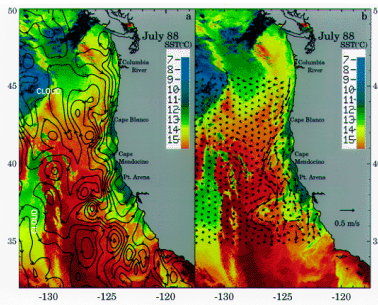# Establishing National Ocean Service Priorities for Estuarine, Coastal, and Ocean Modeling:
Capabilities, Gaps, and Preliminary Prioritization Factors

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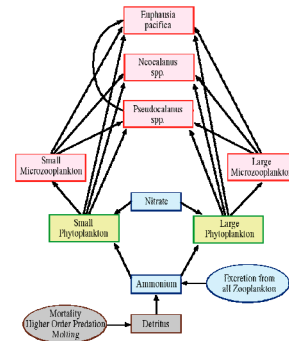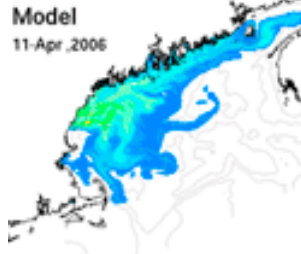**Citation for this Report**

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Establishing National Ocean Service Priorities for Estuarine, Coastal, and Ocean Modeling:
Capabilities, Gaps, and Preliminary Prioritization Factors

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United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
Carlos M. Gutierrez Secretary	Conrad C. Lautenbacher, Jr. Administrator	John H. Dunnigan Assistant Administrator

GOAL OF THIS REPORT

This report was developed to help establish National Ocean Service priorities and chart new directions for research and development of models for estuarine, coastal and ocean ecosystems based on user-driven requirements and supportive of sound coastal management, stewardship, and an ecosystem approach to management.

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EXECUTIVE SUMMARY

The National Oceanic and Atmospheric Administration (NOAA) and National Ocean Service (NOS) Strategic Plans present a vision for protecting, restoring, and managing our nation's aquatic resources through proactive ecosystem approaches to management. These approaches require integrated, multidisciplinary models and coordination across research and modeling activities to provide a sound basis for decision making. For NOS to achieve its mission of providing products, services, and information that promote safe navigation, support coastal communities, sustain marine ecosystems, and mitigate coastal hazards, it must place high priority on *applying existing operational models, transitioning models from research to operations, and developing new models* for estuarine, coastal, and ocean waters. NOS currently provides a suite of models that support coastal management decisions. These models address myriad issues, ranging from tracking oil spills and the movement of harmful algal blooms to predicting water levels, storm surges, and hypoxia. As NOAA moves to integrate its efforts across disciplines and to support regional management, there is a greater need to align modeling efforts across NOS and to fully incorporate stakeholder input into the model development and improvement processes. This document represents an effort to *coordinate approaches to modeling within NOS and with internal and external partners and to bring NOS modeling priorities in line with user communities' requirements.* This report uses four management sectors to represent the breadth of NOS' responsibilities and organize user requirements: Navigation and Commerce, Coastal Hazards, Water Quality and Public Health, and Coastal Habitats. In concordance with the NOAA Requirements-Based Management Process, we have collected and assessed the legal mandates, stakeholder needs, and user requirements and identified longstanding and emerging needs in each of these sectors. The National Centers for Coastal Ocean Science (NCCOS/CSCOR), in conjunction with other NOS offices, has developed this document to identify major management issues requiring modeling support at the federal level; catalog NOS' current capabilities to meet these needs; highlight remaining gaps; and suggest factors to *prioritize future modeling research and development investments*. This document provides a foundation that NOS and its offices can both use now and build on through additional rounds of input from all sectors of the user community. User needs across all four of the management sectors include biological, chemical, ecological, physical, and socioeconomic models and products that can forecast a variety of ecosystem and human-related parameters and that support policy development and management. Overarching needs include:

• Standardized community modeling frameworks
• Integrated models that provide multidisciplinary capabilities
• Improved data access and management
• New approaches to modeling product presentation, documentation, and distribution.

Management information needs (N) that require new or improved modeling approaches include:

N1. Circulation and hydrodynamics
N2. Geomorphology
N3. Constituent transport
N4. Hypoxia
N5. Water quality
N6. Population ecology

N7. Harmful algal blooms (HABs)
N8. Habitat management
N9. Ecosystem change
N10. Human dimensions
N11. Improved decision support tools

We also identify several *modeling approaches* (A) that may prove useful in addressing the above user information needs. Many of these needs are already being partially or wholly addressed within current NOS modeling capabilities, although several needs are not yet being sufficiently met by NOS models. Important modeling methods to address the above user needs include:

A1. Hydrodynamics, including models for 3-D physical circulation and tide, water levels, and coupling coastal and deep ocean circulation
A2. Geomorphology, including sediment transport, subsidence, and coastal change
A3. Transport, including general models and models for chemical loadings, harmful algal blooms, and infectious disease
A4. Population dynamics, including living marine resources, habitat, and trophic transfer
A5. Ecosystem change, including models that integrate climate change scenarios and models that produce hindcasts and trajectories for past and future events
A6. Human dimensions and socioeconomic models
A7. New modeling frameworks, encompassing models in all of the above categories and including linked ecosystem models, models that operate using multiple scales and scenarios, and decision support systems

Table E.1 summarizes the user needs addressed by each of the modeling approaches and details both current NOS capabilities and remaining gaps. These identified capabilities and gaps will inform current and future efforts to prioritize, plan, and budget for research and development that will enhance and expand upon current capabilities.

We suggest six *prioritization factors* (P) for exploring NOS' role in and commitment to developing and operationalizing the above modeling approaches:

P1. Mandate: legislation and executive orders governing NOAA's and NOS' responsibilities
P2. Purview: placement in NOAA and NOS Strategic Plans and Research Plans
P3. Leadership: whether NOS should be in a leading role within NOAA and beyond
P4. Benefits: ability to meet user group and NOS program needs
P5. Investment: level of effort needed to develop the needed capabilities
P6. Time frame: time needed to develop the needed capabilities

For the modeling approaches described above, we suggest a qualitative score (high, medium, or low) for each of the prioritization factors. However, this report does not attempt to rank the various modeling approaches; indeed, many of the approaches received high scores, reinforcing the importance of modeling as a cross-cutting tool for ecosystem approaches to management. Instead, we provide an objective framework that can help link NOS priorities and needs with opportunities to meet those needs through future investments in modeling research and development. The report is a "living document" that will serve as a framework for ongoing identification of users' modeling needs and NOS approaches via presentations, workshops, and surveys of user communities and the NOS modeling community. We anticipate that the report will play an important role in NOS, NOAA, and other partners' continued planning for modeling research and development.

Table E.1. Current NOS modeling capabilities and remaining gaps.

Modeling Approach	User Needs Addressed	Current Capabilities (O = Operational; D = In Development; R = In Research)	Remaining Gaps for Research and Development
A1. Hydrodynamics Including models for 3-D physical circulation and tide, water levels, and coupling coastal and deep ocean circulation	Sediment; Circulation/ hydrodynamics; Constituent transport; Hypoxia; Water quality; Population ecology; HABs; Habitat management; Human activities; Ecosystem change	O: Operational forecast systems (PORTS), VDatum, CATS D: Coastal Storms, Sea level rise, Coupling basin-scale HYCOM to coastal ocean models R: Upwelling prediction Outside NOS: Nesting for ROMS	New locations; Increased access to nowcast/forecast outputs; Accurate 3-D currents; Forecasts for meteorological water level and tidal currents during moderate events; Coupling estuarine and coastal regional models to larger-scale ocean circulation models; Linking watershed models to estuarine and coastal ocean models; Linking hydrodynamic models to ecological models
A2. Geomorphology	Sediment; Constituent transport; Habitat management	O: GEOID06, National Shoreline D: DEMs, Sea level rise	Develop better theory base; Fill gaps in gravity data and fields; Incorporate digital imaging tools and automated feature extraction; Increase available coverage; Reduce/eliminate geometric biases; Improve spatial resolution
A3. Particle transport Including general models and models for chemical loadings, harmful algal blooms, and infectious disease	Sediment; Constituent transport; Water quality; Population ecology; HABs; Human activities	O: GNOME/CATS, Recovery curves, ADIOS, HAB Bulletin D: CBOLT R: 3-D contaminant distribution / transport (short term), Health effects (human, marine mammal) Outside NOS: Particle trajectory (plankton, larval fish), ECOHAB / MERHAB models	Linking particle dynamics (growth, flocculation, sinking, chemical weathering) to hydrodynamics; 3-D transport tracking; Long-term contaminant distribution, transport, and weathering; Improved species-specific HAB models; Long-term exposure risks; Incorporating food web and trophic dynamics; Air dispersion; Linking precipitation, runoff, and non-point sources to beach closures
A4. Population dynamics	Population ecology; Habitat management	Outside NOS: Population dynamics (plankton, larval and juvenile fish), NMFS models	Invasive species introduction and pathways; Models for species of economic or ecological concern; Linking models to environmental variability and water quality; Response to small-scale shocks

Table E.1, cont. Current NOS modeling capabilities and remaining gaps.

Modeling Approach	User Needs Addressed	Current Capabilities (O = Operational; D = In Development; R = In Research)	Remaining Gaps
A5. Ecosystem change Including models that integrate climate change scenarios and models that produce hindcasts and trajectories for past and future events	Constituent transport; Hypoxia; Water quality; Population ecology; HABs; Habitat management; Human activities; Ecosystem change; Decision support tools	D: Sea level rise R: OHH Sentinel Habitat Model Outside NOS: ECOHAB / GLOBEC models	New locations; Modeling additional variables; Applying analyses of historical trends to forecasting future trends
A6. Human dimensions Including socioeconomic models	Sediment; Hypoxia; Population ecology; HABs; Habitat management; Human activities; Decision support tools	R: OHH Conceptual Model	Analyzing impacts of management decisions and ecosystem change on humans; Relationship between human society and the environment
A7. Model improvement Including linked ecosystem models, models that operate using multiple scales and scenarios, and decision support systems	Circulation/hydrodynamics; Hypoxia; Water quality; Population ecology; HABs; Habitat management; Human activities; Ecosystem change; Decision support tools	O: GNOME/CATS/GNOME Analyst, Recovery curves O/R: Habitat equivalency analyses D: Coastal Storms R: HYCOM S. Florida Regional Model, Apalachicola Bay Water Use Outside NOS: Hypoxia models, EcoFore models	Development and integration of models that accommodate multiple media, sources, and paths; Consequences of management strategy interactions; Interfaces that facilitate non-expert interactions with models; Suggested courses of action based on cost-benefit analyses and gaming strategies

Chapter 1: BACKGROUND AND PROCESS

Virtually every service that the National Ocean Service (NOS) provides and every resource management decision it makes or supports depends on and can be improved by having accurate physical, chemical, and ecological predictions of estuarine, coastal, and ocean environments. These predictions can be short-term forecasts of conditions on the order of hours to months or scenarios that estimate the long-term implications of alternative management approaches or significant ecosystem perturbations (e.g., climate change, invasive species). These short-term forecasts and longer-term scenarios provide quantitative data that promote sound decisions for complex management questions faced by federal, state, local, and tribal governments, businesses, and non-governmental organizations. For NOS to achieve its mission of providing products, services, and information that promote safe navigation, support coastal communities, sustain marine ecosystems, and mitigate coastal hazards,[1] it must place high priority on applying existing models and developing new models to forecast future conditions in estuarine, coastal, and ocean waters. In recognition of this important role, NOS has embarked on the strategic process outlined herein to enhance existing capabilities and develop new, state-of-the-art modeling tools that support proactive decision making by coastal managers through model forecasts and scenarios. These priorities will be driven by the needs of the individuals and institutions that are most directly responsible for making decisions and implementing actions that impact the condition of estuarine, coastal, and ocean waters.

Ecosystem Approach and the NOAA/NOS Strategic Plan
Enhanced predictive capabilities are essential to improve coastal and resource management. The National Oceanic and Atmospheric Administration (NOAA) and NOS Strategic Plans present a vision for the protection, restoration, and management of our nation's estuarine, coastal, and ocean resources through proactive ecosystem approaches to management.[2] All four of the NOAA and NOS mission goals (Ecosystems, Climate, Weather and Water, and Commerce and Transportation) depend on modeling capabilities and advances. Ecosystem approaches to management require a suite of integrated, multidisciplinary models and coordination across many NOS research and modeling activities to provide a sound scientific basis for decision making.

NOS currently provides a suite of models that support coastal management decisions. These models address myriad issues, ranging from tracking oil spills and the movement of harmful algal blooms to predicting water levels, storm surges, and hypoxia. As NOAA moves to integrate its efforts across disciplines and to support regional management, there is a greater need to align modeling efforts across NOS and to fully incorporate stakeholder input into the model development and improvement processes. This document represents an effort to coordinate approaches to modeling within NOS and with internal and external partners and to bring NOS modeling priorities in line with user communities' requirements. Implementing the modeling review and prioritization process described in this document represents a strategic opportunity for NOS to make significant advances through the development and linkage of predictive models that can satisfy multiple user-driven requirements within an ecosystem context. These models and forecasts will help to improve decision making for coastal stewardship, mitigate the

impacts of natural events and human activities, reduce impacts of natural hazards, enhance communication between scientists and managers and provide more effective science direction and cross-disciplinary integration.

In concordance with the NOAA Requirements-Based Management Process, we have collected and assessed the legal mandates, stakeholder needs, and user requirements and identified longstanding and emerging needs among the environmental management, commercial, transportation, recreation, and cultural sectors and communities. Using these requirements as a guide, and in coordination with existing science and technology developments, NOS will be able to establish priorities for research and development of estuarine, coastal, and ocean ecosystem models.

This effort to define major user requirements benefits greatly from existing needs assessments. Several studies, workshops, and symposia have addressed the needs of stakeholders for the prediction of coastal and oceanic conditions for navigation, charting, and the balanced use of marine resources. As a first step, the National Centers for Coastal Ocean Science (NCCOS/CSCOR), in conjunction with other NOS offices, has developed this document to synthesize information into a coherent framework that identifies major management issues that require modeling support at the federal level, catalogs NOS' current capabilities to meet these needs, points to remaining gaps, and suggests factors that can be used to prioritize future modeling research and development.

