A NOAA CAPABILITY FOR

Coastal Flooding and Inundation Information and Services at Climate Timescales to Reduce Risk and Improve Resilience

APRIL 2021

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POLICYMAKER SUMMARY

The challenge

U.S. states and territories are increasingly at risk of inundation from rising seas, changing Great Lakes water levels, and more frequent and intense storms in addition to other risks from a changing climate. This increased threat of inundation compels decision makers to plan for adaptation investments that reduce risk and improve resilience to coastal flooding events on time frames ranging from hourly, daily, and weekly (weather timescales) to sub-seasonally, seasonally, annually, decadally, and beyond (climate timescales). To make these difficult and potentially costly decisions regarding inundation, coastal urban and rural/agriculture communities, emergency and natural resource managers, and other types of decision makers and users require and increasingly demand new and improved short- to long-time-horizon coastal flooding and inundation information and services.

NOAA's response

NOAA envisions a centralized, integrated, operational framework of information and services. This capability will provide authoritative and easily accessible data and products complemented by tools, applications, and decision-support services to improve the resilience of the Nation to coastal inundation.

By integrating data and products, information access and applications, and decision support, NOAA will provide and improve a nationally-uniform set of data, products, applications, and other information across time and communities. Ultimately, information and services focused on climate timescales will merge and become seamless with shorter weather timescale coastal-flooding warning and forecast information and services. Through continuous engagement, the data, information, and applications will be tailored to the users' decision-making processes and capabilities. In addition to a baseline of information, the envisioned capability will be founded on the principle of meeting customers where they are through a "boots on the ground" capability and a network of trusted community resilience experts. Further, NOAA's research and development (R&D) partnerships will support the production of these services with the best-available science, from which NOAA's non-governmental weather-water-climate enterprise partners can develop more specific and tailored information and services.

The developmental requirements

Developing and implementing the envisioned integrated system of climate timescale coastal flooding and inundation information and services will require NOAA to leverage existing capabilities and make new investments in the several areas.

Developmental Requirements

High-level developmental requirements necessary to reach NOAA's coastal flooding and inundation capability goals

01 **Research and Development, and Transition.** A sustained and dedicated physical and social science research and development program shaped by, and responsive to, user and stakeholder needs that continuously delivers the best available science to the widest possible audiences; and a robust process for transitioning proven R&D to operations, applications and other uses.

02 **Backbone.** A centralized and operational backbone in order to produce reliable, timely, and actionable information based on sound science.

03 **Networks.** A "boots on the ground" capability of trusted extension and engagement networks that will build upon NOAA's culture of engagement.

04 **Engagement.** Continuous stakeholder feedback and engagement to improve service delivery and ensure information is used by stakeholders.

05 **Partnerships.** Cross-sector partnerships and networks to incorporate the best available science.

06 **Reference frame.** A common spatial reference frame to produce seamless, interoperable and accurate information.

07 **Data and products.** Authoritative, spatially-enabled climatologies, analyses, outlooks, predictions, projections and scenarios based on cutting-edge models and integrated with other geospatial information (e.g., at-risk or critical infrastructure, ecosystems, economic zones, jurisdictional locations, under-served communities, etc.) to support complex decision making.

08 **The Cloud.** Cloud-based storage and computing to address high performance computing needs and support community-based solutions.

09 **Automation.** Artificial intelligence, machine learning and best-state-of-the-science approaches to automate data analysis and processing, improve model capabilities and skill, and create more efficient workflows.

10 **Data services.** Robust data services to support integration and use of NOAA data.

11 **Citizen science.** Citizen science to stay better connected and promote a more engaged public.

12 **Private Industry.** Commercialized benefit of our research, observations and modeling such that private industry can create more tailored flood risk products and visualizations.

What is needed?

To enact the envisioned comprehensive suite of coastal-resilience services, the following steps are necessary:

- Establish a Program Management Structure to oversee the planning, development, implementation, product and service delivery, and ongoing R&D necessary to ensure coordination across NOAA and our partners' organizational roles and responsibilities, effective resource allocation/alignment, and accountability
- Pursue a Partnership Approach to align scientific data and results while partnering with local governments, private-sector enterprises, and academic institutions
- Develop Implementation Plans to outline the tasks, timelines, and personnel/budget resources to meet the goals

- Inform Federal Policymakers about coastal inundation risks in our warming climate, highlight the gaps and capabilities needed to improve coastal resilience, and report on progress made with any initial investments
- Inform the Federal Budget Process by developing budget initiatives across Line Offices to support R&D and product and service development and delivery
- Inform Federal Policies that establish an interagency structure to coordinate coastal inundation research and information

Coastal Inundation Program Management and Oversight

- Conducts interdisciplinary, user-inspired, and regionally relevant research
- Develops/maintains long time-series indicators of inundation variability and change.
- Runs/develops/validates models to produce scientific hind casts and predictions about future water conditions
- Manages and funds competitive and high-priority inundation research and development objectives

- Disseminates scientific predictions about future water conditions
- Provides data and information products at regular and expected intervals
- Develops and provides decision-support and geospatial resources
- Supports program IT and dissemination infrastructure

- Evolves the continuous service delivery pipeline based on social science
- Conducts capacity building and identifies user needs
- Transfers knowledge through training, tools, and products
- Delivers requirements to research and operations

1. PURPOSE AND INTRODUCTION

The purpose of this document is to envision a NOAA capability that produces and provides authoritative data, products, and services that quantify and communicate the risk of subseasonal-to-centennial coastal flooding and inundation[1] for the United States (U.S.) and its territories. This capability will be shaped by and responsive to NOAA stakeholder needs, developed by advancing NOAA capabilities, and sustained by a dedicated research and development (R&D) program that continuously delivers the best-available science.

The NOAA capability described herein is aspirational. A significant gap in resources exists between currently available resources within NOAA and what would be needed to create and maintain the envisioned capability. This holistic vision is a required step toward defining the necessary priorities and resources to lead NOAA to a future in which it delivers a comprehensive suite of national coastal-resilience services underpinned by observations and cutting-edge research, modeling, and social science.

What is the issue?

Although coastal flooding has always been a threat and caused damage, loss of life and property, and other detrimental impacts [1], U.S. coastal areas are now at even greater and increasing risk of flooding from rising seas and heavier, more frequent precipitation associated with our warming climate [2]. In particular, coastal communities—which are home to 42% of the U.S. population, are contributing 48% to the GDP currently, and are projected to grow and further develop [3]—face mounting threats and costs from combinations of increasing tidal flooding, storm surge, heavy precipitation, discharge from rivers, high lake levels, rising groundwater, and other physical processes affecting coastal inundation risk [4] (see Figure 1.1). Aging and deteriorating water management systems that were not designed for new climate flooding normals [5] cannot accommodate more frequent and intense floods; the failure of these systems threatens fresh water supplies, transportation systems, and energy, agricultural, and other types of infrastructure not meant to be inundated, especially with salt water. Increased coastal flooding further endangers public safety, health and wellbeing, economies, and ecosystems. The impacts of coastal inundation risk are even greater for socially and economically vulnerable populations for which the capacity to respond and recover from flooding is much lower [6]. Unfortunately, coastal inundation is likely to become even more frequent and intense [2]. For example, the U.S. annual high tide flooding frequency[2] in 2019 was more than twice that in the year 2000. By 2050, it is likely to be 5- to 15-fold higher and to potentially reach nearly 180 days per year of flooding in some locations, effectively becoming the new high tide [7]. According to one set of warming scenarios presented in the Fourth National Climate Assessment [2], economic damage to the U.S.'s trillion-dollar coastal property market and public infrastructure—the third-most-impacted sector of 22 analyzed—is projected to be up to $118B/yr by 2090.

[1] For the purposes of this document, the terms "coastal flooding" and "coastal inundation" are used together or interchangeably. No accepted difference appears to exist between the definitions of the two terms in the literature [8]. Both refer to the overflow or excess accumulation of water that covers typically dry land at the coast. However, the use of the two terms varies depending on the extent and/or duration of the excess water.

[2] High tide flooding (HTF) begins to occur when coastal water levels reach heights between 0.5 meter (m) and 0.65 m above the mean higher high water. The HTF thresholds are based upon coastal flood thresholds set by NOAA National Weather Service (NWS) Weather Forecasting Offices (WFOs) and on-the-ground local emergency managers who prepare for response to impending conditions. See [7] for more details.

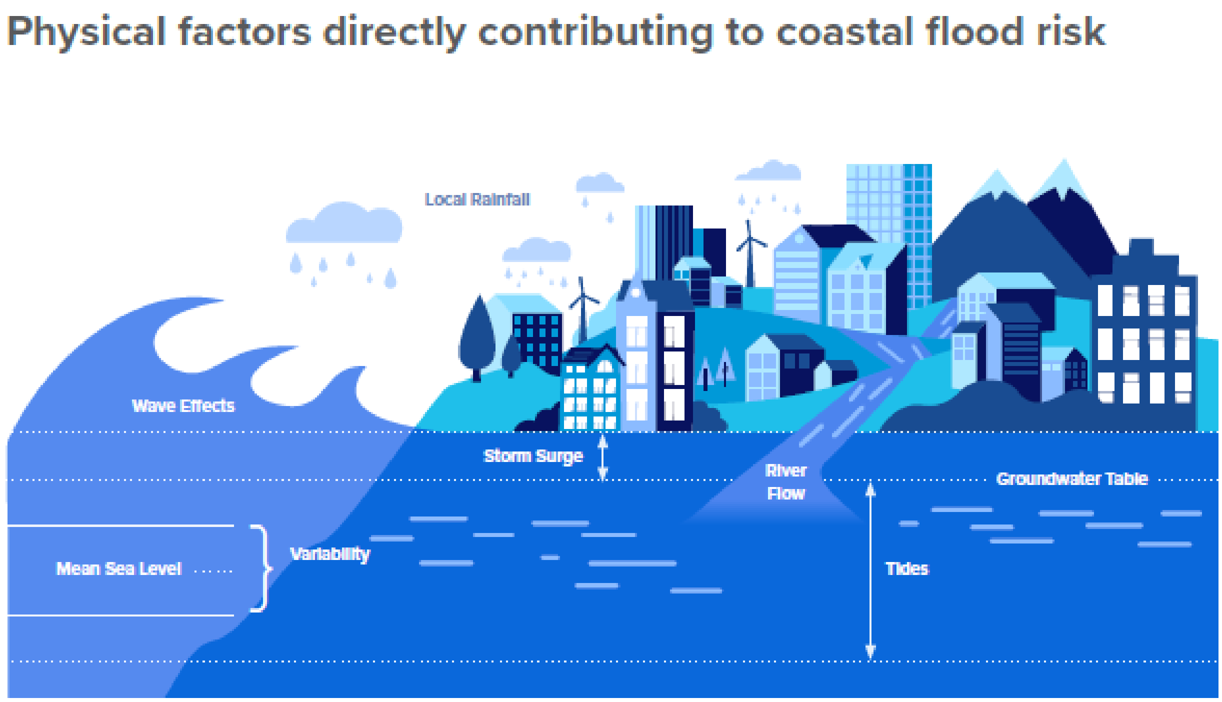

Figure 1.1. Physical factors directly contributing to coastal inundation risk include: mean sea level; tidal range, monthly mean sea-level variability, storm surge, wave effects, precipitation, river discharge, lake level, and groundwater (for a more complete list and discussion, see [9]). Individually and in combination, many of these factors are affected by climate variability and change in ocean circulation and storms.

What is needed?

The increased threat of inundation compels decision makers to consider and plan for adaptation investments to reduce risk and improve resilience to coastal-flooding events on time frames ranging from hourly, daily, and weekly (weather timescales) to sub-seasonally, seasonally, annually, decadally, and beyond (climate timescales). For the near-term, when flooding is imminent, emergency managers need to decide whether, when, and where to evacuate people, mobilize emergency responders, and deploy protective measures such as sand bags. For longer time horizons in which increased flooding impacts are anticipated, communities need to consider planning and undertaking more permanent adaptation measures such as: civil works interventions (green infrastructure, stormwater retrofits, pump stations, sea walls) to elevate or relocate infrastructure; building code alterations to make structures more resilient to flooding; and zoning law revisions to limit or forbid construction in areas at risk of flooding.

To make these difficult and potentially costly decisions regarding inundation, coastal urban and rural/agriculture communities, emergency and natural resource managers, and other types of decision makers and users increasingly need and demand new and improved short to long time horizon coastal inundation information (see Figure 1.2) to supply seamless and authoritative input to their risk questions. These questions include: when and where will it flood; what will the total water depth and duration of the flooding be; how frequently will flooding occur; what will the impacts be to my area of interest; how will each of these factors differ in the future; and how can this information complement social and economic data and analyses to generate fiscally, socially, ecologically, and politically viable decisions for my community?

