is optional and may not be needed, but it re-connects the polygons with the bridge data.
  - a. Geoprocessing > Dissolve
    - i. Input Features: Bwidth\_buffer
    - ii. Dissolve Field: Select all relevant fields
    - iii. Uncheck "Create multipart features"

- b. Select by location
  - i. Target Layer: Dissolved features from the step above
  - ii. Source layer: snapped bridge points
  - iii. Selection method: intersect the source layer feature
  - iv. Start an edit session and delete all of the non-selected polygons from the data
    - 1. Right click layer in the Table of Contents > Edit Features > Start Editing
    - 2. Right click layer in the Table of Contents > Attribute Table > Switch Selection
    - 3. Click the glowing “X” in the Attribute Table toolbar to remove the selected features. *NOTE:* this cannot be undone.
  - v. Save changes and close the edit session
    - 1. From the Editor Toolbar > Editor > Save Edits; Editor > Stop Editing
- c. Analysis Tools > Overlay > Spatial Join
  - i. Target features: Features remaining after step I.b.
  - ii. Join Features: snapped bridge points

**Prepare Other Critical Infrastructure Datasets:**

- A. Import Critical Infrastructure data and clip datasets to the region (including parcel and building footprint data)
  - a. Geoprocessing > Clip
- B. Check all infrastructure types against aerial imagery to ensure location accuracy. If no building footprint(s) exist for the infrastructure, manually create them. Ensure building footprints are completely within a parcel. Use an edit session to adjust any data where needed
  - a. Right click layer in Table of Contents > Edit Features > Start Editing
  - b. To end the edit session:
    - i. From Editor Toolbar > Editor > Save Edits; Editor > Stop Editing
- C. Water Treatment Facilities:
  - a. Select by attributes to extract wastewater treatment facilities
    - i. Right click layer in Table of Contents > Attribute Table > Select by Attributes: FTYPE = 850
      - 1. To verify this is the correct code, select FTYPE and “get unique values”
    - ii. After verifying, export data to new shapefile
      - 1. Right click layer in Table of Contents > Data > Export Data
- D. Keeping them as separate features, buffer Railroads, Airport Runways, National Highways, and Evacuation Routes according to the table below
  - a. Geoprocessing > Buffer
- E. Hazardous Materials Sites
  - a. Select only these interest types from the dataset:
    - i. Hazardous waste landfill, LQG (large quantity generator), RAD NPL (national priority list radioactive sites), RAD WIPP (radioactive waste isolation pilot plant), Superfund NPL (national priority list)
    - ii. Remove the entry if it is not active
- F. Add a rank value to each infrastructure footprints and parcels
  - a. Open Attribute Table > Add Field > “Rank”; Short Integer
  - b. Right click new field > Field Calculator > Rank =

Infrastructure Feature Type	Rank
Parcel	1
Footprint	2

- c. Repeat for all datasets before continuing to the next step
- G. Merge each critical infrastructure feature type to the regional boundary in the following order:
  - a. Boundary, parcel, footprint
  - b. Geoprocessing > Merge
    - i. Repeat for all inputs before continuing to the next step
  - c. Ensure there are no NULL values for the regional boundary after merging. If there are, change them to 0 using the Field Calculator.
- H. Rasterize each critical infrastructure feature polygon
  - a. Conversion Tools > To Raster > Polygon to raster
    - i. Value field: RANK
    - ii. Cell assignment: Maximum Area
    - iii. Priority Field > RANK
    - iv. Cellsize: *varies by region*
- I. Shift each raster input.
  - a. Data Management > Projections and Transformations > Raster > Shift
    - i. Input Raster: Critical Infrastructure raster input
    - ii. Shift X & Y coordinates by: 1 (each)
    - iii. Input snap raster: *varies by region*
- J. Combine all critical infrastructure rasters into one raster.
  - a. Spatial Analyst Tools > Map Algebra > Raster Calculator: add each critical infrastructure raster together, for example: raster1.tif + raster2.tif + raster3.tif...etc.
- K. Shift raster
  - a. Data Management > Projections and Transformations > Raster > Shift
    - i. Input raster: Critical Infrastructure raster output
    - ii. Shift X & Y coordinates by: 1 (each)
    - iii. Input snap raster: *varies by region*

Input	Buffer Size ( <i>meters; method: planar; dissolve type: NONE</i> )
Railroads	10
Airport Runways, National Highways	30

#### ***C.4 Create the Social Vulnerability Input***

Wherever available EPA EJSCREEN data will be used, as reflected in the steps below. See regional reports for differences in methodology and data availability (Dobson et al. 2019; Dobson et al. 2020a-d; Dobson et al. 2021a-b).

