Turning Data into Information: Making Better Use of California's Ocean Observing Capabilities

Prepared for the

California Ocean Protection Council

by

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Acronyms and Abbreviations

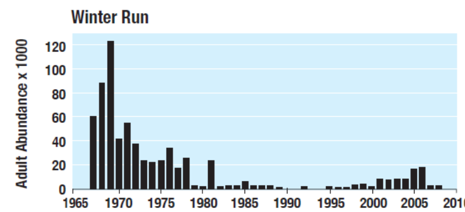
ACP	Area Contingency Plan
ADIOS2	Automated Data Inquiry for Oil Spills
ASBS	Areas of Special Biological Significance
AIS	Automated Information System
ASP	Amnesic Shellfish Poisoning
BCDC	Bay Conservation and Development Commission
BIOS	Biogeographic Information and Observation System
BOEMRE	Bureau of Ocean Energy Management, Regulation and Enforcement
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CalEPA	California Environmental Protection Agency
CCC	California Coastal Commission
CDFG	California Department of Fish and Game
CDIP	Coastal Data Information Program
CDPH	California Department of Public Health
CEDEN	California Environmental Data Exchange Network
CeNCOOS	Central and Northern California Ocean Observing System
CEQA	California Environmental Quality Act
CIWQS	California Integrated Water Quality System
COAMPS®	Coupled Ocean-Atmosphere Mesoscale Prediction System
COCMP	California Coastal Ocean Currents Monitoring Program
CPUC	California Public Utilities Commission
CTR	California Toxics Rule
CWQMC	California Water Quality Monitoring Council
CWT	Coded Wire Tags
CZMA	Coastal Zone Management Act
DAP	Domoic Acid Poisoning
DOE	Department of Energy
DWR	Department of Water Resources
EPRI	Electric Power Research Institute
ESA	Endangered Species Act
FERC	Federal Energy Regulatory Commission
GNOME	General NOAA Operational Modeling Environment
GSI	Genetic Stock Identification
HABMAP	Harmful Algal Bloom Monitoring and Alert Program
HABs	Harmful Algal Blooms
HF	High Frequency
ICS	Incident Command System
IOOS	Integrated Ocean Observing System
IR	Infrared
JSAC	Joint Strategic Advisory Committee
MBARI	Monterey Bay Aquarium Research Institute
MMC	Multipurpose Marine Cadastre
MSP	Marine Spatial Planning
NASA	National Aeronautics and Space Administration

NDBC	National Data Buoy Center
NEBA	Net Environmental Benefit Analysis
NEPA	National Environmental Policy Analysis
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPZ	Nutrient-Phytoplankton-Zooplankton
NRDA	Natural Resources Damage Assessment
NRL	Naval Research Laboratory
NWLON	National Water Level Observation Network
OCS	Outer Continental Shelf
OOS	Ocean Observing System(s)
OPA	Oil Pollution Act of 1990
OPC	California Ocean Protection Council
OR&R	Office of Response and Restoration
OSPAF	Oil Spill Administration Fund
OSPR	Office of Spill Prevention and Response
OST	California Ocean Science Trust
OWET	Oregon Wave Energy Trust
PFMC	Pacific Fishery Management Council
PG&E	Pacific Gas & Electric
PIER	Public Interest Energy Research
PORTS®	Physical Oceanographic Real Time System
POST	Pacific Ocean Shelf Tracking
POTW	Publicly Owned Treatment Works
PSP	Paralytic Shellfish Poisoning
RA	Regional Association
ROMS	Regional Ocean Modeling System
SAR	Synthetic Aperture Radar
SCCOOS	Southern California Coastal Ocean Observing System
SCCWRP	Southern California Coastal Water Research Project
SCOOP	Synthesis for Coastal Ocean Observing Products
SIO	Scripps Institution of Oceanography
SIOSC	State Interagency Oil Spill Committee
SLC	State Lands Commission
SPATT	Solid Phase Adsorption Toxin Tracking
SWRCB	State Water Resources Control Board
TAPII	Trajectory Analysis Planner
TISEC	Tidal In-stream Energy Conversion
TMDL	Total Maximum Daily Load
TOPP	Tagging of Pacific Predators
UC	Unified Command
USACE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
USFWS	US Fish and Wildlife Service
WEC	Wave energy conversion

Executive Summary

California has complex ocean observing systems that gather and analyze extensive amounts of data and are coordinated through regional ocean observing networks. However, the state lacks an overall strategy for effectively applying its complex network of OOS tools to critical management and decision needs. This results in greater risk from spills, increased economic impacts on coastal resources, and the potential for lost economic opportunities due to project delays and conflicts. This report presents the results of a study, the Synthesis for Coastal Ocean Observing Products (SCOOP), intended to provide guidance for California decision makers responsible for managing California's coastal and ocean resources.

Over 20 years ago, a National Academy of Sciences report on marine monitoring in southern California (NRC 1990) found that, despite extensive monitoring efforts that were often technically sophisticated, it was impossible to present a picture of the Southern California Bight as a whole because there was no mechanism for integrating monitoring programs and their results. This finding prompted a coordinated set of efforts, the Southern California Bight Regional Monitoring Program, that is now one of the country's most productive and cost effective regional marine monitoring programs. This current report revisited, but at a statewide level, some of the same issues as the earlier National Academy study. We found a similar set of problems hampering decision making and the effective development and use of ocean observing system[1] (OOS) tools. The result is that key risks are not being prioritized and assessed, important economic impacts and opportunities are not being managed, and the status of ocean resources is not being tracked in a way that enables California to respond adequately to pressures from coastal development and climate change.



Trends in abundance of adult winter run Sacramento River Chinook salmon (source: adapted from PFMC 2011 and Swanson 2010).

For example:

- A major sewer line break in Thousand Oaks in 1998 discharged hundreds of millions of gallons a day of raw sewage for many days to creeks and ultimately to the coastal ocean. Managers' attempts to respond in order to protect human health were limited because of the nearly complete lack of information about the location or direction of the spill. Despite advances in data collection technologies, the refined information products needed for managers to track and respond to this type of spill are not available
- Salmon population declines have created significant impacts on coastal economies throughout much of central and northern California, with commercial and recreational fisheries completely closed in recent years. While declines are due to conditions both in the ocean and in streams, salmon management and restoration programs are unable to use OOS data in a coordinated approach that includes salmon's entire range
- The siting and permitting of coastal desalination plants and offshore wave energy projects hinge on the ability to reliably assess environmental impacts, yet California lacks an accepted methodology for conducting such assessments or for sharing data across multiple projects
- Harmful algal blooms (HABs) are increasing in frequency, as are their impacts on coastal economies, human health, and natural resources. Blooms have the potential not only to cause mass mortalities of

[1] By "ocean observing system" we mean the entire range of data gathering and analysis efforts that includes satellites, ships, autonomous underwater vehicles, aircraft, radars, and human observers, orchestrated by numerous state, municipal, and federal agencies, universities, and private sector entities.

marine organisms but also to shut down desalination plant operations and affect other coastal businesses, but there is only limited ability to predict blooms and then track their movement and extent

- Impacts from oil spills along California's coastline could be both ecologically and economically catastrophic and spill response is critically dependent on accurate projections of the spill's trajectory. Despite this, there is no mechanism for using California's best source of real-time surface current data (the state-funded high-frequency (HF) radar system) in the official spill tracking models used by NOAA

Scene from the 1969 Santa Barbara oil spill (source: http://www.rense.com/general90/barb.htm)

There are three actions California must take to ensure the ready availability of OOS data to meet these needs.

First, the institutional link between agency decision makers and OOS science and technology must be significantly strengthened. This will provide much needed strategic direction to data gathering and the development of useful information products. This can be accomplished by identifying a lead statewide coordinating responsibility for OOS, establishing a dedicated liaison function between agency managers and OOS scientists / technologists, and creating a better defined pathway for incorporating new OOS data and tools into agency decision processes. This will require some restructuring of the roles and responsibilities of the two regional observing system associations in California, the Southern California Coastal Ocean Observing System (SCCOOS) and the Central and Northern California Ocean Observing System (CeNCOOS).

Second, the responsible agencies for each of the five management issues we examined should address the specific recommendations highlighted in the following Summary of Recommendations for Implementing Agencies. These are described more fully in the body of the report and are based on a detailed analysis (in Appendix 2) of the OOS data and information products needed to support specific priority decisions. Implementing these recommendations will require that agencies more systematically base their data gathering and assessment procedures on fundamental management questions and decisions, rather than on more narrowly defined agency tasks that miss the forest for the trees. A useful model of this approach is provided by the California Water Quality Monitoring Council, a joint effort of the Natural Resources Agency, CalEPA, and the Department of Public Health. The Council has established a structured process for identifying priority information needs and then creating workgroups drawn from multiple agencies and user groups to ensure that all the elements of an observing system (e.g., data gathering, data analysis, data management, information products, reporting and data visualization tools) are properly coordinated to effectively meet management information needs.

Third, California must fund the core elements of the OOS capabilities that will enable scientists and managers to successfully resolve the types of problems described above. We identify several key capabilities that cut across multiple issues; some of these capabilities are already operational and some need further development. For example, the HF radar network is operational but the system is now in jeopardy due to a lack of long-term funding. In contrast, the ability to track and/or predict water mass movements, both alongshore and back and forth between the surfzone and the offshore, is crucial to virtually every issue we examined, yet there is no organized effort, informed by agency decision needs, to develop the necessary models.

Addressing these recommendations will necessarily require funding, although many recommendations involve a restructuring of existing efforts rather than entirely new ones. However, substantial funding may be readily available if agency and OOS managers think more creatively. We identify potential funding sources and alternative funding models that could be used to support a portion of the recommended efforts. For example, improved OOS capabilities could substantially lower costs for permittees and project proponents and some of these savings could be recovered in the form of fees or contributions to regional OOS networks.

California's OOS capacity is vital to addressing and resolving key issues facing the state. Developing and sustaining this capacity is neither solely an institutional nor a technical challenge, since both types of factors contribute to and/or inhibit OOS performance. The keystone on which all other recommendations depend is the need for coordinated, statewide, strategic direction based on clearly defined management information needs. Without this, California's OOS efforts will be only partially successful, leaving decision makers at times scrambling to make do with an incomplete picture of key ocean issues.

Summary of Recommendations for Implementing Agencies

This summary highlights key recommendations for those managers in implementing agencies with direct responsibility for managing ocean observing system (OOS) assets and/or for using their data and information products in decision making. (Here and throughout this report, we use OOS to refer to the state's larger network of ocean data gathering, modeling, and assessment capabilities and not just to the National Oceanic and Atmospheric Administration's (NOAA) Integrated Ocean Observing System (IOOS) and its two regional associations (RAs) in California, the Southern California Coastal Ocean Observing System (SCCOOS) and the Central and Northern California Ocean Observing System (CeNCOOS)). The following sections present a brief issues summary, followed by key recommendations, for each of the five management areas we examined (discharges, salmon recovery, renewable ocean energy, harmful algal blooms (HABs), oil spills), as well as for cross-cutting institutional issues and OOS assets.

We emphasize that a combination of institutional and technical factors affect the availability and utility of ocean information in each of the five management areas. Addressing only one or the other type of factor would be insufficient; both technical and institutional constraints must be concurrently resolved for existing and planned observing systems to be fully effective. We also identified a core set of institutional issues at the statewide level that fundamentally limits the ability of all entities, both public and private, to manage OOS capabilities to meet California's needs. Addressing these issues will require sustained leadership by state managers. In addition, a key subset of OOS assets provide critical data and information across multiple management areas, and thus represent possible priorities for continued and expanded long-term state investment.

Framing the Evaluation

- OOS is more than just CeNCOOS and SCCOOS
- OOS encompasses a wide range of raw data and processed information from state, federal, local, and private sources
- Both institutional and technical factors either contribute to or inhibit OOS performance and its ability to address management needs
- Institutional and technical factors must therefore both be addressed
- We present initial steps to improve OOS performance and create momentum toward broader solutions

In each of these contexts (i.e., core institutional issues, the five management areas, key crosscutting OOS assets), we identify a number of initial steps that could help improve OOS performance and create momentum toward more fundamental solutions. However, we also emphasize that these initial steps will not bear fruit without the more fundamental changes to the statewide institutional context we recommend.

Institutional issues

The key issues that prevent the effective use of ocean data fall into four categories:

- Coordination and governance
- Product development targeted at decision needs
- Funding and business model
- Management agency roles

Some issues can be resolved by action within the RAs, but many require action at the statewide level. In particular, California must become more engaged with ocean observing efforts to create strategic direction, actively guide development, and apply lessons learned through other state programs.

Coordination between OOS partners and potential management users is too often diffuse and ineffective and California has no overarching framework for coordinating ocean observing activities and matching OOS capabilities with state needs. Existing governance structures at both state and RA levels are insufficient for this purpose. This is because state agencies focus primarily on parts of problems (the silo effect) and the RAs are not well organized for this purpose, nor are the RAs designed, staffed, or funded to fulfill this function. Examples of successful efforts that meet management needs demonstrate that these issues can be overcome and suggest how California could improve OOS coordination. These include several OOS products targeted at specific users (e.g., port pilots), the State Water Resources Control Board's development of several policies that require new monitoring and assessment (e.g., observing) tools, and California Water Quality Monitoring Council (CWQMC) workgroups responsible for organizing statewide data gathering, analysis, and assessment.

Critical Institutional Issues

- California lacks overall coordination of OOS efforts and their relationship to management needs
- OOS efforts lack a guiding product development strategy that directs the process of turning raw data into useful management information and tools
- RAs are overly dependent on federal funding and OOS overall does not take advantage of potential funding sources beyond agency and grant funds
- Management agency roles are poorly defined with respect to identifying, developing, and maintaining OOS capabilities
- There are existing models of success that provide inspiration and guidance
- There are initial, low-cost organizational adjustments that could address institutional constraints
- Longer-term, there are opportunities to develop other sources of funding

California lacks a consistent, well-defined product development strategy that can consistently match OOS capabilities to management needs by prioritizing the design, development, and implementation of new OOS products. Despite some successes, there are more instances where potentially useful products (e.g., plume and spill tracking tools, HAB forecasts, the use of ocean data in salmon management) are not effectively integrated into decision making or where product development decisions depend on the vagaries of grant funding. As a result, California is vulnerable to events that could easily result in the loss or degradation of key assets.

Both California and the RAs lack effective business and funding models that can help implement strategic direction and product development or provide the amount and stability of funding required to meet management needs for OOS data and products. The RAs receive most of their funding from federal sources and are motivated primarily by the academic research interests of individual investigators. At the state level, there is a narrow reliance on budget allocations and bond funded grant programs.

California lacks overall goal-setting and coordination functions for defining OOS needs and promoting the use of ocean data in agency decision making. In addition, there are insufficient incentives for agency staff to use OOS data and to adjust existing practices to do so. California's size and diversity, and the large number of entities involved in management, make it difficult for new approaches to bubble up from the grassroots without an active state role in defining needs for OOS capabilities. Examples of such effective coordination exist within California although this has been accomplished only sporadically for the ocean.

Institutional Recommendations

(Italics represent near-term, lower cost recommendations)

Coordination and governance

The OPC Steering Committee should create an OOS subcommittee (perhaps led by the Ocean Science Trust (OST)) to identify priority needs for ocean data and to guide and promote agency use of such data

The OOS subcommittee should provide a focus for coordination with OOS partners (workgroups established by the CWQMC, for example the California Wetlands Monitoring Workgroup, provide useful models)

California should develop funding for an OOS liaison to better link state agencies to OOS data sources and developers

California should develop a full-time director position for each RA, using non-federal sources to fund half of the position

The RAs should streamline their committee structures and clarify lines of authority; in particular, addressing the Joint Strategic Advisory Committee's limitations, perhaps by using smaller, issue- or product-specific committees

Product development

Examine product development processes in a range of industry and agency applications to identify models suitable for OOS in California

Define a product development process that includes steps from initial needs assessment through implementation with iterative user feedback, including

- Creating product development teams that include both technical staff and end users
- Defining criteria for determining when a product or capability is ready for implementation

Develop an operations plan to guide ongoing operations and maintenance

Funding and business model

Integrate the RAs' activities into California's overall OOS strategy

Identify diverse funding sources (e.g., fees, partnerships, leveraging existing efforts)

Include funding and management for operating and maintaining core infrastructure

Management agency roles

Identify a lead coordinating responsibility for OOS, perhaps building on preliminary discussions between the CWQMC and the OPC and/or the Ocean Science Trust

Revise existing policies and/or develop new policies in each management area to take advantage of improved ocean data and understanding

Strengthen coordination and synergism among and within agencies and their projects in each management area

OOS assets needed for multiple management areas

Several OOS capabilities cut across multiple management areas, are funded by a variety of sources, and are key to improving OOS's relevance and usefulness. We highlight four core capabilities that require additional attention and recommend that California work with the RAs and other partners to:

- Develop a long-term commitment to existing multi-dimensional circulation (e.g., ROMS) and ecosystem nutrient-phytoplankton-zooplankton (NPZ) models
- Link nearshore and offshore circulation models to support tracking of water and constituents between the nearshore and the offshore
- Rigorously evaluate HF radar applications to clarify and improve their usefulness for specific management areas
- Integrate diverse (biological, chemical, and physical) data and products

Improving Core OOS Capabilities

- Several OOS capabilities that cut across multiple management areas require additional attention
- These provide basic information about water movement along the coast and between inshore and offshore areas, needed for all five management areas
- They also provide information about ecosystem productivity that is a key input to models of HABs and salmon dynamics
- These deserve focused evaluation, funding, and development, and an institutional structure to ensure their long-term operation
- HF radar requires an intensive two-year period of rigorous evaluation
- More attention must be focused on integrating biological data with physical and chemical data

Multi-dimensional circulation models, such as ROMS, and biological NPZ models provide an important foundation for retrospective and real-time analysis, as well as for forecasts applicable to a wide range of management concerns. For instance, basic information about water movement is an essential ingredient to virtually all management issues and OOS applications. These models require additional development, especially for more complex applications in which they are combined, such as spill impact assessment or HABs forecasting. They are currently funded by a fragmented set of grants managed through an informal set of arrangements. The existing capability is critically dependent on a few key individuals who lack both the supporting infrastructure and a succession plan to ensure long-term operations.