This document provides a foundation that NOS and its offices can build upon and improve on through additional rounds of input from all sectors of the user community. These future reviews will assist in continuing synthesis efforts, in defining specific needs for immediate and long-term attention, and in developing a research plan with priorities that are responsive to stakeholder needs. The solicitation process could take several forms, including outreach to stakeholders through special sessions at regional and national meetings, distributing mail or web-based surveys, or requesting public comments via a Federal Register Notice. A schematic representation of this process is shown in Figure 1.1.

Figure 1.1: NOS Modeling Prioritization Process
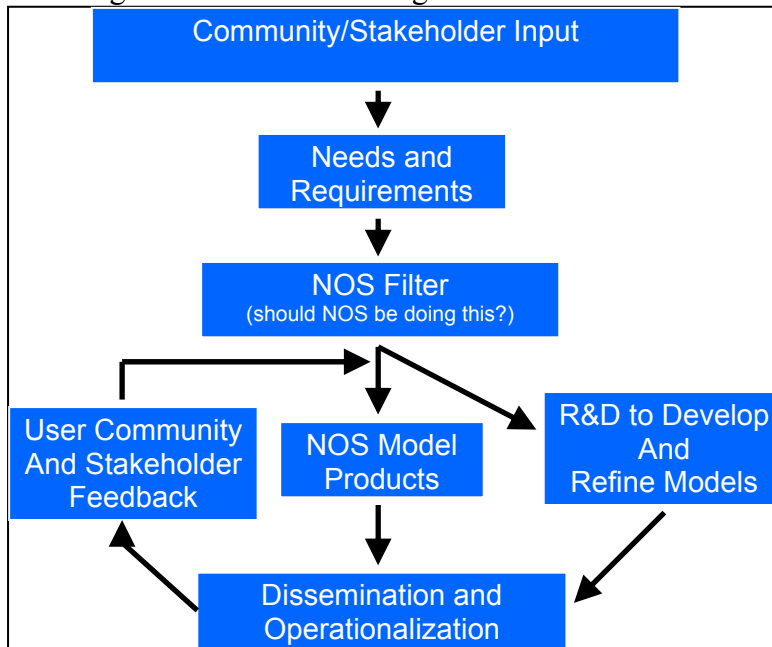
Once the requirements and priorities are established, the collated information will form the foundation for the Requirements-Based Management Process "Need/Opportunity Collection" and "Validation" stages. These support the development of a clear statement of need and directly link to the planning phase of NOAA's Planning, Programming, Budgeting, and Execution System (PPBES) (Figure 1.2).

Figure 1.2: Requirements-Based Management Process in the NOAA Planning, Programming, Budgeting, and Execution System
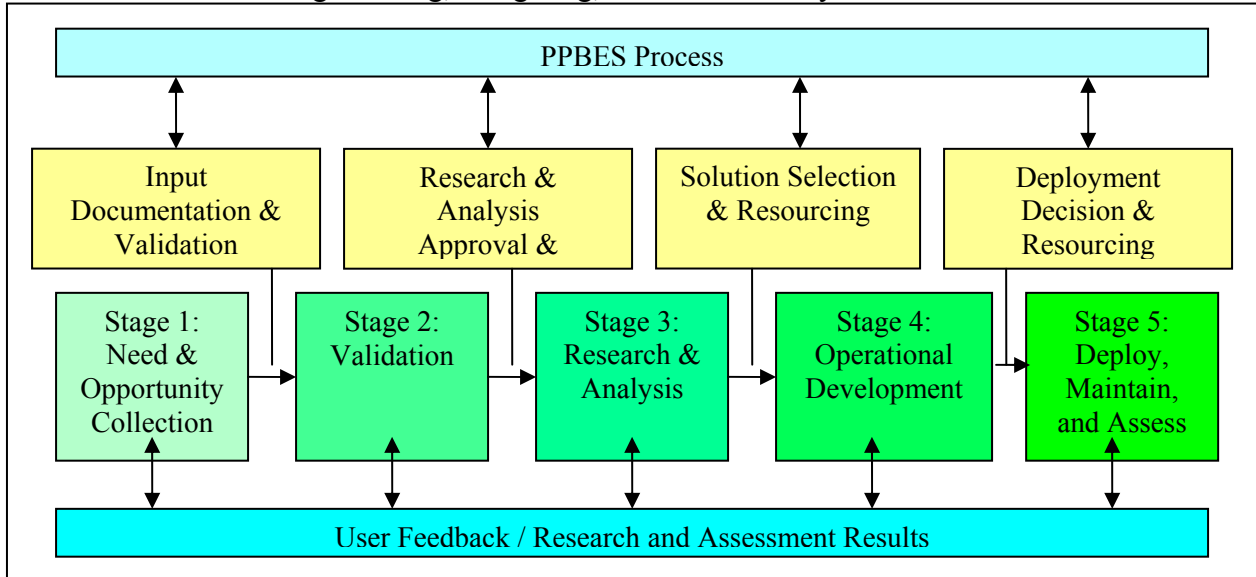
This report uses four management sectors to represent the breadth of NOS' responsibilities and organize user requirements: Navigation and Commerce, Coastal Hazards, Water Quality and Public Health, and Coastal Habitats. For each sector, we have identified needs from published documentation, workshop meeting notes and minutes, Congressional testimony, and other forums. The management needs identified herein include a lack of information, tools, or models required to support science-based management decisions through assessments, predictions, and scenarios. Furthermore, while observations are needed to verify and improve models, models are also needed to fill gaps in existing observations, identify where more observations are needed, and provide predictions of future states of the oceans, coasts, and their associated ecosystems. Thus, there is an important synergy between the modeling needs identified in this report and NOAA and others' efforts in regional and national observing systems.

The course of refining NOS model products does not end with the development of the statements of need in Chapters 2-5. On the contrary, this is a living process that demands frequent and continual interaction with user groups and stakeholders. By continually assessing and reevaluating NOS modeling capabilities and emerging opportunities, such as the integrated ocean observing systems now coming on-line, NOS can develop a strong, integrated, and flexible approach to best serve the science and modeling needs of coastal communities.

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[2] Ibid; National Oceanic and Atmospheric Administration. 2005. New priorities for the 21st century-- NOAA's strategic plan: updated for FY 2006-FY 2011. Washington, DC: National Oceanic and Atmospheric Administration, http://www.spo.noaa.gov/pdfs/STRATEGIC%20PLANS/Strategic_Plan_2006_FINAL_04282005.pdf. [December 13, 2006].

Chapter 2: NAVIGATION AND COMMERCE

Introduction
Our nation's coasts, inland waterways, and ports play a vital role in the daily lives of many citizens. The coastal zone, an area defined as stretching fifty miles inland from the ocean, makes up 17% of the US land area and is home to 53% of the United States population.[1] It is a recreational destination for more than 89 million citizens, provides access to more than 95% of the U.S. overseas trade by volume, and contributes more than $1 Trillion to the U.S. Gross Domestic Product (GDP). Effective management of the navigation and commerce aspects of the coastal zone requires a delicate balancing act between four competing national interest areas: marine safety, marine environmental protection, maritime commerce, and national security.

NOS and the Federal Role in Meeting User Needs
At the heart of NOAA's responsibility for managing the nation's coastal zones are legislative mandates and requirements drivers. These legislative mandates govern NOAA's and NOS' role in providing products, services, and information in support of the nation's navigation and commerce systems. At their core, they are designed to support the commerce and navigation activities in the most effective and efficient manner while simultaneously balancing the competing needs and uses of our nation's trust resources. There are many laws governing navigation and commerce issues in the coastal zones (Appendix A), including crucial legislation such as the Coast & Geodetic Survey Act and the Coastal Zone Management Act. In some instances, the role of fulfilling these mandates rests squarely on the shoulders of NOS and NOAA. In other cases, NOAA and NOS are expected to engage and cooperate with other federal, state, local, and tribal agencies and organizations in an effort to further meet the needs of the commerce and navigation communities. The relative roles and responsibilities in these latter cases can be confusing, and the challenges formidable. In either case, NOS, in cooperation with other federal agencies, must provide the backbone for meeting the needs of the user communities. Without NOS or other federal involvement, meeting these needs would represent a significant and challenging obstacle to the user groups as a whole. In particular, it is necessary for NOS and other federal groups to provide the following:

1. Resources to "help local communities mitigate adverse local impacts derived from Marine Transportation System (MTS) project expansion and increases in global trade."[2]
2. Relevant, timely, and accessible information regarding the environmental performance of the MTS.[3]
3. Resources and guidance on efficient use of land for marine terminal operations and environmental protection.[4]
4. "[T]he means to undertake …an applied research and technology program aimed at furthering the capacity, safety, environmental protection, and security of the nation's ports, intermodal connections, and other marine facilities and services."[5]
5. Scientifically valid and defensible experimental shipboard testing programs for ballast water management technologies and practices aimed at reducing the introduction of aquatic nuisance species.[6]

6. Support for regional intermodal mobility plans that include trunk carriers, highways, etc. to complement port authority operations.[7]

User Needs Related to Models
In addition to the overarching support needed at the federal level, there are numerous research, development, technology, and information needs identified by nongovernmental organizations, navigation associations, and other independent users. Satisfying these needs requires coordinated activities between multiple government agencies and close interaction with different sectors of the marine community. For example, the conservation of marine trust resources by environmental management communities relies on the ability of the marine navigation and transportation communities to limit oil spills, ship groundings, and the introduction of foreign species.

High priority needs identified by one user community also satisfy needs of other user communities. However, many of these needs are identifiable only to specific groups of users or geographic areas. Some of the needs identified by managers, decision makers, and other users include:

1. An examination of the impact of raw sewage and pollution discharge by boats on potential water quality deterioration.[8]
2. Identification of management solutions for dredged materials aimed at facilitating channel dredging and port development while minimizing impacts to marine and cultural resources.[9,10,11]
3. Accurate, real-time information and modeled forecasts to allow ships to safely adjust loads to use available draft margins and accurate tide, current, and wave predictions to reduce travel delays and increase traffic-handling capabilities.[12,13]
4. Accurate nautical charts, real-time tide and current information, and vessel traffic systems are essential to securing the safety of mariners, protecting the environment from accidents and groundings, and efficiently transferring goods in and out of ports.[14]
5. Increased resources to fully support the Physical Oceanographic Real Time System (PORTS).[15]
6. Consistent and effective ballast water management policies to prevent the introduction and spread of non-indigenous species.[16]
7. Provisions for a consistent regulatory umbrella for endangered species, critical habitat recovery and other environmental issues.[17]

Modeling Approaches to Address User Needs
The needs identified above at both the federal and user levels often involve gaps in knowledge, technology, or some combination of the two. Additionally, some information gaps relate to the socioeconomic implications of marine navigation and commerce issues. For example, marine commerce is expected to dramatically increase over the next 20 years. As a result, local, regional, and national decision makers will need better information and tools to assess the short and long term impacts of increased volume of shipping and enhanced dredging to support marine commerce. Some of the needs identified relate explicitly to models:

1. Improve numerical methods for *sediment transport modeling*, including improving our understanding of the basic physics of sediment transport, developing rigorous tests for model uncertainty, and incorporating observing system and data assimilation advances.[18] In particular, advances are needed in:[19]
   a. Water-column processes including turbulence parameterization, particle dynamics, and fluid mud behavior;
   b. Bottom boundary layer hydrodynamics, especially factors controlling near-bed turbulence, bottom stress; and hydraulic roughness;
   c. Processes that occur near the fluid/sediment interface, including sediment erosion and deposition, bedload transport, sheet flow, behavior of mixed sediments, consolidation, bioturbation, diagenesis and evolution of critical shear stresses; and
   d. Influences of biological and geochemical processes on sediment transport mechanics.
2. Coordinate *invasive species research and modeling*[20] to facilitate prevention, early detection, and rapid response. In particular, emphasize research and development to:
   a. Quantify the current absolute and relative importance of all major pathways and predicting the importance of these and future pathways;
   b. Promote monitoring and early detection methods to increase our capacity to detect species in shipments and newly established species;
   c. Provide quantitative screening and risk analysis approaches and make them operational for management and regulation; and
   d. Measure and predict the environmental impacts of aquatic invasive species.
3. Comprehensive *three-dimensional physical hydrodynamic circulation and tide models* and observational systems to support marine navigation and commerce in all of the nation's ports, bays, and estuaries. The information needs from these integrated operational observing systems and models include:
   a. High spatial and temporal resolution nowcasts and forecasts of water levels; and
   b. Currents, temperature, salinity, waves and other critical oceanographic parameters.
4. Updated *mapping and charting* to support marine navigation and commerce, and to facilitate sediment transport, hydrodynamic circulation, and tide models.

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[2] California Marine and Intermodal Transportation System Advisory Council et al. 2003. "California marine transport system infrastructure needs."

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[4] Ibid; U.S. Department of Transportation. 1999. An assessment of the U.S. marine transportation system: a report to Congress. Washington, DC: U.S. Department of Transportation, http://www.dot.gov/mts/report/. [December 6, 2006].

[5] Committee for a Study of the Federal Role in the Marine Transportation System. *The marine transportation system and the federal role: measuring performance, targeting improvement*.

[6] American Association of Port Authorities. 2006. Ballast water management. http://www.aapaports. org/files/PDFs/ballast.pdf. [December 1, 2006].

[7] Case, G. 2000. "Presentation on summary of marine transportation system regional dialog sessions (May-July, 2000)."

[8] Kruczynski, W.L. 2000. Water quality concerns in the Florida Keys: sources, effects, and solutions. Marathon, FL: NOAA Florida Keys National Marine Sanctuary, http://www.fknms.nos.noaa.gov/research_monitoring/wqpp_white_paper.pdf. [December 13, 2006].

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[11] Sturtevant, R. 2004. "Great Lakes ecological forecasting needs assessment." NOAA Technical Memorandum GLERL-131.

[12] U.S. House of Representatives Resources Committee, Subcommittee on Fisheries, Conservation, Wildlife, and Oceans. *Testimony of Frank Hamons*, September 13, 2001.