- A. Prepare the data for the analysis.
  - a. Download and import EPA EJSCREEN data from download file: EJSCREEN\_2018\_StatePctile.gdb
  - b. Clip the layer to the region and reproject

- B. Using the building footprints for the region, create centroids to represent areas where people live
  - a. Data management tools > Features > Feature to Point
    - i. Leave “inside” unchecked (uses the representative center of an input feature as its output point location)
- C. Spatial Join the Social Vulnerability data to the building points
  - a. Analysis toolbox > Overlay toolset > Spatial Join
    - i. Target Features: building points
    - ii. Join Features: Social vulnerability
    - iii. Join operation: one to one
    - iv. Check: Keep all target features
- D. Create Hexagons for the region
  - a. Data Management toolbox > Sampling toolset > Generate Tessellation (Data Management)
    - i. Extent: *set to regional boundary*
    - ii. Shape type: Hexagon
    - iii. Size: 2500 Sq Meters (*note: this size may differ across regions*)
    - iv. Spatial reference: *varies by region*
  - b. The output generated will cover the entire regional extent, including areas in the ocean or that are not in the region. For the next step, there are two options before proceeding:
    - i. Select by location where hexagons intersect the regional boundary
      - 1. *Option 1*: export the selected features to a new feature class
      - 2. *Option 2*: with the features selected, run the tool in the next step. The output of that tool will only include the selected features.
- E. Summarize the social vulnerability building points on the hexagons
  - a. Analysis toolbox > Statistics toolset > Summarize Within
    - i. Input polygons: hexagons (from either option in the step above)
    - ii. Input summary features: social vulnerability building points
    - iii. *Uncheck* keep all input polygons
    - iv. Summary field: social vulnerability (EJSCREEN: ‘VULEOPCT’)
    - v. Statistic: mean
- F. Distribute the averaged social vulnerability in a way that best represents the data
  - a. Exclude values and classify the data
    - i. Right click layer in the Table of Contents > Properties > Symbology > Quantities (Graduated colors) > Classify... > Exclusion...
      - 1. “Mean Social Vulnerability” = 00
    - ii. Continue to distribute the remainder of the data, checking the map to determine the best breaks
- G. Rank the data according to the chosen class distribution
  - a. Right click layer in Table of Contents > Attribute Table
    - i. Add Field > Name: Rank; Type: Short Integer
  - b. Using Select by Attributes, give each class a rank
    - i. Where *mean social vulnerability* <= [lower distribution value] AND *mean social vulnerability* >= [upper distribution value]
    - ii. Show selected records
    - iii. Right click field Rank > Field Calculator > Rank = 1-5 (reference the table below)
    - iv. Repeat for all classes

- H. Convert new layer from vector to raster:
  - a. Conversion Tools > To Raster > Polygon to Raster
    - i. Value Field: Rank
    - ii. Cell assignment type: Maximum Area
    - iii. Priority field: Rank
    - iv. Cellsize: *varies by region*
- I. Shift raster
  - a. Data Management > Projections and Transformations > Raster > Shift
    - i. Input raster: Social Vulnerability raster
    - ii. Shift X & Y coordinates by: 1 (each)
    - iii. Input snap raster: *varies by region*
- J. Clip raster to area of interest for further analysis

### ***C.5 Combining the Community Asset Input Variables***

Similar to the Threat Index, the Community Asset Index is a composite dataset that brings multiple data layers together to identify areas of the landscape that contain densities of assets. The raster inputs are first added together and then reclassified, using a 10-class distribution for the Exposure Index calculation. See each regional report for details on this distribution (Dobson et al. 2019; Dobson et al. 2020a-d; Dobson et al. 2021a-b).

## **D. Detailed Methodology: Calculating the Community Exposure Index**

The Community Exposure Index is the product of the Threat Index and the Community Asset Index. After creating the composite raster layer and reclassifying each index with values 1-10, the two are multiplied to create an output with values 1-100 for all regions combined. In order to create a final Index that is easier to use and understand, the Exposure Index is then also classified into 10 classes.

