CHAPTER 4 VULNERABILITY ASSESSMENT

The vulnerability assessment will lay the foundation for the adaptation strategy. It will help the planning team understand what could happen as climate changes and will help focus attention on the areas, or the specific assets (people, places/buildings/infrastructure, and natural resources) that are most vulnerable as well as the phenomena and associated impacts that could cause the greatest losses. There are numerous definitions for the term "vulnerability," and it is often used interchangeably with, or as a part of, "risk." For the purpose of simplicity, this guide captures the intent of both risk and vulnerability assessments into a vulnerability assessment and defines vulnerability as the potential for loss of or harm/damage to exposed assets largely due to complex interactions among natural processes, land use decisions, and community resilience.[1]

The process described in this chapter for conducting a vulnerability assessment is structured as follows:

Research and Information Collection

- Step 2.1: Identify Climate Change Phenomena
- Step 2.2: Identify Climate Change Impacts and Consequences
- Step 2.3: Assess Physical Characteristics and Exposure
- Step 2.4: Consider Adaptive Capacities

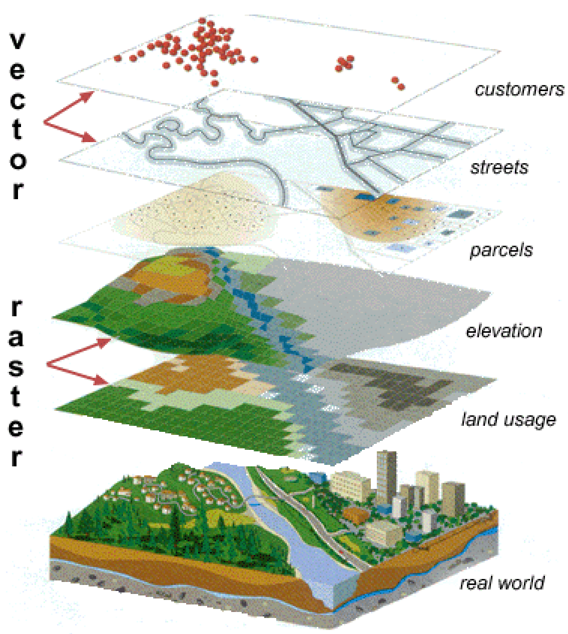
[1] According to the IPCC, "vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC 2007a).

Simulation and Analysis

- □ Step 2.5: Develop Scenarios and Simulate Change
- □ Step 2.6: Summarize Vulnerability and Identify Focus Areas

Steps 2.1 through 2.4 largely involve collecting existing information to set the context. In Steps 2.5 and 2.6, the planning team will use the information collected to fine tune projections, simulate climate change in the planning area, and integrate exposure data (and adaptive capacity as appropriate) into the simulations in order to summarize vulnerability.

Critical to this process will be data about the phenomena, potential impacts, existing stressors, your state's physical geography, and exposed assets (exposure). As the planning team moves through the steps, and to the extent possible, members should collect relevant maps and datasets in a geographic information system (GIS).[2] GIS will play an important role in this assessment, allowing you to store, manage, analyze, and display spatial data. GIS will allow the planning team to compare the extent of impacts and consequences across scenarios and better understand where vulnerability is greatest, which will support decision making.



GIS uses layers of overlapping spatial information to aid in analysis and decision making.

While the vulnerability assessment task may be assigned to a working group (or groups), contributions to the assessment by planning team members and other key stakeholders (see Chapter 3 for suggestions) who might be able to provide resources and valuable information to better inform the assessment will be fundamental to the process. Key Resources for data, information, and tools to help conduct a vulnerability assessment are included at the end of this chapter.

Note: This is a baseline assessment and should be based on best available data. State and local hazard mitigation plans and natural resource plans are good resources for information about existing stressors that are likely to be exacerbated by climate change as well as exposure information. Other plans may also have useful information. **You should not put off adaptation planning efforts because you do not have all the information you need.** This could increase vulnerability and result in high social, natural, and economic costs. Adaptation planning is an adaptive process, and the planning team will need to revisit and adjust the vulnerability assessment, as well as the goals and actions that are based on its assumptions, as new data and capacities are acquired. Take note of where critical data are missing. As a result of this assessment, the planning team may want to include data acquisition and capacity building as actions in the adaptation strategy.

As a public document, the adaptation plan is an educational tool. For this reason, and for ease of updating, the plan should fully document the vulnerability assessment process. In particular, it should explain how the assessment was conducted and its limitations, describe (and illustrate, where possible) the changes that may take place, and capture the data sources.

[2] Your state may already have some of this information centralized in a geospatial clearinghouse.

Learning from others…California Studies Evaluate Potential Impacts of Climate Change
In 2005, through Executive Order S-03-05, the governor of California required biennial science reports on potential climate change impacts in the state. The report released in 2009 synthesizes the findings of more than 30 technical papers and includes information on the impacts and consequences of climate change on California's public health, infrastructure, and natural resources; identifies economic impacts of climate change on California; provides an overview of climate change research in California; and describes state efforts to adapt to current and future effects of climate change. Based on the outputs from six global climate models run for the recent IPCC Fourth Assessment using the A2 and B1 emissions scenarios, the report and its background papers served as the scientific foundation upon which the state developed its climate adaptation strategy. www.climatechange.ca.gov/publications/cat/

Step 2.1: Identify Climate Change Phenomena

The climate change phenomena expected to impact your state, including those that impacted your state in the past, will form the base of the vulnerability assessment. The table of phenomena, impacts, and consequences in Chapter 2 provides a national overview of the climate change phenomena expected to be of greatest importance in coastal regions.

These phenomena are:

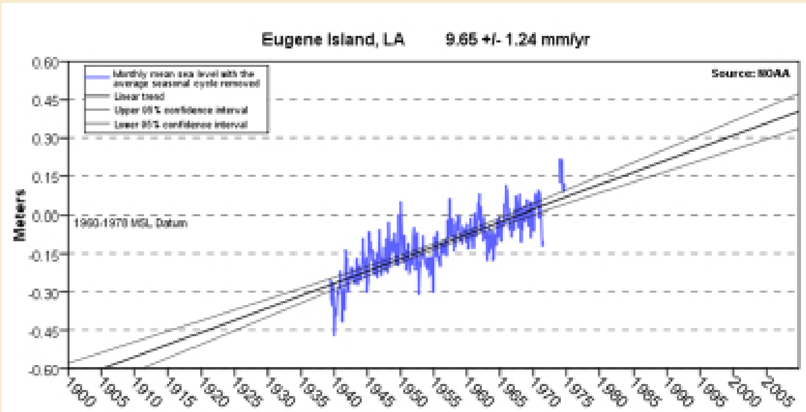
- ☐ Rising Sea Levels
- ☐ Declining Great Lake Levels
- ☐ Increasing Storm Intensity/Frequency
- ☐ Changing Precipitation Patterns
- ☐ Increasing Air Temperature
- ☐ Increasing Water Temperature
- ☐ Ocean Acidification

Because of the strong regional variations in most of these phenomena, and based on the scope of the plan, the planning team will need to decide which phenomena to include in its vulnerability assessment. There are a number of resources available to help with this decision and to provide input into other steps of this assessment. The U.S. Global Climate Research Program's *Global Climate Change Impacts in the United States*, which contains information about potential impacts by region and is the authoritative source on climate change science and impacts in the United States, provides a good starting point. Other good resources for existing projections include research institutions (especially Sea Grant institutions), regional climate centers, state climatologists, and NOAA Regional Integrated Sciences and Assessments programs.