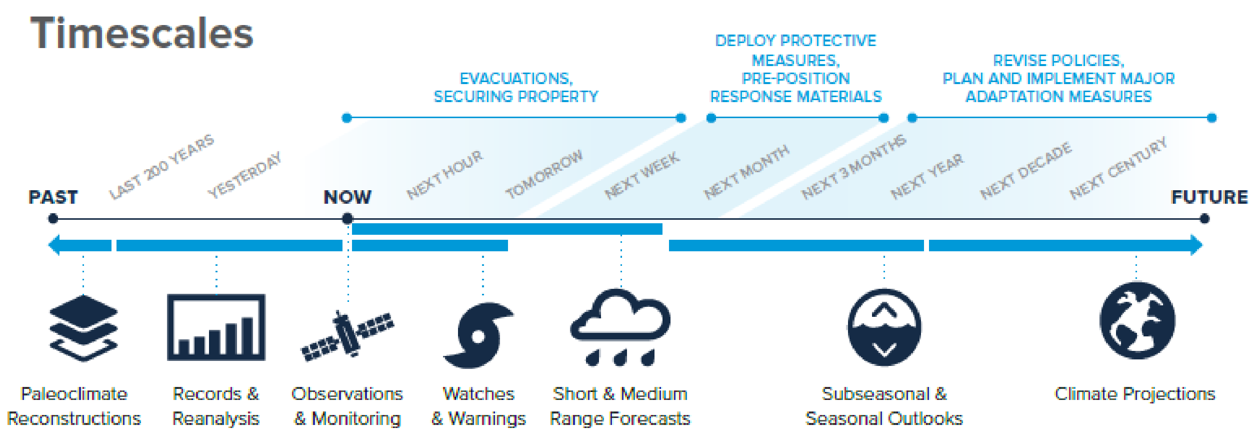

Figure 1.2. Types of decisions and needs for coastal inundation information across timescales.

Across time and space, the physical contributions to and scale of the coastal inundation problem are complex. In addition to changes in global mean sea level, increased tidal flooding, and other factors (see Figure 1.1), coastal erosion, coastal morphology, and anthropogenic activities also affect inundation risk [10]. The timescales involved in coastal inundation risk vary from the duration of individual storms to sea-level-rise projections over the coming century. The range of spatial scales also pose challenges varying from the bathymetry of individual beaches (10s of meters) to ocean-basin-scale storms and ocean circulations (1000s of kilometers). Moreover, effective coastal-building and infrastructure-design projects require specific inundation information such as the identification of water-level-control components, which vary depending on time and location [10]. This complexity necessitates a variety of simplifying assumptions that are often used to make coastal inundation risk assessments more tractable [11] to provide useful information to guide decisions and policy development. As a result, various types of coastal inundation information are currently produced and delivered by a wide community of government, academic, non-profit, and commercial-sector research and service providers [12]. However, these products and services usually focus on specific physical components, time and spatial scales, and geographies of inundation risks, and the reliability of the information from each source can be unknown or questionable [13]. Regardless, decision makers are often left on their own to choose which source of information to use for their application.

Nascent efforts have been made to overcome these challenges and to develop and implement capabilities to provide more comprehensive coastal inundation information. In particular, NOAA—aided by its cross-sector partnership network—recently embarked on a comprehensive water initiative [14] designed to provide better access to the specific water information people and governments need for their unique circumstances so that their plans to address water-related risks and manage water resources more effectively can be informed by the best-available science. A component of the initiative focuses on creating and delivering authoritative and actionable information about coastal-zone water level, flow, and quality to inform decisions. The emphasis of this coastal component of the initiative is on coupling weather, hydrologic, wave, and coastal hydrodynamic models to produce water-level and inundation forecasts on weather timescales from hours to several weeks [15].

The services proposed in this document will complement, enhance, and build from the coastal component of the NOAA Water Initiative by providing a national capability to produce and deliver comprehensive, impact-based coastal-water-level information at subseasonal-to-decadal timescales. Meeting this challenge requires enhancing our data collection and model prediction systems as well as developing the capability to characterize underlying uncertainty in predictions at all timescales. Ultimately, the two capabilities will be linked into seamless coastal-water-information services that provide water-information predictions for hours to decades into the future.

The Need for a Coastal Inundation Capability

There does not exist a capability that provides comprehensive, reliable, and authoritative data, products, and information services regarding future coastal flood risk to the Nation incorporating all key causative fresh and saltwater flooding components and supporting multi-time horizon and multi-spatial scale planning needs.

What does a NOAA national capability look like?

NOAA's science, service, and stewardship mission, mandates, research, and operational capabilities (see Appendix B) have made it a leader in predicting and communicating risks to life, property, economies, and ecosystems from water-related hazards, including coastal inundation. NOAA's water-information services include impact-based decision support; science-based risk assessments; warning, forecasting, predicting, and projecting[3] water information; and capacity building for a host of near- and longer term societal challenges. However, NOAA cannot improve coastal inundation services alone; instead, NOAA will rely on federal and other partners as with the NOAA Water Initiative [14]. The capability will be built by fostering interagency collaborations (for example, the U.S. Global Climate Research Program (USGCRP),[4] Interagency Council for Advancing Meteorological Services (ICAMS), Subcommittee on Ocean Science and Technology (SOST), etc.) and public- and private-sector (enterprise[5]) partners to develop impact-based climate timescale coastal inundation information and services. Consistent with the National Research Council's Fair Weather Report [16] and other public-private-sector partnership

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[3] For the purposes of this document, a **prediction** is a statement of something that will happen in the future based upon what is known today. Predictions quantify the variability from an average condition and should include confidence bounds on the variability. A **forecast** is a "best" prediction made by a particular person or with a particular technique. Forecasts are a combination of scientific information and an expert's best judgment to provide a specific statement about an outcome in the next few hours to days. A **projection** is a probabilistic statement that it is possible that something will happen in the future if certain conditions develop. A projection specifically allows for significant changes in the set of boundary conditions that might influence the prediction, creating 'if this, then that' statements. A **scenario** is a projection of what could happen if a certain set of assumed conditions prevailed in the future; it is neither a prediction nor a forecast of what will happen independent of future conditions.

[4] Workgroups within the USGCRP are identifying priority needs and gaps in scientific knowledge, data and tools, and guidance related to the use of coastal hazards information for decision making as well as working to coordinate new scientific endeavors and better deliver actionable information to coastal decision-makers.

[5] Includes government, academic, industry and non-profit organizations.

recommendations [17], the capability proposed here will provide a national foundation of regional and local climate timescale coastal inundation information and services that will enable a private-sector marketplace of value-added information.

What principles will guide the development of this capability?

As further detailed in the sections below, NOAA will use the following principles when planning, developing, implementing, and sustaining a national capability for coastal inundation information and services at climate timescales:

- NOAA will produce coastal inundation information and services consisting of an authoritative[6] and nationally-uniform set of data, products, and applications. These information and services will be focused on subseasonal to decadal-and-centennial timescales and will be meaningful at local levels[7], from which more specific and tailored information and services can be provided by non-governmental partners to individuals and businesses.

- NOAA will sustain continuous engagement with stakeholders and users to ensure that new/existing products and services are built, refined, and delivered—especially to socially and economically vulnerable populations—to provide actionable information to assist decision making.

- NOAA will leverage our Nation's investments in R&D data, products, and services by working with Federal and other partners to incorporate the best-available science into this capability.

What is in the remainder of this document?

Section 2 provides an overview of known and anticipated stakeholder needs, current capabilities, and the benefits of a national capability. Section 3 envisions the capability and offers sample 5- and 10-year data, product, and service goals supported by the capability as user needs evolve and science and technology advance. Section 4 establishes objectives for how NOAA will develop, implement, and sustain the capability with partners. Section 5 discusses next steps and recommendations.

2. USER NEEDS, CURRENT CAPABILITIES AND GAPS

Even under conservative sea-level-rise and other water-related climate change projections, the U.S. is facing hundreds of billions of dollars [1, 19, 20] in protection and adaptation costs over the next several decades to mitigate much larger costs [1, 11] and other deleterious impacts of coastal inundation, which will be greater yet for socially and economically vulnerable populations. Cost-effective design and implementation of these measures—ranging from those that protect individual homes and commercial buildings, to projects that mitigate flooding at the district-scale, to multi-billion dollar regional interventions that improve coastal inundation protection [21]—will require

[6] In this document the term authoritative is defined as being both actionable (i.e., relevant, reliable, understandable, supportive and co-produced) and based upon the best-available data and science (i.e., transparent, technically credible, useable, legitimate and flexible) as per [18].
[7] Coastal inundation information will be available from the coastline to inland where ocean/Great Lake contributions to inundation cease. Local level is at the scale of/useful to communities but not down to the scale of individual land parcels.

meaningful, reliable, and authoritative regionally- and locally-relevant information about the status, rates, patterns, and trends of the key physical variables that impact coastal inundation risk.

User Needs

Consistent with its other areas of service, NOAA will use a continuous-user-engagement process [22] (see Figure 2.1) to develop and improve the specifics of its coastal inundation information and services and to understand evolving user needs as well as the accuracy and timeliness of NOAA's response to those needs. This will include a focus on social and behavioral science to understand barriers to information delivery and to guide decision-support activities. As a starting point, and for the purpose of providing a foundation for the envisioned NOAA capability,

Figure 2.1. A service delivery model [22] based upon a process of continuous user engagement. NOAA providers: (1) continue to build trusted relationships with NOAA's internal and external users and partners; (2) understand the decisions of those users, their use of NOAA information, and gather the user's information needs**;** (3) translate the needs into technical aspects and review and consider NOAA's capacity to respond; (4) review, assess, and prioritize NOAA's products and services to meet the needs; (5) respond to and address user needs by developing new—or refining existing—products and services across NOAA and making continuous improvements to prediction systems and other foundational capabilities to address changing user needs; (6) deliver these products and services to users; and (7) evaluate the user impact of NOAA's tools and services. It is imperative that as each element of the process is conducted, interactions occur between the trusted NOAA entity, end users, and various partners. Elements are likely to co-evolve and loop forward, across, and behind in the diagram to verify needs and capabilities and ensure the provision of the best products and services.

Table 2.1 provides a summary list of coastal inundation information and services needed to assess and implement risk-reduction measures. The list was synthesized from a review of relevant literature and an analysis of the needs of over 100 types of users (see Table 2.2). The user needs for information and services are organized into the following three categories:

- Data and Products. Observations, model output, analyses, predictions, projections, etc., that users need to inform their decision making
- Information Access and Applications. The push and pull technologies, modes, and formats by which users want to receive and retrieve data and products; and the user-specific applications and tools they need to gather and process information
- Decision Support. Education, training, and other types of outreach and support needed to communicate information to users and to assist them in using it to inform their decisions, including continuous user engagement to benchmark services and to ensure that user needs and expectations are being met

Examples of use cases for each of the sectors identified in Table 2.2 are provided below to illuminate the decision-making context of these needs. Although these examples are generalized for clarity, specific uses and needs within each group can vary. For instance, some cities have a highly-skilled, technically-sophisticated workforce dedicated to accessing data to build their own models, applications, etc. without much assistance, while other cities, particularly smaller ones, may lack the resources necessary to identify and effectively use pertinent coastal inundation information. These differences warrant identification of user engagement levels [22] and require varied partnership strategies and a flexible information and services delivery capability that is responsive to varying levels of user needs and technical sophistication. NOAA and its partners will need to consider how best to build relationships with coastal communities to address needs, interests, and capacities, to ensure two-way learning, and to provide the easiest possible access to NOAA resources.

Energy & Transportation Managers

Recent studies [23] have shown an increased vulnerability of energy infrastructure and petroleum facilities to sea-level rise, storm surge, flooding, and hurricane frequency and intensity. Energy managers need to know about water-level and land-based changes to plan for facility and pipeline siting and maintenance. To maintain service and meet power demands during storm events, they need actionable short-term information, and they must understand historical trends, predictions, and projections, including probabilities and levels of uncertainty.

Transportation managers must plan for increased stress on infrastructure from land and water-level changes, increased use of transportation networks [24], and more frequent inundation and storm surge on roadways. Managers must know how and when critical assets such as bridges, port facilities, and interstate highways will be compromised from these impacts. In low-lying coastal areas, transportation managers need climate-timescale data and products to plan for routine maintenance and necessary changes to infrastructure over the long term.

User Information Needs

Coastal flooding and inundation information and services needed to reduce risk and improve resilience

DATA & PRODUCTS

Coastal Total Water Level Variables

- Tides (high and low extremes)
- Storm surge
- Relative sea level change
- Waves (runup and set up)
- Local rainfall
- River discharge
- Global sea level rise
- Groundwater and saltwater intrusion
- Lake levels
- Compound flooding
- Extreme high and low water levels

Land-based changes

- Long term beach/shoreline
- Vertical Land Motion
- Datum
- Topo/bathy
- Land use

Socioeconomic change and risk

- Population
- Demography
- Economic
- Risk perception
- Coastal real estate

Analysis, Predictions, & Projections

- Historical trends
- Return periods
- Critical thresholds
- Probabilities
- Uncertainty
- Frequency/Duration
- Scenarios

Spatial Resolution

One degree National grid baseline

Time Periods

- Hindcast/Reanalysis
- Subseasonal
- Seasonal
- Yearly
- Decadal
- Century

Update Frequency

Monthly to every 4 years and/ or as conditions change

Geography

- National
- Regional
- State
- County/Parish
- Street
- Point specific (tide/ river gauge)

INFORMATION ACCESS & APPLICATIONS

Dissemination

- Media
- ENS
- TV
- Internet

Mapping services

Data services/APIs

Model and historical data access

Technical assistance

Mapping/ Visualization tools

Risk/Exposure/ Cost Benefit Calculators

DECISION SUPPORT

Outreach

Education

Training

Extension/ Engagement

Community of practice

Regional adaptation networks

Socioeconomic impacts

Guidance/ Best Practices

Capacity building

Table 2.1. A summary of coastal inundation information and services needed to reduce risk and improve resilience synthesized from a review of relevant literature and an analysis of the needs of over 100 types of users (see Table 2.2). Theuser needs for information and services are organized into the three categories: Data and Products, Information Access and Applications, and Decision Support.