## E. Detailed Methodology: Fish and Wildlife Index

### E.1 Create the Terrestrial Index

- A. Download habitat data for the T&E species and species of greatest conservation need from IUCN Red List.
  - a. On the homepage, select Advanced next to the search bar.
  - b. Using the options on the left side of the page, make the following selections:
    - i. Taxonomy: ✓ Animalia
    - ii. Land Regions: ✓ Area of Interest (example: choose Caribbean Islands for Puerto Rico and then narrow down as needed)
  - c. On the top right of the Results section, choose Download > Search Results.
    - i. *NOTE:* if you have not updated your profile settings to include habitats and threats, the download will not include these items.
- B. From the habitats spreadsheet downloaded, extract only the entries relevant to the species found in the State Wildlife Action Plan (SWAP) for that region.
- C. Using the entries extracted, find habitat equivalencies for available data and IUCN Habitats Classification Scheme.
  - a. Going through each habitat type, use extract by attributes to export a new feature class.
  - b. Add two fields to identify the habitat type:
    - i. IUCN; type = float (use to enter the IUCN habitat code)
    - ii. Class; type = text (use to enter the IUCN habitat name)
- D. After creating all of the necessary layers for habitats, merge together habitats by taxonomic group. It is helpful to create a pivot table using the entries extracted to identify all of the habitats by group.
- E. Follow the same workflow to develop threat feature classes by species relevant to the region.
- F. For each taxonomic group, erase the relevant threat layers from the merged habitats.
- G. Use the multipart to singlepart tool for the final potential habitat vector.
- H. Merge together any available Primary Habitat (any federal or state designation datasets) by taxonomic group.
- I. Select potential habitat by location where it intersects Primary Habitat.
- J. Select subset from selected features where they intersect PADUS with a GAP status of 1 or 2 (managed for biodiversity).
- K. Export the remaining selected features as Secondary Habitat.
- L. Clear selections. Select potential habitat by location where it intersects Primary Habitat.
- M. Add to current selection where potential habitat intersects Secondary Habitat.
- N. Export the selected features as Tertiary Habitat.
- O. Rank the habitat layers:
  - a. Primary Habitat Rank = 3
  - b. Secondary Habitat Rank = 2
  - c. Tertiary Habitat Rank = 1
- P. Merge the ranked habitat layers and the region.
  - a. Geoprocessing > Merge
- Q. Rasterize the merged vectors to create the Terrestrial Index.
  - a. Conversion Tools > To Raster > Polygon to Raster
  - b. Value Field: Rank
  - c. Cell assignment type: Maximum Area
  - d. Priority field: Rank

- e. Cell Size: *varies by region*
- R. Important Bird Areas and Key Biodiversity Areas
  - a. Rank based on the number of designations an area has received. It can be either a KBA or IBA (rank = 1) or both (rank = 2).
- S. Create a raster of protected areas with a GAP status of 1 or 2, excluding MPAs
  - a. Select by attributes where the GAP status = 1 or 2. The GAP Status Code is a measure of management intent to conserve biodiversity. Select the following:
    - i. Status Code 1: an area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events are permitted to proceed without interference or are mimicked through management.
    - ii. Status Code 2: an area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance.
  - b. Remove from selected features where management type (manag\_type) = MPA (MPAs will be included in the Marine Index).
  - c. Give all of the protected areas a presence value (rank) of 1.
- T. After preparing all of the relevant datasets for the Terrestrial Index for the region, add all of them together to create the Index.
  - a. Spatial Analyst Tools > Map Algebra > Raster Calculator
- U. Reclassify the result into 4 classes, which will ultimately be used to create the Fish and Wildlife Index.
  - a. Spatial Analyst Tools > Reclass Toolset > Reclassify
  - b. Use a quantile distribution, 4 classes.

## ***E.2 Create the Marine Index***

Similar to the Terrestrial Index, the available data will differ between regions. The following should be considered a baseline standard and changes should be made as necessary.

- A. Prepare all data by clipping to the region and reprojecting, as necessary. There should be two types of data to work with: habitat data (e.g., corals) and conservation designations (e.g., Essential Fish Habitat). The habitat data should be ranked based on its ability to provide a healthy habitat for marine species. The conservation designations are ranked on presence and designation type. See below.
- B. Prepare the coral data as follows:
  - a. Select only these structures from the Benthic Habitat dataset:
    - i. Aggregate reef, aggregated patch reef, individual patch reef, rock/boulder, and spur and groove.
  - b. Using cover data from NOAA's National Coral Reef Monitoring Program, rank the selected corals percent cover using a quantile distribution and 5 classes. The class with the highest amount of cover gets the highest rank (5).
- C. Prepare the seagrass data as follows:
  - a. Select by attributes where biotic cover = seagrass; export to a new feature class.
  - b. Using the cover attribute, rank the seagrass data. Coverage details may differ between regions, however, "continuous" coverage should always receive the highest rank (5).

The “patchy” coverage should be ranked in ascending order. The total number of rank values may depend on data available for each region.

- D. Prepare the mangrove data as follows:
  - a. Using two years of data from the Global Mangrove Watch, a series of geoprocessing steps will be used to determine if mangroves are gained, lost, or maintained in an area.
    - i. Lost: **erase** the most recent data (2016) from the older data (2010).
    - ii. Gained: **erase** the older data (2010) from the most recent data (2016).
    - iii. Maintained: **Intersect** the two years (2010 and 2016) to see where they overlap.
  - b. Rank the data as follows: Lost = 1; maintained = 2; and gained = 3.
  - c. For regions where data is not available, refer to other datasets such as NOAA C-CAP.
    - i. Rank the data with a presence value of 3.
- E. Prepare the conservation designations as follows:
  - a. NOAA Essential Fish Habitat
    - i. Remove from the data any corals (because they are already represented in the benthic cover maps) and where lifestage = all.
    - ii. Rank = 1
  - b. NOAA Habitat Areas of Particular Concern
    - i. Rank = 3
  - c. NOAA Essential Fish Habitat Areas Protected from Fishing
    - i. Rank = 2
    - ii. Determine regionally if all areas are meaningful and remove those that are not. For example, in Puerto Rico, the Caribbean EEZ gear restriction area was not included because it was determined to be irrelevant to the goal of the Assessments.
  - d. Marine Protected Areas from the Protected Areas Database of the U.S.
    - i. Select by attributes where management type (manag\_type) = MPA
    - ii. Give each area a presence value (rank) of 1.
- F. After preparing all of the relevant datasets for the Marine Index for the region, add all of them together to create the Index.
  - a. Spatial Analyst Tools > Map Algebra > Raster Calculator
- G. Reclassify the result into 4 classes, which will ultimately be used to create the Fish and Wildlife Index.
  - a. Spatial Analyst Tools > Reclass Toolset > Reclassify
  - b. Use a quantile distribution, 4 classes.