From this research, the planning team should be able to collect preliminary information about the climate change phenomena that may affect the state's coast in the future. Note observed and projected changes. This information will prove useful in later steps, where you will have the opportunity to further refine projections.

Learning from others…North Carolina Synthesizes Science on Sea Level Rise
The North Carolina Coastal Resources Commission's Science Panel on Coastal Hazards produced a report synthesizing the best available science on sea level rise in the state. Released at an expert and stakeholder forum, the intent of the report is to provide North Carolina's planners and policy makers with a scientific assessment of the amount of rise likely to occur in this century, which was determined to be one meter (39 inches), for policy development and planning purposes. www.nccoastalmanagement.net/

Sea Levels Online from NOAA's Center for Operational Oceanographic Products and Services illustrates regional trends in sea level. The trends are based on data collected from tide stations in NOAA's National Water Level Observation Network (NWLON). The NWLON also tracks water level trends in the Great Lakes. The graphic below illustrates the sea level trends for Eugene Island, Louisiana, one of the most severe examples of sea level rise captured by the network.



The mean sea level rise trend is 9.65 mm (~.380 in)/year with a 95 percent confidence interval of +/- 1.24 mm (~.049 in)/year based on monthly mean sea level data from 1939 to 1974, which is equivalent to a change of 3.17 feet in 100 years. http://tidesandcurrents.noaa.gov/

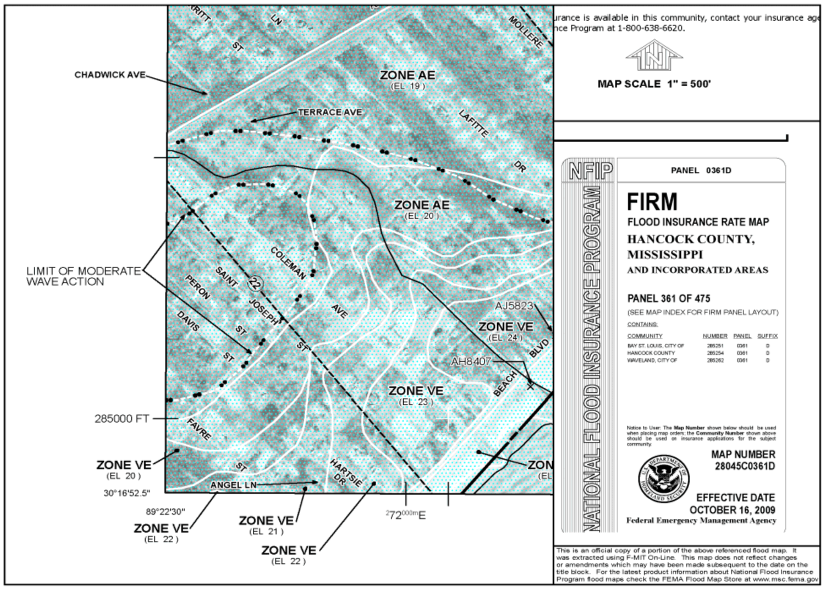
Step 2.2: Identify Climate Change Impacts and Consequences

Climate change impacts and consequences are the changes to the physical, biological, and social systems that occur as a result of climate change phenomena. There are a number of ways to categorize and address these potential impacts and consequences. While this guide categorizes them by phenomenon, you may choose to approach them differently (e.g., by impact, sector, or type of environment—natural vs. built).

Based on the phenomena identified in Step 2.1, the planning team will identify the associated impacts and consequences. The resources consulted in Step 2.1 and the information in Chapter 2 and Appendix C can provide an idea of these impacts. Many, if not all, of these impacts will have been experienced in the past and are likely to be exacerbated by climate change. The planning team may choose to address all of these impacts, and others, or may choose to limit them based on the scope of the plan.

By establishing a baseline that shows how climate change-associated hazards and other stressors have affected the planning area in the past, the team will be better able to envision how they might affect it in the future and will also be well-positioned to monitor

Digital Flood Insurance Rate Maps (DFIRM) are risk-based maps from FEMA that depict areas likely to be flooded by storms with a 1 percent chance and a 0.2 percent chance of occurring in a single year (known as a 100-year and 500-year flood, respectively). Flood hazard information is determined from engineering studies, which include hydrologic and hydraulic models, flood profiles, data tables, digital elevation models, and structure-specific data (e.g., digital elevation certificates and digital photographs of bridges and culverts) overlain on a base map. DFIRMs do not typically consider future conditions. However, communities can elect to include a 100-year floodplain based on future-conditions land use and hydrology on their DFIRM based on their own studies and ordinances and in accordance with FEMA's *Final Guidelines for Using Future-Conditions Hydrology.* http://msc.fema.gov/; www.fema.gov/plan/prevent/fhm/ft_futur.shtm



FIRMettes are full-scale sections of Digital Flood Insurance Rate Maps that can be generated for free online.

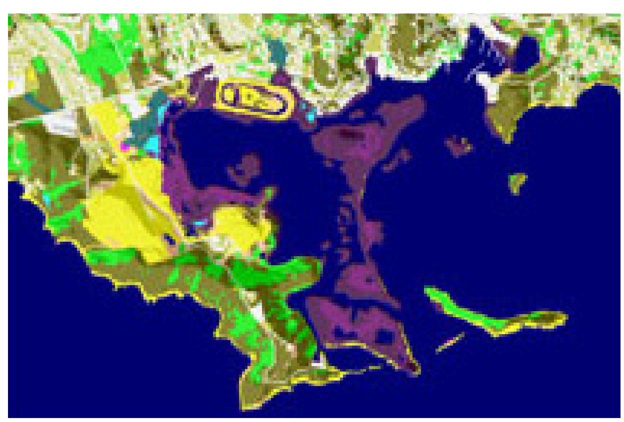
and respond to changes as they occur. The baseline should be based on trends and observed changes to the climate phenomena compiled in Step 2.1 and a review of historical and present day impacts (e.g., storms, floods, droughts, invasive species, harmful algal blooms, hypoxia, ocean acidification, etc.) and their consequences, as well as related cumulative and secondary impacts. Relevant data and maps (e.g., Digital Flood Insurance Rate Maps, shoreline change maps) may already be available from state (and local) agencies involved in planning for managing such events (e.g., in hazard mitigation and natural resource plans). Impact characteristics the planning team may want to collect include existing stressors, timing/seasonality, magnitude, and persistence/reversibility.