Coastal Inundation Decision Makers

An emerging list of decision makers and others who use and need improved coastal flooding and inundation information and services

Energy and Transportation

Department of Energy
Hydroelectric power engineers
Hydro plant operators
Nuclear plant operators
Electrical plant operators
Federal Energy Regulatory Commission
Airports
River navigators
Pilots (ships)
Railways
Road transportation agencies (state DOTs)

Commerce and Industry

Local Businesses
Corporate Businesses
Consultants
Real estate/developers
Insurance and Reinsurance
Landscape architects
Agriculture/Farmers
Fishermen
Seafood/aquaculture industry
Tourism companies
Media (TV, radio, newspaper, reporters, etc.)

Natural Resource Use and Management

Environmental Protection Agency
Environmental Lawyers
Private landowners/land trusts
Arboretums/gardens
Plant nurseries
Federal wildlife management agencies
Wetland managers
Levee districts (within state)
Dam operators
Stormwater managers
Water treatment facility operators
Watershed Managers
Community watershed/water management organizations
International watershed/water management organizations
National Marine Fisheries Service
U.S. Department of Agriculture, Natural Resource Conservation Service & Agricultural Research Service
Seafood/aquaculture industry
National recreation organizations
Ski resorts
Companies offering back country experiences (NOLS; Outward Bound; REI, RMI, etc.)
Pollution control specialists
Ranch (land) managers
Parks (national, state, local, including site managers)
State wildlife management agencies
Wildlife Conservation NGOs
Habitat Conservation NGO‚Äôs
Water authorities
Reservoir managers
Irrigation managers
Wastewater managers
Aquifer/groundwater managers
Water NGOs
State water resource managers
Sub-national watershed/water mgmt. Organizations
Tribes
Real estate developers
Landfill/waste management
Farmers
Aid organizations
Fishermen
Boating organizations
Guides (hiking, mountaineering, kayaking, etc.)
Search and rescue

Federal Partner Agencies & Engagement Networks

National Institute of Health
Department of Energy
U.S. Army Corps of Engineers
U.S. Department of Agriculture, Natural Resource Conservation Service & Agricultural Research Service
Bureau of Reclamation
Sea Grant Universities/Extension
Regional Integrated Sciences and Assessments Teams
National Estuarine Research Reserves
NOAA Regional Collaboration Teams
National Oceanic and Atmospheric Administration
Federal Energy Regulatory Commission
Centers for Disease Control and Prevention
U.S. Navy and US Coast Guard
United States Geological Survey
Federal Emergency Management Agency
Bureau of Ocean Energy Management
Environmental Protection Agency
Land Grant Universities/Cooperative Extension
National Aeronautics and Space Administration
Coastal Zone Management Programs

Scientists and Researchers

Academia/Labs (scientists, educators, researchers)
Water researchers
Water modelers/tool developers
Social, behavioral & economic researchers
Economists
Water policy analysts
Political advocates
Legal advisors

Policy Makers & State, Local, and Tribal Community & Leaders

Community planners
Community resilience planners
Coastal resiliency planners
Urban Planners
Engineers (civil, environmental)
Waste managers
Emergency Managers
Local (including city & county) officials
Urban search and rescue
Animal control agencies
Medical facilities (e.g. hospitals; nursing homes, rehab facilities, surgical venues, etc.)
Community leaders
Coastal residents
Land use, watershed, coastal and environmental policy makers
Floodplain managers
Green infrastructure developers
Landscape architects
Political leaders
Insurance and Reinsurance
Local (including city & county) organizations
Risk Managers (disaster managers, risk reduction specialists, hazard mitigation specialist)
Animal welfare organizations
Local school districts
Floodplain residents

Socially/Economically Underserved Communities

Table 2.2. An emerging list of decision makers, stakeholders, and others—organized by sector—who use and need improved coastal inundation information and services for their decision making at climate timescales.

Natural Resource Use and Management

Land and coastal management organizations and agencies need data to identify threats to natural and human systems, including an understanding of how future coastal flooding and inundation will impact the environmental management of natural resources, nearby communities, and other concerns such as waste disposal and storage. These managers access inundation data through online portals from a variety of sources but need locally-based engagement experts to interact with their end users to develop and improve service delivery and support decision making. End users include small business owners in the farming, ranching, fishing, and aquaculture sectors in which seasonal, annual, and long-term water levels affect farming/harvesting/fishing facilities, activities, and yields. The end users also include other businesses such as those in the tourism and recreation industries that rely on inundation predictions to inform business planning.

> **Case Study: Electric Power Plant Site Manager**
>
> Consider the coastal inundation information and service needs of a site manager for an electric power plant in a medium-sized, low-lying coastal city, such as Charleston, SC. With the increased frequency and strength of storms in the area, the site manager needs to prepare for energy use and facility vulnerabilities for the upcoming hurricane season. The site manager can use existing applications and products such as alerts, watches, and warnings to plan for immediate issues from storms, surges, flooding, and rainfall, but will also need to plan for subseasonal to seasonal impacts using hurricane season forecasts and seasonal flooding outlooks. While some in the energy sector will be able to access this information via data portals, inundation dashboards, and risk calculators, others may require more hands-on assistance including webinars, training, and on-the-ground technical support to ensure that the data and products are properly interpreted for the action or decision it will support.

Scientists and Researchers

Scientists in academic and laboratory settings need straightforward access to comprehensive datasets that include hindcasts, predictions, and projections of coastal inundation variables and indicators to support their R&D. These scientists and researchers rely on NOAA and its partners for real-time, high-resolution, water-level-observing networks as well as historical data and models. This class of users needs access to and tools for analyzing these global, national, and regional data through web portals. Because they generally have a high level of technical expertise and capability, these users may not need much information delivery assistance. However, other researchers may require information and decision-support services to integrate physical and social science data and tools for a more holistic determination of coastal area vulnerability. Although many of these users are technically skilled, they may need engagement and technical assistance to understand and apply cross-disciplinary datasets.

Policymakers and State, Local, and Tribal Community Leaders

Policymakers and community leaders have critical challenges in identifying, accessing, and understanding data, products and the applications they need for their decision making. These users need information to facilitate this process and to bridge existing knowledge networks. They require data analyses that provide clear implications for their policy making. They need near- and long-term data, models, projections, and vulnerability tools, and they require the ability to infer risk from probabilistic projections.

The availability of inundation information is key to those users in the state, local, and tribal communities. This user group may include community, urban, environmental, and emergency and floodplain managers as well as decision makers, community leaders, and residents of coastal areas, all of whom require current near-, and long-term data, models, and vulnerability tools to gain insight into impacts for critical structures and services, identify risks in the development of communities and infrastructure, and determine mitigation strategies to prevent loss of property or life.

Many of these users require a high level of engagement from NOAA and its partners. This user group relies on science and service agencies and on-the-ground engagement programs to help them understand the available information and how to use it to support their decision making.

Commerce and Industry

Increasingly, efforts are being made to integrate information about climate risks into financial decision making and disclosures. Users in the commerce and industry sectors vary widely and include groups such as tourism and recreation organizations, large corporations, small businesses, and the news media. Within this group, inundation information is crucial to assess risks to business productivity. Depending on the industry, these data may even help to identify economic opportunities. Many of these users have the capacity to use existing data portals and data assembly tools with little assistance or decision support. Others, such as small businesses without technical resources, may require more interaction and support from NOAA researchers, forecasters, and engagement professionals. News media organizations have existing relationships with NOAA, which produces briefings and websites to share information with the public. Key considerations for media engagement are message clarity and consistency, particularly when communicating actionable messages for which the time needed to compare output across several research models can be counterproductive to the immediate needs for information to aid evacuation decision making.

Federal Partner Agencies, State and Local Governments, & Engagement Networks

NOAA works with many other federal agencies to collect data and create coastal inundation tools and products. Notably, NOAA has standing relationships with the National Aeronautics and Space Administration (NASA), U.S. Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and other agencies that aid in the co-production of resources, including online coastal-flood-exposure maps, coastal-change maps, and sea-level-change viewers. Other federal agencies have shared information about gaps or requested improvements—such as different time or geographic scales as well as updates to modeling specifications—to existing products to meet their needs. Many federal agencies look to NOAA to provide an authoritative source of information on climate timescales to inform their planning decisions. Still other federal agencies such as the U.S. Army Corps of Engineers (USACE) or FEMA require a more specific approach to coordination and information exchange.

Socially/Economically Underserved Communities

Socially or economically underserved communities are disproportionately at risk for and impacted by changes in climate, including coastal inundation, due to their increased exposure and limited capacity to adapt and respond [25]. Unlike many of NOAA's partners and information users, these communities have not been specifically targeted with resources, services, and decision-support engagement. These groups have a wide variety of technical ability, needs, and uses for data, tools, products, and information and require meaningful engagement on coastal inundation issues and activities that impact their communities.

Current Capabilities to Meet the Needs

An expansive constellation [e.g., 12, 26] of coastal inundation data, products, and applications are currently available from Federal, state, and local government agencies, universities, laboratories, non-profits, and businesses that may meet some of the user needs reflected in Table 2.1. However, these needs collectively cover long time horizons, from data and analyses of inundation climatologies decades in the past to inundation projections and scenarios a century or more into the future. They also encompass a wide spectrum of spatial scales, from inundation risk at individual land parcels up to risk at community- and regional-levels all along our Nation's coasts. Providing reliable [13], authoritative information about future coastal inundation risk is challenging because it is caused by complex interactions among oceanographic, hydrological, geological, meteorological, and climate drivers that act over wide ranges of spatial and temporal scales. Key drivers include astronomical tide, wave set-up, wind set-up, storm surge, precipitation, fluvial discharges, sea level anomalies driven by ocean changes, land subsidence/uplift, coastal erosion, coastal morphology, groundwater processes, and anthropogenic activities. Moreover, the contribution of each of these drivers can vary over time and location (see Table 2.3), resulting in a complex, nonlinear problem [27].

Spatial and Temporal Scales of Geophysical Processes Affecting Water Levels

Physical Process	Spatial Scale			Temporal Scale	Yearly Potential Magnitude
	Global	Regional	Local		
Wind Waves (e.g., dynamical effects, runup)			✓	seconds to minutes	<10m
Tsunami		✓	✓	minutes to hours	<10s of m
Storm Surge (e.g., tropical storms or nor'easters up to 30 ft)		✓	✓	minutes to days	<15m
Tides			✓	hours	<15m
Seasonal Cycles		✓	✓	months	<0.5m
Ocean/Atmospheric Variability (e.g., ENSO response)		✓	✓	months to years	<0.5m
Ocean Eddies, Planetary Waves		✓	✓	months to years	<0.5m
Ocean Gyre and Over-turning Variability (e.g., PDO response)		✓	✓	years to decades	<0.5m
Land Ice Melt/Discharge	✓	✓	✓	years to centuries	millimeters to centimeters
Thermal Expansion	✓	✓	✓	years to centuries	millimeters to centimeters
Vertical Land Motion		✓	✓	minutes to centuries	millimeters to centimeters
Great Lakes' Water Levels		✓	✓	months to years	<1m

Table 2.3. Spatial and temporal scales of geophysical processes affecting coastal water levels (from [28]; < indicates less than).

Consequently, a variety of simplifying assumptions are often employed to produce inundation information that make the complexities of the problem more tractable[8] [11]. Although a comprehensive summary is beyond the scope of this white paper, the following is a high-level overview of the state of the science and a sample of the coastal inundation information at climate timescales currently available.

FEMA identifies "Special Flood Hazard Areas (SFHAs) and Velocity (wave impact) Zones" on their Coastal Flood Insurance Rate Maps. The SFHAs are defined as the areas that will be flooded by a coastal storm event having a 1-percent chance of being equaled or exceeded in any given year (aka a 100-yr event) using 2-D hydrodynamic modeling[9] and/or historical observations with synthetic, non-observed storm simulations to estimate probabilities under current climatic conditions and sea-level and wave-runup using a basic 1-D approach [29]. The scientific literature includes estimates of spatially-gridded Total Water Level (TWL) probabilities based upon hindcast reanalysis [30, 31, 32] and on future conditions using Global Climate Model output (e.g., Coupled Model Intercomparison Project (CMIP)) [33, 34, 35]. Future mean sea level decadal-to-century projections are provided at regional (1-degree) scales [36]. The decadal-to-century probabilistic projections for components of TWL are typically the combinations of sea level rise projections with contemporary extreme water level probabilities (e.g., 1-100-year events) derived at tide gauge locations (without waves included) [37]. Most projections do not consider future changes in tide-range or storm-surge characteristics under higher sea level. The scientific literature [38, 39]—together with commercial, academic, and government modeling systems and products (SLOSH/P-surge [40], Flood Factor [41], National Water Model [42], National Ocean Service Operational Forecast System [43], CERA [44]) and communities of practice [45]—has provided statistical relationships between storm surge and rainfall and storm surge and river discharge using specific sets of co-located rain, river, and tide gauges. However, there are no Federal products that provide decadal-to-century projections based upon changing sea levels and tidal/storm surge characteristics in a spatially-gridded manner.