### ***E.3 Create the combined Fish and Wildlife Index***

- A. Create the combined Fish and Wildlife Index by adding together the two reclassified composite Indices
  - a. Spatial Analyst Tools > Map Algebra > Raster Calculator

## F. Detailed Methodology: Resilience Hubs

This Appendix describes the methods as applied to Regional Assessments developed after 2020 (Dobson et al. 2020a-d; Dobson et al. 2021a-b). The methods detailed below are different from those methods applied to Regional Assessments in the continental U.S. (CONUS); for a detailed description of methods applied to the CONUS Regional Assessments see Dobson et al. (2019).

### F.1 Develop Green Habitat Cores following the Green Infrastructure Methodology

The objective of this process is to identify Green Habitat Cores within the area of interest using the following criteria:<sup>12</sup>

- Habitat core minimum area at 100 acres (40.5 hectares); 10 acre (~4.04 hectares) minimum threshold used for American Samoa and Guam
  - Includes pasture/hay, cultivated, grassland, forested, scrub/shrub, barren, wetlands, and open water as valid land cover types
  - Excludes all developed lands
  - Fragmenting features include roads, railroads, and HUC-12 watershed boundaries
  - Topographic diversity
  - Wetland presence and diversity
  - Soil type and diversity, using SSURGO and the “mukey” attribute
  - Core compactness using an area:compactness ratio
- A. Prepare the data inputs required for the Green Infrastructure methodology
    - a. Consistent projections among inputs
    - b. Consistent resolutions among raster inputs
  - B. Develop habitat cores using a pre-existing Green Infrastructure “Create Cores” python script<sup>13</sup> or by creating your own. For this assessment, NEMAC modified the python script based on the Esri Green Infrastructure methodology
    - a. Run script to generate a raster dataset of Habitat Cores using the regional boundary data as the area of interest (with a 2 kilometer buffer applied)
  - C. Convert the resulting raster to Core polygons
  - D. Add field “acres” as float field type. Calculate the geometry of each Core in acres to ensure that all Cores are a minimum 100 acres in area
  - E. Create field to become a unique id per Core
    - a. Add field “core\_id” as a long integer field type. Calculate “core\_id” to match field “FID” or “OBJECTID”
  - F. This resulting dataset is the Habitat Cores (*no distinction between Blue or Green*)

### F.2 Develop Hexagonal Grid for Blue and Green Habitat Cores

- A. Convert the Habitat Cores polygons (from Step F.1.F) into a hexagonal grid at a 10-acre (4-hectare) hexagonal grid commensurate with the scale of the Assessments
  - a. Horizontal and vertical spacing = 216.17 meters
- B. Create field to become a unique ID per hexagon

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<sup>12</sup> Note that the criteria used for the Green Infrastructure method were determined suitable for the needs of this Assessment and the scale at which the resulting dataset is used to guide this Assessment.

<sup>13</sup> Esri’s Green Infrastructure Toolbox can be found here:

<https://www.arcgis.com/home/item.html?id=d653270fb24847deaf65892f1b3c4b6e> (last accessed 06/15/2020)

- a. Add field "hex\_id" as a long integer field type. Calculate field "hex\_id" to match field "FID" or "OBJECTID"
- C. Add field "acres" as float field type. Calculate the geometry of each hexagon in acres to ensure that all hexagons are a minimum 10 acres in area
- D. Eliminate hexagons that fail to contain at least 50% of Habitat Core geometry within the areas of each hexagon. This removes hexagons that contains less than half of their area overlapping Habitat Cores
  - a. Run Tabulate Intersection or Summarize Within to calculate the areas of the Habitat Cores within each hexagon
  - b. If needed, join resulting summary table back to the hexagons on field "hex\_id"
    - i. Remove hexagons containing less than 50% of intersecting Core geometry
- E. Prepare to identify each hexagon as distinct "Green" or "Blue" hexagons:
  - a. Add field "hex\_type" as a text field type, 5 characters long
- F. Determine whether a hexagon is either a Blue (typically marine) or a Green (typically terrestrial) hexagon using the NHDArea dataset
  - a. Run Tabulate Intersection or Summarize Within to calculate the areas of the hexagons that intersect with the NHDArea polygons, FTYPE = 445 (ocean)
  - b. If needed, join resulting summary table back to the hexagons on field "hex\_id"
    - i. Hexagons containing at least 50% geometry of FTYPE = 445 are Blue
      - 1. Calculate field "hex\_type" to "Blue"
    - ii. Hexagons containing less than 50% of FTYPE = 445 are Green
      - 1. Calculate field "hex\_type" to "Green"
    - iii. Export Blue and Green hexagons into individual datasets
- G. The resulting two datasets are Blue Habitat Hexagons and Green Habitat Hexagons