Step 2.3: Assess Physical Characteristics and Exposure

In this step, the planning team will assess what it is about the planning area that might affect your state's vulnerability to climate change. This could include elevation, the health of wetlands, or the number of buildings repetitively damaged by storm surge flooding. Information about your coastal zone's physical geography and exposure (including social and economic characteristics), and associated datasets, has likely already been collected for similar planning efforts, such as hazard mitigation and natural resource planning, at the state and local level. These plans should provide a good starting point for this step, and the data should be accessible through the authoring agencies or a central state clearinghouse for geospatial data.

Physical Characteristics

Awareness of your coast's physical characteristics is vital to understanding how it may be affected by the impacts of climate change. Generally, physical characteristics include features and processes of the natural environment (which may be altered by



Land cover maps illustrate how much of an area is covered by wetlands, forests, agriculture, impervious surfaces, and other features.

To use data successfully, coastal organizations need more than just data. They need tools, information, and training to turn these data into useful information. NOAA's Digital Coast offers a diverse selection of data (e.g., elevation, land cover, shoreline, benthic, orthoimagery, socioeconomics, etc.) and companion resources. The Coastal Inundation Toolkit shows users how spatial information can be used to help address their inundation issues and includes basic information about inundation, simple visualization tools, easy access to county-level data, and a guidebook and training for creating local inundation maps. Web site content continues to grow with contributions and guidance from Digital Coast partners and users. www.csc.noaa.gov/digitalcoast/

changes in the climate and human activities and should be kept current and monitored over time), such as:

- Topography
- Bathymetry
- Coastal geomorphology
- Hydrography
- Hydrology
- Geology
- Soil characteristics
- Soil saturation
- Land cover
- Land use

Exposure

Exposure is an inventory of the "assets"—people, property, systems, and functions—that could be lost, injured, or damaged due to an impact of climate change. In this section, the planning team will consider:

- What is in the area that the impacts could affect (the coastal zone)?
- What are the specific assets your state and its stakeholders want to protect?
- How are these assets projected to change in the future?

Assets the planning team may want to inventory and map, based on best available data, include the following:

- **Population** (numbers, densities, percentage of state population, social vulnerability (see page 33))
  Potential sources: State demographer, U.S. Census, HAZUS-MH, local governments
- **Buildings** (exclusive of infrastructure, see below) (numbers and densities, purpose, type of construction, elevation, values; specific vulnerabilities, e.g., mobile homes, repetitive losses, structures in hazard zones)
  Potential sources: State department of finance, HAZUS-MH, FEMA (repetitive losses), local governments
- **Infrastructure** (numbers, types, values; specific vulnerabilities, e.g., structurally deficient bridges, levees, shore protection structures; see definition on next page)[3]

If you need to purchase data, such as lidar, consider using the contracting vehicle the NOAA Coastal Services Center has established with geospatial industry leaders. State and local agencies use the existing contracts to collect coastal data and obtain other GIS services. Fund transfers are coordinated through an established memorandum of understanding process. This provides an easy way to get data, and since the center does not charge overhead, 100 percent of state and local dollars applied to the contracts goes to the service requested. csc@csc.noaa.gov

[3] Infrastructure should also be assessed for how it might exacerbate the impacts of climate change (e.g., impermeable roads, shore protection structures that interrupt natural processes, etc.). Additionally, infrastructure associated with hazardous materials and pollutants needs to be protected not just for the services it provides but also for the negative impacts it could have on the environment if it were damaged and contaminants were released.

There are a number of definitions for "critical infrastructure." For the purposes of homeland security and emergency management, your state may have its own. For the purposes of this guide, "infrastructure" means the basic facilities, services, networks, and systems needed for the functioning of a community that if lost or damaged could cause significant disruption (physically, functionally, and economically). This includes:

- Water supplies
- Wastewater systems
- Transportation systems (e.g., roads, highways, bridges, tunnels, railways, airports, ports, harbors, canals, ferries, evacuation routes)
- Electrical systems
- Communications networks
- Medical facilities
- Police and fire stations
- Emergency operations centers
- Government buildings
- Schools
- Shore protection and flood control structures
- Oil and gas production, storage, and transportation
- Hazardous material facilities (including those that handle nuclear materials)
- Military bases
- Prisons

Potential sources: State agencies, HAZUS-MH, U.S. Department of Transportation, U.S. Department of Energy, National Atlas, local governments

- □ **Natural Resources** (numbers, types, values (quantitative or qualitative, if available); e.g., wetlands, beaches, barrier islands, coral reefs, marine protected areas, refuges, reserves, protected species, essential fish habitat, migration corridors, etc.)
  Potential sources: State natural resource agencies, National Wetlands Inventory, National Marine Fisheries Service regional offices and science centers, National Marine Protected Areas Center, National Wetlands Research Center, regional Endangered Species Program offices, local governments, nonprofit organizations, academia
- □ **Historical Resources** (numbers, names, values (quantitative or qualitative, if available))
  Potential sources: State historic preservation office/ register, National Register of Historic Places, local governments
- □ **Cultural Resources** (numbers, names/ types, values (quantitative or qualitative, if available); e.g., museums, parks, public access facilities, recreational resources, tourist attractions, etc.)
  Potential resources: State departments of culture, parks and recreation, natural resources, tourism; tourism bureaus; National Park Service; local governments
- □ **Economic Resources** (names, types, values (quantitative or qualitative), number employed; e.g., major employers, industries, etc.)
  Potential resources: State departments of finance and labor, chambers of commerce, U.S. Census, National Ocean Economics Program, local governments

It is important, where possible, to estimate the value (market and nonmarket) of exposed assets. This will prove useful when determining where to focus adaptation efforts as well as in making the case to

FEMA's GIS-based loss-estimation software, Hazards U.S. Multihazard (HAZUS-MH) is a software program for analyzing potential losses from floods, hurricane winds, and earthquakes. In HAZUS-MH, current scientific and engineering knowledge is coupled with the latest GIS technology to produce estimates of hazard-related damage before, or after, a disaster occurs. The software package contains national datasets, including select boundary maps (states, counties, census tracts), aggregated building information (square footage, building count by occupancy), essential and high potential loss facilities, transportation systems, lifeline utility systems, hazardous materials, and demographic data, which are useful in inventorying exposure. www.fema.gov/plan/prevent/hazus/

decision makers and the public regarding the need for adaptation planning. For the built environment, the most accurate value will include replacement cost, contents value, function value (value of services), and displacement cost (cost associated with temporary relocation). FEMA's HAZUS-MH can help the planning team estimate these values for different types of buildings (i.e., occupancy classes).[4]

It is also important to consider how these assets are projected to change in the future and what that might mean in the context of climate change. For example, what are the projections for growth and development, and where is it expected to occur? Are plans for economic development based on resources that might be threatened by climate change? Are there plans to conduct activities that may stress natural resources that may be further stressed by changes in the climate?