Many decision-support tools exist across the public and private sector[10], as do many portals that link users to various datasets, tools, training, and case studies[11]. Despite these resources, users such as the Coastal States Organization have reported three key challenges for future decision-support tools that serve the coastal management community [46]:

- Generating appropriate tools to address specific problems
- Establishing and communicating credibility to intended users of tools and
- Providing tools at a sufficiently high resolution for decision making

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[8] For example, under certain conditions and depending on the specific risk information needed, the effects of some of the forcing factors can be neglected and others linearly superposed [27].

[9] The model currently used is the ADvanced CIRCulation Model (ADCIRC).

[10] Examples include: NOAA SLR Viewer, USGS Coastal Hazards Change Portal, USGS CosMOS, NOAA Coastal Flood Exposure Mapper, TNC Coastal Resilience Tools, Climate Central Surging Seas, and First Street Flood Factor

[11] Examples include: The Climate Resilience Toolkit, NOAA Digital Coast, Gulf TREE, many IOOS Regional Association portals, and NOAA NowCoast.

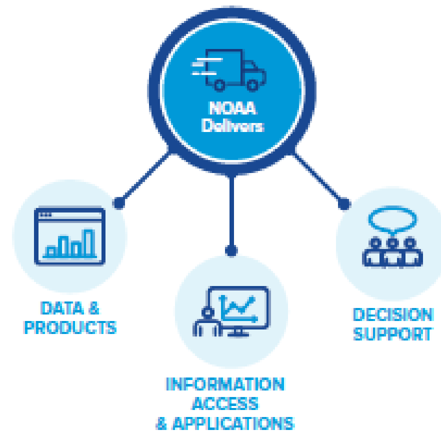
In addition, the curation of authoritative or best available information is not consistent across the existing tool and portal landscape and there is not a “one stop shop” or even a comprehensive directory for coastal inundation information.

In terms of decision-support services, several engagement networks (NOAA Coastal Training Program, Regional Climate Services Centers, Regional Integrated Science and Assessments Program, Sea Grant Extension Programs, etc.) provide service delivery and decision support to practitioners across the country. The National Weather Service (NWS) has a long history of working closely with national, state, local, and tribal emergency-management and other agencies related to disaster management to ensure a planned, coordinated, and effective preparedness and response effort. All of these networks share information and products to help communities identify and implement adaptation strategies. For example, NOAA partners with external engagement networks (e.g., state Sea Grant programs, Coastal Zone Programs, National Estuarine Research Reserves, Integrated Ocean and Coastal Observing Systems programs) and non-governmental organizations (e.g., American Planning Association, Association of State Floodplain Managers, Urban Land Institute) to share web-based products, reports, and online tools. These users require high levels of engagement to provide training on how to use the correct tools as well as how to interpret data to inform decisions.

Gaps

Coastal inundation information for risk identification and amelioration is fragmented and available in many forms through many delivery mechanisms. In addition, the information addresses only certain physical components, time and spatial scales, and geographies. Furthermore, some key factors affecting sea level rise, such as decadal-El Nino, deep ocean heat, and ocean-ice sheet dynamics, are not well-observed or understood. Tools vary across each provider’s mission, stakeholders, and customers, and decision makers and other users are often left to decide which, if any, source of information to use for their applications. No extant tool provides comprehensive, reliable, authoritative data, products, and information regarding future coastal inundation risk while incorporating all key, causative fresh- and saltwater- inundation components across multiple time horizons and spatial scales. Neither is there a comprehensive point of access to these data nor an application that adequately translates science to decision making. To apply integrated water products and information based upon probability and future risk, users need technical and other types of decision support to apply data in meaningful and actionable ways at regional and local levels. NOAA and its partner field-engagement programs lack the resources and abilities to proactively coordinate to fill these gaps. Although collaboration occurs at the state and local levels, it is not always specifically supported across programs and line offices at the federal agency level.

3. ENVISIONED CAPABILITY AND GOALS



To address the broad spectrum of user needs described in Section 2, NOAA envisions a centralized, integrated, and operational framework of data, products, information, and services. This capability will provide authoritative, easily accessible data and products complemented by tools, applications, and decision-support services to improve the Nation's resilience to coastal inundation from climate variability and change. The envisioned capability has three key, integrated service components—***data and products, information access and applications, and decision support***—that are outlined in Table 3.1. More specific 5- and 10-year goals for each of these components are provided below. Although NOAA is proposing this capability, other Federal agencies (NASA, USGS, USACE, NSF, etc.) and academia must play critical roles in supporting the science innovation necessary to develop and sustain the capability. In addition to federal assets, industry will also play an important role in taking what is provided by the federal government and enhancing it with locally-applicable information and approaches tailored to the needs of coastal communities.

These three service components cover the spectrum of end-user needs (as reflected in Table 2.1) and further specify the 'Delivery' portion of the Service Delivery Model (see Figure 2.1) for coastal inundation at climate timescales. Through these three service components, NOAA will provide a nationally-uniform set of data, products, applications, and other information focused on subseasonal to decadal/centennial temporal scales that are meaningful down to the local level. Ultimately, information and services focused on climate timescales will merge and become seamless with shorter, weather timescale coastal inundation information and services. The data, information, and applications will be packaged and disseminated in the context of how users will apply them to their decision-making processes and their capabilities for doing so. In addition to a baseline of information, the envisioned capability will be founded on the principle of meeting customers where they are through a "boots on the ground" capability supported by a network of trusted and engaged community resilience experts. Further, non-governmental partners can build from these NOAA services to create more specific and tailored information and services.

NOAA's Future Coastal Inundation Capability

NOAA's vision for a centralized, integrated, and operational framework of data, products, and information services

	Current Capability	Future Capability
DATA & PRODUCTS	Water prediction at climate timescales either do not exist or are not integrated across the physical drivers of flooding at specific locations and timescales. Information is often provided as point or observations-based data products (i.e., sea level trends at tide gauges) and does not provide the spatial resolution that clearly indicates flood risk across the coastal zone. The Nation needs better regionally and locally consistent predictions for decision makers responsible for community, sector and system-based adaptation and resilience planning and implementation; and partners and intermediate users who want to develop more specific and tailored value-added information and services for individuals and businesses conducting more site specific risk analysis and assessment.	NOAA will work with partners to incorporate the best available science and information into a baseline set of climate timescale coastal flood and inundation prediction data and products at spatial scales meaningful to end users down to the community level. Specifically, NOAA will move to 2-dimensional gridded data and information that support improved spatial and temporal resolution of risk from coastal inundation throughout the coastal zone. This suite of data and products will include improved baseline climatologies, trends and monitoring of long-term change in coastal inundation, subseasonal to annual integrated flood outlooks, decadal to century projections and scenarios of inundation and subsidence, and coastal change outlooks of ocean driven changes in coastal morphology.
INFORMATION ACCESS & APPLICATIONS	Stakeholders are met with significant challenges trying to find water prediction information amongst the disparate landscape of coastal water level products, which often address only certain physical components or are only available on limited time scales. A centralized infrastructure consisting of comprehensive flood prediction and products and services does not exist that both tracks changing conditions, and provides information and tools about coastal flood risk for our Nation. Additionally, information is not often provided through useful and consistent data services that facilitates easy integration into sector or locally-based work processes that facilitates complex decision making.	NOAA will improve access, dissemination, and ease of use of coastal flood risk information by establishing an integrated, centralized and operational cloud and web-based infrastructure that will work in connection with NOAA's "boots on the ground" that support end users and partners. Due to the vast quantities of data that will be produced related to the generation of new flood climatologies, outlooks, projections, and scenarios, NOAA will expand data services, develop additional use cases, and foster public-private partnerships to support integration and use of NOAA data.
DECISION SUPPORT	NOAA has a cadre of communication, education, engagement and extension specialists that support stakeholders with understanding scientific data and information. NOAA also produces a number of tools, applications, training and facilitates regular engagement with stakeholders. Examples include Digital Coast, the Climate Resilience Toolkit, and Impact-Based Decision Support Services (IDSS), with each helping to support core partners such as coastal managers, adaptation practitioners, and emergency managers. An evolving suite of information and decision support services will be needed as water prediction science and technology advances.	NOAA will expand decision support services through engaged, regional capacity building and extension networks. These trusted 'resilience experts' will provide reliable, technical, and science-based information to address local needs, while also transferring user needs back to NOAA. To ensure the services created will continue to meet the Nation's needs, NOAA will expand upon its existing tools and applications, as well as develop next generation tools and visualizations, to help users understand and apply the right types of data and information to their complex decision making needs.

Table 3.1. NOAA's current and future coastal inundation capabilities.

Bounds for the Envisioned Capability

Before describing more detailed 5- and 10-year information and service delivery goals, it is important to state what can and cannot be scientifically and feasibly included in the capability during this timeframe. As discussed above, multiple processes affect coastal inundation at a particular location and time (See Figure 1.1).

A foundation for the capability will be international and national climate-observing, research, modeling, and reporting efforts such as the World Climate Research Programme Coupled Model Intercomparison Project [47], Intergovernmental Panel on Climate Change Assessment Reports [48]), and U.S. Global Change Research Program National Climate Assessments [49].

As NOAA works to develop 'integrated'[12] water at weather timescales, the emphasis has been on continuous, intensive modeling (i.e., NOAA Water Model) of instantaneous contributions of water measurable within basins, which is being coupled to coastal water levels (waves, storm surge, and lake and tide levels). For example, the NOAA Office for Water Prediction has made significant progress in understanding river discharge from the NOAA Water Model that may interact within adjacent estuaries. This capability will help to better understand the interactions of the processes affecting integrated water and to separately model individual components such as river flow and coastal water levels in addition to their joint effects and probabilities.

The envisioned capability for coastal inundation at climate times described here aims to build off of the NOAA Integrated Water Initiative and expand the scope of water prediction to include changes happening at climate timescales, with the goal of merging separate weather and climate efforts into a seamless spectrum of services, science permitting.

The envisioned climate capability will provide products and services on the following timescales:

- baseline climatologies of the mean and variability, including extremes
- variations associated with subseasonal-to-seasonal cycles and year-to-year variations associated with climatic variability such as phases of the El Nino Southern Oscillation
- decadal-to-centennial time projections associated with global atmospheric and ocean heating and cryospheric mass loss

[12]The terms 'Integrated Water Prediction' (IWP) and 'Total Water Level' (TWL) are often used in NOAA forecasting and prediction. In this document, IWP is defined as delivering a suite of more holistic water intelligence products to help communities and industries make better-informed decisions about water management and to better prepare for and respond to extreme water events. IWP specifically brings together the National Weather Service (NWS) and the National Ocean Service (NOS) to transform the nation's water prediction capabilities, particularly at the coast. IWP transforms NOAA's existing water forecasting capability by dramatically improving the density of NOAA's river forecasting models nationwide and combining them with coastal and storm surge models at the coast. IWP will provide new information vital for decision making during high-impact events (e.g., hurricanes, nor'easters, storm surge) and for routine water management (e.g., ecosystem health, low flow, transportation, agriculture). TWL is defined as an above-ground measurement of water level as the result of a combination of factors such as tidal variation, regional oceanographic effects (such as the El Niño-Southern Oscillation), storm surge (including wave setup), local wave action, long-term sea level rise or lake level change, and freshwater input. The term 'Total Water' includes water quality as well as TWL.

With sufficient spatial understanding, probabilities of this variability spanning from the mean to the rare extreme (e.g., regulatory FEMA Base Flood Elevations[13]) of each component as well as their combined effects can be established for U.S. coastlines.

Integrated water-level probabilities continue to be difficult to produce in today's climate, let alone future climates. This is, in part, due to strong trends in mean conditions (e.g., sea level rise), uncertainties in extreme variability, and the integrated sum of changing contributory processes. The challenge to produce probabilities necessitates investment in improved ocean and other types of observations as well as integrated predictions, outlooks, projections, and scenarios that will be the foundational data and products of this capability. Demand for seasonal-to-century-scale predictions and projections for preparedness and longer-term planning is well-established. Information about how sea level rises over the coming seasons, years, and decades will become increasingly important as will changes in variability (e.g., increasing tide range due to increasing sea level; stronger storms with surges occurring over deeper sea levels). This envisioned capability aims to apply statistical and other techniques to understand the joint probability of heavy rains occurring during localized storms and how that might impact extreme events such as those with strong storm surges.

Rising groundwater tables [50] and heavy direct overland rainfall will continue to contribute to localized ponding of water, but their contribution to integrated water prediction needs to be understood and modeled. Thus, for now, we will not attempt to integrate and model these components into our definition of 'integrated water' at climate timescales. NOAA will continue to observe, model, and predict their changes (i.e., NOAA's Precipitation Grand Challenge [51]), and advancements made in precipitation and groundwater prediction will yield material benefits for NOAA's coastal models, products, and services.

Goals of the Envisioned Capability at 5 and 10 Years

Table 3.2 provides more specific capability goals by further categorizing and establishing 5- and 10-year milestones for the three service delivery components: Data and Products, Information Access and Applications, and Decision Support, as discussed above. These aggressive but achievable goals—if properly resourced—address the spectrum of user needs identified in Table 2.1. They also lay the foundation for the development objectives defined in the next section, which NOAA and partners must accomplish to achieve the envisioned capability and thereby improve the Nation's resilience to coastal inundation risks caused by climate variability and change.