Most circulation models for nearshore and offshore zones are distinct and rely on different data inputs and different physics. In addition, nearshore circulation models suffer from data gaps that limit their development and routine use. Many desired applications, such as discharge plume and spill tracking, rely on the ability to link these separate models as water moves back and forth between the two zones.

California has made significant investments in HF radar to measure surface currents and these data have been useful in several management applications such as MPA design and plume tracking. However, its broader use for discharge plume tracking, oil spill response, and salmon forecasting is constrained by limited awareness of the technology and its potential uses, restrictions on its use very close to shore, and barriers to its routine use in oil spill response.

OOS and the RAs are perceived as focusing primarily on physical and chemical data. Biological data are not well integrated with physical and chemical data, thereby limiting the ability to conduct more comprehensive analyses of the effects of physical and chemical changes on the biological resources of primary interest to managers and the public. In addition, biological sampling tools are only beginning to incorporate methods that permit collection of continuous data on finer scales. We recommend enhanced data access and integration tools for biological data, improved sampling methods, and training of state managers and scientists in OOS tools. Over the long term, RAs could play a key role in developing methods to expand and integrate OOS biological data collection via acoustics, tagging, or other techniques, and to support progress towards more automated and widespread sampling programs. The coordinated analysis and display of biological data with other types of oceanographic data would have applications to all five management areas evaluated here and to many other ecosystem management concerns as well.

OOS Assets Recommendations

(Italics represent near-term, lower cost recommendations)

Multi-dimensional models

Develop more reliable state funding for multidimensional circulation and NPZ ecosystem models that would provide significant dividends based on the broad applicability of these tools

Create a more stable, long-term operational capability for circulation and NPZ ecosystem models that is less dependent on the continued involvement of a few critical individuals

Linking nearshore and offshore models

Evaluate the existing capabilities of nearshore circulation models and their linkages to offshore circulation models to identify the requirements for linking the two types of models to meet needs for tracking water and constituents as they move between nearshore and offshore zones

State agencies should help guide and inform development of these linked models at priority locations along the coast, building on the specific management decisions and product needs identified for each of the five management areas

HF radar evaluation

Provide one to two years of additional funding for HF radar to enable a rigorous evaluation of its applicability to state needs

Conduct a workshop including oil spill modelers and responders address barriers to the full and routine official use by federal and state agencies of HF radar-measured currents in spill nowcasts and forecasts

Conduct a workshop to bring together salmon managers, biologists, and modelers to assess the value of HF radar-measured currents in models of salmon distribution and population dynamics

Conduct a workshop to convene discharge agencies, water quality regulators, and modelers to determine the value of HF radar data in tracking discharge plumes and sewage spills to the coastal zone

Complete a summary evaluation that determines if HF radar data can meet management information needs and assesses the availability of sustained funding, considering the option of omitting stations on California's north coast as a cost savings

Integrated products and tools

Develop enhanced data access and integration tools that integrate physical, chemical, and biological data, including dynamic displays or temporal variation

Incorporate these tools into decision support systems used in marine spatial planning

Improve biological data collection via methods such as acoustics, tagging, image analysis, genetic sampling, and tracers, using the RAs' skills acquired in the development of automated systems for physical measurements

Conduct a workshop under the auspices of the CWQMC's Data Management Workgroup and including data managers from the RAs, CalEPA, and the California Resources Agency to develop strategies for dealing with more intensive data streams

Conduct training and education workshops for agency managers and scientists on OOS data and tools

Key management areas

The five management area discussions focus on management questions and decisions unique to each, along with institutional issues that must be resolved to make effective use of ocean observing information in each management area. Although information and OOS capability needs are somewhat specific to respective management areas, we observed important similarities in needs across the five management areas. These similarities reflect the fact that knowledge of ocean circulation and its drivers, such as winds and waves, is fundamental to understanding a wide range of essential ocean processes. Consequently, recommendations for each management area share important common elements (see OOS assets related to multiple issues, above). The data inputs and OOS capabilities needed to support management decisions are detailed in Appendix 2.

Discharges and water quality

The main discharge types include publicly owned treatment works (POTWs) that handle municipal wastewater; wet and dry weather runoff from storm drains, creeks, and rivers. Desalination plants may likely become a major discharge type if/when planned projects become operational. Management decisions include opening or closing swimming beaches to manage human health risk, prioritizing individual discharges and discharge categories (e.g., POTWs vs. rivers) in terms of their relative contribution to different types of impact (e.g., beach closures, effects on ecological resources), and evaluating efforts to maintain and/or improve water quality. There are existing capabilities that must be maintained, including data on currents, waves, discharge flows, and contaminant loads; nearshore and offshore current models; and water quality monitoring programs. OOS gaps that must be filled primarily include new modeling tools for more comprehensive plume tracking, additional data inputs needed to apply these tools, and possibly expanded impact assessment approaches.

Regulatory compliance, spill response, impact assessment, and real-time management could be improved by more integrated use of ocean observing measurement and modeling tools. This will require adjustments to the current management system, such as integrated permitting that considers the combined, or cumulative, effects of different types of discharges and better coordination among monitoring and assessment programs that use new modeling tools. It will also require changes to compliance decision rules and regulatory frameworks that will allow for a broader range of data products (e.g., model output, probability distributions) and denser data streams, in contrast to existing methods based on smaller numbers of discrete data points.

Discharges and Water Quality Recommendations

(Italics represent near-term, lower cost recommendations)

Continue and improve water quality monitoring, including the development of rapid and more reliable bacterial indicators and source tracking methods, more accurate methods for identifying POTW plume boundaries, and standardization of monitoring indicators and methods

Fill data gaps on discharge volume and composition for rivers and creeks by adding routine monitoring of these discharge categories to existing monitoring networks

Maintain and expand the measurement of basic oceanographic information such as surface currents, waves, and water mass characteristics and of key data inputs to multi-dimensional models of discharge plumes

Develop integrated nearshore / offshore current models that will enable tracking of discharge plumes as they move between nearshore and offshore zones, and collect the nearshore bathymetry and local wind data required for nearshore current modeling

Improve the capability to capture and manage the large volumes of raw data generated by real-time, continuous sensors and to convert these data streams to useful information products

Conduct a workshop under the auspices of the CWQMC's Data Management Workgroup to assess potential data management strategies and define the scope of needed development

Revise existing management and regulatory frameworks to enable the broader use of OOS information; this may require adjusting monitoring and reporting requirements and associated criteria for assessing compliance, as well as the procedure for adding water bodies to the 303(d) list of impaired waters

Conduct initial pilot studies with discharge agencies, regulators, and regional monitoring programs to identify and assess the potential for using OOS data and tools more broadly in discharge monitoring and management

Salmon recovery

Salmon populations have declined dramatically in recent decades under a range of impacts stemming from their complex lifestyle, the breadth of habitats they cross, and the diversity of human and natural processes with which they interact. The fact that salmon transit many marine and freshwater habitats during their life cycle creates critical linkages between terrestrial and oceanic processes, impacts, and solutions. Management decisions related to salmon include setting catch limits and the timing and location of fishing, managing hatcheries to support salmon populations, adjusting water withdrawals to help maintain suitable conditions in streams and the Delta, scheduling river mouth breaching to facilitate in- and out-migration, incorporating climate change into recovery plans, and implementing and tracking success measures for mitigation and restoration projects. Despite the increasing awareness of terrestrial and oceanic linkages, impacts and solutions in each system are generally monitored, evaluated, and managed separately, although salmon of course experience these habitats as one integrated whole.

Existing capabilities that must be maintained to assess oceanic impacts on salmon include measurements of ocean conditions from an array of sources, ocean condition indices built from these, and multi-dimensional circulation and ecosystem models. Also, there are several biological sampling programs relevant to salmon prey and the status of ocean food webs, as well as salmon-specific sampling programs to track distribution, abundance, and survival. Gaps that must be filled include improved models that relate ocean conditions (e.g., upwelling and productivity) to salmon survival and growth, retrospective analyses of the effects of ocean conditions, and improved biological monitoring programs for both young and adult salmon.

Several features of the current management system impede the broader use of existing ocean data in decision making. These include traditional management structures and practices, managers' lack of understanding of ocean processes relevant to salmon, and limited communication between ocean scientists and upstream salmon recovery programs. The multiagency complexity and contentious nature of salmon management further complicates the use of OOS data for issues such as hatchery practices, water flows, and rivermouth breaching. However the growing recognition of the importance of ocean conditions to salmon populations provides an excellent opportunity to enhance recovery of this iconic species through greater communication and coordination among oceanic and terrestrial scientists and managers.

Salmon Recovery Recommendations

(Italics represent near-term, lower cost recommendations)

Strengthen short-term salmon modeling efforts by identifying and then routinely measuring the key drivers of ocean condition most relevant to salmon

Develop longer-term salmon ocean forecasts and link these to upstream modeling and management actions, based on retrospective analyses of the relationships between ocean condition and salmon as well as the success of upstream mitigation and restoration projects

Enhance biological monitoring of lower trophic levels through improved technology (e.g., acoustic tracking) and of adult salmon through expanded and improved genetic and age composition analyses

CeNCOOS and other OOS partners should expand their efforts to support automated biological monitoring methods and coordinate scattered database and data access systems

Conduct interagency pilot projects to examine the effect of varying hatchery release times (and thus varying ocean conditions) on salmon survival and growth

Conduct interagency pilot projects to examine whether using data on ocean conditions in decisions about when to breach river mouths will improve salmon smolt survival and growth

Establish an interagency committee and a liaison position under the auspices of the OPC or the OST to identify scientific and management linkages across ocean, estuary, and river salmon programs and integrate the use of ocean information into these programs

Conduct workshops involving ocean, estuary, and river scientists and managers to share scientific information and identify opportunities for more integrated modeling and management

Coordinate ocean scientists' participation in key upstream planning and decision processes

Ocean renewable energy

Wave energy conversion (WEC) is the primary type of ocean renewable energy being considered in California, although there is some limited potential in California for tidal current projects. No WEC projects have yet progressed through permitting to implementation in California, or anywhere in the U.S. The primary decisions related to continued development and implementation of ocean renewable energy are resource assessment and energy plant operations, technology development, and environmental impact assessment. The primary emphasis, for government at federal, state, and local levels, is on the environmental impact assessment process, with the main focus on potential effects on migratory species, the effects of an altered wave field, and spatial management to reduce use conflicts.

Existing capabilities that must be maintained, and in some cases improved or expanded, include wave buoys and wave models, passive acoustic monitoring, marine spatial planning tools, high spatial resolution bathymetry surveys, measurement of ocean conditions from a variety of platform types, and biological survey and tagging programs. Gaps that must be filled include improved tools for estimating how WEC will alter incoming wave fields; validated nearshore wave, circulation and sediment transport models; and a more inclusive marine spatial planning tool. Assessing biological impacts will necessitate knowledge of marine wildlife migratory pathways at relevant locations and spatial scales, models of organisms' behavioral responses to changes in ocean conditions and sound, and validated sound propagation models and ambient noise maps.

Ocean Renewable Energy Recommendations

(Italics represent near-term, lower cost recommendations)

Recognize the early developmental stage of management frameworks, agency expertise, and technical tools by focusing on improving basic capabilities to evaluate data and modeling results used to predict project impacts

Organize WEC project developers, the US Navy, IOOS, and the RAs to produce a statewide ambient noise and sound propagation model

Include ambient noise monitoring as part of permit requirements to support model development and validation

Consider making the RAs the data repository for acoustic data

Support the development of the integrated nearshore / offshore models needed for WEC impact assessment

Improve California's ability to evaluate WEC projects by identifying validated model(s) for impact assessment and through increased staff training

Develop spatial management tools that build on existing efforts and that coordinate access to the multiple databases on living marine resources

Harmful algal blooms (HABs)

HABs are widespread and their frequency is increasing. There are some claims that HABs' severity is also increasing, but the needed time series of data that would demonstrate this are lacking. HABs affect human and wildlife health, degrade water quality, and impact coastal economies (e.g., shellfish harvesting, desalination plants). The California Department of Public Health (CDPH) conducts a successful program to monitor for and mitigate the impacts of blooms, although its capacity to do so is limited by the absence of more comprehensive monitoring and forecasting tools.

Information needs focus on the ability to reliably monitor and predict HAB events. This will require improvements to monitoring networks and methods, understanding of the relative roles of natural and anthropogenic nutrients in stimulating blooms, modeling tools needed for forecasting blooms, and the ability to deliver information to managers to support immediate response and long-term planning. While the CDPH program has successfully protected human health for several decades, the lack of a reliable predictive capability means the program is predominantly reactive rather than proactive. In addition, there are strains on CDPH due to limited resources, and water quality and wildlife health concerns receive less attention. The OPC has funded monitoring and research to assess the magnitude and effects of anthropogenic and natural nutrient loadings in the Southern California Bights and recently funded modeling efforts in Monterey Bay and the Santa Barbara Channel, an important step in developing a HAB predictive capability. OPC also has supported the development of California HABMAP, a grassroots effort to coordinate HAB monitoring in California.

Harmful Algal Bloom Recommendations

(Italics represent near-term, lower cost recommendations)

- Assess economic and technical feasibility of a statewide HAB observing system
- Support technology development by coordinating efforts to improve *in situ*, real-time detection of algae and toxins and by partnering with the Alliance for Coastal Technologies to evaluate new technology
- Work toward a statewide HABs observing system by building on existing observation network, e.g., by expanding pier monitoring in the CeNCOOS region, adding HAB sensors to other monitoring networks, and adding sites in nearshore zone
- Develop operational HAB forecasting models based on linking ROMS circulation and NPZ ecosystem models, building on current pilot projects in Monterey Bay and SB Channel
- Build a HAB early warning system by expanding the existing HABMAP system to add participants and information products
- *Improve data management capabilities by adding additional data sources to the RAs' HAB Info System and integrating this system with other state data management initiatives*
- Support core research on effects of nutrient loading from anthropogenic and upwelling sources, focusing primarily on the Southern California Bight
- *Designate a lead entity to coordinate efforts associated with the full range of potential impacts*
- *Plan for the transition from research methods to routinely deployed operational tools*

Oil spills

Oil enters the ocean through a variety of pathways, with the largest risk of significant spills related to offshore oil exploration and production, and transshipment by pipelines and tankers. Once oil enters the marine environment, its characteristics are quickly changed by a number of physical and chemical processes that affect its distribution and the types of impacts it causes. In 1990, the Lempert-Keene-Seastrand Oil Spill Prevention and Response Act was enacted, which created the California Department of Fish and Game's Office of Spill Prevention and Response (OSPR). OSPR is the state's lead agency for oil spill prevention, response, and natural resource damage assessment and restoration. It is one of the few state agencies in the U.S. with such a broad combination of spill response authority and public trustee authority for natural resources. OSPR also is the lead agency in any coordinated response efforts with the federal government, typically coordinating with the US Coast Guard (USCG) and NOAA for marine spills. In addition, the Marine Facilities Division of the California State Lands Commission (SLC) was created and given certain authority for oil spill prevention at marine oil terminals in California.

Information needs focus on the characteristics of the oil itself, as well as the location, size, and extent in three dimensions (surface spreading and subsurface plumes) of the spill. Forecasts of the spill's movement and dispersion and ultimate fate are critical for directing response efforts and assessing impacts. These information products require a wide array of data inputs (e.g., currents, waves, winds, bathymetry) and modeling tools all coordinated through a complex command and management structure. Because NOAA, under the Oil Pollution ACT of 1990 (OPA) provides spill trajectory modeling to support OSPR's and the USCG response efforts, NOAA practices determine what data are used in such modeling. Emergency responders can deal with dangerous oil spills more effectively and at lower cost if they have information about surface currents at a spill area in real time. Oil trajectories forecasts can be even more accurate if predictions of surface currents are available. Despite the ready availability of HF radar data from COCMP, NOAA's national spill response protocols have so far limited the applicability of HF radar data and data products in spill response in California. This network is in jeopardy due to lack of operational funds. In addition, OSPR's main funding source, the Oil Spill Prevention and Administration Fund (OSPAF), is facing budget shortfalls that would limit OSPR's ability to respond to a catastrophic spill.

Oil Spill Recommendations

(Italics represent near-term, lower cost recommendations)

- Maintain OSPR's unique capabilities for oil spill prevention, response, and restoration
- Maintain existing OOS assets that provide data inputs to spill tracking and forecasting tools
- Enhance the ability to identify impacts and track recovery by expanding monitoring in selected regions with a greater risk of oil spills and/or impacts
- Coordinate efforts with NOAA, BOEMRE, USCG, USGS and industry to develop methods for tracking undersea oil spill plumes, multi-dimensional spill models, updated environmental sensitivity indices, and estimates of oil toxicity on key species
- Develop an oil spill biological effects model for use in both risk and NRDA assessments
- *OPC should initiate an effort to improve the use of remote sensing data, particularly HF radar data, in spill trajectory modeling*
- *OPC should conduct a workshop among NOAA OR&R, OSPR, and COCMP to promote the routine use of HF radar data and products directly in GNOME*

1.0 Introduction

It is not clear whether California's extensive network of ocean observing capabilities is sufficient for decision makers' needs, both now and in the future. It is therefore difficult to determine whether the investment in these systems is paying the desired dividends. This report assesses management information needs in five key issue areas, assesses the degree to which current capabilities meet those needs, and then provides recommendations for needed changes to technical and institutional features of ocean observing systems.

Project background – California has a long and distinguished history of ocean observing successes, but a combination of institutional and technical factors complicate efforts to assess whether investments in observing systems are paying desired dividends and whether existing capabilities will meet the state's future needs. The state must think more strategically about its ocean information needs and rethink current approaches to problem identification, data gathering and assessment, data access, and regulatory and management frameworks.