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[14] American Association of Port Authorities. undated. Partnering in infrastructure investments. http://www.aapaports. org/govrelations/investingdoc.pdf. date unknown].

[15] California Marine and Intermodal Transportation System Advisory Council et al. "California marine transport system infrastructure needs."

[16] Case. "Presentation on summary of marine transportation system regional dialog sessions (May-July, 2000)."

[17] Ibid.

[18] Sherwood, C.R. et al. 2000. "Report of the community sediment transport modeling workshop (June 22-23, 2000)." U.S. Geological Survey Open-File Report 01-32.

[19] ———. 2002. "Toward a community coastal sediment-transport modeling system: report of the second workshop." *Eos* 83, no. 50: 605.

[20] U.S. House of Representatives Committee on Science, Subcommittee on Environment, Technology, and Standards. *Testimony of David M. Lodge*, Hearing on research priorities for aquatic invasive species, June 20, 2002.

Chapter 3: COASTAL HAZARDS

Introduction
The U.S. coastal zones serve critical roles in supporting the economic, social, and ecological vitality of our nation. The coastal regions are home to over half of the nation's population, generate billions in revenue, and are popular recreational destinations. The coastal zones also contain numerous sensitive ecological habitats and natural resources that are vulnerable to both changing environmental conditions and human impacts. These coastal hazards, including natural and anthropogenic chronic and episodic events, threaten the health of coastal ecosystems and communities. Examples of specific coastal hazards include, but are not limited to, hurricanes, tsunamis, erosion, oil and chemical spills, harmful algal blooms, and pollution. Due to the diversity of impacts and their sources, effective management requires efforts to mitigate the impact of severe natural events and the effects of human use and development of the coastal zones.

NOS and the Federal Role in Meeting User Needs
Driving NOAA's responsibility for understanding and managing coastal hazards are legislative mandates and requirements drivers. At the heart of these regulations is the need to protect lives and property from the impacts of natural and anthropogenic hazards and to proactively manage our nation's trust resources in an economically viable and ecologically sustainable fashion. These two often competing demands require considerable coordination within NOS and across NOAA and its national, international, and private partners. While numerous drivers exist, a few of the critical legal mandates include the Coastal Zone Management Act, the Oil Pollution Act, and the Harmful Algal Bloom and Hypoxia Research and Control Act. For an expanded list of relevant legislation, see Appendix A. Due to the complexity of the problems associated with coastal hazards, NOS and other NOAA line offices must clearly establish the needs of local management communities and coordinate with local, national, tribal, and international partners to find effective and efficient solutions to the management problems. As is the case in the previous chapter, substantial information and service needs can be identified at federal, regional, and local levels. These needs further define NOS' role in meeting, and exceeding, the legislative mandates described above. While a comprehensive list of these needs is beyond the scope of this project, numerous overarching needs have been identified in published documentation:

1. To "better integrate and utilize [flood warning and monitoring] data" and "to disseminate information to people at risk in a way that causes them to understand their risk, personalize it, and then take appropriate and timely action."[1]
2. Improved "descriptions of the fundamental relationships between ecosystem dynamics and natural hazards."[2]
3. A "trajectory mapping tool to permit the use of general circulation models in search and rescue, oil spill, and [harmful algal bloom] HAB predictions."[3]
4. To "prevent or minimize threats to existing populations and property from both episodic and chronic coastal hazards" such as coastal erosion and sea level rise.[4]
5. "[T]o develop erosion hazard maps that display the location and extent of coastal areas subject to erosion."[5]

6. Development of adequate tools for oil spill surveillance and predictions of spill trajectory and behavior.[6]
7. New methods to "incorporate biological data into ocean and coastal information products."[7]
8. "[F]urther development of disease transmission models…to assess the risks posed by climatic ecological changes." In regard to coastal hazards, the role of climate change and how it affects transmission of human pathogenic bacterium (*Vibrio* spp.) primarily in ingested shellfish.[8]

User Needs Related to Models

While many of the federal needs can also be applied locally, some of the needs identified have differing priority levels based on regional, state, or local issues. In many cases, these more localized issues can be further broken down to highlight outstanding needs and issues pertinent to the given locale. Additionally, while identification of some of the needs occurred long ago, it is worth noting that many of these issues still stand today. Given the nature and complexity of coastal hazards issues, it would not be possible to identify all of them here. Instead, we focus on a few representative examples that apply to numerous locations:

1. Development of a coastal hazards information system and repository that contains readily available information about coastal hazards and mitigation procedures; this system should be readily accessible and easily comprehended by the general public.[9]
2. Development of "better tools to understand and manage critical sedimentary materials in the nearshore environment," and for "reduced point and non-point pollution of coastal waters."[10]
3. Definition and survey of geomorphological shoreline characteristics, calculation of shoreline change rates, and identification of critical erosion areas in an effort to provide a baseline and serve as guides for coastal management and development decision.[11]
4. Tsunami inundation maps, scenarios, and modeling studies to respond to and mitigate the effects of local and remotely forced tsunamis.[12]
5. "To provide technical and educational programs that examine the forces of climate and hazards and provide information to the public and private sectors on the nature of hazards and how to plan for them."[13]
6. Understanding the "[d]istribution, movement, and fate of toxic substances … to guide riskbased prioritization of future research on the fate of toxic substances in sediments" and to guide management of contaminated sediments.[14, 15]
7. Understanding the response of biological and ecological systems to climate change related "increased coastal flooding and erosion, higher storm surges, increased wind damage, and increased saltwater intrusion into coastal freshwater aquifers."[16]
8. "[M]odels to be used by end-users with limited knowledge of meteorology and oceanography including more visualization tools."[17]

9. Integration of "existing information about climate variability and change (e.g., ENSO forecasts) into emergency preparedness planning."[18]
10. Better understanding of "the impact of atmospheric storms on coastal erosion, especially erosion of barrier islands and shoreline by storm-induced shoreline flooding and wetland loss," including "the societal risks and costs in coastal areas."[19]
11. "Oil trajectory and fate models used to predict the behavior of dispersed oil should be improved, verified, and then validated in an appropriately designed experimental setting or during and actual spill. These models should meet the needs of both planning and real-time decision making in complex nearshore settings."[20]

Modeling Approaches to Address User Needs
As is the case for the Navigation and Commerce and other sectors, the needs expressed for Coastal Hazards involve gaps in our scientific knowledge, technology required to observe the hazards, and the ways information is communicated to managers. Overall, the needs identified span a wide variety of topics ranging from coastal responses to atmospheric and oceanic hazards such as hurricanes, storm surge, and inland flooding; coastal geomorphology (i.e. erosion) due to coastal storms, sea level rise, and subsidence; and hazards to the coastal environment arising from spills of oil or other toxic substances. Clearly, no one tool could satisfy the needs of the entire coastal management community. However, a few general needs applicable to models may be identified. These include:
1. Development of *decision support systems*, incorporating observations and model based assessments and predictions, to be used by end-users with limited knowledge of meteorology and oceanography. This includes improved data access capabilities and enhanced visualization tools.
2. Development of *query-driven retrieval systems* for improved access to databases and model output.
3. Development of *joint probabilities estimation* methodology for improved modeling of high water levels and storm conditions.
4. Improved *coastal geomorphology models* and techniques to aid understanding and prediction of spatial and temporal variability of the nation's shorelines.
5. *Integrated water level model* development incorporating flood and surge impacts from coastal storms.
6. Adoption of a *water level standard* and development of *GIS capable water level displays*, including storm surge forecasts, to be easily understood by users of this information.
7. Enhancement of *tide gage monitoring sites* and *data assimilation methodologies* to support water level and storm surge analysis, assessment, and prediction.
8. *Fate and transport models* to mitigate the impacts of point and non-point source pollution and invasive species introduction.
9. *Coupled land-atmosphere-ocean-biology models* for assessing and predicting ecosystem function, stress, change, and response due to natural and man-made coastal hazards.
10. *Comprehensive storm surge models* incorporating natural tidal variations, atmospheric conditions, and long term geomorphological change.

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Chapter 4: WATER QUALITY AND PUBLIC HEALTH

Introduction
The coastal ocean, estuaries, and Great Lakes are of immense economic and environmental importance to the nation. They provide resources (water, food), recreation and tourism opportunities, and pathways for commerce while also supporting diverse ecosystems containing important habitat and marine species. The cumulative effects of increasing population growth, coastal development, and human activities have degraded many of the nation's water resources and aquatic environments, resulting in significant impacts to water quality, public health, and ecosystem function. These impacts include: nutrient pollution, chemical/biological contamination, harmful algal blooms, hypoxia, and loss of critical habitat. The end results are often economically and socially costly, through the contamination of drinking water and seafood, spread of infectious disease, fish kills and marine mammal mortalities, loss of species abundance and diversity, and disruption of ecosystem function. There is a critical need to understand and predict how coastal ecosystems are changing so managers can make informed decisions regarding water quality, public health, and resource management.

NOS and the Federal Role in Meeting User Needs
As is the case in previous sections, NOAA and NOS play a fundamental role in providing the infrastructure and research and implementation backbone for meeting the nation's needs for water quality, particularly as it relates to human and ecosystem health. In conjunction with other agencies, NOS' efforts to address water quality and public health issues are mandated through a number of statutes. Several of the key mandates include the Clean Water Act, the Harmful Algal Bloom and Hypoxia Research and Control Act, and the National Contaminated Sediment Assessment and Management Act; Appendix A provides a complete list of relevant regulations. NOAA and NOS conduct a wide range of monitoring, research, and modeling activities to satisfy the legal mandates listed above. These activities are guided largely by government and independent reports, scientific literature, and the results of workshops and meetings with scientists and users. Significant needs related to the issues of water quality and public health identified in several recently released key reports include:

1. "[I]ncrease[d] assistance and outreach to provide decision makers with the knowledge and tools needed to make sound land use decisions that protect coastal water quality."[1]
2. "[E]xpanded research efforts in marine microbiology and virology… include[ing]: the discovery, documentation, and description of new marine bacteria, algae, and viruses and the determination of their potential negative effects on the health of humans and marine organisms and the elucidation of the complex inter-relations, pathways, and causal effects of marine pollution, harmful algal blooms, ecosystem degradation and alteration, emerging marine diseases, and climate change in disease events."[2]
3. "[D]eveloping models and strategies for predicting and mitigating pollutant loadings, harmful algal blooms, and infectious disease potential in the marine environment."[3]

4. Coordination and sponsorship of "exploration, research, and new technologies related to examining the connections among the ocean, ecosystem health, and human health;" including the improvement and transfer of "new technologies into management programs that protect human health and the health of ocean and coastal ecosystems."[4]
5. Research aimed at "studying the effects of toxic substances in the marine environment" including "(a) studies on mercury in fish and other species…; (b) the effects of PCBs and other toxic substances on marine mammals-particularly in the polar regions; and (c) the effects of chronic exposure to PAHs on marine species and ecosystems."[5]
6. Development and implementation of a process to identify and correct overlaps and gaps in existing and proposed federal programs that deal with nutrient over-enrichment; including conducting periodic, comprehensive assessments of coastal environmental quality.[6]
7. Expanded and targeted research to improve understanding of the causes and impacts of nutrient over-enrichment.[7]

User Needs Related to Models
Within the broad areas of water quality and public health, user needs are difficult to identify and are often location and issue dependent. Comprehensive management surveys and workshops aimed specifically at identifying the needs of managers are starting to become available and are helping to highlight the unique needs of coastal managers. Identified stakeholder needs that can be addressed specifically by models include:

1. Improved understanding of
   a. Nutrient enrichment (eutrophication, HABs);
   b. Habitat degradation/loss and restoration; and
   c. Pathogens and toxic contamination impacts on National Estuarine Research Reserve System sites and Coastal Zone Management Program areas.[8]
2. Information and tools for coastal managers to help prevent and mitigate HAB impacts on
   a. Public health, safety and enjoyment of coastal waters; and
   b. The economic vitality and fisheries management in the coastal zone.[9]
3. Information and integrated decision support tools combining environmental data with model simulations to make short- and long-term predictions of
   a. Transport of nutrients, contaminants, HABs, and larvae; and
   b. Timing, duration, and location of HABs.[10, 11]
4. Improved understanding of the sources, sinks, and fluxes of nutrients from the landscape under current and future conditions and scenarios.[12]
5. Integrated research aimed at better understanding and quantifying rates of biological, chemical, and physical processes contributing to development of hypoxia.[13]
6. Determination of the short- and long-term, individual- and population-level effects of variations (spatial and temporal) in hypoxia extent on ecologically and commercially important aquatic species.[14]

7. Determining the physiological, biochemical, genetic, and behavioral features and mechanisms that influence harmful algal bloom dynamics (initiation, growth, maintenance, dissipation), general ecology and impacts on trophic structure, processes and interactions.[15]
8. Improved resources and capabilities to predict and prevent marine public health disasters.[16]
9. Development of verified models for the quantitative forecasting of coastal system response to multiple stressors.[17]

Modeling Approaches to Address User Needs
The use of models for environmental decision making has a number of advantages, including the ability to run "what-if" scenarios, test potential/alternative management actions before actual implementation, create short-term and long-term forecasts, and help with ecosystem understanding. Potential modeling approaches to address the user needs specified above include:

1. Integrated monitoring and research using *holistic models* (conceptual, functional, and numerical) that simulate our understanding of overall system function and how management practices can best be implemented.[18, 19]
2. Development of *coupled three-dimensional biological and physical process models* that simulate:
   a. Transport and transformation of nutrients (nitrogen, phosphorus and silica) from natural, urban, and agricultural landscapes to ground water and surface waters;
   b. Inputs and outputs of nutrient flow throughout the landscape to improve estimates of nutrient mass balances;
   c. Biogeochemical cycling and water quality effects of those nutrients on river ecosystems within the drainage basin;
   d. Oceanographic and climate influences on those nutrients and their impacts on productivity;
   e. Impact of increased nutrient flux on productivity, including commercially and recreationally important fisheries;[20, 21] and
   f. Occurrence and movement of harmful algal blooms.[22, 23]
3. Development of regionally based, nationally cohesive *HAB monitoring and prediction programs* capable of providing real-time and near-term forecasts of bloom events and trajectories and longer-term forecasting of trends to allow public health and resource managers to make proactive decisions.[24, 25]
4. Development of *complex models* which include multimedia and multipath sources, intermedia pollutant transfers, and transport and transformations of pollutants.[26]
5. Development of *ecosystem models* to help understand, predict, and assess the current and probable future exposure and response of coastal ecosystems to multiple stressors at multiple scales.[27]
6. Development of *disease transmission models* to assess the risks posed by climatic and ecological changes on human health.[28]