### ***F.3 Rank Green Habitat Cores***

- A. Add field "fw\_mean," floating type, to the Green Habitat Cores dataset
- B. Run zonal statistics (mean) on the Fish and Wildlife Index. This will calculate the mean Fish and Wildlife Index values per Core
  - a. Input feature: Green Habitat Cores
  - b. Zone field: "core\_id"
  - c. Input value raster: F&W Index
  - d. Statistics type: Mean
  - e. Join summary table back to the Green Habitat Cores by "core\_id," if needed
- C. Add field "exp\_mean," floating type, to the Green Habitat Cores dataset. This field is being prepared to carry the mean values of the Community Exposure Index
- D. Buffer Green Habitat Cores by 1 kilometer
- E. Run zonal statistics (mean) on the Community Exposure Index. This will calculate the mean exposure values per Core
  - a. Input feature: 1 kilometer buffered Green Habitat Cores
  - b. Zone field: "core\_id"
  - c. Input value raster: Community Exposure Index
  - d. Statistics type: Mean
  - e. Join summary table back to the (unbuffered) Green Habitat Cores by "core\_id," if needed
- F. Calculate the fields "exp\_mean" and "fw\_mean" to match the values of the two joined tables, one for buffered exposure and one for not-buffered F&W
  - a. Remove all joins, if needed

- G. Add a field “hub\_score,” floating type, to the result. This field is being prepared to carry the combined mean values of the Community Exposure Index and F&W Index
- H. Calculate field “hub\_score” to carry each Green Habitat Core score
  - a. Use the following expression: “exp\_mean” \* “fw\_mean” = “hub\_score”
- I. Add a field “hub\_rank,” floating type. This will contain the final ranking
  - a. Symbolize the field “hub\_score” with a distribution of values that best represents the scale of any given Regional Assessment. For the Regional Assessments, a 10-class distribution using a geometrical classification was applied
  - b. The ten classes symbolized in Step F.3.I.a then determine the 10 Resilience Hub Ranks for Green Habitat Cores
    - i. Lowest “hub\_score” distribution of values = rank of 1; Highest “hub\_score” distribution of values = rank of 10
- J. The resulting data are the ranked Green Habitat Cores to create Resilience Hubs

#### ***F.4 Rank Green Habitat Hexagons***

- K. Add field “fw\_mean,” floating type, to the Green Habitat Hexagons dataset
- L. Run zonal statistics (mean) on the Fish and Wildlife Index. This will calculate the mean Fish and Wildlife Index values per Hexagon
  - a. Input feature: Green Habitat Hexagons
  - b. Zone field: “hex\_id”
  - c. Input value raster: F&W Index
  - d. Statistics type: Mean
  - e. Join summary table back to the Green Habitat Hexagons by “hex\_id,” if needed
- M. Add field “exp\_mean,” floating type, to the Green Habitat Hexagons dataset. This field is being prepared to carry the mean values of the Community Exposure Index
- N. Buffer Green Habitat Hexagons by 1 kilometer
- O. Run zonal statistics (mean) on the Community Exposure Index. This will calculate the mean exposure values per Hexagon (see Dobson et al. 2021a-b for a description of differences in Guam and American Samoa).
  - a. Input feature: 1 kilometer buffered Green Habitat Hexagons
  - b. Zone field: “hex\_id”
  - c. Input value raster: Community Exposure Index
  - d. Statistics type: Mean
  - e. Join summary table back to the (unbuffered) Green Habitat Hexagons by “hex\_id,” if needed
- P. Calculate the fields “exp\_mean” and “fw\_mean” to match the values of the two joined tables, one for buffered exposure and one for not-buffered F&W
  - a. Remove all joins
- Q. Add a field “hex\_score,” floating type, to the result. This field is being prepared to carry the combined mean values of the Community Exposure Index and Fish and Wildlife Index
- R. Calculate field “hex\_score” to carry each Green Habitat Core score
  - a. Use the following expression: “exp\_mean” \* “fw\_mean” = “hex\_score”
- S. Add a field “hex\_rank,” floating type. This will contain the final ranking
  - a. Symbolize the field “hex\_score” with a distribution of values that best represents the scale of any given Regional Assessment. For the Regional Assessments, a 10-class distribution using a geometrical classification was applied
  - b. The ten classes symbolized in Step F.4.S.a then determine the 10 ranks for Green Habitat Hexagons

- i. Lowest “hex\_score” distribution of values = rank of 1; Highest “hex\_score” distribution of values = rank of 10
- T. The resulting data are the ranked Green Habitat Hexagons

### ***F.5 Apply Blue Habitat Cores following the Blue Infrastructure Methodology (and score Blue Habitat Hexagons)***

The Habitat Cores created following the methodology in Section F.1 and that are designated as “Blue” are the initial geometry used to define Blue Habitat Hexagons (see Step F.2.A). Using the region’s bathymetric data, calculate the average water depth per hexagon, where only hexagons with average depths of 10 meters or less are kept. Then determine the Habitat Presence and Habitat Factor scores.