Project approach and constraints – This study addresses five issues: water quality related to discharges, renewable ocean energy, harmful algal blooms, oil spills, and salmon recovery. While funding constraints prevented us from addressing additional issues, these five do encompass very different types of activities, decision processes, spatial and temporal scales, and connections between ocean and land-based processes; this diversity is intended to improve the applicability of our recommendations to both current and future challenges. Our study design was based on first identifying management frameworks and decision processes, and the specific types of information needed to support these and then assessing whether existing observing system capabilities are sufficient to fill these needs. For current capabilities, we prioritized those elements essential to maintaining core capabilities and then identified data gaps and what would be needed to fill them. We focused equally on institutional and technical aspects of observing systems, and the report contains specific recommendations about both institutional and technical issues.

Report structure – The report chapters include 2.0 Institutional Issues, 3.0 Water Quality Related to Discharges, 4.0 Salmon Recovery, 5.0 Ocean Renewable Energy, 6.0 Harmful Algal Blooms (HABs), 7.0 Oil Spills, and 8.0 Assets Needed for Multiple Issues.

California's marine waters are monitored by a complex network of ocean observing systems (OOS) that include satellites, ships, autonomous underwater vehicles, aircraft, buoys, radars, and human observers, operated by numerous state, municipal, and federal agencies, universities, and private sector interests. **Here and throughout this report, we use "OOS" to refer to this larger network of data gathering, modeling, and assessment capabilities** (see Appendix 2) and not just to the National Oceanic and Atmospheric Administration's (NOAA) Integrated Ocean Observing System (IOOS) and its two regional associations (RAs) in California, the Southern California Coastal Ocean Observing System (SCCOOS) and the Central and Northern California Ocean Observing System (CeNCOOS).

This larger collection of systems produces a large volume of raw data and processed information that is potentially useful to support decision making related to management, regulatory, economic, social, and scientific issues, as well as to improve long-term understanding of a changing climate. However, it is not clear whether this network's capabilities are sufficient for California's needs. In addition, many decision makers, as well as scientists in fields other than oceanography, are unaware of the extent of the information these observing systems produce and of the ways in which this information could benefit them. This lack of awareness results from a variety of causes, both technical and institutional, which make it difficult to determine if California's investment in OOS is paying the desired dividends and whether these systems are properly configured to meet future needs. Multiple and overlapping uses of California's ocean waters for recreation; fisheries; energy development; shipping; discharges from treatment plants, storm drains, and rivers; and new water supplies from desalination plants all demand accurate and timely information that effectively meets decision makers' needs.

This report presents the results of a study, the Synthesis for Coastal Ocean Observing Products (SCOOP), intended to provide guidance for California decision makers responsible for managing California's coastal and ocean resources. It is particularly timely given budget constraints both in California and at the federal level, the potential for new observing technologies to cost-effectively produce higher-quality information, and an increased emphasis nationwide on coordinated ocean management through marine spatial planning. In addition, California's two regional ocean observing associations (CeNCOOS and SCCOOS) are moving out of the startup phase and are seeking guidance on the next stage of their development. This study's objectives, which are also in line with those of the 2007 workshop Making Use of Ocean Observing Systems (Coastal States Organization et al. 2007) were to:

- Describe decision-making needs in five critical issue areas (water quality related to discharges, salmon recovery, ocean renewable energy, harmful algal blooms (HABs), oil spills)
- Assess the degree to which current ocean observing capabilities meet those needs
- Identify existing data gaps and future information needs
- Recommend changes to existing observing systems and institutional arrangements needed to improve California's capacity to meet decision-making needs in the five key issue areas

In addition to matching observing system capabilities with managers' current information needs, we recommend a more comprehensive process that will keep needs and capabilities integrated over the longer term. Only in this way will California's leadership be able to determine which investments would best support and advance its goals for managing and protecting its ocean and coastal resources.

1.1 Project background

Ocean observing has a long and successful history in California. For example, the California Cooperative Oceanic Fisheries Investigation (CalCOFI) Program began in 1949 as a partnership among the California Department of Fish and Game (CDFG), NOAA Fisheries Service (NOAA Fisheries), and Scripps Institution of Oceanography (SIO) to investigate the collapse of the sardine fishery. Since then, it has evolved into one of the world's premiere, long-term oceanographic programs. Environmental monitoring around large ocean outfalls highlights the impacts of waste discharges, provided information to prioritize treatment improvements, and has chronicled significant successes in reducing human impacts on the coastal ocean. The Coastal Data Information Program (CDIP), sponsored by the California Department of Boating and Waterways and the US Army Corps of Engineers (USACE), and operated by the SIO, collects wave data and produces wave nowcasts and forecasts suitable for a wide variety of uses, including coastal engineering, shipping, and surfing. The California Department of Public Health's Marine Biotoxin Program routinely monitors levels of toxic phytoplankton to decide when shellfish harvesting should be suspended. Data from bacterial indicator monitoring at swimming beaches throughout California informs the public about the relative safety of swimming at different times and locations.

While successes such as these are significant, California's need for ocean-related data to support planning and management will only increase as new issues, challenges, and opportunities arise (e.g., renewable ocean energy, sea level rise, ocean acidification, increased coastal development and related impacts, new observing and data analysis technologies). In addition, the single-issue approach underlying many current ocean observing programs will no longer suffice for dealing with either current or future problems. Management questions are larger in spatial extent and more complex, and can only be addressed with multidisciplinary approaches that require combining data from several sources. For example, understanding the cumulative impact of discharge plumes depends not only on traditional monitoring information about the volume and makeup of the plume itself, but also on projections of plume direction, extent, and dispersal derived from models that integrate winds, currents, and sediment transport. Similarly, improved salmon management will require information about how ocean conditions affect salmon reproduction, survival, and growth, along with new management policies that integrate this information into decisions involving fisheries catch limits, hatchery releases, and habitat restoration.

The shape of these next generation requirements that require more multidisciplinary approaches is becoming clear. But California's ocean data are not well organized to support more spatially extensive and/or multidisciplinary problem solving, data gathering is not always well coordinated and targeted at management needs, and data are not always accessible, well integrated, or converted to products useful to managers. This is a larger issue for California as a whole, as recognized in reports such as the Statewide Data Strategy Report from the Office of the State Chief Information Officer (OCIO 2009) and the Comprehensive Monitoring Program Strategy for California released by the California Water Quality Monitoring Council (CWQMC 2010) in response to State Senate Bill 1070 (Kehoe). Partly as a result, the possibilities created by new observing, data analysis, and modeling technologies have not been adequately assimilated into management and regulatory policies.

The national IOOS and California's associated state-level RAs represent one approach to resolving the need for appropriately targeted ocean data and products. These efforts have achieved notable successes, but California's ocean observing needs are larger than IOOS and the RAs alone have addressed or can address. The RAs to date have largely been funded with federal appropriations and IOOS's national priorities do not include all of California's high-priority management needs. Further, the RAs' current structure and governance does not always provide the most effective connection to managers' information needs and decision processes. In addition, the OPC, often in partnership with other public and private partners, has initiated a number of workshops, committees, and planning projects that have addressed aspects of data management and integration related to ocean issues. However, these have been targeted in scope and for reasons detailed in Section 2.0 have not fully resolved the challenges and needs facing California's ocean managers.

As a result, California must think and act more strategically with respect to its needs for ocean observing data, how such data can best be converted to information products relevant to manager's decision needs, what capabilities are required to fulfill these needs, and what institutional arrangements would best support these efforts over the long term.

1.2 Project approach and constraints

1.2.1 Project constraints

This study addresses the relationship between management information needs and ocean observing system (OOS) capabilities[1] in the context of the five specific areas identified by the project sponsors:

- Water quality related to discharges
- Salmon recovery

[1] By "capabilities" we refer to data gathering methods and infrastructure, data management systems, models and other data analysis tools, derived data products, and the synthesized assessments that support decision making. OOS capabilities and gaps related to each issue area, as well as to multiple issue areas, are detailed in Appendix 2.

- Renewable ocean energy
- Harmful algal blooms (HABs)
- Oil spills

These topics were chosen because of their importance to California's coastal and ocean management and because they are areas that could potentially benefit from the development of additional links between ocean observing systems and decision makers. Several of these issues, including HABs, renewable ocean energy, and discharges, were identified as topics for future work in the 2007 Coastal States Organization workshop noted above. In recent years, several other issue areas, such as navigation safety and search and rescue, have successfully developed strong connections between OOS and decision makers and therefore were not chosen for further attention here. In addition, funding constraints made it infeasible to survey and address many other important issues that could benefit from stronger ties with OOS, such as sediment management, fisheries, and marine protected areas. These may be addressed in future phases of the work, should additional funding become available. Despite these constraints, the five issues selected do encompass very different types of activities, decision processes, spatial and temporal scales, and connections between ocean and land-based processes (Table 1.1); this diversity is intended to improve the applicability of our recommendations to both current and future challenges. Section 8 describes OOS capabilities that cut across multiple issues and emphasizes the broader utility of much OOS derived data and information.

Table 1.1. Range of activities and decision types included in the evaluation.

Issue area	Type of activity	Decision type	Scale	Ocean / land connection
Discharges	Current and ongoing	Compliance Impact assessment	Local[1] to regional[1]	Entirely marine Marine / coastal zone[1] interaction
Salmon recovery	Long-term process	Prediction Adaptive management	Local to West Coast	Marine / freshwater ecosystem interaction
Ocean renewable energy	Future development	Planning / siting Permitting / licensing	Local	Entirely marine Marine / coastal zone interaction
HABs	Sporadic	Prediction	Local to regional	Marine / coastal zone interaction
Oil spills	Rare Unpredictable	Spill behavior Response	Local to regional	Marine Possible coastal zone interaction

[1.] For purposes of our discussion, local is defined as less than 15 miles in extent, regional as greater than 15 miles in extent, and coastal zone as the immediate shoreline and adjacent surfzone. These definitions are meant simply to help describe the basic characteristics of the different types of issues and not for any formal analytical purpose.

1.2.2 Project approach

Two aspects of our evaluation deserve specific emphasis:

- We defined OOS broadly to include a wide range of data gathering and analysis activities in California's oceans; this evaluation is therefore NOT limited to the two RAs, CeNCOOS and SCCOOS

- The evaluation is based on a detailed analysis of management decisions and related information needs, the OOS products and assets needed to meet these needs, and the current gaps in OOS capabilities; please see Appendix 2 for this detailed analysis

Our primary goal was to identify, for each of the five target issues, the specific management information needs that could be met with ocean observing information, with a particular focus on the needs of California agencies. Thus our starting point for the evaluations was to develop a thorough understanding of each issue and its related management processes and decisions and only then move on to matching these with the technical details of OOS capabilities. As illustrated in Figure 1.1, we first drew on existing documentation and the team's expertise to review and summarize each of the five issues, including the scope of the problem and categories of management solutions. We identified decision roles for the key federal, state, and local agencies involved in each issue and then conducted interviews with over 130 contacts representing approximately 50 agencies and organizations (Appendix 1). We used these interviews to identify key decision processes including:

- Policy making
- Annual and long-term planning
- Implementing regulations and permits
- Permit compliance and environmental impact assessment
- Operations
- Emergency response
- Program success evaluations

Both within and across these decision categories, we then asked contacts to discuss specific management decisions that could most benefit from OOS information and products. These included data, processed information, models and other analysis tools, and products that are currently in use as well as those that could potentially be used in the future. We requested specific information on the types of OOS information needed and when it was needed, e.g. needed continually, at key times of year, or in response to specific events. We also solicited information about the presence of institutional issues or barriers that must be overcome to fully utilize OOS information.

We then used this information to guide an evaluation of existing OOSs to identify assets, data, models, and products that could help fulfill management information needs. We emphasize that we adopted a broad definition of OOS information in evaluating existing capabilities. Although the two RAs, SCCOOS and CeNCOOS, were an important focus of the project, we included the full range of OOS information produced by the broad array of government, academic, and private organizations working in the ocean, whether or not they had any formal affiliation with the RAs. In many cases, these efforts, such as large-scale, permit-driven monitoring activities, represent important and substantial data resources. In addition, there is often no clear boundary between RA efforts and resources and those of other parties. More importantly, we believe California must include all relevant observing system resources when considering how to better match OOS capabilities to management information needs.

As illustrated in Figure 1.1, we then identified critical gaps between the information needed for management decisions and current OOS capacities, and consulted with a wide array of scientific and technical experts to assist in confirming and refining descriptions of these gaps and formulating technical recommendations to fill them. This allowed us to link management decisions to desired products to the information needed to produce those products to the data required to create that information and finally to the essential observing system requirements for each type of data.

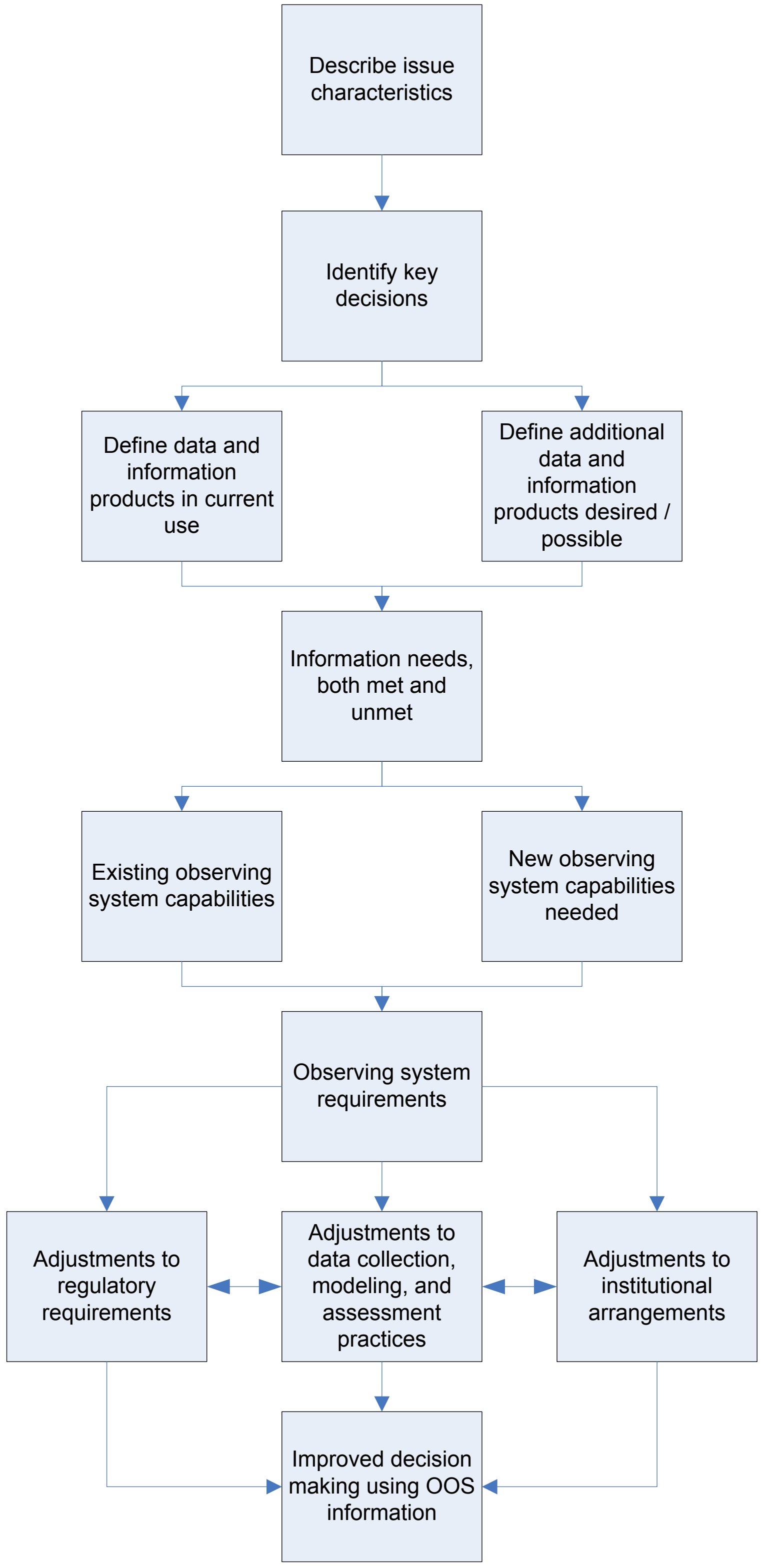


Figure 1.1. Overview of project approach.

We prioritized OOS capacity gaps and the actions needed to fill them in terms of the importance of the specific decision-making process to the overall management of each issue area; the degree to which OOS information could potentially improve the decision process; and the technical, institutional, and economic feasibility of filling the gap. Additionally, we considered the unique capabilities of the major RAs (e.g., making large-scale long-term measurements); and for integrating among various data types and collection programs. We considered recommendations achievable over a relatively short time frame and those requiring a longer-term effort. Issue-by-issue analysis of decisions, needs, gaps, and recommendations are included in Sections 3.0 – 7.0 and key crosscutting capabilities included in Section 8.0.

In addition to evaluating and developing recommendations specific to each individual issue, many institutional factors related to communication, coordination, funding, policies, and product development were fundamental underlying components for all five issues and are addressed separately in Section 2.0 Institutional Issues. Similarly, there is a set of information needs and technical OOS requirements that are important for several management areas; for these we developed specific technical recommendations that are high priorities for California to address (Section 8.0 Assets Needed for Multiple Management Areas).

We considered both technical and institutional issues in evaluating each issue, particularly in defining gaps in existing capabilities and developing recommendations to fill them. This was a crucial part of our evaluation because we found that barriers to the more effective use of OOS information almost invariably stemmed from a combination of technical and institutional factors, neither of which could be resolved independently. Institutional issues included factors such as intra- and interagency practices, perspectives and communication patterns; staff expertise, training and workload; existing regulatory policies and permitting practices; funding sources and patterns; and agency governance structures. While we considered product development needs associated with filling specific data gaps in each management area, we did not include needs related to more basic research.

Throughout the evaluation, we consulted with and shared interim products and report drafts with a project advisory panel consisting of the staff from the California Coastal Conservancy, the California Ocean Protection Council (OPC), the California Ocean Science Trust (OST), CeNCOOS, and SCCOOS.