Socially Vulnerable Populations

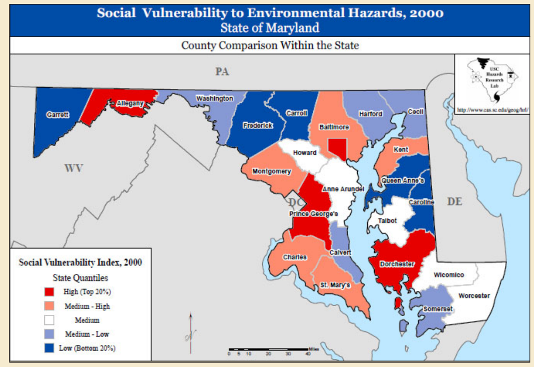
Not everyone will be equally able to respond to climate change. Some groups of people are inherently more vulnerable than others. It is important to understand how social and economic characteristics may affect vulnerability. Socially vulnerable populations will likely need more assistance preparing for, responding to, and recovering from the impacts of climate change.

Characteristics that influence social vulnerability include personal wealth, age, health, density of the built environment, single-sector economic dependence, housing stock and tenancy, race, ethnicity, occupation, and infrastructure dependence. The planning team should identify

"State and Local Governments Plan for Development of Most Land Vulnerable to Rising Sea Level along the U.S. Atlantic Coast" examines where shore protection is likely to be constructed to protect development from rising seas while at the same time limiting the inland migration of wetlands. It classifies coastal lands vulnerable to sea level rise according to the likelihood of shore protection based on existing coastal policies, zoning, and land use and incorporates discussions with local planners to approximate where efforts are likely to be made to hold back the sea. Supplementary material, including state-specific discussions, maps, and GIS data are available online. Studies such as this can help set the stage for creating an adaptation strategy to address sea level rise and other inundation threats. http://risingsea.net/ERL/

[4] If using building values provided by HAZUS-MH, note that these values do not account for total land loss. These values will need to be determined separately for losses attributable to erosion and sea level rise.

The Social Vulnerability Index from the Hazards and Vulnerability Research Institute in the Department of Geography at the University of South Carolina measures the social vulnerability of U.S. counties to environmental hazards. The index synthesizes 42 socioeconomic and built environment variables that research literature suggests contribute to social vulnerability. http://webra.cas.sc.edu/hvri/products/sovi.aspx



where there may be high concentrations of these socially vulnerable populations so it understands the level of support they may need as the climate changes. Also, consider native populations, whose unique social, economic, and cultural characteristics may make them particularly vulnerable.

Vulnerable Ecosystems and Habitats

The extent to which a natural system (e.g., ecosystem or habitat) will be affected by climate change will depend on the degree of change, the sensitivity of the system, and the system's ability to respond. As with human populations, not every system will be equally positioned to respond. As data are collected about natural resources, the planning team may want to consider attributes of these systems that provide a sense of how vulnerable they may be to climate change and, thus, which systems may need the most assistance preparing for and responding to climate change.

To gauge the potential vulnerability of your coastal and marine ecosystems and habitats, consider the following:

- □ **Health**—Healthy systems may be less vulnerable to the added stress of climate change.
- □ **Management plan**—Resources that are well-managed lead to improved biodiversity, shore protection, and food security; a more sustainable income; continuity of fish nursery and breeding; continuity of feeding grounds; and more attractive areas for visitors.
- □ **Monitoring program**—Programs that monitor systems for health, stress, and change allow potential problems in those systems to be identified and addressed early.
- □ **Space to migrate**—Systems with adequate and appropriate space to migrate may be less vulnerable and better able to adapt to sea level rise and other climate change phenomena.
- □ **Connectivity**—Systems that are connected to other systems with similar community structures can migrate if threatened.
- □ **Management integration**—Coordination of management efforts across jurisdictions and owners allows systems to be managed for common goals and objectives and can promote connectivity.
- □ **Threatened, endangered, and other protected species**—Systems with high numbers of protected species may be more sensitive and vulnerable to climate change.
- □ **Stressors**—Systems already threatened by stressors such as coastal development, invasive species, pollution, etc. may be more vulnerable to climate change.
- □ **Impact thresholds**—Systems at or near their impact threshold (after which their vulnerability increases) will be more vulnerable to climate change.

Healthy systems may be less vulnerable to the added stress of climate change.

Any assessment of the vulnerability of ecosystems to climate change should include evaluation of the potential impacts on the goods and services they provide and the cascading effects that could result if the systems were damaged or destroyed. By understanding the vulnerability and value of coastal systems, the planning team will be prepared to make decisions about where to focus protection and adaptation efforts once there is a clearer picture of how they may be affected by climate change.

Step 2.4: Consider Adaptive Capacities

The vulnerability of coastal areas to climate change will depend not only on the physical stressors to the environment, but also on the ability of the affected areas to adapt to those changes. Thus, another key factor in assessing vulnerability is adaptive capacity.

According to the IPCC, adaptive capacity is "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC 2007a). In general, coastal areas or systems with higher adaptive capacities will be better able to react and accommodate to the changes associated with climate change.

Capacity can be described in terms of the ability of your state's governments and their populations to prepare for, respond to, and recover from the impacts of climate change. Due to regional variability, capacity may vary significantly along your coast. In addition to support from elected officials and other leaders, which will be critical to successful adaptation, examples of existing tools and resources that can support the ability of governments to address climate change include, but are not limited to:

- **Regulatory and planning capabilities** (e.g., building codes, development restrictions, real estate disclosure requirements, coastal management regulations, and hazard mitigation, natural resource, land conservation, climate change mitigation, sustainability, sediment management, special area management, shoreline management, capital improvement, transportation improvement, and postdisaster recovery plans)[5]

An example of a tool to assess the vulnerability of a given species of plant or animal to climate change is NatureServe's Climate Change Vulnerability Index. The index allows scientists, natural resource managers, planners, and conservation practitioners to perform rapid assessments of the relative vulnerability of species to the effects of predicted climate change. The scoring system considers a species' predicted exposure to climate change within a defined geographic area and its sensitivity to climate change. Each species is scored on a detailed set of factors, such as dispersal ability, natural and manmade barriers to dispersal, sensitivity to changes in temperature and precipitation, physical habitat requirements, and genetic variation. Total scores reflect whether a given species will likely suffer a contraction in range, reduction in population, or both in coming decades and are rated as extremely vulnerable, highly vulnerable, moderately vulnerable, not vulnerable—presumed stable, not vulnerable—increase likely, and insufficient evidence. The index and guidance are available for free download. www.natureserve.org/prodServices/climatechange/ClimateChange.jsp

[5] Federal laws and executive orders that may also contribute to states' adaptive capacity are included in Appendix B.