[13] FEMA Base flood elevation (BFE): Elevation of surface water resulting from a flood that has a 1% chance of equaling or exceeding that level in any given year. The BFE is shown on the Flood Insurance Rate Map (FIRM) for zones AE, AH, A1–A30, AR, AR/A, AR/AE, AR/A1– A30, AR/AH, AR/AO, V1–V30 and VE

DATA & PRODUCTS TIMESCALES

Current Status	5 Years	10 Years
Baseline Climatologies. Mean and extreme still water level and freshwater (river flow, rainfall) at in situ point observations, via some numerical models and remotely-sensed via satellite altimetry with limited ties to coastal inundation. Mean lake levels in the Great Lakes. Climatologies of waves and water levels are generally at different locations and are different products.	National 2-dimensional (2D) gridded 40-year climatology of still and dynamic still ('still' + wave setup) water levels at 1 kilometer resolution along the coastline and Great Lakes.	National 2D gridded climatology and associated probabilities of integrated total water level (TWL: coupled 'still' water, wave setup, and freshwater input) means and extremes at 100m resolution.
Trends and Monitoring. Real-time and historical sea level and coastal flood information at select water level gauge locations and satellite altimetry. This includes: Long-term sea level change or changes in Great Lake levels and associated inundation (high tide flooding/extremes) assessed at in situ point observations; Land motion assessed via point GNSS observations; Regional and global SLR assessed via in situ observations and satellite altimetry; and minor flood frequency for the previous calendar year at in situ point observations.	National coverage of basic coastal flood monitoring to include reporting of the magnitude and frequency of means and extremes of in situ and remote sensed sea level.	National coverage of enhanced coastal flood monitoring to include reporting of the magnitude and frequency of components and processes affecting relative TWL (e.g., waves, rainfall, rivers) and vertical land motion (VLM) utilizing in situ and remote sensed observations.
Monitoring Patterns and Processes. No real time attribution or analysis of coastal inundation is provided. Some monthly tracking of Great Lake levels are monitored and assessed with precipitation. Analysis of patterns and assessing processes occurs offline and often on an annual basis.	Identification and quantification of primary modes of variability of still and dynamic water levels at in situ gauge locations. Seasonal attribution of processes leading to coastal inundation in the contest of large-scale atmospheric, oceanic and lake modes of variability.	Identification and quantification of primary modes of variability of total water levels at in situ gauge locations and gridded modeled output. Near real-time attribution of processes leading to coastal inundation in the context of large-scale atmospheric, oceanic and lake modes of variability.
National Sub-seasonal Integrated Water Predictions. National 10-day and monthly hydrologic water outlooks, currently not fully coupled with coastal models. Weekly-to-monthly projections of Great Lake levels. Regional outlooks of likely high tide flood days relying on tides and climatologies at in situ gauges (High Tide Bulletin).	2D coastal hydrodynamic models and machine learning/statistical methods are used to predict subseasonal magnitude and frequency of still water coastal inundation. Models are connected to seasonal riverine predictions, including land surface runoff at watershed scale resolutions, to provide sub-seasonal outlooks of coastal inundation.	2D coastal hydrodynamic models utilize hydrologic boundary conditions to predict sub-seasonal integrated total water at 1km resolution. National coverage of sub-seasonal probabilistic coastal inundation includes information on flood magnitude and frequency.
National Sub-seasonal to Seasonal Outlooks. Regional outlooks of likely flood days updated seasonally (High Tide Bulletin, Great Lake levels) and annual (Annual High Tide Flooding Outlook) at in situ gauges. Limited model-based monthly forecasts for some regions.	An integrated monthly-to-annual outlook of the probabilities of coastal inundation, including the likely days and frequency of still water coastal inundation at gauge locations.	An integrated monthly-to-annual outlook of the probabilities of coastal inundation, including the likely days and frequency of TWL coastal inundation at 100m resolution.

DATA & PRODUCTS TIMESCALES

Current Status	5 Years	10 Years
National Decadal to Century Projections/Scenarios. National 1 degree gridded and tide gauge specific sea level rise projections (ocean and vertical land motion component separate). NOAA (2017)/NCA4 global sea level rise scenarios including 1-degree gridded estimates of still water (tide gauge measured) probabilities.	National gridded projections of mean and extreme sea level probabilities, or lake level variability, at 500m resolution along the coast line and Great Lakes out to 2100. Projections will consider changes in relative and global mean sea level or lake level including InSAR measurements of land subsidence but include only climatological variability.	National gridded projections of total water level probabilities at 500m resolution along the coast line and Great Lakes out to 2150. Projections will consider changes in relative and global mean sea level or lake level including InSAR measurements of land subsidence, as well as future changes in extremes, morphology, and the joint probability from river flows and waves.
National Coastal Change Outlooks. Limited to weather scale or event scale coastal change forecasts are disseminated through disparate cross-agency applications.	An operational weekly-to-monthly probabilistic coastal change outlook at 1km resolution along a subsection of national ocean and Great Lakes coastlines.	An operational weekly-to-annual probabilistic coastal change outlook at 1 km resolution along a majority of national ocean and Great Lakes coastlines.

INFORMATION ACCESS & APPLICATIONS TIMESCALES

Current Status	5 Years	10 Years
Integrated, Centralized and Operational Infrastructure. Coastal inundation information is disseminated disparately across different NOAA Line Offices and Program Offices. Some offices have centralized access points within their websites, but these are limited in tools and scope.	Existing coastal inundation applications will include an integrated web-based framework and a prototype dissemination interface with necessary backend infrastructure.	A "one stop" centralized dissemination infrastructure for coastal inundation information. The infrastructure will include a web-based framework with outlooks and applications to provide users and partners baseline data and decision-support information, thus enabling value-added information and services.
Engaged Partners. Current Status. Engagement occurs disparately within specific NOAA Program Offices and partners and limited coordination.	A guiding board of non-governmental partners provides expertise in a wide range of policy and technical issues related to coastal inundation on climate timescales.	A coastal inundation partner engagement framework and capacity which will include regular contact with partners to evaluate existing products and identify new products or improvements to meet user needs.
Accessible, Discoverable and Useful Data and Information Services. Coastal inundation data is inconsistently available through different services and formats. Some data is available through API or GIS services, while others are only available through CSVs, data reports, or are locally stored and not generally accessible.	NOAA Big Data Program to include coastal inundation data services. Identify all existing sources of climate coastal inundation data and develop a uniform and consistent data services framework to enable access to both internal and external data users.	A coastal inundation on climate timescales community of practice of industry and government partners, regularly convened to assess the application of future flood and risk data to their industry and services. Evaluation and measurement of the use of our coastal inundation tools and information.

DECISION SUPPORT TIMESCALES

Current Status	5 Years	10 Years
Next Generation Coastal Inundation Tools and Training. Coastal inundation at climate timescales data and products have not been consistently packaged and/or integrated into existing decision support tools, applications, and training.	A user-needs assessment of the next-generation assemblage of coastal inundation data services, applications, tools, and training to support the sector based decision-making needed from the new data and products capabilities.	A next-generation assemblage of coastal inundation applications, tools, and training informed by new predictions, outlooks and projections at climate timescales to support sector based decision-making.
Regional Capacity Building. Coastal constituents struggle to know where and how to engage with NOAA related to their technical questions and risks associated with regional and local coastal inundation at climate timescales.	Community-based adaptation specialists and extension agent networks are trained on availability and delivery of NOAA coastal inundation tools, products, and services.	A trusted 'boots on the ground' network of experts that provides reliable, technical, and science-based information regarding coastal inundation at climate timescales to address local needs, while also transferring research and data service needs back to improve the existing services.

Table 3.2. NOAA's current coastal inundation capabilities, and projections for 5- and 10-years from now.

4. DEVELOPMENT OBJECTIVES

To develop and implement the integrated system of climate timescale coastal inundation information and services envisioned in Section 3, NOAA, with partners, will need to leverage existing capabilities and make new investments in R&D, research transition, infrastructure, implementation, operations, infrastructure (e.g., high-performance computing), and human resources. As discussed in Section 2, NOAA will use a continuous-user-engagement process (see Figure 2.1 and [22]) to guide, develop, and improve the specifics of its coastal inundation information and services delivery. The envisioned capability in Section 3 is the foundational framework for the 'Delivery' portion of the service improvement model. In this section, capability development objectives in the value chain, leading up to improved service delivery, are presented. Table 4.1 provides a high-level summary of the developmental requirements of the envisioned capability and 5- and 10-year goals presented in Section 3.

Developmental Requirements

High-level developmental requirements necessary to reach NOAA's coastal flooding and inundation capability goals

01 Research and Development, and Transition. A sustained and dedicated physical and social science research and development program shaped by, and responsive to, user and stakeholder needs that continuously delivers the best available science to the widest possible audiences; and a robust process for transitioning proven R&D to operations, applications and other uses.

02 Backbone. A centralized and operational backbone in order to produce reliable, timely, and actionable information based on sound science.

03 Networks. A "boots on the ground" capability of trusted extension and engagement networks that will build upon NOAA's culture of engagement.

04 Engagement. Continuous stakeholder feedback and engagement to improve service delivery and ensure information is used by stakeholders.

05 Partnerships. Cross-sector partnerships and networks to incorporate the best available science.

06 Reference frame. A common spatial reference frame to produce seamless, interoperable and accurate information.

07 Data and products. Authoritative, spatially-enabled climatologies, analyses, outlooks, predictions, projections and scenarios based on cutting-edge models and integrated with other geospatial information (e.g., at-risk or critical infrastructure, ecosystems, economic zones, jurisdictional locations, under-served communities, etc.) to support complex decision making.

08 The Cloud. Cloud-based storage and computing to address high performance computing needs and support community-based solutions.

09 Automation. Artificial intelligence, machine learning and best-state-of-the-science approaches to automate data analysis and processing, improve model capabilities and skill, and create more efficient workflows.

10 Data services. Robust data services to support integration and use of NOAA data.

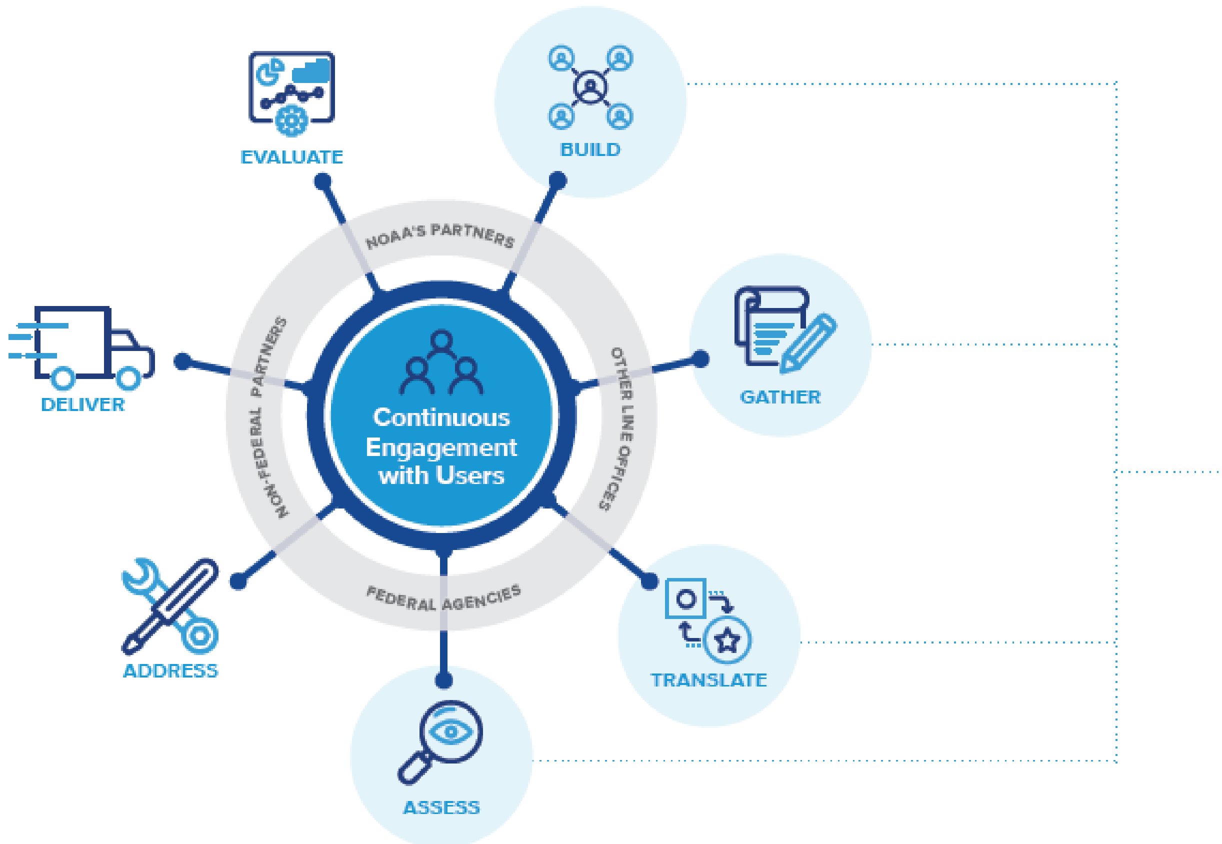
11 Citizen science. Citizen science to stay better connected and promote a more engaged public.