1.3 Report structure

The report is organized into the following main sections that address different aspects of the overall evaluation:

- 2.0 Institutional Issues presents an overall analysis and recommendations related to California's institutional infrastructure for supporting the development, implementation, and maintenance of OOS capabilities. These recommendations are based on a synthesis of insights from the separate evaluations of each of the five core issue areas
- 3.0 Discharges and Water Quality focuses on monitoring, assessment, and management of point and nonpoint discharges to the coastal zone
- 4.0 Salmon Recovery focuses on a range of decisions related to salmon populations, including fisheries, hatcheries, habitat restoration, flow management, and breaching of river mouths to enhance migration and survival
- 5.0 Ocean Renewable Energy focuses primarily on wave energy and the information requirements for permitting and environmental assessment
- 6.0 Harmful Algal Blooms (HABs) focuses on the monitoring and modeling needed to predict, identify, and track algal blooms with a variety of toxic and other impacts
- 7.0 Oil Spills concentrates on the tracking and prediction of plumes from oil spills that might stem from a range of sources

- 8.0 OOS Assets Needed for Multiple Issues identifies key assets required across multiple management areas and recommends specific actions California and others should take to ensure these assets are developed, implemented, and/or maintained as needed
- Appendix 1 List of Interviewees
- Appendix 2 Observing System Requirements and Capabilities provides the detailed analysis of information needs and observing system capabilities and gaps associated with specific decisions in each management area

2.0 Institutional Issues

Overview – There are key issues that prevent the effective use of ocean data. These are related to communication, product development, funding and business models, governance and staffing, and agency coordination. Some of these can be resolved by action within the RAs but many require actions at the state level. In particular, the state must become more engaged with ocean observing efforts to create strategic direction, actively guide their development, and apply lessons learned in other state programs.

Communication and coordination – Communication between OOS partners and potential management users is too often diffuse and ineffective. Solutions that enhance abilities to communicate across bureaucratic boundaries will require that agency roles be better defined and coordinated, that governance be improved, and that business models be updated.

Product development – California and the RAs lack a product development strategy that can consistently match OOS capabilities to management needs. California must take advantage of the wealth of experience available in other agency and industry settings to create a more structured development process.

Funding and business model – The RAs lack a business model that can guide their integration into the California's OOS and management frameworks. This results from the RAs' focus on federal IOOS priorities as well as California's lack of an overall OOS strategy. A successful business model will prioritize developing products and services critically needed for management decisions and will identify those that customers are willing to pay for.

Governance and staffing – Governance structures at both state and RA levels are insufficient for matching OOS capabilities with California's needs. Staffing policies at the RAs further limit their ability to implement a more effective business plan. California should engage more directly with the RAs and contribute to funding a full-time director for each RA, while the RAs should streamline their committee structures.

Management agency roles – California lacks overall goal-setting and coordination functions for defining OOS needs and promoting the use of ocean data in agency decision making. Initial steps have been taken by the CWQMC and the OPC but remain preliminary. California and the OPC must take a number of specific steps to improve coordination across users of ocean data and information and to provide clear messages to the RAs and other data providers about the state's priority needs.

NOTE: Please see Appendix 2 for the detailed analysis of decision information needs and OOS capabilities on which much of the following discussion is based.

Identifying and resolving institutional issues is fundamental to the success of ocean observing efforts and such issues are admittedly one of the hardest barriers to success to overcome. The arrangements that determine priority setting, decision making, funding and staffing, communication, and product development are more important to the successful use of ocean data and information than any single set of technical recommendations about OOS components. Stated another way, the targeted recommendations described below (Sections 3.0 – 8.0) cannot be implemented effectively or updated as needed if the institutional issues described here are not addressed. These issues are closely interconnected; resolving some but not others will undermine California's ability to develop and effectively use ocean information to support management decisions.

As mentioned in the Introduction, we understand OOS in California to encompass more than just the two RAs (see Appendix 2). We believe this is a key shift in perception that will allow California to more effectively meet the challenge of developing and implementing a strategic plan for using ocean data in decision making. The RAs have achieved notable successes with tight funding and staffing constraints, including developing technical infrastructure, data management capabilities, and scientific partnerships. However, their first responsibility is to meet national IOOS objectives and they are not well positioned or funded to meet all California's needs or to fully develop and/or integrate the range of observing tools and products required for each of the five management areas we examined. It is therefore an opportune time for California, and the RAs, to move beyond the RAs' startup phase to a more mature stage of development, one based on a strategic plan that encompasses all OOS capabilities and better defines their application to management decisions.

2.1 Overview of institutional issues and recommendations

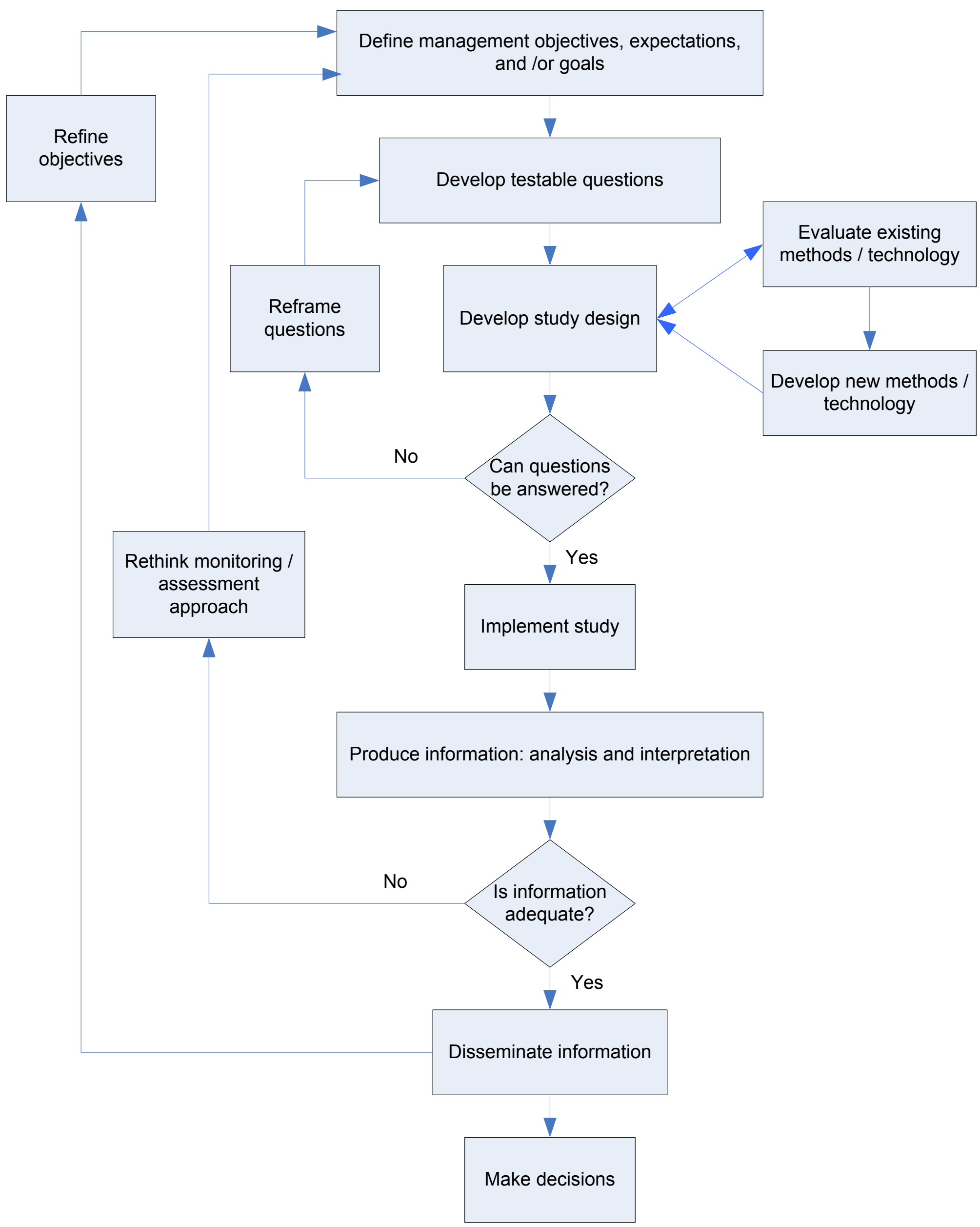
Ocean observing efforts in California are prey to an all too common set of problems that plague data gathering and assessment programs intended to support decision making. They also must take advantage of new technology by managing the transition from research and development to reliable operational products. We identified five basic issues (described more fully below) that cut across all the management areas we examined:

- Communication between OOS staff and information users in management agencies is not always consistent or effective
- There is no formal or recognized process for developing reliable, operational OOS capabilities and products such as plume tracking tools, HAB forecasting models, coordinated freshwater / ocean salmon population models, or protocols for evaluating assessments of wave energy project impacts on wave fields
- Funding for certain key OOS efforts is limited and/or insecure and the RAs' business model is inadequate to meet agency decision needs
- The RAs' governance structure does not support the strategic decision making required to meet agencies' decision-making needs
- There are inadequate incentives and processes for coordination among state agencies

In addition to the specific recommendations provided below, meeting each of these challenges and taking advantage of the opportunities they represent requires that:

- California provide more overall strategic direction to ocean observing efforts by
  - Becoming more directly engaged with the RAs specifically and with ocean observing efforts more generally
  - Actively requesting and guiding the development of new products rather than waiting for them to bubble up from below
  - Fostering longer-term strategic relationships between RAs and other research, monitoring, and management efforts
  - Applying lessons learned in other state programs that successfully combined the development of new policy with new monitoring and assessment (i.e., observing) tools
- New funding mechanisms be developed that stretch beyond the agency or grant funding that is currently the norm
- The RAs conduct business differently with the resources they have in order to effectively engage their users and meet their needs

The higher-level strategic direction called for throughout our discussion of institutional challenges should begin with a set of management-driven requirements (as described in Appendix 2) and then determine what is needed from observation and information systems to meet these requirements. This is best approached from an adaptive monitoring and management perspective, in which approaches are revised as new evidence becomes available or as requirements change. One such monitoring and assessment framework, developed for the marine environment by the National Research Council (NRC 1990) is illustrated below. It shows how observing activities and capabilities should be driven by management objectives and ultimately support decision making. It also highlights a role for new technology as needs arise. More recently, analogous management- and question-driven approaches to defining observing system requirements have been articulated by the CWQMC (CWQMC 2008, 2010) and the State Water Board (Bernstein 2010) to guide the development of large-scale coordinated observing and assessment programs.



2.2 Coordination and governance

The absence of an organizing framework for coordinating ocean observing activities means that communication about OOS capabilities and between OOS partners and potential management users is too often diffuse and ineffective. Remedying this situation will depend on actions taken to resolve the other institutional issues, link communication to strategic goals, and enhance California's structural capacity to initiate and sustain needed communication across bureaucratic boundaries.

2.2.1 Coordination and governance findings

Despite the existence of a number of committees and advisory bodies (for the OPC, the OST, and the RAs), we found that California has no overarching framework for coordinating ocean observing activities and ensuring their relevance to management priorities. More specifically, governance structures at neither the statewide nor the RA levels effectively assign roles and responsibilities, define channels of communication, or resolve key organizational tensions, such as that between centralized and distributed decision making. As a result, relationships and lines of communication between ocean observing efforts and potential users and decision makers are too often sporadic, diffuse, and poorly defined. There is insufficient targeted, focused communication with potential users of ocean data and information.

Key managers in federal, state, and local agencies are often unaware of ocean observing data or capabilities; for example, ocean managers in a key federal agency did not realize the value of HF radar data in discharge and spill tracking. In addition, potentially useful relationships are often not pursued and fully developed; for example, several potential users noted they could not find information about who to contact at the RAs to explore ideas about new products or that initial planning meetings about such products were never followed up. To an unfortunate extent, the burden of communicating with the user community, in both science and management, has fallen to the RAs, who have not used their admittedly limited resources as effectively as possible. As a result, such communication is a mix of broad outreach (e.g., workshops, advisory committee meetings), passive presentation of possibly useful data and information on websites, and targeted interactions with specific users (e.g., meetings with individual dischargers). Some of this is effective and much is not, important audiences (e.g., water quality and resource managers at USEPA Region IX and the California Resources Agency, respectively) are not being communicated with, and some potential participants have stopped attending meetings of RA-sponsored advisory committees because of the lack of strategic direction.

Tracking Sewage Spills

There are many sewage spills in the coastal zone every year. Many of these are small but some are large, like the 1998 Thousand Oaks spill that discharged hundreds of millions of gallons of raw sewage a day and the September 2011 San Diego spill that discharged between one and two million gallons. Information on the direction, speed, and extent of the spill in the coastal ocean would be valuable to managers, whose response is now limited due to the lack of such information.

Operational plume tracking tools could fill this data gap but they have not been validated for the nearshore. Even were they available, existing regulations require sewage agencies to report the volume of a spill, but not whether it reaches the receiving water (e.g., stream, river, ocean). There is thus no specific trigger that would initiate a spill tracking effort.

Meeting coastal managers' needs will therefore involve the targeted development of technical tools as well as revisions to regulatory requirements. At the moment, there is no entity or person charged with the responsibility to manage the separate pieces of this and similar management information needs.

Statewide coordination. While the OPC's responsibilities (see Section 2.5 Management Agency Roles) position it to lead the development and implementation of a statewide OOS strategy, it has not always succeeded at engaging other agencies in higher-level efforts at strategic planning and coordination. There is no standing committee, workgroup, or other body charged with identifying and prioritizing management information needs statewide and matching them with OOS capabilities. The CWQMC has approached the OPC and the OST about creating and overseeing a set of formal workgroups related to ocean management, observing, and assessment that would parallel those for other areas (e.g., wetlands, seafood consumption safety), but this has not proceeded beyond preliminary discussions.

Coordination by the RAs. The two RAs have attempted to accomplish a planning and coordination function with governance structures that include a Board of Governors, an Executive Steering Committee, and the Joint Strategic Advisory Committee (JSAC), with functions and processes defined in bylaws and other documents. Despite this formality, there is no adequate role for state agency involvement, or for ensuring meaningful input from other than the core group of scientists. The Executive Steering Committees' membership contributes to insularity because they include former chairs of the committee and because the committees are not always fully staffed. The JSAC, which is intended to engage potential users and customers more directly, is diffuse and lacks the kind of focus, structure, and follow through seen in effective management and strategic planning efforts. Finally, the RAs' governance structure lacks any explicit product development and/or implementation function.

While criticism of the RAs' coordination and communication efforts is valid, it does not recognize that the RAs are attempting to fill a vacuum they are not designed, staffed, or funded to fill. The RAs are staffed primarily by academic scientists. While this is suitable for the RAs' research, analysis, and some product development functions, it is often a poor fit for other purposes related to coordination and strategic planning. Thus, decisions about whom to talk to, about what topics, on what timeframe, and in what larger management context are being made in a fragmented and *ad hoc* manner in the absence of any overall statewide strategy or guidance. The RAs can focus on specific information needs and products but they cannot by themselves create statewide strategy or OOS policy.

Seeds of success. Within this larger picture of inconsistent coordination, there are successes that provide a basis for building effective links between the ocean observing community and the management users of ocean information. For example, CDIP produces wave data and forecasts that are widely used by coastal engineers and planners, harbor masters, lifeguards, mariners, and many others to understand present conditions and predict future hazards. The sponsoring agencies, California Department of Boating and Waterways and USACE, are also primary users, and the communication chain between them and SIO, which manages the program, is both short and direct. Similarly, SCCOOS has worked directly with pilots and others at the Ports of Los Angeles and Long Beach to produce a tool that provides timely information about ocean conditions to safely guide ships in and out of sometimes treacherous harbors. These successes involved little in the way of formal structures or processes because they did not require organizing ongoing communication among a wider set of developers and users. In contrast, the State Water Board has implemented a formal process to ensure effective communication and oversight as new monitoring and assessment (i.e., observing) tools are developed for a number of new management policies (Sediment Quality Objectives, Nutrient Numeric Endpoints, Biological Objectives for Perennial Streams). These involve a designated science team, stakeholder and regulatory advisory committees, and an external science review panel that all function throughout a long-term development and policy implementation process. Such systematically focused and structured processes were rare or absent elsewhere in the broader OOS arena.

These successes highlight an important missing piece in California's efforts to integrate OOS information into management. Many state agency managers and scientists who work on coastal issues are trained as lawyers, policy analysts, or biologists. They therefore lack the skills to understand both ocean science and information technology to the degree needed to use existing OOS products and help define and create new ones. This is exacerbated by the heavy emphasis on physical and some chemical observations within the federal OOS network, which makes it difficult for many end users to see the relevance of these OOS datatypes to issues that involve biological resources. Training workshops as well as a formal user support function could help agency staff better understand and utilize the various types of OOS data and products.

2.2.2 Coordination and governance recommendations

Effective coordination and planning depend on goals and policies that define its purpose, and on governance structures and processes that describe how these should occur. In particular, strong links must be forged between technical efforts to gather data and develop new information products and managers' uses of information.

Both California and the RAs need updated governance structures designed to support the development and implementation of an overall state strategy for OOS. These structures should help to overcome the organizational distance between the RAs and state agencies by fostering more direct involvement of state agency staff in RA governance.

We recommend that California and the RAs work together to ensure that:

- The OPC Steering Committee create an OOS subcommittee (perhaps led by the OST) to identify priority needs for ocean data and to guide and promote agency use of such data
- The OOS subcommittee address barriers to communication within and between agencies and provide a focus for coordination with OOS partners (workgroups established by the CWQMC, for example the California Wetlands Monitoring Workgroup, provide useful models)
- California develop funding for an OOS liaison to better link state agencies to OOS data sources and developers in order to
  - Institutionalize a role for state agency decision makers in OOS and RA governance
  - Identify opportunities for new products and refine existing products useful to managers
  - Conduct targeted and strategic marketing and training
  - Identify instances where new policies, procedures, or perspectives could improve data utilization
- California develop a full-time director position for each RA
  - The director should have knowledge of, and experience in, both science and policy
  - Non-federal sources should fund half of the position to ensure attention to and accountability for California interests
- The RAs streamline their committee structures and clarify lines of authority; in particular, addressing the JSAC's limitations, perhaps by using smaller, issue- or product-specific committees
- OPC, OST, and the RAs conduct training and education workshops for agency managers and scientists on OOS data and tools that could include sharing expertise among agencies, the use of expert panels, or direct interaction between agency managers and OOS partners

2.3 Product development

The absence of a clearly defined product development strategy results in the inefficient use of financial and technical resources, missed opportunities, and unmet management needs. While successful products are sometimes created, these stem from specific sets of favorable circumstances and not from a reliable and repeatable process. Resolving this situation will require learning from the wealth of experience available in other industry and agency settings, greater involvement from a state coordinating function, and implementing a more structured development process.