Learning from others…GOMA Aims to Inventory Hazards Resilience Capabilities Gulfwide

The Gulf of Mexico Alliance's (GOMA) Governor's Action Plan II includes the preparation of an inventory of existing capabilities and tools to address coastal hazards in the Gulf region, identify important gaps, and, where needed, develop new methods to enhance regional and local resilience. Action steps include compiling and maintaining an inventory of existing resilience-related data, projects, tools, and policies from across the Gulf region; developing a Resilience Index self-assessment tool for coastal communities; creating and packaging planning and hazard mitigation tools for use in management at the local and state levels; and researching existing policies guiding coastal development and making recommendations to enhance resilience. http://gulfofmexicoalliance.org/pdfs/ap2_final2.pdf

- □ **Administrative and technical capabilities** (e.g., dedicated staff, climate change experts/ champions, planners, engineers, and GIS and mapping and modeling resources (staff and equipment))
- □ **Fiscal capabilities** (e.g., taxes, bonds, grants, impact fees, withholding spending in hazard zones, and insurance)
- □ **Infrastructure** (e.g., flood and erosion control structures, evacuation routes, and redundant water, wastewater, and power systems)

To improve capacity, think about how the effects of climate change can be better integrated into these existing tools and resources. In addition, consider how some of them may work at cross purposes, hindering climate change adaptation, and how conflicts could be resolved.

Your state's adaptive capacity will also depend on the adaptive capacity of its natural systems. As has been demonstrated in the past, given time, natural systems can adjust to changes in climate by relocating or changing the timing of life cycle events. However, anticipated changes may happen more quickly than in the past, and nonclimate stressors will present obstacles to adaptation. Humans will need to be prepared to address the needs of natural systems, which will include altering their activities. Natural systems with the greatest capacity to adapt to change will be those that are healthy, are able to migrate (based on space and elevation), and/or are connected to other systems, which allows for species migration.

Determining your state's overall adaptive capacity is largely a subjective exercise, but it can help the planning team identify strengths and weaknesses as well as existing mechanisms that can be leveraged to increase capacity. Once the planning team has an understanding of where capacity needs to be built or enhanced, this information can be combined with the other vulnerability information compiled in this process to identify where adaptation efforts should be focused. Actions to build adaptive capacity can then be included in the adaptation strategy, which is discussed in Chapter 5.

Step 2.5: Develop Scenarios and Simulate Change

So far, the planning team has identified the phenomena likely to affect the coast, examined the associated impacts, and assessed what it is about the coast that may affect its vulnerability to climate change (physical characteristics, exposure, and capacity). In this step, based on the information collected in Steps 2.1 through 2.4, the planning team will develop scenarios that illustrate potential projected impacts and consequences of climate change.

Scenario planning is a tool for developing a science-based decision-making framework in an environment of uncertainty. The goal is to develop a range of plausible climate change outcomes (impacts and consequences) based on multiple points of time and on multiple emissions levels that can provide the basis for further analysis and decision making. For example, the planning team could establish and define low, moderate, and high emissions levels (which would correspond to low, moderate, and high degrees of

The future is not a static continuation of the past; scenarios recognize that several potential futures are feasible from any particular point in time. Scenario studies commonly target issues which are sensitive to stakeholders and they provide the means by which decision makers can anticipate coming change and prepare for it in a responsive and timely manner. Through exploration and evaluation of feasible future conditions, scenario studies enable assessment of system vulnerabilities and possibilities for adaptation measures (Mahmouda et al. 2009).

climate change) and project each of them out to 20, 50, and 100 years from now (see Washington example on the next page).[6] This would result in nine scenarios as indicated in the table below (additional scenarios may be developed to account for regional differences within your state).

Each completed scenario should include quantitative projections of the climate change phenomena and descriptions of the potential associated impacts and consequences (qualitative if not quantitative) relevant to the plan (e.g., if the planning team is focusing adaptation planning on specific management issues, it may choose to only include a subset of the impacts in the scenarios). Consider seasonality and extremes, not just annual averages. More robust scenarios will include consideration of cumulative impacts (e.g., a wetland threatened by sea level rise will also be more vulnerable to storms) and adaptation actions already planned for.

For the purposes of this plan, it may be easiest to evaluate event-related consequences based on a single event (e.g., a 100-year flood), keeping in mind that these events may occur more than once, with the potential to cause repetitive damage and losses. The baseline established in Step 2.2 can help the planning team envision what the consequences might be at low-level emissions.

Note: The baseline was largely based on current and historical trends. Changes are likely even if emissions are decreased, so the low-level emissions scenario at 20 years may show incremental changes from the baseline. In addition, the review of your state's physical characteristics and assets was also based on current conditions. Where possible, the scenarios should reflect expected changes over time (e.g., changes in population, development, land cover, etc.). Similarly, when projecting out into the future, adjust dollar values to account for inflation.

Climate Modeling

Scenarios based on global climate models will likely be the most reliable. Global climate models use mathematical equations to simulate how, on a global scale, the earth's physical processes will react to changes. It must be emphasized that while models are extremely valuable tools for simulating and understanding climate change, shortcomings

Examples of Scenarios for Assessing Vulnerability

	Low-Level Emissions	Moderate-Level Emissions	High-Level Emissions
20 years	Scenario 1	Scenario 4	Scenario 7
50 years	Scenario 2	Scenario 5	Scenario 8
100 years	Scenario 3	Scenario 6	Scenario 9

[6] While there is much more uncertainty associated with the longer time horizon, it is important to acknowledge that many of your current decision processes (land use, transportation, infrastructure, conservation) have a longer design life and should consider projected conditions much further out than 20 years. Much of the literature and research, including that conducted by the IPCC, provide projections through 2100.