12 Private Industry. Commercialized benefit of our research, observations and modeling such that private industry can create more tailored flood risk products and visualizations.

Table 4.1. Summary of high-level developmental requirements necessary to reach the 5- and 10-year goals for the coastal inundation capability (see Table 3.2) These requirements are dependent on other strategies/initiatives within NOAA, including the Earth Prediction Innovation Center (EPIC), Big Data Program, Precipitation Grand Challenge, Citizen Science Strategy, Artificial Intelligence Strategy, and Blue Economy Strategic Plan.

The Detailed Development Objectives (see Appendix C) provides specific sets of objectives for each of the twelve information and service goals in Table 3.2. These objectives are summarized below across the twelve goals and organized under the service delivery improvement model categories depicted in Figure 2.1 and further discussed [22]. These categories have been tailored and explained in the context of the envisioned coastal-inundation-at-climate-timescales capability.

Capability Development Objectives and Actions



BUILD, GATHER, TRANSLATE AND ASSESS

Build trusted relationships; gather user needs and understand them in the context of their decisions; review and translate into the capacities needed to respond; assess and prioritize product and service development.

OBJECTIVES AND ACTIONS:

- Involve current partnerships across NOAA to include both internal and external collaborators in planning.
- Build new trusted relationships around coastal inundation risk and create an environment to learn how to address it better as partners interact regularly.
- Support a social environment around human learning that relates to NOAA's coastal flooding data and services.
- Continuously invest in engagement within NOAA and with external users and partners to fully understand the use of coastal inundation information and the scope of information needs.
- Develop data use cases about how to apply data and outlooks to specific applications and decision making.
- Establish an inundation at climate time scales community of practice around NOAA's data and services.
- Support partners in making connections around NOAA data and enhance practice of coastal risk management
- Translate user needs into technical aspects NOAA and partners will use to make decisions for mission improvement or enhancement.
- Develop key partnerships in the effort for co-development/production of risk based that could be available through the centralized web-interface and dissemination framework.
- Ensure a pathway for partner needs and information gaps are identified and shared across NOAA
- Assess needs against NOAA and partner mandates and missions, applicability and alignment with priorities, urgency and other criteria. Build trusted relationships around a shared concern and create an environment to learn how to do it better as partners interact regularly.
- Support a social environment around human learning that relates to NOAA's data and services.

ADDRESS

In order to address user needs with new and improved data, products, and other coastal flooding and inundation information, it will be necessary to:

Sustain, Enhance and Exploit Observations

Data are required to observe, monitor, analyze, model, forecast, and evaluate coastal inundation information, refreshed with appropriate frequency. Observation analysis is required to aggregate data to provide real-time situational and climatological awareness to predict and project coastal inundation in the coastal zone.

OBJECTIVES AND ACTIONS:

- Increase the coverage of NOAA and partner in situ riverine, Great Lakes and coastal water level and wave observations and co-locate with rain and groundwater observations.
- Improve satellite altimetry to better enable nearshore and estuarine coverage and monitor sea level anomalies.
- Improve our ability to observe and monitor important climate indices such as ENSO and AMOC.
- Regularly capture current ground conditions from LIDAR or satellite remote sensing for changes in land-use conditions and movement.
- Improve remote sensed (e.g. land-based cameras, satellite, UxS) observations of flooding on land.
- Improve data collection that enhances coupled data assimilation to support modeling skill assessment.
- Improve global observations of ocean temperatures, including deep ocean, that drive steric sea level changes.
- Improve observations of changes in glaciers and other land-based reservoirs of ice.

Perform Physical Science Research and Development

Improve the understanding of coupled — ocean, climate, land, hydrologic, hydrodynamic, wave — contributions to mean and extreme total water level. Improve the understanding of key physical processes that are drivers of coastal inundation and sea-level changes and incorporate this knowledge into the next versions of the modeling systems. Future modeling systems include physical processes affecting water levels and variations in topography, bathymetry, and land cover.

OBJECTIVES AND ACTIONS:

- Improve our understanding of coupled (still, waves, freshwater) contributions to mean and extreme TWL.
- Improve the understanding of atmospheric, oceanic, and cryospheric drivers on sea level rise, including ocean heat uptake, the interactions between the oceans and ice-sheet dynamics, and the rate and impact of glacial and land-based ice melt on sea level change.
- Identify sources of predictability from processes (e.g., storm surge, wave runup and swash, precipitation, river discharge) or climate phenomena (e.g., ENSO, AMOC, tropical cyclones, etc.).
- Understand the ocean and Great Lakes response to climate change (e.g., rate of ocean/lake heat uptake, dynamical response warming, develop forcing scenarios that feed into the probabilistic projections).
- Determine impact-based flood thresholds that depend on the exposure coastal infrastructure.
- Improve our understanding of how large-scale ocean/atmosphere variability drives changes in coastal water level at high resolution.
- Determine the approach and technologies for creating seasonal to annual flood products in the Great Lakes.
- Understand the changing frequency of hurricanes, tropical cyclones and storms in future climate scenarios.
- Understand vertical land motion and how it will change in the future.
- Work across user groups to determine important critical thresholds for planning and design and incorporate historical and future projections relative to them in tools.

Perform and Apply Social Science Research.

Better understand user needs, especially of historically underserved and climate vulnerable communities. Improve understanding of how users learn and incorporate new information into their decision making and how to inform behavior changes. Value ecosystem services and develop other economic data to assess with communities the economic impact of future inundation risk, as well as the costs and benefits of potential adaptation strategies. Build on improved understanding about what creates a resilient community to develop quantifiable resilience measures.

OBJECTIVES AND ACTIONS:

- Better understand how to communicate and visualize climatological information to users and stakeholders.
- Understand how to communicate probabilistic forecasts or outlooks to specific audiences.
- Understand secondary and tertiary indicators explaining socio-economic effects.
- Understand how crowdsourced information can connect to prediction/outlook products to ensure impact based decision making.
- Understand what external groups need related to robust geospatial and API data services that enable users and stakeholders to access outputs and integrate into their local products.
- Understand how to communicate combined scenario and event-based sea level projections.
- Establish needs assessments and use cases for coastal change outlook products.
- Conduct needs assessments across the users groups / sectors for next-generation tools, applications, and training.
- Survey users about how they perceive climate

Figure 4.1. Summary of NOAA's detailed development objectives.

5. NEXT STEPS AND RECOMMENDATIONS

This white paper describes an aspirational NOAA capability that would holistically improve community-level coastal resilience against the increasing threats of inundation in our warming climate. To make the envisioned comprehensive suite of coastal-resilience services a reality, the following steps are recommended:

- Establish a Program Management Structure. It is essential to define and establish a program management structure to oversee the planning, development, implementation, product and service delivery, and ongoing R&D needed to sustain the capability to ensure coordinated NOAA and partner roles and responsibilities, effective resource allocation/alignment, and accountability. The coordination role will be especially important because of the number of NOAA and partner programs that currently provide information on sea level rise and coastal inundation. The following diagram outlines a recommended program management concept for the NOAA Coastal Flooding and Inundation at Climate Timescales capability based upon an integrated system framework composed of three functional components: 1) Research and Science, 2) Operations and Infrastructure, and 3) Engagement and Extension.

- Conducts interdisciplinary, user-inspired, and regionally relevant research
- Develops/maintains long time-series indicators of inundation variability and change.
- Runs/develops/validates models to produce scientific hind casts and predictions about future water conditions
- Manages and funds competitive and high-priority inundation research and development objectives

- Disseminates scientific predictions about future water conditions
- Provides data and information products at regular and expected intervals
- Develops and provides decision-support and geospatial resources
- Supports program IT and dissemination infrastructure

- Evolves the continuous service delivery pipeline based on social science
- Conducts capacity building and identifies user needs
- Transfers knowledge through training, tools, and products
- Delivers requirements to research and operations

- Pursue a Partnership Approach. A whole-of-government approach is required to combat the increasing risks of coastal inundation. Coordinated federal science, partnered with local government insight and private sector and academic innovation and resources, is the only way to effectively address this complex and increasingly urgent issue in ways that are both locally and nationally relevant. NOAA should engage with federal partner agencies on the envisioned capability; federal buy-in and alignment of resources and activities will ensure that the needs of local communities are addressed.
- Develop Implementation Plans. Implementation planning is important to ensure that the capability goals and objectives outlined in this white paper become actionable. In particular, the implementation plans should outline the tasks, timelines, and personnel and budgetary resources needed to meet the goals. In addition, organizational and resource planning should be conducted to promote effective change management that impacts high-level processes and culture down to individual roles.
- Inform Federal Policymakers. In 2020, NOAA was directed by Congress to provide two reports related to this white paper: "*Improving Understanding of Coastal Flood Risk Including Impacts of Sea Level Rise*" and "*Coastal Flood Risk Prediction and Resilience Research and Development Plan.*" NOAA should proactively seek opportunities to further engage and educate Congress on coastal inundation risks in our warming climate, highlight the gaps and capabilities needed to improve coastal resilience, and report out on progress made with any initial investments.
- Inform the Federal Budget Process. A significant gap in resources exists between what would be needed to create and sustain the envisioned capability and those resources currently available within NOAA. NOAA should proactively develop budget initiatives across Line Offices to support and sustain the R&D, infrastructure (e.g., high-performance computing), and product and service development and delivery.
- Inform Federal Policies. Congressional authorization of a program is necessary to establish statutory authorities and to gain stable, multi-year congressional authorizations that will properly support the program. Similar to the National Integrated Drought Information System (NIDIS) program [52], NOAA should seek authorization by Congress and establish an interagency mandate to coordinate coastal inundation research and information. The interagency mandate would be important to ensure that interagency collaborative arrangements can be developed to coordinate activities, transition research into operations and applications by NOAA, and encourage co-development of decision-support services.

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APPENDIX B: NOAA MANDATES TO CONDUCT RESEARCH AND PRODUCE COASTAL PRODUCTS AND SERVICES

- Public Law 115-25, Weather Research and Forecasting Innovation Act
- Public Law 111-11, Integrated Coastal and Ocean Observation Act
- Public Law 92-583, Coastal Zone Management Act of 1972
- NOAA Strategic Priority of Reducing Risks of Extreme Weather and Water
- Executive Order 13840 on Ocean Policy
- Executive Order 13990 on Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis
- Ocean and Coastal Mapping Integration Act (33 U.S.C. §§ 3501 – 3507)
- Science and Technology for America's Oceans: A Decadal Vision, November 2018
- Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act. - requires NOAA to produce detailed "post-storm assessments" in the aftermath of a damaging tropical cyclone that strikes the U.S. or its territories
- Weather Service Organic Act 15 U.S.C. § 313
- National Climate Program Act15 U.S.C. § 2901 et seq.
- Global Change Research Act15 U.S.C. §§ 2931 et seq.
- Flood Control/River Forecasting Authority33 U.S.C. § 706
- Provision of Data for Navigation of Marine, Air Commerce and Research into Geophysical Sciences 33 U.S.C. §§ 883a-e, & I
- National Sea Grant College Program Act 33 U.S.C. § 1121 et seq.
- America COMPETES Act 33 U.S.C. §§ 893, 893a & 893b

APPENDIX C: DETAILED COASTAL FLOODING AND INUNDATION INFORMATION AND SERVICES AT CLIMATE TIMESCALE CAPABILITY DEVELOPMENT OBJECTIVES

This document supplements the "A NOAA Capability for Coastal Flooding and Inundation Information and Services at Climate Timescales to Reduce Risk and Improve Resilience" White Paper. It provides sets of development objectives (i.e., the improvements needed) to reach the envisioned capability's 5- and 10-year goals, which are listed in Table 3.2 of the White Paper. The objectives are organized according to pertinent categories of the service-delivery model and value chain discussed in the White Paper. For these improvements to occur, NOAA will need to leverage existing capabilities and make new investments in R&D, research transition, infrastructure, implementation, and operations, which will be further detailed in follow-on plans.

DATA & PRODUCTS TIMESCALES

Baseline Climatologies

Current Status	5 Years	10 Years
Mean and extreme still water level and freshwater (river flow, rainfall) at in situ point observations, via some numerical models and remotely-sensed via satellite altimetry with limited ties to coastal inundation. Mean lake levels in the Great Lakes. Climatologies of waves and water levels are generally at different locations and are different products.	National 2-dimensional (2D) gridded 40-year climatology of still and dynamic still ('still' + wave setup) water levels at 1 kilometer resolution along the coastline and Great Lakes.	National 2D gridded climatology and associated probabilities of integrated total water level (TWL: coupled 'still' water, wave setup, and freshwater input) means and extremes at 100m resolution.