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Chapter 5: COASTAL HABITAT

Introduction
Coastal habitats are economically, ecologically, and socially critical to the nation. Coastal areas are hubs of commerce and transportation. The coasts are used by millions of Americans annually for recreation and support a surging tourist trade. Healthy coastal habitats are vital to estuarine and marine fish and shellfish; approximately 75% of the nation's commercial fish and shellfish depend on estuaries at some stage in their life cycle.[1] In addition, a majority of the nation's endangered and threatened mammal and bird species rely on coastal habitats.[2] The United States' coastal population is expected to grow by 7 million people from 2003 to 2008.[3] The demands of each of these competing uses place coastal areas under considerable stress. Clearly, the continued vitality of our coastal areas demands wise use and stewardship of coastal habitats. Indeed, coastal habitat change and loss has been cited by coastal managers as being one of their top areas of concern in every triennial survey done by the Coastal Services Center,[4] as well as a recent survey by the Coastal States Organization.[5]

NOS and the Federal Role in Meeting User Needs
Unlike in the previous chapters, where NOS and its partners help provide critical infrastructure and implementation backbones, most coastal habitat areas are managed wholly or partially by states. Therefore, the majority of NOS' effort in supporting coastal habitat conservation is centered around promoting sound decision making on the local and state levels through sound research and development programs. NOS and NOAA do play a significant role in managing or co-managing National Estuarine Research Reserves, National Marine Sanctuaries and Monuments, and other Marine Protected Areas. While mandated at the federal level through the Magnuson-Stevens Fishery Conservation and Fish and Wildlife Coordination Acts (among others, see Appendix A), coastal habitat efforts are often driven by guidance from national organizations such as the Coastal States Organization, regional planning and management entities such as the Gulf of Maine Council on the Marine Environment, and local and state groups such as the California Coastal Commission. In general, the reports generated by these groups identify common areas of need in managing coastal habitat, but do not break down needs specific to single habitat types. Identified national modeling needs[6] and areas where model results could help in understanding and managing coastal habitats include:

1. Modeling techniques to understand and forecast impacts of stressors.
2. Effects of nutrient enrichment on hypoxia, loss of SAV habitats or HAB occurrence.
3. Ecosystem model development to help understand, predict, and asses the current and probable future exposure and response of coastal ecosystems to multiple stressors at multiple scales.
4. Evaluation of social, ecological, and economic factors and their linkages.
5. Trends analyses to evaluate changes over time.
6. Cumulative impact assessments to track chronic and longer-term impacts.
7. Evaluation of the effectiveness of restoration/protection techniques, leading to Best Management Practices for habitat restoration.

User Needs Related to Models

Several national-level documents and assessments provide general information on science needs related to habitat change. While they frequently do not specifically address priorities for modeling activities, many of the needs expressed for coastal habitats can be met, at least in part, through a modeling framework. The development and use of models for prediction and simulation has been identified as a priority activity by several national and regional surveys of coastal managers[7, 8] and reports from the National Academy of Sciences.[9] These modeling needs have also been high priorities in the triennial surveys of coastal managers done through the Coastal Services Center.[10] The 1996 survey expressed the desire of managers to develop a "network of experts in modeling processes to make information available and conduct interactive problem-solving, and make commonly-used programs available through an on-line service." While numerous modeling needs can be identified, and the challenges associated with each examined in detail, here we highlight needs that support coastal habitat efforts across geographical regions or boundaries. These include:

1. Activities supporting coastal habitat conservation efforts,[11] including development of specific models on
    a. Water flow and sediment transport around and through wetlands;
    b. Nitrogen loadings effects on eelgrass loss;
    c. Predicting freshwater inflow into estuaries; and
    d. Forecasting future nutrient loads under various management scenarios and effects on seagrass restoration.
2. Improved siting, implementation, management and evaluation of Marine Protected Areas and National Marine Sanctuaries[12, 13] via
    a. Enhanced larval transport prediction abilities;
    b. Evaluation of biological/ecological impacts of current closures;
    c. Social science needs on topics such as socioeconomic impacts, public opinions, and cultural values;
    d. User-friendly mechanisms for managers to access research findings; and
    e. Projections of potential impacts of climate change on MPA placement and effectiveness.
3. Improved understanding of the dynamics of habitat distribution, including growth, reproduction, and mortality of target species, to support National Marine Sanctuaries programs.[14]
4. Research and development of tools (e.g. comprehensive ecosystem models) supporting decision making for important habitats (including coral reefs and Great Lakes Areas of Concern),[15, 16, 17] including tools necessary to
    a. Determine probable impacts of management actions regarding reef management;
    b. Evaluate what ecosystem components and processes may change or be particularly sensitive to certain activities or natural environmental changes; and
    c. Evaluate the impact of management strategies on the restoration of beneficial uses.

In addition to the specific areas above, an important consideration in developing models and assessing the federal role is to take into account the requirements for models and for model results to be useful to managers and decision makers. In general, for models to be most useful to managers there must be:

5. A hierarchy of models for different forecast questions;
6. Multiple models for the same question for ensemble forecasting;
7. Honest assessments of model accuracy, sensitivity, and error and a way to account for uncertainty in model forecasts;
8. Model output that is user friendly, and a standard model interface; and
9. Cost benefit analyses of proposed forecasts.[18]

Modeling Approaches to Address User Needs
Forty-five percent of coastal management agencies use environmental models to aid in the management of coastal resources.[19] These are mostly hydrologic and water quality models that are needed principally to determine the probable impacts of management actions and evaluate how ecosystem components and processes may change or be particularly sensitive to certain activities or natural environmental changes. In addition to data on ocean, habitat, and living resource structure and function, models should incorporate, to the extent possible, existing data and user knowledge of resource natural history and relationships of species to each other and to their habitats. While not exhaustive, the representative modeling approaches required to meet the user needs include:

1. Developing *water level modeling*, especially the integration of digital elevation models and accurate tidal models[20] to understand
    a. Sea level rise prediction of tidal regime expected after marsh restoration, relative to current geomorphology;[21]
    b. The susceptibility of coastal wetlands to sea-level rise;
    c. How sea-level rise, flooding of coastal embayments, and loss of wetlands will affect economically important fish populations;
    d. The impact of changing storm frequency on coastal erosion;
    e. Habitats at risk from coastal hazards; and
    f. How predicted changes in climate and climatic variability may affect coastal habitat restoration efforts and how these impacts can be mitigated.[22]
2. Making *hydrodynamic modeling* (e.g. trajectory, transport, surface/1-D, and multi-layer /2-D/3-D models) useful for coastal habitats[23, 24] by
    a. Resolving nearshore physics and their coupling to inner shelf processes and models;
    b. Fully encompassing oceanic, estuarine, and watershed domains;
    c. Including spill and marine toxin movement, dispersion and dilution, and trajectory analysis;
    d. Linking watershed inputs (groundwater, sediments, contaminants) to coastal habitats; and
    e. Tracking sources and drift of marine debris.

3. Developing *population dynamics models*, including multispecies and metapopulation models to help estimate the impact of marine reserves on biomass at all trophic levels in a system[25] and to examine the stability and persistence of marine populations.[26] These include models to elucidate
   a. Species/habitat relationships (including, e.g., critical habitats for ephemeral events, such as spawning and rearing young);
   b. Marine reserve effectiveness on single species of interest (based on size or number and relevant rates of recruitment, growth, mortality, and reproduction);
   c. Seagrass bed recovery (natural and human enhanced);
   d. Coral community recovery (natural and human enhanced);
   e. Intertidal recovery (natural and human enhanced); and
   f. Trophic interactions (trophic structure, energetics, predator-prey dynamics, cascade effects, and removal effects).
4. Developing *coupled model systems* capable of
   a. Linking spatially-explicit models of watershed loading, coastal circulation, and ecosystem dynamics to predict or simulate habitat change;[27]
   b. Improving understanding of larval behavior, larval transport, and population dynamics (biological-physical circulation/stratification/transport models);[28, 29]
   c. Developing 3-D circulation models in order to understand stratification conditions important for primary productivity and hypoxic events;[30]
   d. Improving predictions of invasion pathways, risk assessment and spread of invasive species or disease progression through marine communities and ecosystems;
   e. Assessing sediment toxicity, contaminant impacts, and bio-accumulation on coastal habitats;
   f. Improving understanding and prediction of harmful algal bloom initiation, growth, trajectory, and decline;
   g. Providing assessments of bleaching susceptibility of corals; and
   h. Projecting the movement and effects of spills on coastal habitats.[31]
5. Developing *socioeconomic models* to
   a. Assess the impacts of coastal development, human use and demand, and implications of regulations and management actions on coastal habitats;
   b. Predict human and economic responses to changing ecosystem attributes;[32] and
   c. Provide methods for valuing ecosystem services.
6. Improving *hindcast models* for analysis of past events and impacts (e.g. storms, El Niño, and climate change), to improve future impacts assessments and models, and to foster trend and trajectory analysis of habitat change.
7. Developing *conceptual models* to promote simple ways of understanding complex systems, including
   a. "Cartoon"-style representations of important parameters and processes;
   b. Flow diagrams that represent the cycle of energy and elements through systems; and

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c. Box models that show interactions and interconnections between various
       important system components.
  8. Using *gaming strategies* as an effective method of
     a. Evaluating the long-term tradeoffs and interactions among management
        decisions and the potential consequences and outcomes of these decisions
        (e.g., a simulation game for oil spill response can be used to compare
        planning and response decisions and the ecological and socio-economic
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     b. Communicating these long and short-term environmental tradeoffs to
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Chapter 6: COMMONALITIES OF MODELING NEEDS AND GAP ANALYSIS

Requirements
User needs across the navigation and commerce (T), coastal hazards (Z), water quality and public health (Q), and coastal habitats (H) sectors include biological, chemical, ecological, physical, and socioeconomic models and modeling products that can be used to forecast a variety of ecosystem and human-related parameters and to support policy development and management actions. Overarching needs include standardized community frameworks, integrated models that provide multidisciplinary capabilities, improved data access and management, and new approaches to modeling product presentation, documentation, and distribution. Many of these modeling and modeling management needs have been identified across multiple user sectors. Specific management issues that require new or improved modeling approaches include the following needs (N):

N1. Circulation and hydrodynamics (H, T, Q, Z). Predictions and forecast guidance are needed for tides, water levels, and currents support commercial and resource management activities, including moving ships safely in and out of ports. Models for water flow through wetlands and estuaries support coastal conservation and restoration efforts and serve as the drivers for constituent transport models. Models are also needed to predict changes in circulation and hydrodynamics due to irregular events such as storms and tsunamis.

N2. Geomorphology (T, Z). Models of shoreline change and sediment movement are needed to identify critical erosion areas, plan dredging activities, manage contaminated sediments, and calculate the impacts of erosion of social and economic concerns. Updated surveys of geomorphology and shoreline characteristics will support these models.

N3. Constituent transport (H, Q, T, Z). Models are needed to predict the movement of a number of physical, biological, and chemical materials, including sediments, fish larvae, harmful algal bloom masses, invasive species, nutrients, and contaminants. These models will be used to plan for conservation and restoration activities, prevent or mitigate disasters such as oil and chemical spills and harmful algal bloom landfall, and predict how species (desirable or undesirable) will move through a given environment.

N4. Hypoxia (H, Q, Z). Models that predict the spatial and temporal distribution of hypoxia will be used to quantify the effects of hypoxia on species of economic or ecological interest.

N5. Water quality (H, Q, T, Z). Models that focus on identifying and tracking point and nonpoint source pollution, including discharges from boats and nutrient enrichment from coastal watersheds, will support water quality monitoring and management.

N6. Population ecology (H, Q, T). Models are needed to track larval, juvenile, and adult population dynamics for ecologically and economically important species, including invasive species.

N7. Harmful algal blooms (HABs) (H, Q, Z). Models forecasting the formation, movement, landfall, and spatial and temporal extent of harmful algal blooms will

assist in investigating the ecology of harmful algal blooms and the impacts of blooms on social and economic concerns, including health, safety, fisheries, and tourism.

N8.   Habitat management (H, Q, T). Models are needed to support a number of habitat management activities, including models to estimate critical habitat dynamics (loss and recovery rates) and to explore species-habitat interactions. Other needs include models that forecast the impacts of management strategies on ecosystems and that include social and economic factors such as public opinion, cultural values, and economic impacts associated with management activities.

N9.   Ecosystem change (H, Q, Z). Models that incorporate long-range forecasts and scenarios for climate change and models that integrate multiple stressors and multiple scales are needed to assess how ecosystems have changed in the past and might change in the future.

N10. Human dimensions (H, Q, T, Z). Human interactions with the environment need to be better represented, including models that show interactions between human society and the environment and models to assist in emergency preparedness and disaster prevention planning.

N11. Improved decision support tools (H, Q, T, Z). In addition to model hierarchies and model ensembles to address complex problems, models and their outputs must be tailored for end-users by providing specific assessments (e.g., cost-benefit analyses), accessible interfaces, and documentation that includes a discussion of model accuracy, sensitivity, error, and uncertainty.

Capabilities and Gaps

There are several modeling approaches that may prove useful in addressing the user needs listed above. Many of the user needs identified above are being partially or wholly addressed within current NOS modeling capabilities (Table 6.1). However, several user needs are not yet being sufficiently met by NOS models, either because there have not yet been significant efforts to develop a particular capability or because the needed models are still in research or development mode (Table 6.2). In addition, some models may be better suited to research, development, and operation in another NOAA line office or by a separate government agency. Important modeling approaches (A) that can help address the above issues include:

A1.   Hydrodynamics

A1-1. THREE-DIMENSIONAL PHYSICAL HYDRODYNAMIC CIRCULATION AND TIDE MODELS serve as the bases for most NOS ocean modeling. These models provide information on water levels, currents, water temperature, salinity, waves, and other parameters that are essential to navigation and commerce. These models support management needs in circulation and hydrodynamics, geomorphology, constituent transport, hypoxia, water quality, population ecology, HABs, habitat management, ecosystem change, and human dimensions. Operational forecasting systems (PORTS) (CSDL, CO-OPS) are currently operational in 13 locations; models for additional sites are in development. VDatum (CSDL) and CATS (ORR) are operational. Coastal Storms (CSDL) is in development.