- A. Obtain the “Blue” hexagons from Step F.2.A
- B. Using a coastal relief model or other known bathymetric data source, use zonal statistics on each hexagon to determine average depth on a newly created field “avg\_depth.”
  - a. Run zonal statistics (mean) on the bathymetric data. This will calculate the mean depth value per Hexagon
    - i. Input feature: Blue Habitat Hexagons
    - ii. Zone field: “hex\_id”
    - iii. Input value raster: bathymetric raster data
    - iv. Statistics type: Mean
    - v. Output field name: “avg\_depth”
  - b. Remove those hexagons whose depths exceed 10 meters
- C. With those remaining hexagons that have depths of 10 meters or less, a Habitat Depth factor is then determined
  - a. Add a field to contain a factor of depth for each hexagon. Hexagons with average depths of 0 to 3 meters receive a depth factor score of 3; hexagons with depths of 3 to 5 meters receive a depth factor of 2; and hexagons with depths of 5 to 10 meters receive a depth factor of 1.
    - i. Add field, short integer type: “depth\_fac”
    - ii. Select by attributes where “avg\_depth” is 0 to 3 meters
    - iii. Calculate the field “depth\_fac” to have those selected features receive a value of 3.
    - iv. Repeat for other depths 3.01 to 5 meters (where “depth\_fac” = 2) and 5.01 to 10 meters (where “depth\_fac” = 1)
- D. Determine habitat presence for each Blue Habitat Hexagon. The four habitats covered in the Regional Assessments include beaches/dunes, corals, seagrass, and mangroves, where applicable. The result of this step shows which hexagons are within 1.5 kilometers of these habitats. Hexagons not containing or are not within 1.5 kilometers of these habitats are removed from the assessment. In this step, hexagons within 1.5 kilometers of each habitat type are given a value of “1,” while hexagons not within this distance of these habitat types are given a value of “0” (see Dobson et al. 2021a-b for a description of differences in Guam and American Samoa).
  - a. Add fields “b\_pres” for beaches, “c\_pres” for corals, “s\_pres” for seagrass, and “m\_pres” for mangroves; short integer type
  - b. Using a vectorized, feature layer of the beaches/dunes habitat type, run a Select by Location to determine those hexagons that are within a 1.5-kilometer distance of beaches
  - c. Calculate field “b\_pres” to have selected hexagons = 1

- d. Replicate Step F.5.D.b to continue determining presence (within a 1.5-kilometer distance) of the other habitat types
- E. Create a field that contains the sum of all the habitat presence values. This is the calculated presence factor
  - a. Add field, short integer type: "pres\_fac"
  - b. Calculate field "pres\_fac" to equal the sum of habitat presence
    - i.  $"B\_pres" + "c\_pres" + "s\_pres" + "m\_pres = "pres\_fac"$ 
      1. The maximum possible summed value is 4, the minimum possible value is 0. Where "pres\_fac" = 4, that hexagon is within a 1.5-kilometer distance of or contains one of the four habitat types.
      2. A presence factor of 0 indicates none of the hexagons contain or are within 1.5 kilometers of these habitats and should be removed from the Assessment. Delete those hexagons where "pres\_fac" = 0
- F. Determine the mean area coverage of each habitat type for each remaining Blue Infrastructure hexagon. Instead of determining presence within a distance, the result of this step will show which hexagons contain—and by how much—each of these habitats.
  - a. Add fields "b\_mean" for beaches, "c\_mean" for corals, "s\_mean" for seagrass, and "m\_mean" for mangroves; short integer type
  - b. Using the rasterized version of the beaches/dunes habitat type, calculate zonal statistics
    - i. Input raster: "beaches.tif"
    - ii. Input geometry: Blue Infrastructure hexagons
    - iii. Statistics type: mean
  - c. Replicate Step F.5.F.b to continue determining mean area coverage for each hexagon on the other habitat types
- G. Determine the Habitat Factor of each hexagon with an expression that addresses this statement:  
 "Habitat Factor equals the sum of the mean habitat coverages multiplied by the product of the Habitat Depth and Habitat Presence factors."
  - a. Add field, floating integer: "hab\_fac"
  - b. Field calculate the habitat factor in field "hab\_fac" using the expression below:  
 $((\text{"b\_mean"} + \text{"c\_mean"} + \text{"s\_mean"} + \text{"m\_mean"}) * (\text{"depth\_fac"} * \text{"pres\_fac"})) = \text{"hab\_fac"}$
  - c. The result is the Habitat Factor score for each remaining Blue Infrastructure hexagon.
- H. Calculate the hub score on the Blue Infrastructure hexagons
  - a. Run zonal statistics (mean) on the Blue Infrastructure hexagons using the Fish and Wildlife Index as the input raster. This average cover of the Fish and Wildlife Index scored within each hexagon is the Fish and Wildlife Index score
  - b. Buffer the Blue Infrastructure hexagons by 1 kilometer to get the average Community Exposure Index score for each buffered hexagon
    - i. Using the field "hex\_id," Join by Attribute the score values of the Community Exposure Index from each 1-kilometer buffered hexagon to each hexagon in the non-buffered Blue Infrastructure hexagon layer
  - c. Add field "hub\_score," floating integer, to the non-buffered Blue Infrastructure layer
    - i. Calculate field "hub\_score" to be the product of the Fish and Wildlife and Community Exposure Indices. In other words: "hub\_score" = F&W mean \* Community Exposure mean
- I. Calculate the final Resilience Hub score for each Blue Infrastructure hexagon.
  - a. Add field "rank\_score," floating integer, to the Blue Infrastructure hexagons layer