2.3.1 Product development findings

There are many OOS products that fulfill important scientific and management needs. These range from long-term research efforts such as the CalCOFI program, to the Regional Ocean Monitoring System (ROMS) circulation model that supported marine reserve design work, and the multitude of permit-mandated monitoring programs that assess compliance with regulatory objectives. There are more instances where potentially useful products (e.g., plume tracking tools) are not effectively integrated into decision making, product development decisions depend on the vagaries of grant funding or personal connections (e.g., development of integrated nearshore / offshore plume tracking tools), or clear management needs go unmet (e.g., incorporation of ocean data into salmon management protocols). In addition, various state agencies engage in a variety of mostly uncoordinated activities including funding for research and development, tracking others' research and development efforts, partnering with federal agencies and NGOs, and running operational observing networks. For example, we found poor coordination between freshwater and marine salmon population modeling, among planning efforts focused on ocean wave energy, and across the development of data management systems, among others. The absence of a product development strategy or philosophy means that California does not benefit from opportunities for synergy or shared learning among these activities.

California lacks a consistent, well-defined process to guide the prioritization, design, development, and implementation of new OOS products. As a result of the absence of such input and guidance, there is no mechanism for taking California's larger interests into account when making decisions about which OOS product to develop, nor is there meaningful integration among products. In particular, there is no agreed-on process, with explicit criteria, for moving products through the transition from developmental to operational stages. With few exceptions (e.g., rapid bacterial indicators of beach contamination), we found no development efforts that included all the expected components of a complete product development plan, including, for example, a description of the product need along with field testing and evaluation, and end use.

In addition, there are no criteria for deciding when a product is ready for release. Instead, individual scientists make such decisions on their own, and only occasionally are agency managers involved in evaluating whether a product meets their needs (e.g., for accuracy and precision) and there is no opportunity for the iterative testing and revision process essential to effective product development. The emphasis on individuals follows through to implementation and there are key assets that remain dependent on one or a very few scientists. The lack of a plan for operational capability makes California extremely vulnerable to events that could easily result in the degradation or loss of key assets.

2.3.2 Product development recommendations

An effective OOS that addresses management needs must include a product development plan that links product development to management needs and includes a clear path from research and development through full implementation. A single approach will not fit all situations, and there are readily available examples, from both industry and agencies, that could provide models applicable to OOS in California. OOS program managers in California are for the most part unaware of the experience gained in these other arenas and as a result are unnecessarily repeating mistakes that could have been avoided and relearning lessons already learned by others.

We recommend that OOS managers:

- Examine product development processes in a range of industry and agency applications to identify models suitable for OOS in California (e.g., integrated product design and development in the auto industry, usability testing in the software industry, close interaction between end users and design engineers in space missions, new product innovation processes used by industrial design consulting firms)

- Define a product development process that includes steps from initial needs assessment through implementation with iterative user feedback, including
  - Creating product development teams that include both technical staff and end users who remain engaged through the entire process
  - Defining criteria for determining when a product or capability is ready for release and broader implementation
- Distinguish between development and operational phases and assign responsibility accordingly; developers may not be the best entities to manage full-time operations
- Include liaison from the state-level coordinating role in the product development process

2.4 Funding and business model

The RAs do not have a business model[2] that guides their effective and sustainable integration into California's OOS and management frameworks. This is partly due to the RAs' focus on federal IOOS priorities, their prioritization of academic research interests, and the absence of the larger context that would be furnished by a statewide OOS strategy. Nor does California have a larger OOS funding plan that effectively deals with current state and federal budget realities. Improving the effectiveness and long-term viability of the RAs and of OOS as a whole will therefore depend on developing business and funding models that provide the resources needed to sustain core OOS capabilities.

2.4.1 Funding and business model findings

The RAs' business models are insufficient to enable them to provide the strategic direction California needs, to implement a robust product development process, or to support agency decision makers' long-term goals. The business models do not ensure the amount or stability of funding needed for the RAs to fulfill an expanded role in California's OOS strategy. In part, this reflects the fact that the RAs receive the bulk of their funding from IOOS appropriations and must therefore meet IOOS' national goals. This creates a kind of Catch-22 situation in which the RAs focus much of their effort on IOOS priorities because they lack other sources of funding and they lack other sources of funding because they focus much of their effort on IOOS priorities.

However, this is not the whole story. The RAs' proposals to IOOS refer to management needs but specific projects tend to reflect the research interests of individual principal investigators rather than a focused product development strategy. As a result, funding requests and patterns tend to focus inward on academic interests rather than outward on managers' and other customers' needs. In addition, the RAs have devoted effort to fulfilling broad service functions (often to meet IOOS requirements such as providing access to a wide variety of data types) that do not provide income. They have been unsuccessful at creating products and services income streams from a sufficient number of private and public customers. No RAs in other regions have met this challenge. While some RA staff have marketing or entrepreneurial skills, fostering this capacity has not been a high priority. Even where such skills do exist, the staffs are less productive than they could be because RA business models do not provide clear goals, and the absence of an overarching state strategy for OOS leaves them without needed guidance. Thus,

[2] A business model defines the essential elements of an organization (e.g., mission, strategy, infrastructure, customers or market segments, marketing, distribution, finance) through which it creates and delivers value. Such models can be either explicit or implicit and the model that directs an organization's activities can differ markedly from the formal model stated in plans or strategies.

even when the RAs succeed at producing funded projects or products, their linkage to strategic state interests is poorly defined.

At the statewide level, key efforts that are used in multiple management areas (e.g., ROMS, HF radar) lack sustained and reliable funding (see Section 8.0 OOS Assets Needed for Multiple Issues). While this is partly due to constrained budgets, it also reflects a narrow reliance on budget allocations and bond funded grant programs. California has not taken as much advantage as it might of alternative funding mechanisms that have been successfully used in other arenas.

2.4.2 Funding and business model recommendations

The RAs' activities must be organized around a business model that is designed to support both national and state level strategic goals and provide for a sustainable revenue stream by meeting managers' and other customers' core needs. Such a business model must fit within the larger context defined by a statewide OOS strategy and the coordinated agency roles that implement the strategy. Thus, the RAs cannot design their business model independently without close interaction with the California agencies responsible for California's overall OOS strategy. At a minimum, the RAs' business model must describe:

- How the RAs' activities support state strategy and users' needs
- Processes for product development and implementation
- Diversified funding sources and mechanisms that enhance longevity and stability
- More specifically, how to fund the transition to operations
- How to strengthen and sustain monitoring / project operations, whether inside or outside of academic settings (e.g., CDIP, Southern California Coastal Water Research Project (SCCWRP), National Data Buoy Center (NDBC), or a West Coast Data Center)

Beyond the RAs, California should address the challenge of intermittent and unreliable funding for OOS efforts. While we acknowledge the difficult budget climate, we also believe that a statewide OOS strategy that is linked to clear management needs and that coordinates agency roles will provide a more compelling case for new funding and for leveraging existing funding. In particular, California has made inadequate use of user and permit fees to finance OOS and we recommend that state agencies develop fee based funding mechanisms (see text box examples) tied directly to support for OOS assets and activities.

Such approaches are beginning to be applied by California agencies. For example, the State Water

Fee-Based Funding

There are many useful examples of fee-based funding that support public goods – goods and services typically provided by government – and that are applicable to OOS. These are supported by extensive economic theory and analysis on their pricing and management.

Business improvement districts involve businesses levying taxes on themselves to provide extra services (see http://tinyurl.com/3gu52ey for the New York City Business Improvement District. Ronald Coase, winner of the 1991 Nobel Prize in Economics, described in a now-classic article how lighthouses, generally considered a public good, were funded by private interests as far back as the 18th century (http://tinyurl.com/3gu52ey).

In California, the Oil Spill Prevention and Administration Fund is supported by fees on oil deliveries and similar funds have operated in Louisiana and Texas. The oil industry funds several joint industry projects on oil spill response that could be potential partners for related OOS efforts.

Board's Surface Water Ambient Monitoring Program (SWAMP) is charged with coordinating methods development and standardization for monitoring and assessment for both freshwater and coastal / marine waters. SWAMP is increasingly funded by discharger permit fees and some municipal stormwater dischargers are considering paying an additional fee for SWAMP to conduct their permit-mandated monitoring and assessment. SWAMP managers agree that some portion of fees from municipalities discharging to the ocean could be available to support ocean observing. Similarly, project proponents (e.g., desalination plants, wave energy projects) could be required to pay fees that would help support the core OOS assets that produce data useful for planning, siting, and environmental assessment.

2.5 Management agency roles

California lacks both overall goal-setting and coordinating functions for defining OOS needs and promoting their use in agency decision-making processes. Some initial steps have been taken to fill this gap but they remain preliminary. California must take specific steps to improve coordination across potential users of ocean data and information and to provide clear messages to the RAs and other developers of ocean data products about California's priority needs.

2.5.1 Management agency roles findings

Our analysis of each management area highlighted a set of key shortcomings that prevent California from making the most effective use of OOS capabilities and information. California's size and diversity, combined with the number of local, regional, state, and federal entities involved in many management processes, only exacerbate these problems and emphasize the need for an overall coordinating function to develop and strengthen California's use of OOS data.

In addition to the absence of an overall organizing function that would coordinate agency roles, we found that there are insufficient incentives for agency staff to use OOS data, especially when this would require changing existing practice or new interpretations of established law or policy (e.g., salmon hatchery management policies). Without an active state role in defining needs for new OOS capabilities, there is neither the staff time nor the process for involving agency staff in the development of new tools and products.

2.5.2 Management agency roles recommendations

There are two critical roles that must function effectively for California to achieve the benefits available from ocean data and information. The first is a strategic role that defines goals and sets direction, in part by requesting new products rather than waiting for them to bubble up from scientists.

Wetlands Coordination

The California Wetlands Monitoring Workgroup (CWMW) provides one example of how a diverse set of observing activities can be effectively organized statewide.

The CWMW operates under the sponsorship and oversight of the CWQMC and coordinates the monitoring and assessment of wetland status and extent statewide. It includes 13 state, five federal, and five non-governmental participants.

It functions under a formal charter, roles, and responsibilities, and has a committee structure to address specific technical and policy issues. The CWMW targets six explicit management questions and focuses on providing scientifically valid answers to these at statewide, regional, and local scales.

The CWMW leads development of technical mapping, monitoring, and assessment methods as well as data quality standards. It also defines data management and reporting protocols. Its methods are now being incorporated into both regulatory and non-regulatory monitoring (i.e., observing) and assessment programs statewide.

There are useful examples of this in freshwater and estuarine systems (see Section 2.2.1 Communication and coordination) where a state agency has requested new monitoring and assessment (i.e., observing) capabilities to meet specific policy needs. The second key role is a coordinating one that organizes the needs, skills, and resources of multiple agencies and other entities in order to accomplish these goals.

While this has been accomplished only sporadically for the ocean, we noted several examples of successful coordination within California that could provide models for improved OOS coordination. For example, the California Wetlands Monitoring Workgroup, under the auspices of the CWQMC, is managing and developing a complex and coordinated state and federal interagency approach to wetland mapping, assessment, and restoration efforts statewide. The Southern California Bight Monitoring Program conducts periodic regional assessments of ocean and coastal conditions, coordinating the goals, information needs, and participation of nearly 100 participants.

Based on its core responsibilities, the OPC is ideally positioned to fill this central coordinating role.

We recommend that California:

- Identify a lead coordinating responsibility for OOS, perhaps building on preliminary discussions between the CWQMC and the OPC and/or the OST, including
    - Creating new workgroups and other structures to guide and promote agency use of ocean data, overcome institutional boundaries, and define requirements for ocean data
    - Using a liaison function to increase communication and foster the identification of problems and opportunities
- Revise existing policies and/or develop new policies to take advantage of improved ocean data and understanding
- Strengthen coordination and synergism among and within agencies and their projects
- Improve OOS project initiation and oversight, including communicating expectations regarding management outcomes, fostering agency interaction with key state agencies, focusing product development, and training

3.0 Decision Information Needs: Discharges and Water Quality

Overview –The main discharge types include publicly owned treatment works (POTWs) that handle municipal wastewater; wet and dry weather runoff from stormdrains, creeks, and rivers; and desalination plants. Regulatory compliance, spill response, impact assessment, and real-time management could be improved by more integrated use of ocean observing measurement and modeling tools.

Discharge characteristics – POTWs discharge treated effluent continuously at depth, usually several miles offshore, while desalination plants discharge continuously close to shore. The volume of untreated discharges from stormdrains, creeks, and rivers varies with season and the amount of rainfall, and plumes can extend many kilometers offshore for large river discharges. Sanitary sewer spills from sewer line breaks, pump failures, and other mishaps can release raw sewage directly into the nearshore zone. Discharge impacts may include risks to human health from swimming in contaminated waters, direct toxicity to exposed organisms in the water column and sediment, indirect toxicity due to food chain effects, and algal blooms in response to nutrient enrichment.

Discharge management and decision framework – Discharges are managed and permitted under a variety of state and federal laws and regulations. Many of these include monitoring requirements to ensure that discharges, and their effects, meet specific regulatory requirements. The majority of discharges are permitted and managed individually.

Discharge information needs – Management decisions include opening or closing swimming beaches to manage human health risk, prioritizing individual discharges and categories of discharge (e.g., POTWs vs. rivers) in terms of their relative contribution to different types of impact (e.g., beach closures, effects on ecological resources), and evaluating efforts to maintain and/or improve water quality. There are existing capabilities that must be maintained, including data on currents, waves, discharge flows, and contaminant loads; nearshore and offshore current models; and water quality monitoring programs. Gaps that must be filled primarily include new modeling tools for more comprehensive plume tracking, additional data inputs needed to apply these tools, and possibly expanded impact assessment approaches.

Discharge institutional issues – The current management system must be adjusted to make full use of observing system capabilities. This will require integrated permitting that considers all discharges' combined effects and better coordination among monitoring and assessment programs that also use new modeling tools. It will also require changes to compliance decision rules and regulatory frameworks to allow for a broader range of data products (e.g., model output, probability distributions), and denser data streams, in contrast to existing methods based on smaller numbers of discrete data points.

Recommendations – We recommend continuing and improving water quality monitoring through the development and standardization of more efficient and reliable indicators, filling key data gaps related to rivers and creeks, ensuring the availability of oceanographic measurements needed for models, and developing current models that integrate offshore and nearshore processes. We also recommend that the state improve data management capabilities needed to accommodate ocean data and revise management and regulatory frameworks to take advantage of new data and increased understanding of ocean processes.

NOTE: Please see Appendix 2, Tables A2.1 and A2.2, for the detailed analysis of decision information needs and OOS capabilities on which the following discussion is based.

3.1 Discharge issue overview

Maintaining the quality of coastal and ocean waters, and improving it where needed, is essential to many important recreational and commercial uses of ocean resources, as well as to the health of ocean ecosystems. A major threat to water quality stems from contaminants carried to the ocean by a variety of discharges, contaminants that can potentially contribute to a range of impacts on marine organisms and human health. While these discharges are regulated under state and federal legal frameworks, monitoring and assessment of their impacts has not always been able to support real-time decision needs or to fully respond to regulatory requirements. As a result, our ability to adequately assess and manage water quality impacts could be improved in many cases by the more integrated use of ocean observing measurement and modeling tools.

For purposes of this evaluation, we define water quality in terms of the impacts of four types of discharges:

- Publicly owned treatment works (POTWs) discharging treated municipal wastewater
- Spills of raw sewage (sanitary sewer overflows) from pipe breaks and other malfunctions of wastewater treatment systems
- Wet and dry weather stormwater runoff from storm drains, creeks, and rivers
- Desalination plants

These four types of discharges are similar in that they all discharge water that differs in salinity from ocean water and that contains potentially problematic contaminants. The discharges differ in location and in the timing, intensity, and composition of each discharge (Figure 3.1, Table 3.1). These similarities and differences are important in determining the types of observing system products and capabilities most appropriate to answering management questions. The following subsections summarize key discharge characteristics, the existing management framework, and which essential management information needs can be met by current and/or enhanced ocean observing capabilities.

3.2 Discharge characteristics and impacts

As Table 3.1 shows, both POTW and desalination plant plumes are continuous, while sewage spills and both wet and dry weather stormwater plumes are highly variable, both spatially and temporally. Though POTW discharges are located offshore, their plumes may move inshore to the nearshore zone (shallower than 10 m) depending on winds and currents (Figure 3.1). Conversely, dry weather stormwater plumes are mostly contained in the nearshore, while higher-volume wet weather stormwater plumes, especially from rivers and large creeks, can travel into the offshore zone. Sewage spills from coastal treatment plants typically affect the nearshore, although very large spills could be transported offshore. Plumes from desalination plants are entirely contained within the nearshore. Because none of these plumes are neutrally buoyant, their multi-dimensional dispersion and transport throughout the water column is important to understand. Finally, both POTW and stormwater plumes contain particulates, and particulate-bound contaminants, that settle out to the bottom. Desalination plant discharges may also contain particulates from filter backwash, but without the sorts of contaminants associated with POTW and stormwater discharges.