Learning from others…Washington Projects Sea Level Rise for Use in Scenario Planning
Sea Level Rise in the Coastal Waters of Washington State, a report from the University of Washington Climate Impacts Group and the Washington Department of Ecology, features scenarios for sea level rise based on the IPCC's projections for global sea level rise. The following table from the report shows very low, medium, and very high estimates of Washington sea level change for 2050 and 2100, accounting for local variability in vertical land movement (VLM) and atmospheric dynamics, for the northwest Olympic Peninsula, the central and southern Washington coast, and Puget Sound. Negative VLMs represent vertical uplift and negative totals represent sea level drop. The very low and very high estimates are considered low probability scenarios. www.cses.washington.edu/db/pdf/moteetalslr579.pdf

SLR Estimate	Components	2050			2100		
		NW Olympic Peninsula	Central & Southern Coast	Puget Sound	NW Olympic Peninsula	Central & Southern Coast	Puget Sound
Very Low	Global SLR	9 cm			18 cm		
	Atm. Dynamics	-1 cm			2 cm		
	VLM	-20 cm	-5 cm	0 cm	- 40 cm	- 10 cm	0 cm
	Total	- 12 cm(- 5″)	3 cm (1″)	8 cm (3″)	- 24 cm (-9″)	6 cm (2″)	16 cm (6″)
Medium	Global SLR	15 cm			34 cm		
	Atm.Dynamics	0 cm			0 cm		
	VLM	-15 cm	-2.5 cm	0 cm	- 30 cm	- 5 cm	0 cm
	Total	0 cm(- 5″)	12.5 cm(5″)	15 cm(6″)	4 cm(2″)	29 cm(11″)	34 cm(13″)
Very High	Global SLR	38 cm			93 cm		
	Atm. Dynamic	7 cm			15 cm		
	VLM	- 10 cm	0 cm	10 cm	- 20 cm	0 cm	20 cm
	Total	35 cm(14″)	45 cm(18″)	55 cm(22″)	88 cm(35″)	108 cm(43″)	128cm(50″)

remain. "Their main shortcomings are limited observations, incomplete understanding of climate processes and their interrelationships, imperfect model representations of the processes, and relatively large grid boxes that don't represent smaller terrain features" (Meted 2009). It is important to recognize these deficiencies, understand the uncertainties, and consider results from multiple models, as well as how results track with observations, to account for the range of uncertainty and variability among them.

To model climate change in your state, consider 1) using the results of the scenarios generated for 2100 for the IPCC's Fourth Assessment Report[7] and adjusting global projections to account for local conditions (e.g., add local subsidence projections to global sea level rise projections) and to estimate shorter-term projections or 2) downscaling global climate data.

Since global climate models have relatively coarse spatial resolution, downscaling is required to achieve the finer spatial resolution needed to understand regional impacts. Downscaling should result in better projections of how the phenomena may change in your state and thus better inputs for other models and maps to illustrate the potential impacts and consequences on your coast.

[7] The IPCC based its six scenarios on four "storylines" that represent different assumptions about demographic, social, economic, technological, and environmental change (in the absence of new climate policies).

Scenarios are also useful in project planning to determine the level of protection an individual project needs to provide. The U.S. Army Corps of Engineers is now incorporating direct and indirect physical effects of projected future sea level change in managing, planning, engineering, designing, constructing, operating, and maintaining Corps coastal projects and systems of projects. They use a multiple scenario approach that considers low, intermediate, and high rates of change.

These activities are guided by *Water Resource Policies and Authorities Incorporating Sea-Level Change Considerations In Civil Works Programs*, which also recommends determining how sensitive alternative plans and designs are to these rates of future sea level change, how this sensitivity affects calculated risks, and what measures should be implemented to minimize adverse consequences while maximizing beneficial effects. It instructs project designers to consider planning for adaptive management, designing to facilitate future modifications, and designing for a more aggressive future sea level change scenario. http://140.194.76.129/publications/eng-circulars/

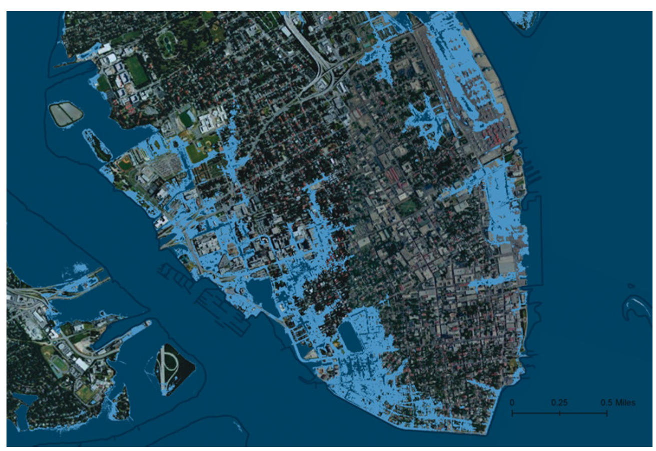
If the planning team has access to the capacity, downscaling could be incorporated into the vulnerability assessment. **However, experts are still cautious about making regional predictions and stress the need to accept the limitations of downscaled climate models and understand potential sources of errors, which include the potential to compound errors in global models.** Consider results from a number of models, and if they diverge from each other or from observed trends, be careful about how they are used in decision making (Schiermeier 2010). It will be up to the planning team to decide how much uncertainty the state is willing to accept, and this may differ by phenomenon/impact/consequence.

Note: Modeling activities require extensive resources. They can be costly and complicated, and they require a robust information technology infrastructure (high-performance, fast, dedicated computer systems). Make sure your state has the technical capacity to run these applications before acquiring them. Research institutions may have the necessary capacity and may be able to assist in these efforts. Alternatively, the planning team could propose developing the capacity as an action in the adaptation strategy (see Chapter 5).

Mapping and Visualization

The use of mapping (both simple and interactive) and other visualization techniques to illustrate the potential impacts of climate change will greatly ease and increase the effectiveness of the planning process. While modeling is the set of rules and procedures for representing a phenomenon or predicting an outcome, mapping is the process of graphically depicting that outcome, or other spatial information.

By using GIS, the data collected throughout this assessment and the outputs from the scenarios or other modeling efforts, the planning team will be able to map projected future conditions, decide where to focus adaptation efforts, and, later, evaluate the results of these efforts. These visuals, which will clearly illustrate what is vulnerable, should also be useful in outreach



Inundation mapping can be used to visualize where flooding may occur as climate changes.

Coastal inundation maps are based on model outputs and can be used to simulate inundation from a variety of processes. There are a number of models available, which may also be coupled with other models (e.g., wave models); each has its own applications and limitations, both of which should be well-understood. Modeling experts can help select and run models and educate the planning team about the limitations. The following are some of the most commonly used inundation models, however other models are also available or under development that may be more appropriate based on your state's circumstances and needs.