Remaining gaps in this area include expanding PORTS to new locations, increasing the ability to access nowcast and forecast outputs for use in transport models, incorporating accurate three dimensional currents into transport models, and linking with IOOS through data assimilation for real-time applications.

A1-2. WATER LEVEL MODELS can be improved by integrating models with up-to-date digital elevation and bathymetric data and creating models that allow users to include the effects of tide variations, atmospheric conditions and storms, and changes in geomorphology on water levels. These models support management needs in circulation and hydrodynamics, habitat management, ecosystem change, and human dimensions. NOS is currently working on two modeling platforms to meet these needs: Coastal Storms (CSDL) and a sea level rise model for the North Carolina coast (NCCOS) are in development.

Remaining gaps in this area include better forecasts for meteorological tides and currents during moderate (non-extreme) events.

A1-3. COUPLED COASTAL AND DEEP OCEAN CIRCULATION MODELS are needed to better link offshore and near-shore processes and resolve how these areas influence each other. These models support management needs in constituent transport, hypoxia, water quality, population ecology, and HABs. CSDL is working with NCEP (NWS) to develop models that couple NWS' basin-scale YCOM to NOS' coastal models. Upwelling prediction models (CSDL) are in research. Projects funded by the Global Ocean Ecosystems Dynamics (GLOBEC) research program (NCCOS) have developed nesting techniques for Regional Ocean Modeling Systems (ROMS) models to link coastal ocean and basin dynamics.

Remaining gaps in this area include coupling estuarine and coastal regional models to largerscale ocean circulation models; addressing the challenges of linking watershed models to estuarine and coastal ocean models, including resolving differences in the units of measurement used in various model types; and linking hydrodynamic models with ecological models.

A2. Geomorphology

A2-1. COASTAL GEOMORPHOLOGY MODELS need to be improved to better understand and predict spatial and temporal changes along shorelines, including sediment transport, subsidence, and coastal change. These models support management needs in geomorphology, constituent transport, and habitat management. Models are being developed in NGS that address multiple issues surrounding coastal geomorphology. Operational models include GEOID06, which allows a simple transformation between GPS-derived heights and orthometric heights, and National Shoreline, which delimits the legal oceanic boundaries (e.g., EEZ). Other products in development include topographic models (digital elevation models, DEMs) derived from lidar and IfSAR data, which are typically created on a case-by-case basis. Sea level rise is in development in NCCOS and will provide a number of capabilities related to coastal change.

Remaining gaps include explicitly addressing coastal change within models by analyzing models across various temporal scales. Because coastal areas are changing (sometime quite rapidly), it is important to both model temporal change and to provide a "snapshot" of the shape at a particular time. Changes to the Earth's gravity field occur due to coastal geodynamics, which can affect the geoid model. Periodic updates to coastal topography models are needed to support coastal change analysis. In additional, improved shallow water bathymetry (including swash zone and near shore area) is required to support NOS modeling activities.

A3. Transport

A3-1. PARTICLE TRANSPORT MODELS will help resolve the basic physics of constituent transport, improve understanding of water column and bottom boundary-layer processes, and advance understanding of how the sources and fates of a variety of living and non-living materials. These models support management needs in geomorphology, constituent transport, water quality, population ecology, and HABs. The GNOME/CATS model (ORR) is an operational particle tracking model developed or oil spill trajectory modeling, and it has been used for fish larvae, HABs and other uses. CSDL and CSC are developing the Chesapeake Bay Oyster Larvae Transport (CBOLT) tool. Projects funded through NCCOS are researching and developing particle trajectory (ECOHAB, MERHAB) and ecosystem models (CRES, EcoFore, GLOBEC) for phytoplankton, zooplankton, coral spawning, and larval fish transport; some of these models include growth of organisms as they are transported.

Remaining gaps include linking particle dynamics (including growth, flocculation, sinking, and chemical weathering) with hydrodynamics models. The GNOME model needs further work in order to track transport and subsurface oil in three dimensions.

A3-2. MODELS TO PREDICT AND MITIGATE CHEMICAL LOADINGS that include mass balance, sources and sinks of various chemicals, and dispersal and dilution of spills and toxins across an area are important to planning for and preventing disasters and implementing mitigation. These models support management needs in geomorphology, constituent transport, water quality, and human dimensions. Several NOS models contributed by ORR address these needs, including the operational GNOME/CATS, models for recovery curves following oil spills, and ADIOS; in addition, ORR is currently researching a model for short-term contaminant distribution and transport in three dimensions. Health effects models for humans and marine mammals (OHH, NCCOS) are in research. Projects funded through MultiStress (NCCOS) are also researching and developing ecosystem models in this area.

Remaining gaps include modeling long-term distribution and transport of contaminants, long term oil weathering modeling, and extending oil and chemical spill models to three dimensions for dispersed oil and soluble chemicals.

A3-3. MODELS TO PREDICT, PREVENT, AND MITIGATE HARMFUL ALGAL BLOOMS and the

development of regionally-based, nationally-cohesive HAB monitoring and prediction programs will allow for short-, medium-, and long-term forecasts that allow public health and resource managers to respond proactively to HAB events. These models support management needs in constituent transport, water quality, HABs, and human dimensions. The HAB Bulletin (CO-OPS, NCCOS, CSC) is operational. Upwelling prediction (CSDL) and health effects (OHH, NCCOS) models are in research mode. The ECOHAB and MERHAB programs (NCCOS) support research, development, and application of needed models in academic and management settings.

Remaining gaps include improving species-specific models, modeling the long-term risks of exposure to HAB toxins at the individual and population levels, incorporating food web and trophic dynamics, and predicting air dispersion of HAB particles in the surf zone.

A3-4. MODELS TO PREDICT AND MITIGATE INFECTIOUS DISEASE POTENTIAL that focus on disease transmission are needed to assess the marine mammal and human health risks posed by climate and ecological change. These models support management needs in constituent transport and human dimensions. Health effects models (OHH, NCCOS) are in research.

Remaining gaps include linking precipitation events, runoff, and nonpoint sources to beach closure events.

A4. Population Dynamics

A4-1. POPULATION DYNAMICS MODELS that track the behavior, survival, and species-habitat relationships of individuals or cohorts will facilitate managing species of interest (including invasive species and species of ecological or economic concern) and associated habitats. These models support management needs in population ecology and habitat management. A number of programs in NCCOS support the research and development of harmful algal bloom models (ECOHAB, MERHAB), hypoxia models (CHRP, NGOMEX), and ecosystem models (CRES, EcoFore, GLOBEC, MultiStress, S. Florida) that include population dynamics components.

Remaining gaps include creating models for invasive species, including introduction pathways and settlement in systems, models for species of economic and ecological concern, linking higher-level population dynamics models to lower-trophic water quality models, and models of response to local events such as oil and chemical spills.

A5. Ecosystem Change

A5-1. INTEGRATED CLIMATE CHANGE SCENARIOS will be important for determining how changes in temperature, storm frequency, and other atmospheric conditions might affect terrestrial and aquatic variables such as nutrient cycling and sea level rise. These models support management needs in constituent transport, hypoxia, water quality, population

ecology, and ecosystem change. A model for the effects of sea level rise along the North Carolina coastline (NCCOS) is currently in development.

Remaining gaps include extending sea level rise effects models to other geographic regions, modeling additional variables linked to climate change (e.g., coastal habitat change, population dynamics, and fresh water hydrodynamics), downscaling global climate change models to local and regional scales, and linking climate and ecosystem models.

A5-2. ECOSYSTEM HINDCAST AND TRAJECTORY MODELS are used to analyze past events, improve forecasts of future impacts, and provide a basis for trend and trajectory analysis of ecosystem changes. These models support management needs in constituent transport, water quality, HABs, habitat management, ecosystem change, human dimensions, and decision support tools. OHH is researching a sentinel habitat model, a conceptual model to discern the connections between land use changes in the coastal zone and changes in ecological. This model is currently used to focus research efforts on water quality and ecosystem changes, and potentially provides decision support tools for ecosystem managers. A number of programs in NCCOS support the research and development of harmful algal bloom models (ECOHAB, MERHAB), hypoxia models (CHRP, NGOMEX), and ecosystem models (CRES, EcoFore, GLOBEC, MultiStress, S. Florida) that are often developed and tested using a hindcast approach and may be used to provide nowcasts to guide, e.g., sampling strategies.

Remaining gaps include developing models to assist in analyzing historical trends and applying these results to forecasting future trends.

A6. Human Dimensions

A6-1. SOCIOECONOMIC MODELS are needed to assess the impacts of coastal development and other human use and demand on the environment and impacts of ecosystem changes on human social and economic concerns. These models support management needs in geomorphology, hypoxia, population ecology, HABs, habitat management, human dimensions, and decision support tools. The OHH conceptual model (OHH) currently in research illustrates the connections between the negative impacts of development in the coastal zone (e.g., flooding and degradation in habitat quality) with socio-economic parameters (e.g., parcel density, population, and income). NCCOS currently supports researching and developing ecosystem models that incorporate human dimensions include CRES, EcoFore, and MultiStress.

Remaining gaps include models to analyze impacts of management decisions and ecosystem change on humans and the relationship between human society and the environment.

A7. New Modeling Frameworks

This category requires improvements encompassing all of the modeling approaches categories described above and includes:

A7-1. LINKED ECOSYSTEM MODELS that join physical, chemical, biological, ecological, and socioeconomic components are needed to show how terrestrial, atmospheric, aquatic, and social systems interact. These models support management needs in circulation and hydrodynamics, geomorphology, constituent transport, hypoxia, water quality, population ecology, HABs, habitat management, ecosystem change, human dimensions, and decision support tools. Several NOS models support this approach, including operational models such as GNOME/CATS (ORR), habitat equivalency analyses (NCCOS, some areas operational, others in research), and recovery curves (ORR). Models in development include Coastal Storms (CSDL) and sea level rise in North Carolina (NCCOS). Harmful algal bloom (ECOHAB, MERHAB), hypoxia (CHRP, NGOMEX), and ecosystem models (CRES, EcoFore, GLOBEC, MultiStress) are being researched and developed through support from NCCOS.

Remaining gaps include further development of models that integrate multiple media, multiple sources, and multiple paths.

A7-2. MULTIPLE SCALE AND SCENARIO MODELS that allow users to adjust the scales and management scenarios being analyzed will assist in understanding, predicting, and assessing current and future responses of coastal ecosystems to stressors. These models support management needs in habitat management, ecosystem change, and decision support tools. Current NOS modeling activities in the research stage include the HYCOM South Florida Regional Model and water use in Apalachicola Bay, both under NCCOS.

Remaining gaps include forecasting the consequences of management interactions, including the ability to model ecosystem response to short term stresses such as oil and chemical spills and subsequent response activities.

A7-3. DECISION SUPPORT SYSTEMS should allow users to engage a variety of visualization and analysis tools that present data, model results, comparisons between outputs of interest, and information about the uncertainty bounds of model results. These models support management needs in habitat management, ecosystem change, human dimensions, and decision support tools. ORR's GNOME and GNOME Analyst provide static outputs, including uncertainty reports, to support decision makers. The sea level rise and EcoFore programs (NCCOS) support projects working to develop decision support systems in collaboration with resource managers.

Remaining gaps include models that provide interfaces that facilitate non-expert interactions with models, outputs including suggested courses of action based on cost-benefit analyses and gaming strategies, and presentations of model uncertainty, accuracy, and sensitivity.

Table 6.1. Modeling approaches to meet user needs and current NOS modeling capabilities.

Modeling Category	Specific Modeling Approach	User Needs Addressed	Current Capabilities	NOS Office	Status
A1. Hydrodynamics	A1-1. 3-D physical hydrodynamic circulation and tide models	N1. Circulation/hydrodynamics N2. Geomorphology N3. Constituent transport N4. Hypoxia N5. Water quality N6. Population ecology N7. HABs N8. Habitat management N9. Human activities N10. Ecosystem change	PORTS VDatum CATS Coastal Storms	CSDL, CO-OPS CSDL ORR CSDL	Operational Operational Operational Development
	A1-2. Storm surge and water level models	N1. Circulation/hydrodynamics N8. Habitat management N9. Human activities N10. Ecosystem change	Coastal Storms Sea level rise	CSDL NCCOS	Development Development
	A1-3. Coupled coastal and deep ocean circulation models	N3. Constituent transport N4. Hypoxia N5. Water quality N6. Population ecology N7. HABs	Coupling basin-scale HYCOM (NWS) to coastal (NOS) models Upwelling prediction Nesting for ROMS	CSDL, NCEP (NWS) CSDL GLOBEC (NCCOS)	Development Research Outside NOS
A2. Geomorphology	A2-1. Coastal geomorphology models	N2. Geomorphology N3. Constituent transport N8. Habitat management	GEOID06 National Shoreline DEMs Sea level rise	NGS NGS NGS NCCOS	Operational Operational Development Development
A3. Particle Transport	A3-1. Particle transport models	N2. Geomorphology N3. Constituent transport N5. Water quality N6. Population ecology N7. HABs	GNOME/CATS CBOLT Particle trajectory (plankton, larval fish)	ORR CSDL, CSC GLOBEC, ECOHAB, (NCCOS)	Operational Development Outside NOS
	A3-2. Models to predict and mitigate chemical loadings	N2. Geomorphology N3. Constituent transport N5. Water quality N9. Human activities	GNOME/CATS Recovery curves ADIOS 3-D contaminant distribution / transport (short term) Health effects (human, marine mammal)	ORR ORR ORR ORR OHH, NCCOS	Operational Operational Operational Research Research

Table 6.1, cont. Modeling approaches to meet user needs and current NOS modeling capabilities.