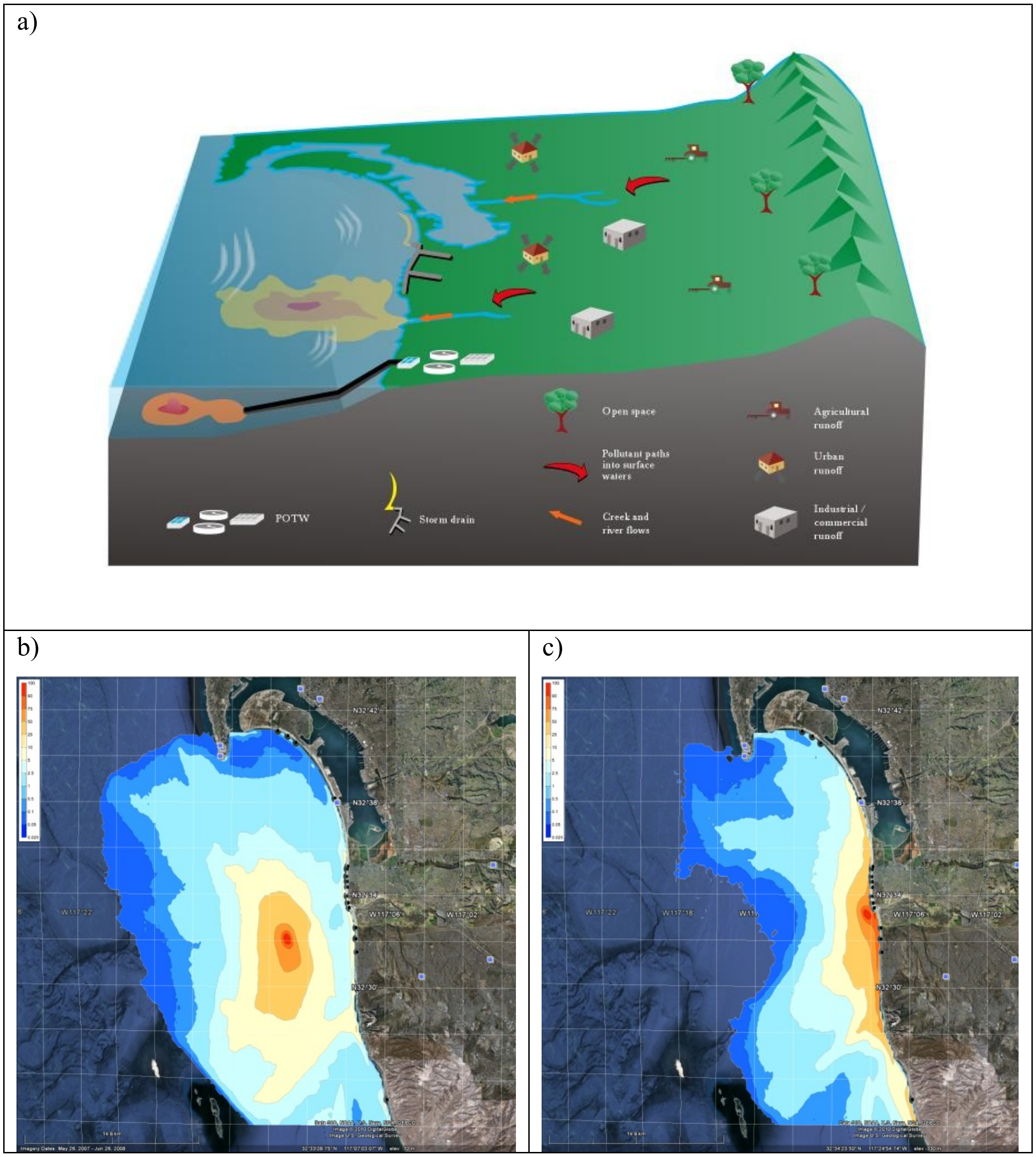


Figure 3.1. Representative discharge locations and plume configurations. a) Schematic of plume locations and trajectories typical of each type of discharge. In this illustration, based loosely on the San Diego, CA region, a large river plume has moved offshore, while a storm drain plume is entrained along the shoreline (as would a sewage spill), and a POTW plume disperses at depth offshore. b) Overall probability distribution of the South Bay Ocean Outfall near San Diego for those days over a four-year period when the plume surfaced offshore. Red and orange indicate higher probability and progressively darker blues lower probability. c) Overall probability distribution of the Tijuana River plume over the same four-year period only when the river was flowing. Note that river plume is concentrated nearshore compared to the outfall plume. (source for b) and c): Kim et al. 2007)

Table 3.1. Basic characteristics of each discharge type.

Discharge type	Location	Timing	Extent and volume	Composition
POTW	Offshore Few sites	Continuous	Many kms Mostly offshore but can move inshore Consistent volume	Treated municipal wastewater Contains particulates
Sewage spill	Coastline Many sites	Sporadic	Local to many kms Mostly in nearshore Variable volume, sometimes high	Untreated municipal wastewater Contains particulates
Stormwater[1] – dry weather	Coastline Many sites	Chronic or sporadic	Many kms Mostly in nearshore Low, variable volume	Untreated urban, agri-culture, open space runoff Contains particulates
Stormwater – wet weather	Coastline Many sites	Episodic	Many kms From nearshore into offshore High, variable volume	Larger volumes of rainfall runoff containing untreated urban, agriculture, open space runoff Contains particulates
Desalination	Coastline Few sites	Continuous	Local Nearshore Consistent volume	Concentrated brine

[1] Stormwater is used broadly here to refer to coastal discharges from storm drains, creeks, and rivers.

Depending on size, location, and composition, discharges can create a variety of impacts on human health and coastal and ocean resources (Table 3.2).

Table 3.2. Potential human health and ecosystem impacts from POTW, sewage spill, stormwater, and desalination plant discharges.

Discharge type	Swimming beach contamination	Direct toxicity to organisms	Indirect toxicity (foodwebs)	Contribution to HABs
POTWs	If offshore plumes move to shore	To pelagic and benthic organisms exposed to elevated levels of contaminants	To aquatic and benthic organisms that bioaccumulate toxic contaminants To wildlife and humans that consume contaminated organisms	If nutrients in discharge promote algal blooms If plumes increase stratification which may promote blooms
Sewage spills	During and after spills	NA	NA	If nutrients in discharge promote algal blooms
Stormwater – dry weather	If discharges are contaminated	To pelagic and benthic organisms exposed to elevated levels of contaminants	To aquatic and benthic organisms that bioaccumulate toxic contaminants To wildlife and humans that consume contaminated organisms	If nutrients in discharge promote algal blooms
Stormwater – wet weather	During and after major discharge events	To pelagic and benthic organisms exposed to elevated levels of contaminants	To aquatic and benthic organisms that bioaccumulate toxic contaminants To wildlife and humans that consume contaminated organisms	If nutrients in discharge promote algal blooms If plumes increase stratification which may promote blooms
Desalination	NA	To pelagic and benthic organisms in immediate vicinity of discharge	NA	NA

3.3 Discharge management and decision framework

Existing coastal discharges are regulated under provisions of the federal Clean Water Act and the California Porter Cologne Act, which assigned primary responsibility for water quality regulation to the state, acting through the State Water Board and the nine Regional Water Quality Control Boards. Six of these regional boards (North Coast, San Francisco Bay, Central Coast, Los Angeles, Santa Ana, San Diego) have jurisdictions along the coast.

Discharges to state waters (within three nautical miles of shore) are permitted by the state, while those in federal waters (e.g., the Los Angeles Hyperion 7-Mile Outfall) receive federal permits prepared jointly with the state. In general, agencies with responsibility for point source discharges (e.g., wastewater treatment plants, industrial discharges, power plants, desalination plants, stormwater programs) are required to receive a National Pollution Discharge Elimination System (NPDES) permit that mandates compliance with provisions of the California Ocean Plan or the California Toxics Rule (CTR) (for stormwater discharges) and the objectives defined in each region's Basin Plan. These frameworks include a combination of numeric and narrative criteria, compliance with which is assessed through a variety of monitoring programs. Rivers are not regulated as ocean discharges, although inputs to rivers upstream are regulated under freshwater permits and standards. Agricultural discharges are managed under a separate system of waivers which generally mimic the discharge, monitoring, and reporting requirements of NPDES permits.

California's Areas of Special Biological Significance (ASBS), now numbering 34, were first designated in the 1970s and are an issue of particular concern for two main reasons. First, they represent areas of exceptional ecological value that are a high priority for monitoring, assessment, and management. Second, because of their sensitivity, state regulations prohibit point source or thermal discharges to any of these areas, a policy that became problematic several years ago when stormwater discharges were classified as NPDES point source discharges (i.e., in the same category as POTWs), greatly expanding the scope of the prohibition. As a result, there are many more discharges and potential cumulative effects that must be identified, assessed, and managed.

A recent policy change related to coastal electric power generating plants in California will directly affect the design of desalination plants and the management of their highly saline discharge plumes. This new policy calls for reducing the use of once-through cooling water by 93% to reduce impacts on marine life. As a result, desalination plants will not be able to dilute their discharges by colocating them with those of coastal power plants and the State Water Board has begun examining models and other OOS tools for assessing the impacts of these brine discharges as part of the permitting process.

Depending on the severity of impacts to beneficial uses (Table 3.2), Regional Water Boards may implement Total Maximum Daily Load (TMDL) programs. These allocate the total amount of a discharged pollutant to specific sources and establish schedules for reducing loads to specified levels that will not impact water quality. Dischargers, or permittees, are typically responsible for collecting and interpreting the vast majority of water quality monitoring information and reporting this to the Regional Water Boards. Thus, permittees would be one of the primary generators and users of ocean observing information, with regulatory agencies and the public as the ultimate users.

In some parts of California, discharges can be assessed and managed independently because they are widely spaced along the coastline. However, in more populated and developed parts of California, discharge plumes overlap, their interactions are more complex, and it can be more challenging to identify both individual and collective locations, extents, and impacts. Potential discharge impacts (Table 3.2), which underlie management concerns and therefore data and information needs, stem from their respective characteristics. Table 3.2 shows that many of the potential impacts are similar across discharge types, with differences stemming mainly from disparities in the location, size, and persistence of plumes, as well as from the specific mix of contaminants in each.

In the case of desalination plants, which would require new construction, the lead California Environmental Quality Act (CEQA) agency would be the city, county, or water district that would own or utilize the project, or in some cases the California Public Utilities Commission (CPUC). The California Coastal Commission (CCC) would issue a coastal development permit and the Regional Water Board the required NPDES discharge permit. The State Water Board would issue the required permit for water intakes, with the specific regulatory provision depending on whether the intake would be a new structure or would piggyback on existing intakes. If any desalination plant facilities are located on state lands such ungranted tide and submerged lands in the ocean then a lease from the State Lands Commission (SLC) would be required. All of these regulatory decisions would depend on information from environmental impact reviews that would include assessments of discharge characteristics and potential impacts.

For all discharges, other agencies also fulfill management roles in specific instances, for example, where discharges pose risks to public health at swimming beaches (county health departments), potentially affect threatened or endangered species protected under the federal and California Endangered Species Acts (US Fish and Wildlife Service (USFWS), NOAA Fisheries, and CDFG), or impact essential fish habitat regulated under the Magnuson-Stevens Fishery Conservation and Management Act (NOAA Fisheries). In addition, local planning, resource management, and habitat restoration programs along the coast are often significant users of information about the nature, extent, and effects of coastal discharges.

3.4 Discharge information needs

There are six categories of decisions related to the types of discharges described above, stemming from the nature of their potential impacts (see Figure 3.2 for the data inputs and model outputs fundamental to each):

- Opening or closing swimming beaches after contamination events (including sewage spills and stormwater runoff) to protect human health, based on the degree of contamination by indicator bacteria and/or actual pathogens
- Assessing POTW discharger compliance with California Ocean Plan and other permit requirements
- Assessing impacts on ASBSs and the contribution to these impacts of multiple discharges in the same area
- Predicting the behavior of brine discharges from desalination plants and effluent discharges from POTWs for design and permitting purposes
- Managing desalination plant operations to minimize the effects (e.g., filtration system clogging) of algal blooms
- Managing POTW disinfection operations to target higher-risk beach contamination scenarios

In addition to these six issues, POTW and stormwater discharges may come under increasing pressure to reduce nutrient loads if further research shows that such nutrient loading contributes significantly to harmful algal blooms. At present, there is scientific consensus that nutrient loading and HABs are linked (Anderson et al. 2008, Heisler et al. 2008) but direct evidence for specific sites in California is difficult to come by (Kudela et al. 2008); therefore it remains a possibility managers are concerned about.

Table A.2.1 provides a detailed overview of the specific management questions, and ocean information and OOS products and product needs in each of these decision categories. Table A.2.2 then matches these decisions and information needs with a more detailed description of current observing system capabilities and gaps.

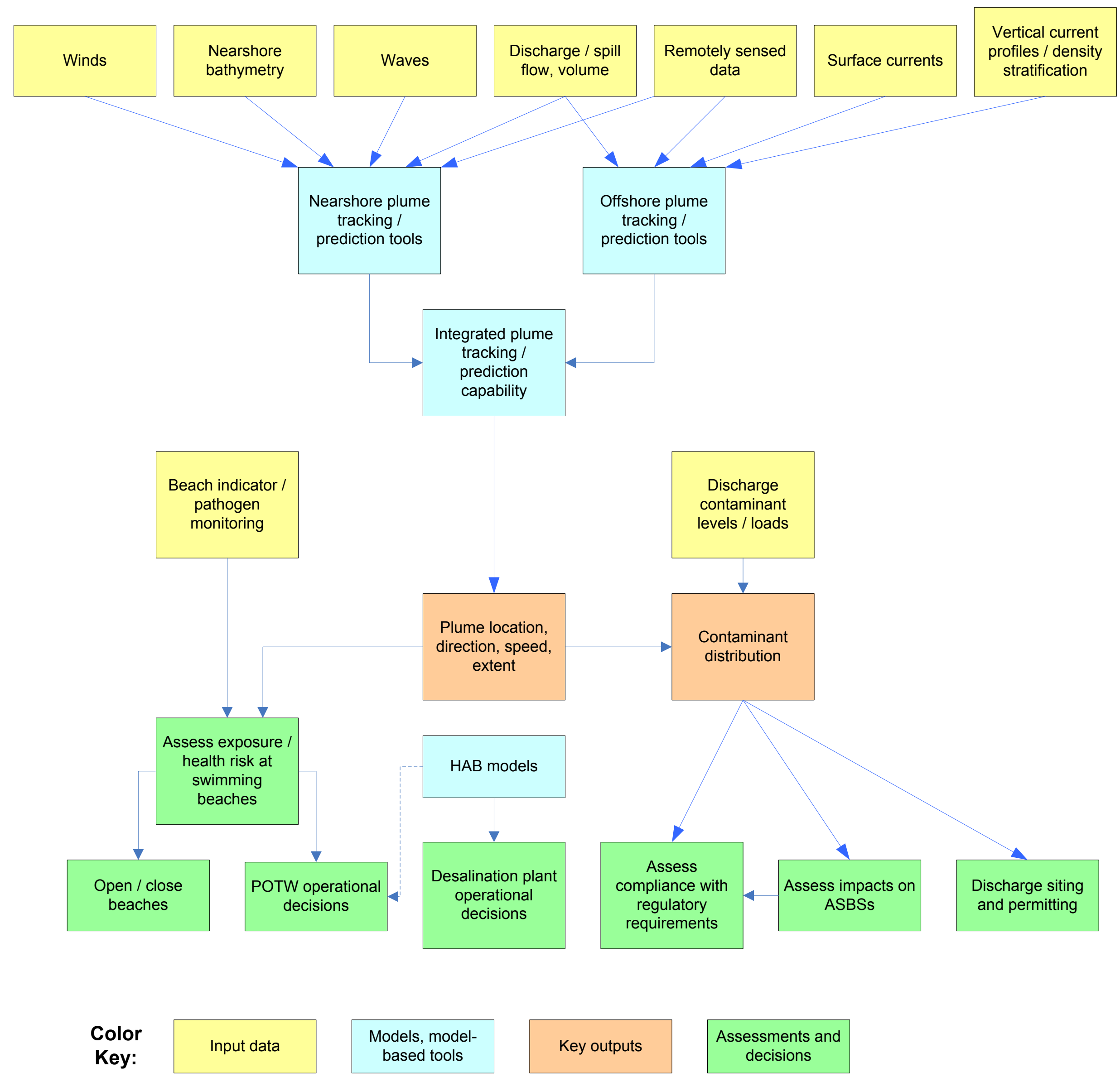


Figure 3.2. A schematic illustration of how ocean data, models, and tools can inform key aspects of decision making related to coastal discharges. Note that multiple decisions flow from two primary information outputs.

Closures of swimming beaches to manage health risks are a major concern, primarily in heavily populated areas, because of their economic costs. The economic impact of closing beaches in Los Angeles and Orange Counties for one year has been estimated (Wiley et al. 2006) at $1.6 billion in output, $913.3 million in value added, $586 million in income, and 21,234 full and part-time jobs. Decisions related to opening or closing swimming beaches depend on information about the levels of indicator bacteria and/or pathogens, and about the location, trajectory, and dispersal of plumes from POTWs, stormwater runoff, nonpoint discharges, and spills. Sewage spills are of particular concern to the State and Regional Water Boards, because of the large number of spills in the coastal zone each year and the limited ability to track or predict the movement of a spill. For example, a major sewer line break in Thousand Oaks in 1998 discharged hundreds of millions of gallons a day of raw sewage for many days to creeks and ultimately to the coastal ocean, and managers' attempts to respond in order to protect human health were limited because of the nearly complete lack of information about the location or direction of the spill. While the ability to track offshore plumes and spills within San Francisco Bay (e.g., M/V *Cosco Busan* spill in 2007) has improved in the interim, nearshore plumes remain difficult to track because this involves different data inputs and models.

Assessing regulatory compliance also depends on information about the location, trajectory, and dispersal of POTW plumes, and about the concentration of contaminants in plumes. While the economic costs of noncompliance are variable and difficult to predict, they can be substantial and involve additional monitoring, fines and legal costs, or modifications to operational procedures. Thus compliance assessment is a high stakes activity for dischargers, regulators, and public interest groups. Accurately locating plumes in real time can be challenging because of the inherent variability in ocean conditions. The State Water Board is therefore currently working with major dischargers to develop improved and standardized methods for defining the location of POTW plumes using markers of anthropogenic input. When completed and incorporated into the California Ocean Plan, this would enable more reliable and consistent comparison of water quality parameters within plumes to reference conditions. While this effort focuses on individual plumes from major POTW discharges, plumes from multiple discharges of all kinds can combine to impact ASBSs in the coastal zone, as illustrated in Fig. 3.1 and Text Box 3.1. Information about the dispersal and overlap of plumes from all sources in a region can be essential for characterizing impacts on ASBSs and prioritizing management attention among these sources.