- b. Calculate field “rank\_score,” where Habitat Factor \* F&W mean score \* Community Exposure mean score = “rank\_score”
- J. Determine the final Resilience Hub Rank for each Blue Infrastructure hexagon
  - a. Add field “Hub\_Rank,” short integer, to the Blue Infrastructure hexagons layer
  - b. Distribute the values in the field “rank\_score” in a manner that is most suitable to the scale of the assessment, where the number and type of distribution is appropriate. This Assessment employed a 10-class, geometric interval distribution
  - c. Select by Attribute and calculate the field “Hub\_Rank” to represent the distribution selected. For example, the values in the lowest of the 10-class distribution get a Hub Rank of 1, whereas the values in the highest of the 10-class distribution get a Hub Rank of 10
  - d. The resulting layer, when symbolized on the field “Hub\_Rank,” are the final Blue Infrastructure hexagon Resilience Hub rankings

### ***F.6 Create the Blue Habitat Cores***

This section takes the remaining scored Blue Habitat Hexagons and groups them by underwater bathymetric basin. These are the final grouped geometries that will define each Blue Habitat Core. Similar to how a digital elevation model (DEM) is used to delineate basins and sub-basins on above-ground terrain, basins to delineate Blue Habitat Cores serve as a means to group Blue Habitat Hexagons in an otherwise open, fluid, and non-fragmented underwater environment.

- A. Prepare the bathymetric data to delineate underwater basins to group hexagons
  - a. There are multiple ways to achieve this, but the Assessments incorporated the standard hydrographic analysis using the GRASS module r.watershed to process this step
    - i. Load the bathymetric or coastal relief model into the r.watershed module, where the bathymetric data serves as the input raster DEM. The resulting raster shows the underwater basins
      - 1. Minimum size of basin = 25,000 meters; Maximum length of surface flow = 1,000 meters
      - 2. Output raster: “blue\_basins.tif”
    - ii. Using a Raster to Feature conversion, convert the “blue\_basins.tif” to polygon features
      - 1. Input: “blue\_basins.tif”
      - 2. Output: “blue\_basins.shp” (do not simplify features)
    - iii. Add a field to calculate a basin ID per feature
      - 1. Add field “basin\_id”, long integer type
      - 2. Calculate field “basin\_id” to match OBJECTID or other similar feature ID
      - 3. spatial join the basins vector to the marine hex layer. join the basins by their unique id. This will attribute a basin id to each hexagon.
- B. Spatial Join the basin polygons to the Blue Habitat Hexagons. This will carry each basin ID to each hexagon, allowing hexagons to be grouped by basin
- C. Dissolve the boundaries of each Blue Habitat Hexagon group on field “basin\_id”
- D. Smooth the resulting grouped hexagons by 500 meters
- E. Run the Multipart to Singlepart tool to ensure each multipart feature is its own unique core group
- F. Create a unique core ID per feature
  - a. Add field, long integer type: “core\_id”
  - b. Calculate field “core\_id” to match OBJECTID or other similar feature ID

- G. The resulting layer are the geometries for the Blue Habitat Cores

### ***F.7 Rank the Blue Habitat Cores***

Determine the Habitat Depth, Habitat Presence, mean habitat coverage, and the resulting Habitat Factor for each Blue Habitat Core. The Habitat Factor score will then be used along with the scores of the Fish and Wildlife and Community Exposure Indices to determine the Resilience Hub rank of each Blue Habitat Core. These steps are very similar to those in Section F.5, but instead of running each step on the hexagons, the Blue Habitat Cores are used as the geometry.