Modeling Category	Specific Modeling Approach	User Needs Addressed	Current Capabilities	NOS Office	Status
A3. Particle transport, cont.	A3-3. Models for predicting, preventing, and mitigating HABs	N3. Constituent transport N5. Water quality N7. HABs N9. Human activities	HAB Bulletin Upwelling prediction Health effects ECOHAB / MERHAB models	CO-OPS, NCCOS, CSC CSDL OHH, NCCOS ECOHAB, MERHAB (NCCOS)	Operational Research Research Outside NOS
	A3-4. Models for predicting and mitigating infectious disease potential	N3. Constituent transport N9. Human activities	Health effects	OHH, NCCOS	Research
A4. Population Dynamics	A4-1. Population dynamics models	N6. Population ecology N8. Habitat management	Population dynamics (plankton, larval & juvenile fish) NMFS models	GLOBEC (NCCOS) NMFS	Outside NOS Outside NOS
A5. Ecosystem Change	A5-1. Integrated climate and coastal circulation models	N3. Constituent transport N4. Hypoxia N5. Water quality N6. Population ecology N7. HABs N10. Ecosystem change	Sea level rise	NCCOS	Development
	A5-2. Ecosystem hindcast / trajectory models	N3. Constituent transport N5. Water quality N8. Habitat management N9. Human activities N10. Ecosystem change N11. Decision support tools	OHH Sentinel Habitat Model ECOHAB / GLOBEC models	OHH ECOHAB, GLOBEC (NCCOS)	Research Outside NOS
A6. Human Dimensions	A6-1. Socioeconomic models	N2. Geomorphology N4. Hypoxia N6. Population ecology N7. HABs N8. Habitat management N9. Human activities N11. Decision support tools	OHH Conceptual Model	OHH	Research

Table 6.1, cont. Modeling approaches to meet user needs and current NOS modeling capabilities.

Modeling Category	Specific Modeling Approach	User Needs Addressed	Current Capabilities	NOS Office	Status
A7. Model Improvement	A7-1. Ecosystem models that link terrestrial, atmosphere, and hydrosphere dynamics	N1. Circulation/Hydrodynamics N4. Hypoxia N5. Water quality N6. Population ecology N7. HABs N8. Habitat management N9. Human activities N10. Ecosystem change N11. Decision support tools	GNOME/CATS Recovery curves Habitat equivalency analyses Coastal Storms Hypoxia models EcoFore models	ORR ORR NCCOS CSDL Hypoxia (NCCOS) EcoFore (NCCOS)	Operational Operational Operational/ Research Development Outside NOS Outside NOS
	A7-2. Multiple scale forecasts produced using a variety of management scenarios	N8. Habitat management N10. Ecosystem change N11. Decision support tools	HYCOM S. Florida Regional Model Apalachicola Bay water use	NCCOS NCCOS	Research Research
	A7-3. Decision support systems	N8. Habitat management N9. Human activities N10. Ecosystem change N11. Decision support tools	GNOME/GNOME Analyst EcoFore models	ORR NCCOS	Operational Outside NOS

Table 6.2. Current NOS modeling capabilities and remaining gaps.

Modeling Approach	User Needs Addressed	Current Capabilities (O = Operational; D = In Development; R = In Research)	Remaining Gaps
A1-1. 3-D physical hydrodynamic circulation and tide models	N1. Circulation/Hydrodynamics N2. Geomorphology N3. Constituent transport N4. Hypoxia N5. Water quality N6. Population ecology N7. HABs N8. Habitat management N9. Human activities N10. Ecosystem change	O: Operational forecast systems (PORTS), VDatum, CATS D: Coastal Storms	New locations; Increased access to nowcast/forecast outputs; Accurate 3-D currents
A1-2. Storm surge and water level models	N1. Circulation/Hydrodynamics N8. Habitat management N9. Human activities N10. Ecosystem change	D: Coastal Storms, Sea level rise	Forecasts for meteorological water level and tidal currents during moderate events
A1-3. Coupled coastal and deep ocean circulation models	N3. Constituent transport N4. Hypoxia N5. Water quality N6. Population ecology N7. HABs	D: Coupling basin-scale HYCOM to coastal ocean models R: Upwelling prediction Outside NOS: Nesting for ROMS	Coupling estuarine and coastal regional models to larger-scale ocean circulation models; Linking watershed models to estuarine and coastal ocean models; Linking hydrodynamic models to ecological models
A2-1. Coastal geomorphology models	N2. Geomorphology N3. Constituent transport N8. Habitat management	O: GEOID06, National Shoreline D: DEMs, Sea level rise	Develop better theory base; Fill gaps in gravity data and fields; Incorporate digital imaging tools and automated feature extraction; Increase available coverage; Reduce/eliminate geometric biases; Improve spatial resolution
A3-1. Particle transport models	N2. Geomorphology N3. Constituent transport N5. Water quality N6. Population ecology N7. HABs	O: GNOME/CATS D: CBOLT Outside NOS: Particle trajectory (plankton, larval fish)	Linking particle dynamics (growth, flocculation, sinking, chemical weathering) to hydrodynamics; 3-D transport tracking

Table 6.2, cont. Current NOS modeling capabilities and remaining gaps.

Modeling Approach	User Needs Addressed	Current Capabilities (O = Operational; D = In Development; R = In Research)	Remaining Gaps
A3-2. Models to predict and mitigate chemical loadings	N2. Geomorphology N3. Constituent transport N5. Water quality N9. Human activities	O: GNOME/CATS, Recovery curves, ADIOS R: 3-D contaminant distribution / transport (short term), Health effects (human, marine mammal)	Long-term contaminant distribution and transport; Long-term oil weathering; 3-D dispersed oil and soluble chemical tracking
A3-3. Models to predict, prevent, and mitigate HABs	N3. Constituent transport N5. Water quality N7. HABs N9. Human activities	O: HAB Bulletin R: Upwelling prediction, Health effects Outside NOS: ECOHAB / MERHAB models	Improved species-specific models; Long-term exposure risks (individual & population); Incorporating food web and trophic dynamics; Air dispersion of HAB particles in the surf zone.
A3-4. Models to predict and mitigate infectious disease potential	N3. Constituent transport N9. Human activities	R: Health effects	Linking precipitation, runoff, and non-point sources to beach closures
A4-1. Population dynamics models	N6. Population ecology N8. Habitat management	Outside NOS: Population dynamics (plankton, larval and juvenile fish), NMFS models	Invasive species introduction and pathways; Models for species of economic or ecological concern; Linking models to environmental variability and water quality; Response to small-scale shocks
A5-1. Integrated climate change scenarios	N3. Constituent transport N4. Hypoxia N5. Water quality N6. Population ecology N7. HABs N10. Ecosystem change	D: Sea level rise	New locations; Modeling additional variables
A5-2. Hindcast / trajectory models	N3. Constituent transport N5. Water quality N8. Habitat management N9. Human activities N10. Ecosystem change N11. Decision support tools	R: OHH Sentinel Habitat Model Outside NOS: ECOHAB / GLOBEC models	Applying analyses of historical trends to forecasting future trends

Table 6.2, cont. Current NOS modeling capabilities and remaining gaps.

Modeling Approach	User Needs Addressed	Current Capabilities (O = Operational; D = In Development; R = In Research)	Remaining Gaps
A6-1. Socioeconomic models	N2. Geomorphology N4. Hypoxia N6. Population ecology N7. HABs N8. Habitat management N9. Human activities N11. Decision support tools	R: OHH Conceptual Model	Analyzing impacts of management decisions and ecosystem change on humans; Relationship between human society and the environment
A7-1. Ecosystem models that link terrestrial, atmosphere, and hydrosphere dynamics	N1. Circulation/Hydrodynamics N4. Hypoxia N5. Water quality N6. Population ecology N7. HABs N8. Habitat management N9. Human activities N10. Ecosystem change N11. Decision support tools	O: GNOME/CATS, Recovery curves O/R: Habitat equivalency analyses D: Coastal Storms Outside NOS: Hypoxia models, EcoFore models	Development and integration of models that accommodate multiple media, sources, and paths
A7-2. Multiple scale forecasts produced using a variety of management scenarios	N8. Habitat management N10. Ecosystem change N11. Decision support tools	R: HYCOM S. Florida Regional Model, Apalachicola Bay Water Use	Consequences of management interactions, including responses to short-term stresses
A7-3. Decision support systems	N8. Habitat management N9. Human activities N10. Ecosystem change N11. Decision support tools	O: GNOME/GNOME Analyst Outside NOS: EcoFore models	Interfaces that facilitate non-expert interactions with models; Suggested courses of action based on cost-benefit analyses and gaming strategies; Presentations of model uncertainty, accuracy, and sensitivity

Chapter 7: CONCLUSIONS AND RECOMMENDATIONS

Mandate for Ecosystem-Based Ocean Modeling
Developing robust modeling and forecasting capabilities for oceans and coasts is identified as a priority within NOS and NOAA and by a number of external reports.

Internal Motivations:
NOAA's mission is "[t]o understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs."[1] Modeling and forecasting play an integral role in fulfilling this mission by supporting each of the four NOAA mission goals: 1. Protect, restore, and manage the use of coastal and ocean resources through an ecosystem approach to management (Ecosystems); 2. Understand climate variability and change to enhance society's ability to plan and respond (Climate); 3. Serve society's needs for weather and water information (Weather and Water); and 4. Support the nation's commerce with information for safe, efficient, and environmentally sound transportation (Commerce and Transportation).[2] NOAA's Strategic Plan emphasizes that achieving each of these goals will require creating, improving, and applying predictive models and other decision support technologies.[3] The NOS Strategic Plan further enforces modeling as an important strategy, noting that models are critical to policy making and resource management, especially models that operate at ecosystem scales, incorporate drivers such as weather and climate, integrate socioeconomic information, and provide decision support tools.[4] NOAA's 5-year research plan establishes earth system modeling as a key direction for research; such a large-scale modeling effort calls for improving and linking models across disciplines to support predictions and management at local to global scales.[5] The 5-year research plan also forwards a number of milestones that require models; the milestones that are pertinent to the modeling approaches highlighted in this document are discussed in the "Priority Modeling Needs" section of this chapter. Finally, the NOAA 20-year research vision points out the need and ability to develop increasingly complex and holistic modeling systems that support description, understanding, and prediction of how various parts of the environment interact and to inform ecosystem approaches to management.[6]

External Motivations:
Reports from both the Pew Oceans Commission and the U.S. Commission on Ocean Policy highlight the need for improved models and tools for interpreting and visualizing model outputs.[7] Several of the specific recommendations from these documents are included in the needs listed in Chapters 2-5 of this document. Building on these recommendations, the United States Joint Subcommittee on Ocean Science and Technology's (JSOST) Ocean Research Priorities Plan points out that "[t]he understanding and capability to forecast certain ocean and ocean-influenced processes and phenomena will change how society takes action in the future."[8] Models that account for economic, social, and environmental factors are needed to support each of the societal themes identified in the report: stewardship of natural and cultural ocean resources, increasing resilience to natural hazards, enabling marine operations, discerning the ocean's role in climate and enhancing ecosystem and human health. Models and model

products are important to both of the cross-cutting themes from the report: developing tools (such as models) and making a difference (by providing information to support decision making). The report further calls for developing new and existing models to explore relationships between ecosystem components, to forecast the impacts of changes in natural and human dimensions, and to hindcast previous conditions to better understand ecosystem responses. These models can also provide information to support decision making by integrating research results with adaptive management efforts and translating research results into products. Another important step is to transition developing technologies such as models into operational capabilities.

Prioritization Factors

We suggest six factors for exploring NOS' role in and commitment to developing and operationalizing each of the modeling approaches described in Chapter 6. For each of the modeling approaches, the factors can be scored as high, medium, or low depending on NOS and NOAA responsibilities, commitments, and benefits related to the approach.

P1. What is the mandate for NOS and NOAA's coastal responsibilities? This factor considers whether primary responsibility for developing and operating the modeling capability is assigned to NOS or NOAA by a Congressional statute, Presidential Executive Order, or other high level document. A score of "high" indicates that there is a clear mandate; a score of "low" indicates a weak mandate.

P2. Where does this activity fall within NOAA's and NOS' purview? This factor considers how the modeling activity is addressed in NOAA and NOS Strategic Plans, short- and long-term research plans, and other NOAA-level planning documents. A score of "high" indicates that the modeling activity is within NOAA's and NOS' purview; a score of "low" indicates that it is not clearly within this purview.

P3. What level of leadership should NOS take in developing this capability? This factor considers whether NOS should be lead line office in developing a particular capability (score "high"), should share leadership within one or more other line offices (score "medium"), or should have limited involvement in developing the capability (score "low").

P4. What are the likely benefits of developing this capability? This factor considers both internal and external benefits expected to arise from developing NOS' modeling capabilities, including the ability to build partnerships and leverage resources within NOS and NOAA, across government agencies, and among academic constituents. A score of "high" indicates that there are several internal and external benefits for developing this capability; a score of "medium" indicates that there are some benefits; a score of "low" indicates that there are few benefits that would be realized.

P5. What is the expected level of investment needed to develop this capability? This factor considers the personnel and monetary commitments that NOS will need to make in

order to develop and operationalize a particular modeling capability. The score is given as level of effort, rather than a ranking as high, medium, or low.

P6. What is the time frame for developing this capability? This factor considers how quickly the capability can be developed. The score is given in terms of the time in years to develop the capability, rather than as a ranking as high, medium, or low.

Priority Modeling Needs
This section explains how each of the modeling approaches discussed in Chapter 6 can be characterized according to the above prioritization factors. Table 7.1 summarizes the scores for each of the modeling approaches. Although we have assigned a qualitative score (high, medium, or low) for each of the prioritization factors, this report does not attempt to rank the modeling approaches. In the final section of this chapter (*Next Steps*), we have provided a map for future use of the information in this report to develop a ranking system and to identify NOS priorities for future modeling endeavors.