Desalination plant permitting, which involves environmental impact assessments of their brine discharges, is a costly and time consuming process that depends in part on accurate predictions of the behavior of the discharge plume and its potential impacts on marine organisms. While models exist that can make such predictions, the State Water Board has an interest in promoting comparability and quality control across environmental assessments and is working toward a brine discharge policy by identifying preferred modeling tools that can be consistently applied to all projects. This would be similar to current practice for new ocean POTW outfalls, for which staff at the State Water Board conduct dispersion studies using a validated set of modeling tools. Once desalination plants become operational, they run the risk of lost production if filtration systems become clogged by plankton blooms. Accurate model predictions of phytoplankton blooms could therefore enable preemptive temporary shutdowns to avoid the much larger cost of prolonged outages to remedy clogged filters.

A final site-specific issue is related to disinfection operations at individual POTW discharges. In cases where discharges are closer to shore or where there is concern about plumes reaching the shoreline, discharges are routinely chlorinated at a cost of as much as $10 million per year. Some agencies consider this a useful investment in ensuring that instances of beach contamination will not be attributed to them. Others, however, would prefer to target disinfection, with its economic and environmental costs, to times when current conditions increase the probability that their plume will move into the nearshore.

In each case, developing information needed for decision making depends on the synthesis of raw data inputs and modeled descriptions of plume behavior and processes that lead to impacts of concern. Figure 3.2 also shows that an important common denominator across all these issues is the ability to track and/or predict the location, trajectory, and dispersal of discharge plumes in three dimensions, and to integrate this ability across both the nearshore and the offshore. This is necessary because plumes may move back and forth from the nearshore to the offshore and plumes from separate sources can overlap and combine to create cumulative effects that cannot be identified or managed by treating each plume separately. Once this basic capability is available, it then provides the basis for predicting the dispersal of contaminants, assessing compliance, and estimating impacts.

The overview in Figure 3.2 is based on an analysis of the more specific and detailed management questions and information needs associated with each decision category (Table A.2.1). These information needs are then matched with a more detailed description of observing system capabilities and gaps in Table A.2.2. The important outcome of this process is the definition (in the right-hand columns of Table A.2.2) of key existing observing system assets and gaps needed to fulfill the information requirements for each management decision and/or question.

Key existing capabilities that must be maintained to fully address management questions include:

- Measurements of variables such as currents, waves, winds, density stratification, discharge flows, and contaminant loads
- Nearshore and offshore current models
- Programs that support monitoring of water quality condition and impacts, although these may need to be adjusted to take better advantage of the full suite of observing system capabilities

Gaps in observing system capability that must be filled to fully address management questions fall into the following major categories:

- Continued development and implementation of improved monitoring methods such as rapid bacterial indicators of beach contamination and more reliable measures of POTW plume boundaries
- New modeling capabilities that couple the nearshore and offshore circulation
- New modeling tools (e.g., integration of nearshore and offshore plume models) needed for tracking and predicting plumes and their constituents and for estimating impacts
- Data inputs needed to apply modeling tools across the spatial extent required for answering management questions (e.g., expanded nearshore bathymetry, vertical current profiles around discharge points)
- Revised assessment approaches that take advantage of observing system capabilities
- Revised regulatory and management approaches that utilize observing system capabilities
- A framework for continuously prioritizing management information needs and developing or applying observing system capabilities to meet these

The first four bullets above focus on technical aspects of observing system capacity and the final three bullets relate to institutional adjustments needed to make better use of observing system capabilities and are discussed in the following subsection.

3.5 Discharge institutional issues

Section 2.0 (Institutional Issues) described overarching adjustments to the existing institutional framework needed to ensure that ocean observing capabilities are well matched to management decision-making needs. In addition, there are two fundamental features of the existing management system specific to discharges that limit the effective use of some types of ocean observing products. First, to a large extent, these features reflect a traditional perspective that has split discharges into separate categories (e.g., POTW, industrial, storm drains), is focused primarily on individual discharges, and does not directly address outflows from rivers and creeks. Second, regulatory approaches and the mechanisms used to implement them have typically required monitoring measurements taken at discrete points in space and time and used tests for regulatory compliance based on a relatively small number of such discrete measurements.

Making full use of the information products described in Figure 3.2 and Table A.2.2 would be enhanced by:

- Developing improved and more broadly standardized monitoring methods and assessment approaches

- Incorporating such methods and approaches into more coordinated and comparable permitting, monitoring, and assessment programs
- Improving the ability to assess and manage cumulative impacts on specific locations such as ASBSs, which may involve integrated permitting that bases discharge permit conditions on the combined effects of multiple discharges
- Changes to regulatory frameworks such as the 303(d) listing process[3] to accommodate a broader range of information products
- Making parallel improvements to State Water Board reporting databases (e.g., California Environmental Data Exchange Network (CEDEN), California Integrated Water Quality System (CIWQS)) to accommodate a broader range of information products

Accomplishing these goals will involve continued and expanded leadership from the State Water Board of the sort shown with POTW plume compliance, rapid bacterial indicators, and desalination plant discharge modeling. In addition, the State Water Board is leading the development of a new Sediment Quality Objectives policy in coastal bays and estuaries, a Nutrient Numeric Endpoint policy in coastal estuaries and freshwater streams, and a Biological Objectives policy in freshwater streams. All these policies involve improving the consistency of data gathering, developing new assessment approaches based on substantial data analysis and modeling efforts, and the consideration of revisions to regulatory frameworks. In terrestrial watersheds, the State and Regional Water Boards are implementing watershed-scale permitting approaches that consider all discharges and their cumulative effects in one management process. Achieving the goals listed above will therefore require the State Water Board to expand to the ocean the approaches it has begun implementing in streams, bays, and estuaries. It will also require careful analysis of the data and information pathways related to decision making. For example, tracking and forecasting of the direction of sewage spills into the coastal zone is hampered not only by the lack of operational nearshore models but also by the fact that agencies are required to report to the Sanitary Sewer Overflow database only the volume of the spill, not whether it reached receiving waters (e.g., streams, rivers, ocean).

Efforts to develop and then implement improved ocean observing tools of this sort are constrained by a lack of ready funding. However, there are well developed funding mechanisms, some already used in the water quality arena and others that have been applied elsewhere, that could provide additional funding. For example, the State Water Resource Control Board's SWAMP is charged with coordinating methods development and standardization for compliance monitoring and assessment for both freshwater and coastal / marine waters. SWAMP is increasingly funded by discharge permit fees and small and medium sized municipalities that will soon be regulated under a Phase II stormwater permit are considering paying an additional fee to have SWAMP conduct monitoring and assessment required under the permit. To the extent that coastal municipalities discharge stormwater runoff to the ocean, some portion of these funds would be available to support ocean observing. This and other funding options are discussed in more detail in Section 2: Institutional Issues.

If the changes described above are not made, and the status quo is maintained, or capabilities even reduced, as has happened recently for some water quality monitoring at swimming beaches, then the regulatory and management infrastructure will continue to function and decisions will continue to be made. Given the policies in place to maintain and/or improve discharge quality, water quality will likely continue the trend of improvement seen over the past 20 – 30 years. However, reliance on traditional monitoring, assessment, and management approaches will consume more resources than needed, decisions about managing discharges will be less cost-effective, and our understanding of water quality impacts will be less complete than if the capabilities outlined in Figure 3.2 were more widely available.

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[3] The listing process is a formal procedure, conducted at the state level, which identifies specific water bodies or water body segments as impaired under provisions of Section 303(d) of the Clean Water Act.

As a result, California will be less able to respond appropriately, within the context of potentially severe fiscal constraints, to future challenges stemming from increased coastal development and pressures on ocean resources.

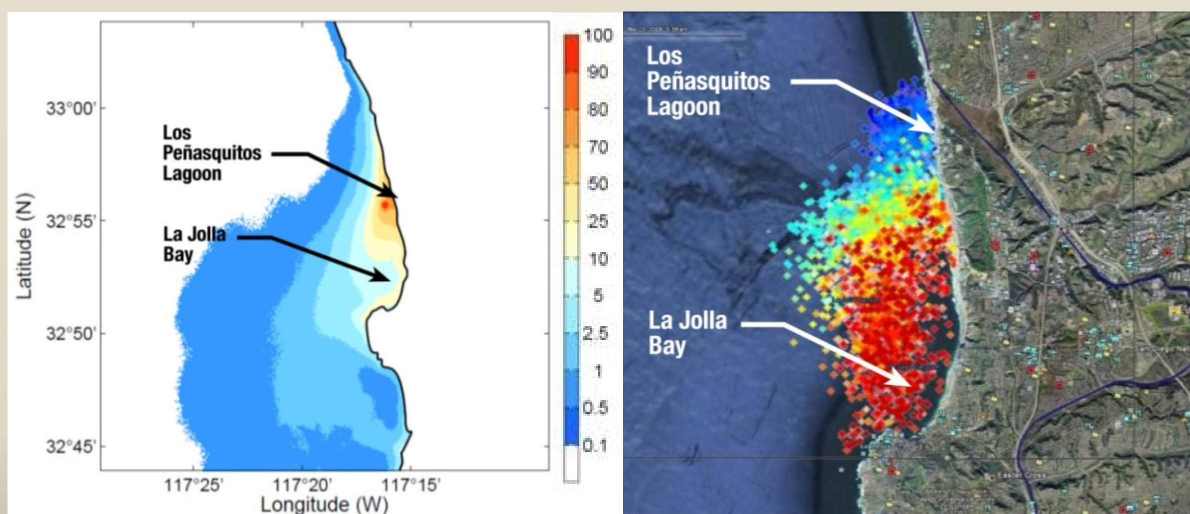
One illustrative example of how observing system information might help improve decision making is provided by the plume maps shown in Figures 3.2b and c. Without the capability to model plume extent, it would not be possible to reliably determine if contamination of swimming beaches along the coastline south of San Diego was predominantly due to the South Bay Ocean Outfall or the Tijuana River. Without this information, management attention and treatment resources could easily be allocated, mistakenly and inefficiently, to the outfall. Another example, described in the text box below, illustrates how plume modeling at a larger spatial scale quantifies the potential influence on the San Diego Marine Life Refuge and the San Diego-La Jolla Ecological Reserve of the outflow from Los Peñasquitos Lagoon eight km to the north. Traditional management approaches would tend to focus attention primarily on local discharges within La Jolla Bay which would be less cost-effective and run the risk of misidentifying all the sources of potential problems.

Cumulative and Distant Plume Impacts

Existing water quality monitoring is usually conducted at a grid of points in the ocean or along the shoreline at varying intervals that range from daily or weekly for beach monitoring to monthly or longer for ship-based ocean monitoring. Plume behavior is then inferred by interpolating among grid points that are widely spread in both space and time. As a result, understanding of the plumes' location, extent, and behavioral variation under different conditions is limited. In contrast, newer methods based on near real-time measurements of surface currents, data collected from towed or autonomous platforms, remote sensing information, and plume dispersion modeling reveal patterns and processes that provide a more complete assessment of plume impacts.

For example, in the figure below, modeling of plume trajectories from Los Peñasquitos Lagoon north of La Jolla shows the plume moving at least eight km southward along the coast to La Jolla Bay within the three-day lifetime of fecal indicator bacteria used to measure potential human health risk to swimmers.

Another analysis, illustrated in the following figure, used surface current data measured by HF radars over an entire year to estimate the year-round probability distribution of the plume from Los Peñasquitos Lagoon. This analysis showed that the protected areas in La Jolla Bay (the San Diego Marine Life Refuge and the San Diego-La Jolla Ecological Reserve) can be influenced by the lagoon's plume up to 10% of the time. This information can be combined with estimates of the volume of the lagoon's outflow and the levels of contaminants in the plume to compare the relative impact of the more distant lagoon to the smaller discharges in La Jolla Bay. At some times, such as during rainy periods, the lagoon's discharge may have a greater influence on conditions in these protected areas than do local discharges. Insights of this kind can help direct management attention and resources where they will achieve the most cost-effective results.



(Left) Year -round probability distribution of the Los Peñasquitos Lagoon plume in surrounding coastal ocean receiving waters; colored scale indicates probability of plume occurrence; (Right) Modeled plume trajectories from Los Peñasquitos Lagoon based on measurements of surface currents; colored scale indicates the plume's estimated percent duration in each area, with plume age ranging from one-half day (dark blue) to three days (red). Source: Terrill et al.

3.6 Discharge recommendations

As noted above in Section 3.4 (Discharge Information Needs) and in more detail in Table A.2.2, there are a variety of specific ocean observing platforms, programs, and models that should be sustained, expanded, or created to provide basic information related to discharge water quality. These include various oceanographic platforms for tracking physical and chemical variables, circulation models, and basic water quality sampling programs. From among these, we highlight priority recommendations needed to fully and effectively utilize these data and information products, many of which call for specific actions by the State Water Board.

3.6.1 Continue and improve water quality monitoring

Existing water quality monitoring programs for beach contamination and discharge plumes provide essential information for assessing compliance with regulations and for determining the extent and magnitude of impacts. These programs should be continued and improved with the addition of more reliable indicators. Rapid bacterial indicators that provide more timely measures of beach contamination should be implemented where logistically feasible to furnish more accurate information to health departments about when and where to close or open beaches. The development and testing of source tracking methods that distinguish anthropogenic from natural sources of beach contamination should be continued and then implemented at beaches with persistent contamination problems. This would enable regulatory and discharge agencies to target management attention to those contamination problems that stem from controllable, anthropogenic sources.

The State Water Board's current effort to develop more accurate and reliable methods for identifying POTW plume boundaries should be continued and a standardized indicator (e.g., ammonia, bacteria, colored dissolved organic matter) then incorporated into POTW discharge monitoring programs. This will enable state managers to more consistently assess and compare water quality conditions throughout California's coastal zone, and to track trends with greater confidence. In general, the State Water Board should promote standardization of monitoring indicators and methods across all related discharge monitoring programs.

3.6.2 Fill key discharge data gaps

An important input to any ability to track and/or predict discharge plume distribution and impacts is data on discharge volume and composition. These data exist for POTW and urban stormwater discharges from major coastal storm drains. However, discharges to the ocean from rivers and creeks are not regulated and thus are not routinely monitored, except for flow gauging stations on larger rivers and occasional special studies focused on specific contaminants such as bacterial indicators. The State Water Board, in cooperation with discharge agencies and regional monitoring programs, should lead an effort to add routine contaminant monitoring in river and creek discharges to existing monitoring networks. This would improve managers' ability to compare the relative magnitude of impacts from different sources on ASBSs and to develop a more complete picture of water quality impacts to the coastal ocean.

3.6.3 Maintain and expand oceanographic measurements

Another critical input to plume tracking and/or prediction capability is the availability of basic oceanographic information on surface currents, waves, winds, and other parameters needed for modeling. Existing data gathering programs should be continued and expanded to supply needed inputs to multi-dimensional modeling of offshore plumes (e.g., vertical density and current profiles) and nearshore current modeling at depths less than 10 m (e.g., bathymetry, coastal winds). See specific recommendations related to current modeling in Section 8.0 (Assets Needed for Multiple Issues).

3.6.4 Develop integrated nearshore / offshore current models

As illustrated in Figure 3.1 and the text box above (Cumulative and Distant Plume Impacts), plumes from discharges and spills can at times move between the nearshore and the offshore, depending on the size of the plume and the strength and direction of winds, waves, and currents. Because direct plume monitoring occurs only infrequently, accurately tracking and predicting plume movements therefore depends on the ability to link nearshore and offshore circulation. As explained more fully in section 8.0 (Assets Needed for Multiple Issues) this will require developing an operational nearshore current model and integrating it with offshore current models, as well as collecting the nearshore bathymetry and local wind data required for nearshore current modeling.

3.6.5 Improve data management capability

Ocean water quality monitoring generates large volumes of data and derived information products and the use of real-time data in monitoring and modeling programs will significantly increase the sheer volume as well as the complexity of data to be managed. Existing water quality monitoring and reporting databases are primarily designed to manage point source data and have severe limitations in terms of their ability to provide ready access for users and to integrate different data types from different sources (CWQMC 2008). The State Water Board, through its participation in the CWQMC and the efforts of its SWAMP, should continue to improve the capabilities of California's data management policies and infrastructure to accommodate OOS data and to support the modeling applications described earlier in this chapter and in Tables A.2.1 and A.2.2.

3.6.6 Revise management and regulatory frameworks

OOS capabilities allow for assessment and decision-making approaches that have not yet been fully incorporated into regulatory and management frameworks. For example, plume tracking / prediction tools and *in situ* sensors that produce continuous data could enable more, and more efficient, real-time management responses to contamination events and more accurate assessments of regulatory compliance and environmental impact. However, to achieve such benefits will require revisions to current regulatory and management practices. For instance, compliance standards in permits are often stated as single numbers that do not necessarily provide an adequate basis of comparison for more spatially extensive and intensive monitoring data. In addition, the 303(d) listing process that identifies impaired waters is based on a conceptual model that assumes a finite number of discrete monitoring data points, an approach not well suited to continuous data streams of the sort collected by automated sensors (either fixed, autonomous, or towed by vessels). We recommend that the State Water Board, in cooperation with discharge agencies and regional monitoring programs, conduct pilot studies to determine how new OOS tools could best be incorporated into management and regulatory frameworks. Such pilot studies would help speed the development and implementation of such OOS tools by demonstrating how and where they could be most useful.

4.0 Decision Information Needs: Salmon Recovery

Overview – Impacts on salmon stem from their complex lifestyle, the range of habitats they cross, and the diversity of human and natural processes with which they interact. Despite this complexity, there are numerous opportunities for improving management decision making and outcomes for salmon through enhancing the use of ocean data in modeling and decision making.

Impacts on salmon populations – Impacts result from variable ocean conditions, watershed and habitat degradation, fishing, hatchery policies, and climate change. These processes act on a range of temporal and spatial scales and often interact in synergistic ways.

Salmon management and decision framework – Salmon management involves many federal, state, and local agencies with responsibility for different aspects of salmon habitat and life cycle. Salmon management is characterized by its complexity and the high degree of uncertainty associated with major decisions.