- A. Determine habitat presence for each Blue Habitat Core. The four habitats covered in this step include beaches/dunes, corals, seagrass, and mangroves, where applicable. The result of this step shows which Blue Habitat Cores contain or are within 1.5 kilometers of these habitats. Blue Habitat Cores containing or are within 1.5 kilometers of each habitat type are given a value of “1,” while Blue Habitat Cores not within this distance of these habitat types are given a value of “0.”
- a. Add fields “b\_pres” for beaches, “c\_pres” for corals, “s\_pres” for seagrass, and “m\_pres” for mangroves; short integer type
  - b. Using a vectorized, feature layer of the beaches/dunes habitat type, run a Select by Location to determine those Cores that are within a 1.5-kilometer distance of beaches
  - c. Calculate field “b\_pres” to have selected Cores = 1
  - d. Replicate Step F.5.D.b to continue determining presence (within a 1.5-kilometer distance) of the other habitat types
- B. Create a field that contains the sum of all the habitat presence values. This is the calculated presence factor
- a. Add field, short integer type: “pres\_fac”
  - b. Calculate field “pres\_fac” to equal the sum of habitat presence
    - i. “B\_pres” + “c\_pres” + “s\_pres” + “m\_pres = “pres\_fac”
      1. The maximum possible summed value is 4, the minimum possible value is 0. Where “pres\_fac” = 4, that Core is within a 1.5-kilometer distance of or contains one of the four habitat types (see Dobson et al. 2020a-b and Dobson et al. 2021a-b for a description of differences in habitat types and distance factors for each region).
- C. Determine the mean area of coverage for each habitat type in the remaining Blue Habitat Cores. Instead of determining presence within a distance, the result of this step will show which Cores contain—and by how much—each of these habitats exists within each Core.
- a. Add fields “b\_mean” for beaches, “c\_mean” for corals, “s\_mean” for seagrass, and “m\_mean” for mangroves; short integer type
  - b. Using the rasterized version of the beaches/dunes habitat type, calculate zonal statistics
    - i. Input raster: “beaches.tif”
    - ii. Input geometry: Blue Habitat Cores
    - iii. Statistics type: mean
  - c. Replicate Step F.7.C.b to continue determining mean area coverage for each Core on the other habitat types
- D. Determine the Habitat Factor of each Core with an expression that addresses this statement: “Habitat Factor equals the sum of the mean habitat coverages multiplied by the product of the Habitat Depth and Habitat Presence factors.”
- a. Add field, floating integer: “hab\_fac”

- b. Field calculate the habitat factor in field “hab\_fac” using the expression below:  

$$((\text{“b\_mean”} + \text{“c\_mean”} + \text{“s\_mean”} + \text{“m\_mean”}) * (\text{“depth\_fac”} * \text{“pres\_fac”})) = \text{“hab\_fac”}$$
      - c. The result is the Habitat Factor score for each remaining Blue Habitat Core
- E. Calculate the Hub score on the Blue Habitat Cores
  - a. Run zonal statistics (mean) on the Blue Habitat Cores using the Fish and Wildlife Index as the input raster. This average cover of the Fish and Wildlife Index scored within each Blue Habitat Core is the Fish and Wildlife Index score
  - b. Buffer the Blue Habitat Cores by 1 kilometer to get the average Community Exposure Index score for each buffered Core
    - i. Using the field “hex\_id,” Join by Attribute the score values of the Community Exposure Index from each 1-kilometer buffered Core to each Core in the non-buffered Blue Habitat Cores layer (see Dobson et al. 2021a-b for a description of differences in Guam and American Samoa).
  - c. Add field “hub\_score,” floating integer, to the non-buffered Blue Habitat Cores layer
    - i. Calculate field “hub\_score” to be the product of the Fish and Wildlife and Community Exposure Indices. In other words: “hub\_score” = F&W mean \* Community Exposure mean
- F. Calculate the final Resilience Hub score for each of the Blue Habitat Cores.
  - a. Add field “rank\_score,” floating integer, to the Blue Habitat Cores layer
  - b. Calculate field “rank\_score,” where Habitat Factor \* F&W mean score \* Community Exposure mean score = “rank\_score”
- G. Determine the final Resilience Hub Rank for each Blue Habitat Core
  - a. Add field “Hub\_Rank,” short integer, to the Blue Habitat Cores layer
  - b. Distribute the values in the field “rank\_score” in a manner that is most suitable to the scale of the assessment, where the number and type of distribution is appropriate. This Assessment employed a 10-class, geometric interval distribution
  - c. Select by Attribute and calculate the field “Hub\_Rank” to represent the distribution selected. For example, the values in the lowest of the 10-class distribution get a Hub Rank of 1, whereas the values in the highest of the 10-class distribution get a Hub Rank of 10
  - d. The resulting layer, when symbolized on the field “Hub\_Rank,” are the final Blue Habitat Core Resilience Hub rankings

### ***F.8 Combine the Blue and Green Habitat Cores***

- A. Merge the Ranked Blue and Green Habitat Cores into one dataset
  - a. The resulting layer is the Combined Resilience Hub Groups
  - b. Run tool “Feature to Raster” on the “Hub\_Rank” field to create a raster version of the Combined Resilience Hub Groups

### ***F.9 Combine the Blue and Green Habitat Hexagons***

- A. Merge the Ranked Blue and Green Habitat Hexagons into one dataset
  - a. The resulting layer is the Combined Resilience Hub Hexagons
  - b. Run tool “Feature to Raster” on the “Hub\_Rank” field to create a raster version of the Combined Resilience Hub Hexagons