Areas Requiring Improvements to Reach the Envisioned Capability	
Observations	• Increase in situ ocean observations of deep ocean heat and decadal process (i.e., AMOC) to constrain models • Increase the coverage of NOAA and partner in situ coastal water-level and wave observations to support model skill assessment • Improve the resolution of satellite altimetry to better enable nearshore and estuarine coverage
Physical Science Research and Development	• Expand understanding of coupled (still, waves, freshwater) contributions to mean and extreme TWL

Social Science Research and Applications	• Improve communication and visualization of climatological information to meet users' and stakeholders' needs
Modeling Systems (including numerical/statistical)	• Enhance models of coastal still and dynamic TWL through improved model physics, data assimilation, and AI and machine-learning techniques • Improve models of statistical distributions of TWL including associated extremes • Reanalyze and regularly update high-resolution, 40-year, coastal U.S. baseline data models
Information Access	• Establish the cloud infrastructure necessary to store and provide access to the underlying model reanalysis and to perform analysis and product development • Develop the geospatial and API interfaces to enable users and stakeholders to access climatology, mean, and extreme TWL information • Create a public-facing mapping and visualization product of climatology, mean, and extreme TWL information

DATA & PRODUCTS TIMESCALES

Trends and Monitoring

Current Status	5 Years	10 Years
Real-time and historical sea level and coastal flood information at select water level gauge locations and satellite altimetry. This includes: Long-term sea level change or changes in Great Lake levels and associated inundation (high tide flooding/extremes) assessed at in situ point observations; Land motion assessed via point GNSS observations; Regional and global SLR assessed via in situ observations and satellite altimetry; and minor flood frequency for the previous calendar year at in situ point observations.	National coverage of basic coastal flood monitoring to include reporting of the magnitude and frequency of means and extremes of in situ and remote sensed sea level.	National coverage of enhanced coastal flood monitoring to include reporting of the magnitude and frequency of components and processes affecting relative TWL (e.g., waves, rainfall, rivers) and vertical land motion (VLM) utilizing in situ and remote sensed observations.

Areas Requiring Improvements to Reach the Envisioned Capability	
Observations	• Generate summary statistics of hourly SWL including maximum and minimum elevations (tides and non-tidal residuals) observed in NOS tide stations • Gather daily counts of water levels above the NOS/NWS minimum calibrated flood threshold at those same stations • Create regional maps of the mean sea level anomaly (MSLA) based upon data from satellite altimeters. • Compare all information to climatology to provide context and illuminate exceptional conditions across a given region
Physical Science Research and Development	• Improve attribution of changes in global mean sea level to regional sea level rise • Develop improved coastal flood threshold definitions • In situ ocean heat and ice sheet monitoring and satellite altimetry contributions

Social Science Research and Applications	• Explain effects of secondary and tertiary indicators at the socioeconomic level
Information Access	• Modify and repackage extant products • Generate visual aids such as tide calendars to easily identify days of the month when water levels are expected to be exceptionally high or low at any given tide station location
Other (e.g., Production)	• Establish coastal inundation branding similar to what already exists for drought in the form of NIDIS (drought.gov) and for coral bleaching in the form CRW (coralreefwatch.noaa.gov)to strengthen cross-NOAA connections and harmonize complementary activities related to coastal inundation • Generate national-level monitoring and reporting to oversee the creation and maintenance of a more extensive set of regionally-relevant coastal inundation indices and impacts indicators that catalog the location, frequency, magnitude, and duration of coastal inundation events (means and extremes) and their impacts

DATA & PRODUCTS TIMESCALES

Monitoring Patterns and Processes

Current Status	5 Years	10 Years
No real time attribution or analysis of coastal inundation is provided. Some monthly tracking of Great Lake levels are monitored and assessed with precipitation. Analysis of patterns and assessing processes occurs offline and often on an annual basis.	Identification and quantification of primary modes of variability of still and dynamic water levels at in situ gauge locations. Seasonal attribution of processes leading to coastal inundation in the contest of large-scale atmospheric, oceanic and lake modes of variability.	Identification and quantification of primary modes of variability of total water levels at in situ gauge locations and gridded modeled output. Near real-time attribution of processes leading to coastal inundation in the context of large-scale atmospheric, oceanic and lake modes of variability.

Areas Requiring Improvements to Reach the Envisioned Capability	
Observations	• Increase measurement of global ocean temperatures—including deep ocean—that drive steric sea-level changes (i.e., sea-level trends) • Increase measurement of the Atlantic Meridional Overturning Circulation (AMOC), a driver of coastal inundation in the U.S. East and Northeast coasts • Enhance measurements from satellite altimeter and TAO arrays following TPOS 2020 recommendations related to El Niño/La Niña, a driver of coastal inundation in the Pacific Region • Capture measurements of current ground conditions from LIDAR or satellite remote sensing for changes in land-use conditions and movement • Analyze observational records to determine linkages, processes, and mechanisms of coastal inundation • Expand the national network of tide gauges to validate high-resolution predictions and forecasts and make them more reliable • Improve data collection and enhance coupled data assimilation
Physical Science Research and Development	• Enhance coupled data assimilation and improve data collection to monitor physical processes that lead to pattern changes that drive realtime inundation

	• Understand and model process combinations that generate TWL among regions • Understand the ocean and Great Lakes response to climate change (e.g., rate of ocean/lake heat uptake, dynamical response warming, develop forcing scenarios that feed into the probabilistic projections) • Research best approaches such as the sufficiency of 2D models, especially at 1 km resolution • Improve the understanding of cryospheric, oceanic and atmospheric drivers of sea-level rise, and use them to improve future sea-level predictions, projections, and associated estimations of uncertainty • Identify sources of process predictability (e.g., storm surge, wave runup and swash, precipitation, river discharge) or climate phenomena (e.g., ENSO, AMOC, tropical cyclones, etc.)
Social Science Research and Applications	• Communicate probabilistic forecasts to stakeholders and the general public
Modeling Systems (including numerical/statistical)	• Understand how large-scale ocean/atmosphere variability—especially the fraction of variability that is predictable on these timescales—drives coastal inundation at a fine scale • Develop high-resolution coupled ocean models (10km or finer) to adequately resolve coastal processes • Develop dynamic coupling of global climate models with hydrodynamic models including the Great Lakes • Advance NOAA's regional modeling systems (e.g., regional MOM6)
Information Access	• Provide remote, cloud-based access to large datasets • Generate tools that go well beyond the usual data visualization, such as for climate diagnostic analysis • Design tools with the input of IT personnel and data scientists as well as climate scientists and coastal oceanographers
Other (e.g., Production)	• Significantly increase computing capability/HPC/data storage to handle high-resolution models

DATA & PRODUCTS TIMESCALES

National Sub-seasonal Integrated Water Predictions

Current Status	5 Years	10 Years
National 10-day and monthly hydrologic water outlooks, currently not fully coupled with coastal models. Weekly-to-monthly projections of Great Lake levels. Regional outlooks of likely high tide flood days relying on tides and climatologies at in situ gauges (High Tide Bulletin).	2D coastal hydrodynamic models and machine learning/statistical methods are used to predict subseasonal magnitude and frequency of still water coastal inundation. Models are connected to seasonal riverine predictions, including land surface runoff at watershed scale resolutions, to provide sub-seasonal outlooks of coastal inundation.	2D coastal hydrodynamic models utilize hydrologic boundary conditions to predict sub-seasonal integrated total water at 1km resolution. National coverage of sub-seasonal probabilistic coastal inundation includes information on flood magnitude and frequency.

Areas Requiring Improvements to Reach the Envisioned Capability	
Observations	• Expand the coverage of NOAA and partner in situ networks of riverine and coastal water level (still water) and wave observations to validate high-resolution predictions and forecasts and to increase reliability • Capture regular topo/bathy data at the land-water interface with LIDAR and/or satellite remote sensing that include changes in land-use conditions • Gather remote-sensed (e.g., cameras, satellite) observations of flooding on land • Improve data collection that enhances coupled data assimilation to support modeling skill assessment
Physical Science Research and Development	• Analyze observational records to determine linkages, processes, mechanisms, and impacts of coastal inundation and to better understand large-scale ocean/atmosphere variability that drives changes in the coastal environment • Determine impact-based inundation thresholds that depend on coastal infrastructure exposure • Understand and model of process combinations that generate TWL among regions to improve

	understanding of coupled (still, waves, freshwater) contributions to mean and extreme TWL ● Understand the ocean and Great Lakes response to climate change (e.g., rate of ocean/lake heat uptake, dynamical response warming, develop forcing scenarios that feed into the probabilistic projections) ● Research best approaches such as whether 2D models are sufficient or if 3D is necessary, especially at 1 km resolution ● Improve understanding of atmospheric and oceanic drivers of sea level rise and use them to improve future sea level predictions, projections, and associated estimations of uncertainty ● Identify sources of process predictability (e.g., storm surge, wave runup and swash, precipitation, river discharge) or climate phenomena (e.g., ENSO, AMOC, tropical cyclones, etc.)
Social Science Research and Applications	● Understand users' needs around products and information delivery ● Understand how crowdsourced information can connect to prediction/outlook products to ensure impact-based decision making ● Understand what external groups need related to robust geospatial and API data services to access and integrate outputs into their local products ● Understand how to communicate probabilistic inundation forecasts/outlooks to specific audiences through risk communication best practices
Modeling Systems (including numerical/statistical)	● Further develop of high-resolution coupled ocean models (10km or finer) to adequately resolve coastal processes ● Develop dynamic coupling of global climate models with hydrodynamic coastal models including the Great Lakes ● Advance NOAA's regional modeling systems (e.g., regional MOM6) ● Develop dynamic coupling of hydrologic models (including both riverine and precipitation inputs) to coastal models and improved data assimilation to understand the physical processes leading to prediction of the frequency and magnitude of

	integrated coastal inundation prediction beyond 10 days
Information Access	● Enhance hydrologic models and riverine/precipitation data analysis to run remotely at the National Water Center ● Integrate precipitation, riverine, coastal, and ocean models in the cloud ● Improve product delivery and data visualization of integrated water prediction at climate timescales consistent with the product line being produced at the OWP at weather timeframes ● Generate will require cross- office, integrated teams and IT solutions to create consistent water predictions at weather and climate timeframes ● Develop robust geospatial and API data services that enable users and stakeholders to access model output and downstream hindcast and forecast predictions
Other (e.g., Production)	● Increase computing capability/HPC/data storage to handle high-resolution models ● Develop systems to provide community and external modeling solutions and reanalysis outside of NOAA

DATA & PRODUCTS TIMESCALES

National Sub-seasonal to Seasonal Outlooks

Current Status	5 Years	10 Years
Regional outlooks of likely flood days updated seasonally (High Tide Bulletin, Great Lake levels) and annual (Annual High Tide Flooding Outlook) at in situ gauges. Limited model-based monthly forecasts for some regions.	An integrated monthly-to-annual outlook of the probabilities of coastal inundation, including the likely days and frequency of still water coastal inundation at gauge locations.	An integrated monthly-to-annual outlook of the probabilities of coastal inundation, including the likely days and frequency of TWL coastal inundation at 100m resolution.

Areas Requiring Improvements to Reach the Envisioned Capability	
Observations	• Increase coverage of NOAA and partner in situ coastal water-level and wave observations to support model skill assessment • Improve satellite altimetry resolution to better enable nearshore and estuarine coverage • Improve remote-sensed (e.g., cameras, satellite) observations of flooding on land
Physical Science Research and Development	• Determine impact-based inundation thresholds that depend on the exposure of coastal infrastructure • Improve understanding of coupled (still, waves, freshwater) contributions to mean and extreme TWL • Improve understanding of how large-scale ocean/atmosphere variability (especially the fraction of variability that is predictable on S2S timescales) drives changes in coastal water level at high resolution • Determine the approach and technologies for creating seasonal-to-annual flood products in the Great Lakes to analyze the factors that affect lake-wide average levels at those timescales
Social Science Research and Applications	• Understand how to communicate probabilistic forecasts to the general public

Modeling Systems (including numerical/statistical)	• Improve models of coastal, still, dynamic TWL at S2S timescales through improved model physics, data assimilation, and AI/ML techniques • Improve accuracy of statistical distributions of TWL including associated extremes • Develop S2S coupled atmosphere/ocean prediction systems • Increase coupled model resolution to be fine enough to adequately resolve coastal processes • Downscale coarser climate or global model output to high-coastal resolution or force high-resolution coastal ocean models and determine how to optimally couple these modeling systems • Gather a substantial model hindcast database to assess skill of different models, approaches, and ensembles
Information Access	• Create cloud-based, big-data infrastructure to enable storage and access of model reanalysis, hindcast, and forecast data • Develop geospatial and API interfaces to enable users and stakeholders to access model output and downstream hindcast and forecast predictions • Create a public-facing mapping and visualization product of S2S inundation forecasts
Other (e.g., Production)	• Build HPC resources to develop and run higher-resolution prediction systems and multiple ensemble members

DATA & PRODUCTS TIMESCALES

National Decadal to Century Projections/Scenarios

Current Status	5 Years	10 Years
National 1 degree gridded and tide gauge specific sea level rise projections (ocean and vertical land motion component separate). NOAA (2017)/NCA4 global sea level rise scenarios including 1-degree gridded estimates of still water (tide gauge measured) probabilities.	National gridded projections of mean and extreme sea level probabilities, or lake level variability, at 500m resolution along the coast line and Great Lakes out to 2100. Projections will consider changes in relative and global mean sea level or lake level including InSAR measurements of land subsidence but include only climatological variability.	National gridded projections of total water level probabilities at 500m resolution along the coast line and Great Lakes out to 2150. Projections will consider changes in relative and global mean sea level or lake level including InSAR measurements of land subsidence, as well as future changes in extremes, morphology, and the joint probability from river flows and waves.