A1. Hydrodynamics.
A1-1. THREE-DIMENSIONAL PHYSICAL HYDRODYNAMIC CIRCULATION AND TIDE MODELS.
> P1. Mandate. *High.* A mandate for this activity is provided under 15 USC §313c and 33 USC §883a.
> P2. Purview. *High.* This activity will support achieving NOAA/NOS Strategic Plan goals 1 (Ecosystems) and 4 (Commerce and Transportation). It also supports the following NOAA 5-Year Research Plan milestones: development of a transition zone modeling system to integrate river, estuarine, and coastal models; and develop and evaluate advanced ocean forecasting system for currents and ocean status.
> P3. Leadership. *Medium-high.* NOS should have major involvement with this activity and other line offices or agencies should filling supporting roles.
> P4. Benefits. *High.* Internally, NOS' programs in emergency response, coastal management planning, and IOOS will benefit. It also provides the opportunity to leverage the resources of the US Army Corps of Engineers and academic institutions.
> P5. Investment. *Concentrated effort.*
> P6. Time Frame. *3 to 5 years.*

A1-2. WATER LEVEL MODELS.
> P1. Mandate. *High.* A mandate for this activity is provided under 15 USC §313c.
> P2. Purview. *High.* This activity supports NOAA/NOS Strategic Plan goals 2 (Climate) and 4 (Commerce and Transportation). It also supports the following NOAA 5-Year Research Plan milestone: improve NOAA's understanding and forecast capability in coasts, estuaries, and oceans.
> P3. Leadership. *Medium-high.* NOS should have major involvement with this activity and other lines offices and agencies should fill supporting roles.
> P4. Benefits. *High.* Internally, NOS' programs in emergency response, coastal management planning, and IOOS will benefit. Externally, NOS will be able to work with and leverage support from NWS, FEMA, US Army Corps of Engineers, and academia.

P5. Investment. *Concentrated effort.*
P6. Time Frame. *1 to 3 years.*

A1-3. COUPLED COASTAL AND DEEP OCEAN CIRCULATION MODELS.

P1. Mandate. *High.* A mandate for this activity is provided under 15 USC §313c and 33 USC §883a.

P2. Purview. *High.* This activity will support achieving NOAA/NOS Strategic Plan goals 1 (Ecosystems) and 4 (Commerce and Transportation). It also supports the following NOAA 5-Year Research Plan milestones: development of a transition zone modeling system to integrate river, estuarine, and coastal models; and develop and evaluate advanced ocean forecasting system for currents and ocean status.

P3. Leadership. *Medium-high.* NOS should have major involvement with this activity and other lines offices and agencies should fill supporting roles.

P4. Benefits. *High.* Internally, NOS' programs in emergency response, coastal management planning, and IOOS will benefit. NOS will also be able to leverage support and cooperation from the US Navy and academia.

P5. Investment. *Concentrated effort.*
P6. Time Frame. *3 to 5 years.*

A2. Geomorphology

A2-1. COASTAL GEOMORPHOLOGY MODELS.

P1. Mandate. *High.* A mandate for this activity is provided under 33 USC §883a.

P2. Purview. *High.* This activity supports NOAA/NOS Strategic Plan goals 2 (Climate) and 4 (Commerce and Transportation). It also supports the following NOAA 5-Year Research Plan milestone: improve NOAA's understanding and forecast capability in coasts, estuaries, and oceans.

P3. Leadership. *Medium-high.* NOS should have major involvement with this activity and other lines offices and agencies should fill supporting roles.

P4. Benefits. *Medium.* Internally, this activity will benefit NOS' program coastal management. NOS will also be able to leverage support from the US Corps of Engineers and US Geological Survey.

P5. Investment. *Moderate effort.*
P6. Time Frame. *1 to 3 years.*

A3. Transport

A3-1. PARTICLE TRANSPORT MODELS.

P1. Mandate. *High.* A mandate for this activity is provided under 15 USC §313c.

P2. Purview. *High.* This activity supports NOAA/NOS Strategic Plan goal 4 (Commerce and Transportation). It also supports the following NOAA 5-Year Research Plan milestone: improve NOAA's understanding and forecast capability in coasts, estuaries, and oceans.

P3. Leadership. *Low-medium.* NOS should have moderate involvement in this activity with other offices and agencies filling leadership roles.

P4. Benefits. *High.* NOS' programs in coastal zone management planning and event response would benefit. NOS will also be able to leverage support from the US Army Corps of Engineers, US Geological Survey, and academia.

P5. Investment. *Moderate effort.*

P6. Time Frame. *3 to 5 years.*

A3-2. MODELS TO PREDICT AND MITIGATE CHEMICAL LOADINGS.

P1. Mandate. *High.* A mandate for this activity is provided under 33 USC §2761.

P2. Purview. *High.* This activity supports NOAA/NOS Strategic Plan goal 1 (Ecosystems). It also supports the following NOAA 5-Year Research Plan milestone: Develop the appropriate ecosystem models to understand indicators of beach closings, anoxia, and selected water quality parameters in order to make these operational.

P3. Leadership. *Medium-high.* NOS should have major involvement with this activity and other lines offices and agencies should fill supporting roles.

P4. Benefits. *Medium.* NOS' programs in event response will benefit from this activity. In addition, NOS will be able to leverage support and cooperation from EPA.

P5. Investment. *Moderate effort.*

P6. Time Frame. *1 to 3 years.*

A3-3. MODELS TO PREDICT, PREVENT, AND MITIGATE HARMFUL ALGAL BLOOMS.

P1. Mandate. *High.* A mandate for this activity is provided under 16 USC §1451.

P2. Purview. *High.* This activity supports NOAA/NOS Strategic Plan goal 1 (Ecosystems). It also supports the following NOAA 5-Year Research Plan milestones: develop and test ecosystem forecasts of HABs, beach closings, water quality, fish recruitment, anoxia, and sea nettle abundance in various coastal and marine ecosystems; and define the primary forcing factors and time and space scale that cause HABs and anoxia for selected coastal, ocean, and Great Lakes regions.

P3. Leadership. *Medium-high.* NOS should have major involvement with this activity and other lines offices and agencies should fill supporting roles.

P4. Benefits. *Medium.* NOS' programs in resource management and human and animal health would benefit from this activity. Early monitoring and prediction of HAB events provides critical information about water quality and impacts on fishery and habitat resources that assists coastal managers in deciding when to close shellfisheries and beaches. Connecting predictive models with observing systems will provide a continuous stream of information for protecting human health. NOS will also be able to leverage support from academia.

P5. Investment. *Concentrated effort.*

P6. Time Frame. *1 to 3 years for some regions, longer for other systems.*

A3-4. MODELS TO PREDICT AND MITIGATE INFECTIOUS DISEASE POTENTIAL.

P1. Mandate. *High.* A mandate for this activity is provided under 33 USC § 3101.

P2. Purview. *High.* This activity supports NOAA/NOS Strategic Plan goal 1 (Ecosystems) and 2 (Climate). It also supports the following NOAA 5-Year Research Plan milestone: conduct interdisciplinary research to explore marine biological and physical processes and their implications for human health.

P3. Leadership. *Medium.* NOS should share the leadership of this activity equally with other offices and agencies that have human health responsibilities.

P4. Benefits. *Medium.* NOS' program in Oceans and Human Health will benefit from this activity. NOS will also be able to leverage support and cooperation from the OAR, NIH, and academia.

P5. Investment. *Concentrated effort.*

P6. Time Frame. *3 to 5 years.*

A4. Population Dynamics

A4-1. POPULATION DYNAMICS MODELS.

P1. Mandate. *High.* A mandate for this activity is found in 16 USC §1431-1445.

P2. Purview. *High.* This activity supports NOAA/NOS Strategic Plan goal 1 (Ecosystems). It also supports the following NOAA 5-Year Research Plan milestones: understand how anthropogenic stresses, extreme environmental events, and climate influence population dynamics of coastal and marine ecosystems; and develop the next generation of multi-species fisheries and food web production models.

P3. Leadership. *Medium.* NOS should share the leadership of this activity equally with other offices and agencies.

P4. Benefits. *Medium.* NOS' programs in marine protected areas will benefit from this activity, as successful siting and design of MPAs requires coupled population and transport models. NOS will be able to leverage support from NMFS, OAR, NSF, and academia.

P5. Investment. *Moderate effort.*

P6. Time Frame. *5 or more years.*

A5. Ecosystem Change

A5-1. INTEGRATED CLIMATE CHANGE SCENARIOS.

P1. Mandate. *High.* A mandate for this activity is provided under 33 USC §2761.

P2. Purview. *High.* This activity supports NOAA/NOS Strategic Plan goals 1 (Ecosystems), 2 (Climate), 3 (Weather and Water) and 4 (Commerce and Transportation). It also supports the following NOAA 5-Year Research Plan milestones: understand the impacts of climate variability and change on marine ecosystems to improve management; develop regional-scale coupled physical-biological models that incorporate climate variability for ecological forecasts, assessments, and "if-then" scenarios; and produce a suite of physical and ecological indicators based on modeling and observations to help determine the current and future status of the climate and ecological systems.

P3. Leadership. *Medium-high.* NOS should have major involvement with this activity and other lines offices and agencies should fill supporting roles.

P4. Benefits. *Medium.* NOS' programs in coastal zone management would benefit from this activity. Understanding the potential impacts of climate change on resources such as habitat and fisheries will be important for planning protection and remediation actions. NOS will be able to leverage support from NMFS, OAR, NSF, and academia.

P5. Investment. *Concentrated effort.*

P6. Time Frame. *3 to 5 years.*

A5-2. HINDCAST AND TRAJECTORY MODELS.

P1. Mandate. *High.* A mandate for this activity is provided under 33 USC §2761.
P2. Purview. *High.* This activity supports NOAA/NOS Strategic Plan goal 1 (Ecosystems). It also supports the following NOAA 5-Year Research Plan milestone: improve NOAA's understanding and forecast capability in coasts, estuaries, and oceans.
P3. Leadership. *Medium.* NOS should share the leadership of this activity equally with other offices and agencies.
P4. Benefits. *High.* This activity will benefit NOS programs that respond to extreme events such as oil and chemical spills and habitat destruction. NOS will be able to leverage support and cooperation from NWS, OAR, and academia.
P5. Investment. *Moderate effort.*
P6. Time Frame. *1 to 3 years.*

A6. Human Dimensions
A6-1. SOCIOECONOMIC MODELS.
P1. Mandate. *High.* A mandate for this activity is provided in 16 USC §1456 b,c.
P2. Purview. *High.* This activity supports NOAA/NOS Strategic Plan goals 1 (Ecosystems) and 4 (Commerce and Transportation). It also supports the following NOAA 5-Year Research Plan milestone: develop methodologies and tools for estimating non-monetary ecosystem value that can be translated into decision support tools for stewardship of coastal and marine ecosystems.
P3. Leadership. *Medium.* NOS should share the leadership of this activity equally with other offices and agencies.
P4. Benefits. *High.* Ecosystem models that incorporate socioeconomic inputs and outputs are essential to ecosystem approaches to management and are therefore important to a wide variety of NOS programs. In addition, NOS will be able to leverage support and cooperation from NMFS, NWS, OAR, and academia.
P5. Investment. *Moderate effort.*
P6. Time Frame. *5 or more years.*

A7. New Modeling Frameworks
A7-1. LINKED ECOSYSTEM MODELS.
P1. Mandate. *High.* A mandate for this activity is provided under 33 USC §2761.
P2. Purview. *High.* This activity supports NOAA/NOS Strategic Plan goals 1 (Ecosystems), 2 (Climate), and 3 (Weather and Water). It also supports the following NOAA 5-Year Research Plan milestones: create biophysical coupling models of water mass movements and effects on biological productivity, including fisheries recruitment and distribution; develop and test ecosystem forecasts for HABs, beach closings, water quality, fish recruitment, anoxia, and sea nettle abundance in various coastal and marine ecosystems; and develop sufficient scientific understanding of multiple stressors to provide meaningful guidance to decision makers in coastal, coral reef, and Great Lakes regions and in National Marine Sanctuaries and National Estuarine Research Reserves.
P3. Leadership. *Medium-High.* NOS should have major involvement with this activity and other lines offices and agencies should fill supporting roles.
P4. Benefits. *High.* Ecosystem models form the basis of ecosystem approaches to

management are therefore important to a wide variety of NOS programs. In addition, NOS will be able to leverage support and cooperation from NMFS, NWS, OAR, EPA, NASA, NSF, and academia.

P5. Investment. *Moderate effort.*

P6. Time Frame. *5 or more years.*

A7-2. MULTIPLE SCALE AND SCENARIO MODELS.

P1. Mandate. *High.* Although there is no direct mandate specifying this approach, models that are able to handle multiple scales and scenarios are essential to supporting a number of activities mandated by, e.g., 16 USC 32, 16 USC 33 and 42 USC § 4321 et seq.

P2. Purview. *High.* This activity supports NOAA/NOS Strategic Plan goal 1 (Ecosystems). It also supports the following NOAA 5-Year Research Vision milestones: develop sufficient scientific understanding of multiple stressors to provide meaningful guidance to decision makers in coastal, coral reef, and Great Lakes regions and in National Marine Sanctuaries and National Estuarine Research Reserves; and understand how anthropogenic stresses, extreme environmental events, and climate influence population dynamics of coastal and marine ecosystems.

P3. Leadership. *Medium.* NOS should share the leadership of this activity equally with other offices and agencies.

P4. Benefits. *High.* A number of NOS programs will benefit from models that are able to work at multiple scales and to evaluate multiple scenarios, including coastal management and event response. The ability to assess, analyze, and support management scenarios at multiple scales is necessary for effective management of resources such as National Marine Sanctuaries. NOS will be able top leverage support and cooperation from NMFS, OAR, EPA, NSF, and academia.

P5. Investment. *Moderate effort.*

P6. Time Frame. *5 or more years.*

A7-3. DECISION SUPPORT SYSTEMS.

P1. Mandate. *High.* A mandate for this activity is provided in 16 USC §1456 b,c.

P2. Purview. *High.* This activity supports NOAA/NOS Strategic Plan goals 1 (Ecosystems), 2 (Climate), 3 (Weather and Water), and 4 (Commerce and Transportation). It also supports the following NOAA 5-Year Research Plan milestones: understand how anthropogenic stresses, extreme environmental events, and climate influence population dynamics of coastal and marine ecosystems; develop tools that support prevention, preparedness, and response decisions at the community level; develop new experimental tools (including methods, models, and educational and outreach materials) that communicate climate information and deliver techniques for incorporating that information and analysis into specific decision scenarios.