- The **Advanced Circulation Model for Oceanic, Coastal, and Estuarine Waters** (ADCIRC) is a hydrodynamic model, which means it projects the motion of water. It can be used to model (in two or three dimensions) tide and wind driven circulation, to project storm surge and flooding, and for other applications. The model can also be used to predict wave height and run-up, particularly when seamless bathymetric and topographic data are available.
- The **Sea, Lake, and Overland Surges from Hurricanes** model (SLOSH) is a scenario-based model developed by the NOAA National Hurricane Center. It is used to estimate storm surge heights and winds resulting from historical, predicted, or potential hurricanes by taking into account storm pressure, size, forward speed, track, and winds. The model also considers characteristics specific to a locale's shoreline, incorporating the unique bay and river configurations, water depths, bridges, roads, and other physical features.
- The **Sea Level Affecting Marshes Model** (SLAMM) simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea level rise. It can account for inundation, erosion, accretion, overwash, and even wetland migration to adjacent upland areas (saturation).
- The **Sea-Level Rise Rectification Program** (SLRRP) is a software program designed to generate a suite of future sea level projections from various Global Circulation Models (GCM) and emissions scenario options. The model allows users to select a region-based tide station, GCM model, and emissions scenario to generate a graph and output file of future sea level change. SLRRP also shows the inundation process and period for which sea level will overtop a given landscape feature or elevation under a future changing climate.

efforts to help secure political and public support for the need to adapt to climate change.

Step 2.6: Summarize Vulnerability and Identify Focus Areas

At this point, the planning team should have a good understanding of how climate change may affect the coast. The final step of the assessment process is summarizing vulnerability based on your findings. This step is critical, as this summary will be used to identify where to focus adaptation efforts and to set goals and select the actions your state will take to meet them (see Chapter 5).

This step provides a good opportunity for the planning team to re-engage the stakeholders identified in Step 1.4 (see Chapter 3). Present them with the results of the scenarios and involve them in deciding

Learning from others…Maryland Visualizes Sea Level Rise to Support Planning

The Maryland Coastal Program and local partners acquired high resolution topographic lidar data for the majority of the state's coastal counties. These data have been used to develop models that demonstrate both the impact of gradual sea level rise inundation over time, as well as impacts associated with increased storm surge from episodic flood events. Sea level rise modeling has been completed for some of the state's most vulnerable areas. The models are already proving useful to state and county planners and emergency responders as they plan for a coastal region faced with a high likelihood of damaging coastal storms and rising sea level. The project partners are exploring ways to integrate the models into future research efforts and land use decision making. Sea level inundation maps are integrated into Maryland's online interactive shoreline mapping program. www.dnr.state.md.us/ccp/coastalatlas/shorelines.asp which consequences are of greatest concern and where the state should invest its climate adaptation resources.

This summary should reflect the outcomes the planning team thinks are most realistic and best reflect the extent of acceptable impacts in the planning area. If the planning team develops scenarios based on three levels of emissions, it is not likely it will plan for all three (although it should still plan for multiple points in time). It is also not likely it will focus all adaptation activities based on the possible outcomes projected by one level of emissions. It may be determined that the potential losses to one sector projected at the highest level of emissions are too great to risk, but that other potential losses at that level are acceptable. In other words, when the stakes are low, the planning team may want to plan based on the outcomes of a low-emissions scenario, but when the stakes are high (e.g., significant losses, irreversible consequences), it may want to consider planning for a higher-emissions scenario. The potential consequences of low probability, high consequence impacts should be recognized so that they can be adequately addressed.

The summary should highlight areas, systems, sectors, or assets that the planning team has determined to be most vulnerable to the impacts of climate change (i.e., potential damage/losses that would have most the significant impact). Criteria that may help prioritize where to focus adaptation efforts include:

- Importance or value of a system, asset, or sector
- Magnitude of impacts
- Timing of impacts
- Persistence and reversibility of impacts
- Certainty of projected impacts
- Threats from existing stressors

It may help to ask questions such as the following:

- What locations along the coast are most vulnerable to climate change impacts?
- What environments (natural, built) are most vulnerable to climate change impacts?
- What assets are most important to your state's coastal values, identity, culture, and economy?
- Which impacts of climate change are likely to inflict the greatest losses (economically, socially, environmentally, etc.)?

It may also be useful to include the associated phenomena and impacts, as there may be actions that can be taken to alleviate the consequences that may cross sectors and/or protect multiple assets. In addition, for each potential loss, indicate which scenarios the decisions were based on and why. This will be useful in future plan updates.

Key Resources

General

- □ Adapting to Coastal Climate Change: A Guidebook for Development Planners, U.S. Agency for International Development. www.crc.uri.edu/index.php?actid=366
- □ ArcGIS Online Resource Center, ESRI. http://resources.esri.com/arcgisonlineservices/index.cfm
- □ Climate Ready Estuaries Coastal Toolkit, EPA Climate Ready Estuaries. www.epa.gov/cre/toolkit.html
- □ NOAA Climate Service. www.climate.gov/
- □ Digital Coast, NOAA Coastal Services Center. www.csc.noaa.gov/digitalcoast/
- □ eCoastal, U.S. Army Corps of Engineers. http://ecoastal.usace.army.mil/
- □ Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies, United Nations Environment Programme. http://dare.ubvu.vu.nl/bitstream/1871/10440/1/f1.pdf
- □ HAZUS-MH, FEMA. www.fema.gov/plan/prevent/hazus/
- □ Introduction to Hazard Mitigation (online training), FEMA. http://training.fema.gov/EMIWeb/IS/
- □ National State Geographic Information Council. www.nsgic.org/
- □ Planning for Climate Change, NOAA Estuarine Reserves Division. http://nerrs.noaa.gov/CTPIndex.aspx?ID=455
- □ Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments, ICLEI–Local Governments for Sustainability. www.icleiusa.org/action-center/planning/adaptation-guidebook/
- □ Regional Integrated Science and Assessment Program, NOAA Climate Program Office. www.climate.noaa.gov/cpo_pa/risa/
- □ Road Map for Adapting to Coastal Risk (training), NOAA Coastal Services Center. www.csc.noaa.gov/digitalcoast/training/coastalrisk.html
- □ Understanding Your Risks: Identifying Hazards and Estimating Losses, FEMA. www.fema.gov/plan/mitplanning/resources.shtm

Identify Climate Change Phenomena

- □ Climate Change 2007: The Physical Science Basis, IPCC. www.ipcc.ch/
- □ Climate Change 2007: Synthesis Report, IPCC. www.ipcc.ch/
- □ Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change, National Assessment Synthesis Team, U.S. Global Change Research Program (2000, includes regional and sectoral assessments). www.globalchange.gov/publications/reports/scientific-assessments/first-national-assessment
- □ Global Climate Change Impacts in the United States, U.S. Global Change Research Program. www.globalchange.gov/publications/reports/scientific-assessments/us-impacts
- □ Great Lakes Water Levels, U.S. Army Corps of Engineers Detroit District. www.lre.usace.army.mil/greatlakes/hh/greatlakeswaterlevels/
- □ Synthesis and Assessment Products, Climate Change Science Program. www.globalchange.gov/publications/reports/scientific-assessments/saps
- □ Tides and Currents, NOAA Center for Operational Oceanographic Products and Services. http://tidesandcurrents.noaa.gov/