Areas Requiring Improvements to Reach the Envisioned Capability

Observations

- Gather observations of global ocean temperatures, including deep ocean, that drive steric sea-level changes (i.e., sea-level trends)
- Gather observations of changes in glaciers and other land-based reservoirs of ice
- Gather observations of the Atlantic Meridional Overturning Circulation (AMOC), a driver of coastal inundation in the U.S. East and Northeast coasts
- Enhance measurements from satellite altimeter and TAO arrays following TPOS 2020 recommendations related to El Niño/La Niña, a driver of coastal inundation in the Pacific Region
- Gather simultaneous measurements of variability along the coasts in water level, waves, and major rivers
- Gather measurements of ground elevations from LIDAR and vertical land motion from satellite remote-sensed estimates
- Gather simultaneous observations of river, wave, rain, and groundwater to assess joint probabilities between processes

Physical Science Research and Development	● Understand how future patterns of change in variability (e.g., tide range, storm characteristics, storm surge, and wave behavior on top of higher sea levels) ● Understand sources of ocean heat uptake and the dynamical ocean response to warming ● Understand generational differences in the underlying ocean models and forcing scenarios that feed into probabilistic scenarios ● Understand the rate and impact of glacial and land-based ice melt, including ocean-ice interactions, on sea level ● Reduce uncertainty of projections of future glacial and land-based ice melt ● Understand the changing frequency of hurricanes, tropical cyclones, and storms in future climate scenarios ● Understand vertical land motion and how it will change in the future
Social Science Research and Applications	● Understand and communicate future scenarios of combination risks such as increased sea level (i.e., trend) plus episodic events like storm surge and a stalled extreme precipitation event ● Understand and communicate future scenarios of increased sea level (i.e., trend) plus a high-risk, low-probability event such as a Category 5 hurricane or tsunami flooding
Modeling Systems (including numerical/statistical)	● Develop high-resolution ocean models (10km or finer) to support the move to higher-resolution probabilities ● Develop dynamic coupling of global climate models with hydrodynamic models including large lakes ● Improve climate modeling with embedded models of the Great Lakes to assess likely outcomes ranges over climate timescales ● Accelerate improvements to NOAA's climate models to create an Earth system prediction system that leads to robust and confident climate change projections, including the effects of dynamically coupled ice-sheets ● Improve modeling of vertical land movement to include in models of future coastal inundation

Information Access	• Determine criteria to generate probabilistic models of change patterns for Great Lakes regions • Transition modelling technology to an enterprise partner
Other (e.g., Production)	• Increase computing capability to handle high-resolution models • Increase existing modeling infrastructure resources to configure the models differently to address coastal inundation

DATA & PRODUCTS TIMESCALES

National Coastal Change Outlooks

Current Status	5 Years	10 Years
Limited to weather scale or event scale coastal change forecasts are disseminated through disparate cross-agency applications.	An operational weekly-to-monthly probabilistic coastal change outlook at 1km resolution along a subsection of national ocean and Great Lakes coastlines.	An operational weekly-to-annual probabilistic coastal change outlook at 1 km resolution along a majority of national ocean and Great Lakes coastlines.

Areas Requiring Improvements to Reach the Envisioned Capability	
Observations	• Gather partner data to conduct short-term observations for wave validation • Increase ocean/coastal/Great Lakes observations to resolve nearshore waves/water level/water quality issues, focusing on open coast locations • Improve technology related to remote sensing (camera systems) and traditional gauges and develop low-cost in-situ technology • Generate and support partnerships to gather and verify high-resolution and -accuracy data with annual baselines on coastal elevations and land cover using LIDAR, satellites, and low-elevation imagery
Physical Science Research and Development	• Coordinate across and leverage existing NOAA and other agency activities and modeling efforts of coupled wave/coastal models • Develop models in a coupling framework, preferably via NEMS/CMEPS caps as is currently the case for ADCIRC (ESTOFS system), WW3 (waves), and NWM (within COASTAL Act) • Disseminate forecast guidance through a single, holistic system • Connect open-coast TWL forecast tool and estuarine/back bay shoreline
Social Science Research and Applications	• Generate needs assessments and use cases for coastal change outlook products

Modeling Systems (including numerical/statistical)	● Create 2-D models of surface of TWL forecast transects for developing inundation extent/depth grids/polygons used for depth/damage estimates to infrastructure ● Map NOS high tide flooding thresholds (minor, moderate, major; minor mapped) ● Map NWS coastal flooding thresholds (minor, moderate, major; Eastern region mapped)
Information Access	● Develop a new coastal change outlooks decision-support tool/integrated user interface based upon gathered user requirements for output and housing in nowCOAST or initially in the NOS testbed
Other (e.g., Production)	● Determine which format best supports the transition of data/information into NOAA and the climate timescales integrated framework

INFORMATION ACCESS & APPLICATIONS TIMESCALES

Engaged Partners

Current Status	5 Years	10 Years
Current Status. Engagement occurs disparately within specific NOAA Program Offices and partners and limited coordination.	A guiding board of non-governmental partners provides expertise in a wide range of policy and technical issues related to coastal inundation on climate timescales.	A coastal inundation partner engagement framework and capacity which will include regular contact with partners to evaluate existing products and identify new products or improvements to meet user needs.

Areas Requiring Improvements to Reach the Envisioned Capability	
Service Delivery Framework	● Utilize NOAA Service Delivery and Decision Support Framework in all phases of development to: ○ Build // Building Trusted Relationships ○ Gather // Connecting Lessons about Use of Information with User Needs ○ Translate // Review and Consider NOAA's capacity to respond ○ Assess // Review and Prioritize Product and Service Development ○ Address // Respond to User Needs ○ Deliver // Deliver Products to Users

INFORMATION ACCESS & APPLICATIONS TIMESCALES

Integrated, Centralized and Operational Infrastructure

Current Status	5 Years	10 Years
Coastal inundation information is disseminated disparately across different NOAA Line Offices and Program Offices. Some offices have centralized access points within their websites, but these are limited in tools and scope.	Existing coastal inundation applications will include an integrated web-based framework and a prototype dissemination interface with necessary backend infrastructure.	A "one stop" centralized dissemination infrastructure for coastal inundation information. The infrastructure will include a web-based framework with outlooks and applications to provide users and partners baseline data and decision-support information, thus enabling value-added information and services.

Areas Requiring Improvements to Reach the Envisioned Capability	
Gather	• Develop use cases about data applications and decision making • Create a robust set of data services
Translate	• Develop key partnerships to co-develop/produce risk-based tools and applications available through the centralized web-interface and dissemination framework
Address	• Develop key partnerships to co-develop/produce of risk-based tools and applications to address local user needs

INFORMATION ACCESS & APPLICATIONS TIMESCALES

Accessible, Discoverable and Useful Data and Information Services

Current Status	5 Years	10 Years
Coastal inundation data is inconsistently available through different services and formats. Some data is available through API or GIS services, while others are only available through CSVs, data reports, or are locally stored and not generally accessible.	NOAA Big Data Program to include coastal inundation data services. Identify all existing sources of climate coastal inundation data and develop a uniform and consistent data services framework to enable access to both internal and external data users.	A coastal inundation on climate timescales community of practice of industry and government partners, regularly convened to assess the application of future flood and risk data to their industry and services. Evaluation and measurement of the use of our coastal inundation tools and information.

Areas Requiring Improvements to Reach the Envisioned Capability	
Social Science Research and Applications	• Research user needs
Information Access	• Build a robust set of data services • Provide a variety of access paths and trainings that link to NOAA critical data, information, tools, products, and services
Build	• Build trusted relationships around a shared concern and create an environment to learn how to do it better as partners interact regularly • Support a social environment around human learning that relates to NOAA's data and services
Gather	• Establish an inundation-at-climate-timescales community of practice around NOAA data and services • Support partners in making connections around NOAA data and enhance practice of coastal risk management
Translate	• Identify and share pathways for partner needs and product-use capabilities across NOAA

Deliver	• Build useful, usable, and used tools to provide technical assistance and training and evaluate their use

DECISION SUPPORT TIMESCALES

Next Generation Coastal Inundation Tools and Training

Current Status	5 Years	10 Years
Coastal inundation at climate timescales data and products have not been consistently packaged and/or integrated into existing decision support tools, applications, and training.	A user-needs assessment of the next-generation assemblage of coastal inundation data services, applications, tools, and training to support the sector based decision-making needed from the new data and products capabilities.	A next-generation assemblage of coastal inundation applications, tools, and training informed by new predictions, outlooks and projections at climate timescales to support sector based decision-making.

Areas Requiring Improvements to Reach the Envisioned Capability	
Observations	• Provide access to historical and real-time observations via robust cloud-based data services • Update current ground conditions data (elevation, geodetic control, tidal datums, bathymetry, VLM, groundwater, etc.) to reflect changing conditions (e.g., storm impacts) over time and to enable modeling of future conditions at sufficient temporal and spatial scales • Curate crowd-based, quality-assured observations to fill in gaps in existing observations and to better understand to local impacts (e.g., Cooperative Observer Network)
Physical Science Research and Development	• Coordinate user groups to determine critical thresholds for planning and design and incorporate historical and future projections relative to those thresholds into tools
Social Science Research and Applications	• Conduct needs assessments across the users/groups/sectors for next-generation tools, applications, and training • Survey users about how they perceive climate timescale risk and the best ways to illustrate future risk for efficient decision-making

Modeling Systems (including numerical/statistical)	• Provide statistical trend and frequency analysis that shows non-stationarity where it exists and how that will change return frequencies in the future • Include easy-to-use calculators and what-if scenarios in decision-support tools and applications to enable the user to enter multiple scenarios
Information Access	• Centralize data collection in cloud platforms to enable users to access the entire historical record and customize output for their needs • Provide data services in multiple formats that support open-source and proprietary applications
Other (e.g., Production)	• Coordinate NOAA education and training programs about coastal inundation at climate timescales (e.g.,ater level training, inundation mapping training, geodetic training) • Combine training and curricular efforts into a central training database that allows users to search for needed training • Determine audiences and instructors for training (e.g., private sector, public, academics) • Develop online and in-person trainings for improved access • Develop training curricula on extant coastal inundation resources, how to use them, which ones are for which purposes, which are best for specific needs, and what goes into them • Provide high-touch technical assistance for NOAA users with e assistance at individual local levels, leveraging NOAA's regional network • Develop an in-house NOAA training on coastal inundation for employees and on-the-ground networks so that they have a baseline understanding of the data and product suite • Co-develop data and products with user communities incorporating feedback to constantly improve products

DECISION SUPPORT TIMESCALES

Regional Capacity Building

Current Status	5 Years	10 Years
Coastal constituents struggle to know where and how to engage with NOAA related to their technical questions and risks associated with regional and local coastal inundation at climate timescales.	Community-based adaptation specialists and extension agent networks are trained on availability and delivery of NOAA coastal inundation tools, products, and services.	A trusted 'boots on the ground' network of experts that provides reliable, technical, and science-based information regarding coastal inundation at climate timescales to address local needs, while also transferring research and data service needs back to improve the existing services.

Areas Requiring Improvements to Reach the Envisioned Capability	
Observations	• Survey existing user communities about top needs for capacity building • Monitor and track user interactions “on the ground” and develop metrics for successful implementation
Physical Science Research and Development	• Schedule regular check-ins with regional staff on research and data needs to inform existing and new services
Social Science Research and Applications	• Gather research focused on human behaviors in coastal communities • Track and document use cases for communities using coastal inundation at climate timescale data • Determine if current and future products and services can be understood and used • Share experiences via communities of practice
Modeling Systems (including numerical/statistical)	• Perform social network analysis
Information Access	• Provide examples of how regional communities use NOAA products and services as well as what has hindered them from being used

	• Leverage or develop communities of practice for sharing experiences, work flows, policy steps, risk communication, etc.
Other (e.g., Production)	• Develop an online community for sharing resources, stories, etc. or add to existing access points like Digital Coast or CRT

APPENDIX D: MEMBERSHIP, LISTED ALPHABETICALLY BY LAST NAME

NAME	LINE OFFICE
Allie Allen	NWS
Adrienne Antoine	OAR
Diego Arcas	OAR
Neil Christerson	OAR
Rob Cifelli	OAR
Mary Culver	NOS
LuAnn Dahlman	OAR
Ricardo Domingues	OAR
Greg Dusek	NOS
Jesse Feyen	OAR
Gustavo Goni	OAR
Roger Griffis	NMFS
Robert Hallberg	OAR
Paul Hirschberg	OAR
Blair Holloway	NWS
Fiona Horsfall	NWS
David Kidwell	NOS
John Krasting	OAR
Arun Kumar	NWS

NAME	LINE OFFICE
Eric Leuliette	NESDIS
Sandy Lucas	OAR
Audra Luscher	NOS
John Marra	NESDIS
Doug Marcy	NOS
Emily McGraw	NWS
Summer Morlock	OAR
Edward Myers	NOS
Matt Newman	OAR
Claudia Nierenberg	OAR
Mark Osler	NOS
Roger Pulwarty	OAR
Elizabeth Rohring	OAR
Emily Smith	OAR
William Sweet	NOS
John Ten Hoeve	NWS
Marina Timofeyeva	NWS
Andre Van der Westhuysen	NWS
Darren Wright	NWS

 Steering Committee Member

APPENDIX E: VERSION CONTROL (IN REVERSE CHRONOLOGICAL ORDER)

Changes	Version	Date