P3. Leadership. *Medium.* NOS should share the leadership of this activity equally with other offices and agencies.

P4. Benefits. *High.* Ecosystem models are the bases of ecosystem approaches to management and therefore support a variety of NOS programs, including coastal management, event response, and IOOS. In addition, conceptual approaches to

presenting ecosystem information may be critical to communicating and consolidating complex information into accessible formats for managers, decision makers, and the public. NOS will be able to leverage support and cooperation from NMFS, OAR, NGO partners such as the Coastal States Organization, and academia.

P5. Investment. *Moderate effort.*

P6. Time Frame. *1 to 3 years for some systems, longer for others.*

Next Steps

Ongoing Identification of Modeling Needs

This report is intended to be a "living document" that will serve as a framework for ongoing identification of users' modeling needs and NOS approaches to address these needs. We anticipate new needs will continue to arise as observation systems, data assimilation and sharing techniques, and information technologies advance and present new opportunities. As NOS develops and improves its modeling capabilities to meet user needs, the identified capabilities and gaps will also change. NOS will continue to lead updates of these lists through presentations, workshops, surveys, and other means. Several efforts are already underway or expected in the near future. At the Coastal Zone 2007 conference (July 2007, Portland, OR), a Panel Session will focus on existing modeling approaches, while a Café Conversation will provide the opportunity to engage a variety of managers and other resource professionals in a dialogue on additional modeling needs. The National Marine Sanctuaries Program plans to work with research coordinators from each Sanctuary to solicit current needs and to identify priorities and anticipated shortfalls.

Developing Rankings and Prioritizing Modeling Research and Development

The discussion of priority factors above does not include a ranked list for short- and long-term modeling research and development. Instead, we have identified factors that might be used to rank the approaches in the future and have provided supporting information and qualitative scores. In order to advance a ranked list, NOS leadership will need to convene a discussion on how to assign weights to each of the factors and how the qualitative rankings should be translated into quantitative scores.

Once NOS has developed a ranked list of modeling approaches, it will be able to use this list to prioritize modeling research and development in program planning and budgeting processes. This will include introducing modeling research and development activities as Alternatives in the annual PPBES cycle and integrating short- and long-term plans into the 5 year and 20 year research planning and visioning activities. In addition to evaluating modeling research and development within its own offices, NOS should coordinate its prioritization process with other NOAA offices and with state and federal partners in order to best align our efforts and leverage shared opportunities. Additional NOAA partners that NOS should look to engage in these planning processes include NMFS, NWS, and OAR. Federal partners that are likely to serve similar user communities or have related modeling needs include the Defense Department (US Navy, US Army Corps of Engineers), the Department of the Interior (Mineral Management Service, US Geological Survey, US Fish and Wildlife Service), and the Environmental

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Protection Agency. Local and regional partners include advisory councils at National Marine Sanctuaries and National Estuarine Research Reserves, state coastal management agencies, IOOS Regional Associations, and the academic community.

[1] National Oceanic and Atmospheric Administration. New priorities for the 21st century--NOAA's strategic plan:
updated for FY 2006-FY 2011.
[2] Ibid.
[3] Ibid.
[4] *National Ocean Service. Strategic plan of the National Ocean Service 2005-2010.*
[5] National Oceanic and Atmospheric Administration. 2005. "Research in NOAA: toward understanding and predicting earth's environment. A five-year plan: fiscal years 2005-2009."
[6] ———. 2005. "Understanding global ecosystems to support informed decision-making: a twenty-year research
vision."
[7] Pew Oceans Commission. America's living oceans: charting a course for sea change; U.S. Commission on Ocean
Policy. An ocean blueprint for the 21st century, final report.
[8] Joint Subcommittee on Ocean Science and Technology. 2006. Charting the course for ocean science in the United
States: research priorities for the next decade. Washington, DC: NSTC Joint Subcommittee on Ocean Science and
Technology, http://ocean.ceq.gov/about/docs/jsost_chartcourse_083006.pdf. [December 13, 2006].

Table 7.1. Priority scores for modeling approaches to meet user needs.

Modeling Category	Approach	P1. Mandate	P2. Purview	P3. Leadership	P4. Benefits	P5. Investment	P6. Time Frame
A1. Hydrodynamics	A1-1. 3-D physical hydrodynamic circulation and tide models	H	H	M-H	H	Concentrated effort	3 to 5 years
	A1-2. Storm surge and water level models	H	H	M-H	H	Concentrated effort	1 to 3 years
	A1-3. Coupled coastal and deep ocean circulation models	H	H	M-H	H	Concentrated effort	3 to 5 years
A2. Geomorphology	A2-1. Coastal geomorphology models	H	H	M-H	M	Moderate effort	1 to 3 years
A3. Particle Transport	A3-1. Particle transport models	H	H	L-M	H	Moderate effort	3 to 5 years
	A3-2. Models for predicting and mitigating chemical (pollutants, nutrients) loadings	H	H	M-H	M	Moderate effort	1 to 3 years
	A3-3. Models for predicting and mitigating HABs	H	H	M-H	M	Concentrated effort	1 to 3 years +
	A3-4. Models for predicting and mitigating infectious disease potential	H	H	M	M	Concentrated effort	3 to 5 years
	A3-4. Models for predicting and mitigating infectious disease potential	H	H	M	M	Concentrated effort	3 to 5 years
A4. Population Dynamics	A4-1. Population dynamics models	H	H	M	M	Moderate effort	> 5 years
A5. Ecosystem Change	A5-1. Integrated climate change scenarios	H	H	M-H	M	Concentrated effort	3 to 5 years
	A5-2. Hindcast / trajectory models	H	H	M	M	Moderate effort	1 to 3 years
A6. Human Dimensions	A6-1. Socioeconomic models	H	H	M	H	Moderate effort	> 5 years
A7. Model Improvement	A7-1. Ecosystem models that link terrestrial, atmosphere, and hydrosphere dynamics	H	H	M-H	H	Moderate effort	> 5 years
	A7-2. Multiple scale forecasts produced using a variety of management scenarios	H	H	M	H	Moderate effort	> 5 years
	A7-3. Decision support systems	H	H	M	H	Moderate effort	1 to 3 years +

Appendix A: PERTINENT LEGISLATIVE MANDATES AND DRIVERS

Navigation and Commerce
• National Weather Service Organic Act (15 U.S.C. § 313): "Sec of Commerce shall have charge of forecasting of weather, the issue of storm warnings, and display of weather and flood signals for the benefit of agriculture, commerce, and navigation …"
• Coast & Geodetic Survey Act of 1947 (33 U.S.C. § 883a): organic authority for NOS navigation services – "To provide charts and related information for the safe navigation of marine and air commerce, and to provide basic data for engineering and scientific purposes and for other commercial and industrial needs, …"
• Coastal Zone Management Act of 1972 (16 U.S.C. 33): - authorizes NOAA to "assist the states to exercise effectively their responsibilities in the coastal zone through the development and implementation of management programs to achieve wise use of the and and water resources of the coastal zone, giving full consideration to ecological, cultural, historic, and esthetic values as well as the needs for compatible economic development, …"
• Executive Order 12234 (30 September 1980) directing "[t]he Secretary of State, the Secretary of the Department in which the Coast Guard is operating, the Secretary of Commerce, and the Federal Communications Commission [to] (a) perform those functions prescribed in the [International] Convention [for Safety of Life at Sea] that are within their respective areas of responsibility, and (b) cooperate and assist each other in carrying out those functions."

Coastal Hazards
• National Weather Service Organic Act (15 U.S.C. § 313): "Sec of Commerce shall have charge of forecasting of weather, the issue of storm warnings, and display of weather and flood signals for the benefit of agriculture, commerce, and navigation …"
• 15 U.S.C. § 313c: The National Oceanic and Atmospheric Administration, through the United States Weather Research Program, shall … "improve the capability to accurately forecast inland flooding (including inland flooding influenced by coastal and ocean storms) through research and modeling; …"
• Oil Pollution Act of 1990 (33 U.S.C. § 2761): Establishes an Interagency Coordinating Committee on Oil Pollution Research with the responsibility to "establish a research program to monitor and evaluate the environmental effects of oil discharges" which includes as a program element "(t)he development of improved models and capabilities for predicting the environmental fate, transport, and effects of oil discharges".
• Coastal Zone Management Act (16 U.S.C. § 1452): establishing national policy to manage "coastal development to minimize the loss of life and property caused by improper development in flood-prone, storm surge, geological hazard, and erosion-prone areas and in areas likely to be affected by or vulnerable to sea level rise, land subsidence, and saltwater intrusion, and by the destruction of natural protective features such as beaches, dunes, wetlands, and barrier islands".
• Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 (16 U.S.C. § 1451 note (Pub. L. No. 105-383, Title VI, 112 Stat. 3447 (Nov 13, 1998))): establishing an interagency task force to assess ecological and economic impacts of: 1) Harmful Algal Blooms on the ecosystems in which they live, 2) hypoxia (reduced oxygen concentration

within sea water, caused in part by the presence of harmful algal blooms) in United States coastal waters, and 3) to develop alternatives for reducing, mitigating, or controlling those impacts.

Water Quality and Public Health
• Clean Water Act (33 U.S.C. § 1251 et seq.): governing water quality and regulating direct and indirect discharge of pollutants into the Nation's waters including oil and other hazardous substances into navigable waters and waters of the contiguous zone, as well as onto adjoining shorelines, that may be harmful to the public or to natural resources (CWA section 311(b)(1)).
• Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 (16 U.S.C. § 1451 note (Pub. L. No. 105-383, Title VI, 112 Stat. 3447 (Nov 13, 1998))): establishing an interagency task force to assess ecological and economic impacts of: 1) Harmful Algal Blooms on the ecosystems in which they live, 2) hypoxia (reduced oxygen concentration within sea water, caused in part by the presence of harmful algal blooms) in United States coastal waters, and 3) to develop alternatives for reducing, mitigating, or controlling those impacts.
• National Coastal Monitoring Act (33 U.S.C. §§ 2801-2805): requiring NOAA, in conjunction with other Federal, state and local authorities, jointly to develop and implement a program for the long-term collection, assimilation, and analysis of scientific data designed to measure the environmental quality of the nation's coastal ecosystems and to submit to Congress a report, every other year, on the condition of the nation's coastal ecosystems.
• National Contaminated Sediment Assessment and Management Act (33 U.S.C. § 1271): requiring the Environmental Protection Agency, in consultation with NOAA and the Department of the Army, to conduct a comprehensive national survey of data regarding sediment quality and a continuing program to assess such quality.
• Ocean Dumping Act (33 U.S.C. §§ 1401-1445): establishing a comprehensive and continuing monitoring and research program on the effects of dumping into ocean waters, coastal waters or waters of the Great Lakes and their connecting waters, including research on the longrange effects of pollution, overfishing, and man-induced changes in the environment.
• The Safe Drinking Water Act (42 U.S.C. § 300f et seq.): requiring the EPA to establish National Drinking Water regulations in an effort to protect public health and welfare through health-based standards specifying and limiting contaminant levels in drinking water through Maximum Contaminant Levels (MCLs) and treatment techniques. This statute is a statute of general applicability to NOAA.
• Oceans and Human Health Act (33 U.S.C. §3101) which establishes NOAA's Oceans and Human Health Initiative, including three research centers and intramural and extramural funding programs.

Coastal Habitats
• Magnuson-Stevens Fishery Conservation Act (Public Law 94-265) which provides Essential Fish Habitat (EFH) Guidelines (50 CFR 600) for identification of habitats of particular concern and minimization of adverse effects of fishing on EFH (Subpart J), and

to promote the protection of EFH in the review of federal and state actions that may adversely affect EFH (Subpart K).

• Coastal Zone Management Act Of 1972 (16 U.S.C. 33), as amended through P.L. 104-150, The Coastal Zone Protection Act of 1996 mandating the Secretary to "conduct a progam of technical assistance and management-oriented research necessary to support the development and implementation of State coastal management program(s)" which foster "international cooperative efforts and technical assistance in coastal zone management" (§ 1456b,c) and establishing the National Estuarine Research Reserve System (§ 1461).

• National Marine Sanctuaries Act (16 U.S.C. 32), authorizing the Secretary of Commerce to designate and manage areas of the marine environment with special national significance due to their conservation, recreational, ecological, historical, scientific, cultural, archeological, educational, or esthetic qualities as National Marine Sanctuaries. The primary objective of this law is to protect marine resources, such as coral reefs, sunken historical vessels or unique habitats.

• The Coral Reef Conservation Act (16 U.S.C. §§ 6401-6409) requiring the Secretary of Commerce to develop a national coral reef action strategy and to fund state and local projects that advance that strategy to the extent funding is available. Additional authorized activities include: mapping, monitoring, assessment, restoration, and scientific research; enhancing public awareness, education, understanding, and appreciation of coral reefs and coral reef ecosystems; providing assistance to states in removing abandoned fishing gear, marine debris, and abandoned vessels from coral; and cooperative conservation and management of coral reefs and coral reef ecosystems with local, regional, or international programs and partners. The main research objective in the Act is to: "Develop sound scientific information on the condition of coral reef ecosystems and the threats to such ecosystems."

• Fish and Wildlife Coordination Act (16 U.S.C. §§ 661-666c) requiring Federal departments and agencies to first consult with the U.S. Fish and Wildlife Service, Department of the Interior; the National Marine Fisheries Service (NMFS), Department of Commerce; and appropriate state fish and wildlife agencies, before taking action that modifies any body of water.

• The National Environmental Policy Act (42 U.S.C. § 4321 et seq.) requiring Federal agencies to take certain steps in their decision making processes to ensure consideration of environmental impacts and alternatives. If an action is likely to significantly affect the quality of the human environment, the Secretary must develop, an "environmental impact statement" (EIS) which analyzes the environmental impacts of the proposed action as well as those of reasonable alternatives to the action.

• State laws and regulations: most coastal habitat is under state jurisdiction and governed by state coastal management acts (e.g., MA Clean Waters Act, MA Coastal Wetlands Restriction Act, NC Coastal Area Management Act, CA Marine Resources Protection Act, California Coastal Act of 1976, NJ Waterfront Development Act, NJ Tidelands Act).

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