Identify Climate Change Impacts and Consequences

- ◻ Climate Monitoring, NOAA National Climatic Data Center. http://lwf.ncdc.noaa.gov/climate-monitoring/
- ◻ The Economic Impacts of Climate Change and the Costs of Inaction, Center for Integrative Environmental Research, University of Maryland. www.cier.umd.edu/climateadaptation/
- ◻ FEMA Mapping Information Platform, FEMA. https://hazards.fema.gov/
- ◻ FEMA Map Service Center, FEMA. http://msc.fema.gov/
- ◻ Multi-Hazard Identification and Risk Assessment, FEMA. www.fema.gov/library/viewRecord.do?id=2214
- ◻ National Assessment of Coastal Vulnerability to Sea-Level Rise, U.S. Geological Survey. http://woodshole.er.usgs.gov/project-pages/cvi/
- ◻ The NatureServe Climate Change Vulnerability Index, NatureServe. www.natureserve.org/prodServices/climatechange/ClimateChange.jsp
- ◻ NCDC Storm Events, NOAA National Climatic Data Center. www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms
- ◻ NOAA Regional Climate Centers, NOAA National Climatic Data Center. www.ncdc.noaa.gov/oa/climate/regionalclimatecenters.html
- ◻ PERI Presidential Disaster Declaration Web Site, Public Entity Risk Institute. www.peripresdecusa.org/
- ◻ Spatial Hazard Events and Losses Database for the United States, Hazards and Vulnerability Research Institute, Department of Geography, University of South Carolina. http://webra.cas.sc.edu/hvri/products/sheldus.aspx
- ◻ United States Historical Climatology Network, NOAA National Climatic Data Center. http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn.html

Assess Physical Characteristics and Exposure

- ◻ Bathymetry and Global Relief. NOAA National Geophysical Data Center. www.ngdc.noaa.gov/mgg/bathymetry/relief.html
- ◻ Coastal Change Analysis Program Land Cover, NOAA Coastal Services Center. www.csc.noaa.gov/landcover/
- ◻ Data Basin Climate Center, Conservation Biology Institute. www.databasin.org/climate-center
- ◻ Demographic Baseline Report of U.S. Territories and Counties Adjacent to Coral Reef Habitats, NOAA NOS Special Projects Office. www.coris.noaa.gov/activities/coral_demographics/
- ◻ Endangered Species Program, U.S. Fish and Wildlife Service. www.fws.gov/endangered/
- ◻ Geospatial One Stop. www.geodata.gov/
- ◻ Likelihood of Shore Protection Data Set. http://risingsea.net/ERL/data.html
- ◻ Mapping Socio-Economic Variables Using 2000 Census Data, NOAA Coastal Services Center. www.csc.noaa.gov/digitalcoast/inundation/_pdf/census_methodology.pdf
- ◻ MPA Inventory, NOAA National Marine Protected Areas Center. http://mpa.gov/dataanalysis/mpainventory/
- ◻ National Atlas. www.nationalatlas.gov/
- ◻ National Land Cover Database, Multi-Resolution Land Characteristics Consortium. www.mrlc.gov/nlcd.php

- The National Map Seamless Server, U.S. Geological Survey. http://seamless.usgs.gov/
- National Ocean Economics Program. http://noep.mbari.org/
- National Register of Historic Places, National Park Service. www.nps.gov/history/nr/
- National Wetlands Inventory, U.S. Fish and Wildlife Service. www.fws.gov/wetlands/
- National Wetlands Research Center, U.S. Geological Survey. www.nwrc.usgs.gov/
- NOAA Shoreline Website, NOAA Coastal Services Center. http://shoreline.noaa.gov/
- NOAA's State of the Coast, NOAA. http://stateofthecoast.noaa.gov/
- Resilience Assessment of Coral Reefs, International Union for Conservation of Nature Climate Change and Coral Reefs Marine Working Group. http://data.iucn.org/dbtw-wpd/edocs/2009-020.pdf
- Social Vulnerability Index, Hazards and Vulnerability Research Institute, Department of Geography, University of South Carolina. http://webra.cas.sc.edu/hvri/products/sovi.aspx
- Spatial Trends in Coastal Socioeconomics, NOAA Coastal and Ocean Resource Economics Program. http://marineeconomics.noaa.gov/socioeconomics/
- Species Protected under the Endangered Species Act, NOAA Office of Protected Resources. www.nmfs.noaa.gov/pr/species/esa/
- U.S. Census Bureau, www.census.gov/

Develop Scenarios and Simulate Change

- Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Decisionmaking, U.S. Climate Change Science Program. www.globalchange.gov/publications/reports/scientific-assessments/saps
- CanVis, NOAA Coastal Services Center. www.csc.noaa.gov/digitalcoast/tools/canvis/
- Climate Modeling, Geophysical Fluid Dynamics Laboratory. www.gfdl.gov/climate-modeling/
- Climate Models: An Assessment of Strengths and Limitations, Climate Change Science Program. www.globalchange.gov/publications/reports/scientific-assessments/saps
- Coastal Inundation Mapping (training), NOAA Coastal Services Center. www.csc.noaa.gov/digitalcoast/training/inundationmap.html
- Coastal Inundation Mapping Toolkit, NOAA Coastal Services Center. www.csc.noaa.gov/digitalcoast/inundation/
- Final Guidelines for Using Future-Conditions Hydrology, FEMA. www.fema.gov/plan/prevent/fhm/ft_futur.shtm
- GIS Climate Change Scenarios, National Center for Atmospheric Research. www.gisclimatechange.org/
- HAZUS Training, FEMA. http://training.fema.gov/EMICourses/
- IPCC Data Distribution Centre, IPCC. www.ipcc-data.org/
- NCAR Models & Modeling, National Center for Atmospheric Research. www.ncar.ucar.edu/tools/models/
- Special Report on Emissions Scenarios, IPCC. www.ipcc.ch/publications_and_data/publications_and_data_reports.htm
- U.S. National Assessment of the Potential Consequences of Climate Variability and Change Scenarios & Data, U.S. Global Change Research Program. www.usgcrp.gov/usgcrp/nacc/background/scenarios/
- Vertical Datum Transformation, NOAA National Ocean Service. http://vdatum.noaa.gov/