Salmon information needs – Management decisions include setting catch limits and the timing and location of fishing, managing hatcheries to support salmon populations, adjusting water withdrawals to help maintain suitable conditions in streams and the Delta, scheduling river mouth breaching to facilitate in- and out-migration, incorporating climate change into recovery plans, and implementing and tracking success measures for mitigation and restoration projects. Existing capabilities that must be maintained include ocean condition sampling from an array of sources, ocean condition indices built from these, three-dimensional circulation and ecosystem models, several biological sampling programs relevant to salmon prey and the status of ocean food webs, and salmon-specific sampling programs to track distribution, abundance, and survival. Gaps that must be filled include improved models that relate ocean conditions to salmon survival and growth, retrospective analyses of the effects of ocean conditions, and improved biological monitoring programs for both young and adult salmon.

Salmon institutional issues – Several features of the current management system impede the broader use of ocean data in decision making. These include traditional management structures and practices, managers' lack of understanding of ocean processes relevant to salmon, and limited communication between ocean scientists and upstream salmon recovery programs. The multiagency complexity and contentious nature of salmon management further complicates the use of OOS data for issues such as hatchery practices, water flows, and rivermouth breaching.

Salmon recommendations – We recommend strengthening short-term salmon modeling efforts; developing longer-term forecasts of ocean conditions and salmon and linking them to upstream conditions; and enhancing biological monitoring methods and the integration of biological, chemical, and physical data. In addition, we recommend pilot projects to test methods of adapting the timing of both hatchery releases and river mouth breaching to ocean conditions. The priority recommendation involves a series of steps to overcome existing institutional barriers to using ocean data in decisions about salmon management. These steps include developing a dedicated agency liaison and an interagency committee focused on incorporating ocean information into decisions and improving the overall integration of ocean and upstream science and policy.

NOTE: Please see Appendix 2, Tables A2.3 and A2.4, for the detailed analysis of decision information needs and OOS capabilities on which the following discussion is based.

4.1 Salmon recovery issue overview

Salmon and steelhead are an iconic group of species in California that play critical roles in diverse ecosystems, in state and local economies, and as an integral part of California's history and culture. However salmonid populations have experienced dramatic and long-term declines from historic levels in both abundance and biodiversity. As a result, most salmon populations are now on federal and state threatened or endangered species lists. Major collapses of key runs of fall Chinook salmon in the Sacramento and Klamath Rivers in recent years led to extensive closures of commercial and recreational salmon fishing seasons, with widespread economic and social impacts. The recent collapse of the fall Chinook run compounded the dramatic decline in the winter and spring runs returning upriver that has occurred over the past several decades (Figure 4.1).

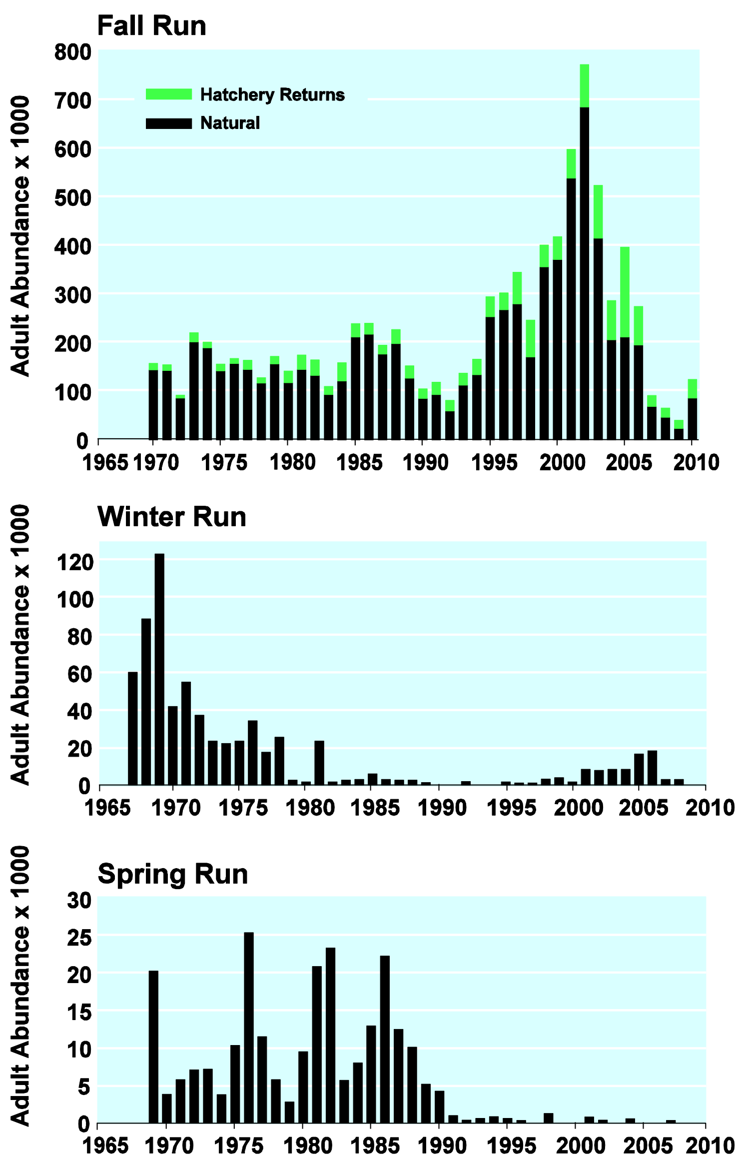


Figure 4.1. Trends in abundance of adult Sacramento River Chinook salmon (escapement) (source: adapted from PFMC 2011 and Swanson 2010).

A complex, interrelated suite of causes has contributed to salmon population declines and a wide range of management measures to enhance recovery are either underway or being considered. The fact that salmon transit many marine and freshwater habitats during their life cycle creates critical linkages between terrestrial and oceanic processes, impacts, and solutions. For example, the proximate cause of the collapse of the Chinook populations during 2008 and 2009 was likely poor ocean feeding conditions due to warm sea surface temperatures and delayed upwelling in 2005 and 2006 when smolts entered the ocean. Long-term declines in abundance, biodiversity, and genetics / run diversity due to widespread upstream impacts have likely left salmon populations without the capacity to respond to such natural variations in ocean conditions (Lindley et al. 2009). Despite the increasing awareness of such linkages between terrestrial and marine systems, impacts and solutions in each system are generally monitored, evaluated, and managed separately, although salmon of course experience these habitats as one integrated whole.

Complicating the situation further, salmon management is a highly complex, contentious, and politically charged process. It involves many stakeholders, economic interests, water rights conflicts, and disagreements as to what sectors or factors are responsible for negative impacts. All of these issues complicate the degree to which ocean data can be effectively incorporated into the salmon recovery process. However, broader and more integrated use of OOS data has important long-term potential for improving the effectiveness of salmon management, both in the ocean and upstream.

4.2 Impacts on salmon populations

There is a wide array of impacts to salmon populations due to the complexity of their life cycle, the range of habitats they cross, and the resultant diversity of human and natural processes with which they interact. The brief summary of impacts below begins with oceanic factors since they are most directly related to OOS, but also includes critical impacts upstream since many upstream decisions could also benefit from OOS information. Detailed reviews of various types of impacts to salmon populations can be found in Moyle et al. (2008), Lindley et al. (2009), Cummins et al. (2008), and Pacific Coast Salmon Oversight Panel (2010).

4.2.1 Ocean conditions

Strong natural variability in ocean conditions occurs on daily, weekly, seasonal, interannual, and interdecadal time scales, including the timing and intensity of annual upwelling, El Niño events, and the Pacific Decadal Oscillation (PDO). Large-scale biological regime shifts, dramatically altering species distributions, can result from changing ocean conditions. These sources of variability play an important role in interannual and interdecadal changes in salmon abundance, productivity, and diversity. However, salmon populations today are less resilient than in the past to this natural oceanic variability because changes in upstream conditions have led to small population sizes, reduced biodiversity, and more synchronous spawning. This lack of resilience, or environmental buffering capacity, creates a greater risk of population collapse and/or local extinction when ocean conditions are poor. This can occur, for example, when recruitment fails because broods enter the ocean at a time of weak upwelling, warm surface temperatures, low prey densities, or higher predation and mortality.

Table 4.1. Potential impacts to salmon populations from a variety of natural and anthropogenic sources in both oceanic and terrestrial systems. Impacts are not independent and often interact with each other in synergistic ways.

Source	Location	Timing	Processes	Impact
Ocean condition	Ocean	Daily to annual Interannual Decadal	Upwelling Seasonal currents El Niño Pacific Decadal Oscillation Biological regime shifts	Altered ocean productivity Altered food supply Altered smolt survival Altered adult abundance and distribution
Climate change	Ocean Watersheds	Decadal Centennial	Warmer temperature Increased stratification Acidification Changed upwelling Changed precipitation and spring flows More frequent extreme events	Altered ocean productivity Reduced food supply Earlier, less successful out-migration Reduced smolt survival Poor year classes
Fishing	Ocean Watersheds	Annual	Directed catch Bycatch	Mortality
Watershed / habitat	Watersheds	Annual Interannual	Reduced flows Altered flows Reduced habitat Barriers to migration Pumping mortality Invasive species	Less successful migration Reduced spawning Reduced smolt survival
Hatchery practices	Watersheds	Annual Interannual	Focus on one or a few runs Synchronous spawning and release Artificial release points	Reduced genetic diversity Reduced population diversity Reduced longer-term adaptability Reduced shorter-term resilience

4.2.2 Anthropogenic climate change.

In addition to natural oceanic variability on short to medium time scales, the effects of anthropogenic climate change in the ocean are expected to occur over longer-term multidecadal to centennial scales. Such changes include warmer temperatures, increased stratification of the water column, changes in intensity and timing of upwelling, and increased acidification, all of which have the potential to alter primary and secondary productivity and reduce carrying capacity for salmon populations. Climate change is also predicted to increase environmental variability and the frequency of extreme events, and there is some evidence of this over the past several decades in various oceanic and terrestrial climate indices relevant to salmon, such as stream and ocean temperatures, stream flow, and ocean productivity. More extreme fluctuations in such factors can put additional strain on small, genetically homogenous salmon populations and may lead to more highly erratic variations in abundance.

The specific nature and timing of climate change impacts is uncertain, but some potential scenarios are becoming clearer. For example, changes in the seasonal timing of the onset of coastal upwelling or peak streamflow may reduce growth and survival of salmon year classes. Earlier snowmelt and higher spring flows could reduce survival by causing earlier emigration of salmonid smolts to the ocean. Survival may be further reduced by projected delays in springtime coastal upwelling and productivity. Analogous climate-related mismatches between migration and the resources needed to ensure survival have already affected other species. Such impacts are not likely to occur in isolation, but will interact with other climate-induced changes. Thus, warming and altered stream flows, combined with existing impacts due to dams and habitat alteration, would reduce available cold water salmon habitat in streams, increasing stress on these populations. Ocean acidification and consequent reduced carbonate availability may also impact key planktonic prey items of salmonids, further reducing food supply. Climate change mitigation and adaptation may include improving species diversity, population resilience, and/or the quality of freshwater habitat. Preliminary discussions on incorporating climate change impacts into existing planning, policy, or regulatory structures are underway among relevant state and federal agencies.

4.2.3 Fishing

Fishing can impact salmonid populations by reducing the population of fished species and through bycatch of threatened or endangered species by other fisheries. Fishery regulations focus on controlling these effects in part by setting an allowable catch each year. The amount allocated to the fishery is based on the number of adults projected to return from the ocean to spawn upstream in the coming year in comparison to the number of spawners needed to meet conservation objectives and stock rebuilding plans. If the projected number returning is larger, then the excess is available for the fishery. However, there are large uncertainties in this calculation. The number of adults expected to return from the ocean is based on the number of young, precocious males (jacks) that returned upriver in the previous year. This projection can sometimes be inaccurate due to inadequate models and variability in environmental factors between the fall return of jacks and the return of adults one year later. Inaccurate predictions can lead to allowing too much or too little fishing that year.

Regulations also manage the timing and location of the fishing season to protect threatened and endangered salmon species from excessive bycatch of salmon during fishing for other commercially available species. These annual regulations use historical patterns in multispecies catch records to estimate where the various stocks may occur each year. These estimates can be highly uncertain and scientists have recently begun to integrate ocean condition measurements and forecasting with salmon forecasting in an attempt to improve the accuracy of these predictions.

4.2.4 Watershed issues and habitat degradation

Extensive long-term degradation of historical freshwater and estuarine habitats critical to California salmon began in the 1800s and includes many factors such as:

- Reduced water flows with increased water diversions for urban and agricultural use
- Reduced Sacramento-San Joaquin River Delta marshlands
- Rising stream temperatures from reduced flows, climate warming, and riparian zone degradation
- Altered salinity in the Delta due to transport and diversion of freshwater
- Altered natural waterways due to barriers such as dams and channelization

- Artificial flow patterns created by water diversions which can disorient salmon or siphon them into water pumps
- Increased loading to streams of sediments, nutrients, and other pollutants from urban and agricultural sources
- Competition and predation from introduced species

Habitat degradation and water diversions are a critical cause of long-term declines in salmon population size and biodiversity. Certain types of ocean data could improve and then help monitor the effectiveness of inland management measures designed to address these impacts.

4.2.5 Hatchery practices and biodiversity

The impacts described above have reduced the sizes of native salmon subpopulations that previously spawned across different seasons, with the result that many rivers are now dominated by hatchery runs that spawn synchronously. For example, only 10% of California's ocean population of fall run Chinook salmon is wild; the remainder come from hatcheries that release young salmon within a very short time period. Hatcheries also sometimes mix fall and spring run individuals within the hatchery or release smolt at river mouths rather than upstream. Such practices, combined with synchronous hatchery releases, while they streamline hatchery operations, can reduce genetic diversity and the ability of populations to adapt to changing environmental conditions such as periods of high ocean temperature or reduced upwelling and productivity.

4.3 Salmon management and decision framework

Salmon management involves a complex array of federal, state and local agencies addressing impacts on all stages of the life cycle, including fisheries, water allocations and infrastructure, hatcheries, and restoration of salmonid habitat. This includes components such as annual and long-term planning, regulations and permits, policies, and the funding of major restoration programs. Coordination and communication among all these parties, whose responsibilities extend from the Sierra to the ocean, is a particularly daunting challenge. The key agencies involved and their roles are outlined below, and additional information on their specific management decisions is provided below in Section 4.4 (Salmon Information Needs).

California Department of Fish and Game (CDFG) manages salmon in state waters out to three nautical miles under the Marine Life Management Act. It develops and oversees California's salmon management plan, collects and reviews technical data, recommends management measures to the Pacific Fishery Management Council (PFMC) and the Fish and Game Commission, and implements fishing regulations adopted by the Commission. CDFG also monitors natural populations and manages California's hatchery operations.

CDFG coordinates extensively with PFMC and NOAA Fisheries to ensure complementary state/federal annual decisions regarding fisheries. PFMC manages ocean salmon in federal waters as mandated by the Magnuson-Stevens Act. It draws on annual data summaries and projections from a Salmon Technical Team and reviews management options developed by a Salmon Advisory Panel in order to develop annual decisions regarding total fish caught and how they should be allocated among user groups and over space and time.

NOAA Fisheries provides extensive technical input to PFMC decisions, reviews and recommends approval of any PFMC salmon recommendation by the US Department of Commerce and implements the resulting federal fishery regulations. It also oversees recovery plans for protected salmon and steelhead populations under the Endangered Species Act (ESA), and issues permits required for fisheries that may impact endangered stocks.

USFWS oversees two national fish hatcheries in California and various fish passage programs. It partners with NOAA Fisheries and California in recovery programs under ESA to improve instream and riparian habitat for salmon and other fish species, including regions of the Klamath River, Humboldt Bay and Central Valley.

Water management in California includes many issues relevant to salmon. The California Department of Water Resources (DWR) focuses on water supply issues that may have direct impact on the quantity and quality of water available for salmon. It operates the State Water Project that controls water in the Delta, monitors physical and biological variables in San Francisco Bay and the Delta and evaluates the information relevant to salmon environmental standards.

Another major state agency in salmon water needs is the Sacramento-San Joaquin Delta Conservancy, a newly created organization tasked with implementing ecosystem restoration in the Delta, including conditions for salmon. The Conservancy coordinates with additional new organizations, the Delta Stewardship Council and the Delta Independent Science Board, all of them successors to the CALFED Bay-Delta Program. In addition, various local agencies and water districts play a role in the management of water needs for salmon throughout California, and must meet water flow and habitat requirements to sustain salmon as required by NOAA Fisheries and CDFG.

Various other state agencies play important roles in salmon recovery. The Ocean Protection Council and the Coastal Conservancy provide grant funding for various salmon projects, including instream flow analyses and the preparation and implementation of watershed management plans for major coastal river systems and coastal streams. They also fund salmon forecasting research and collaborative fisheries research with Pacific States Marine Fisheries Commission. California Resources Agency is an umbrella agency that includes CDFG, DWR, OPC, Coastal Conservancy and other state agencies. It has a strong focus on interagency coordination and on coordination with Washington and Oregon on all ocean and coastal issues, including salmon. The Resources Agency drafted California's Coastal Salmon and Watersheds Program focused on population recovery and coordinated implementation.

4.4 Salmon recovery information needs

There are six categories of decisions related to salmon recovery and managing the impacts described above that could potentially utilize OOS information (see Figure 4.2 for the data inputs and model outputs fundamental to each):

- Fisheries, including the amount of fish allocated annually to the fishery and the timing and location of fishing
- Hatcheries, including the amount of annual production, release dates, and biodiversity planning for multiple stocks
- Water flows, including allocating flows necessary to support out-migration of young and upstream migration of returning adults
- River mouth breaching, especially optimal timing relative to salmon growth and survival
- Incorporating climate change into recovery plans and projects
- Identifying and implementing success measures for salmon mitigation or restoration projects

Table A.2.3 provides a detailed overview of the specific management questions, and ocean information and OOS products and product needs in each of these decision categories. Table A.2.4 then matches these decisions and information needs with a more detailed description of current observing system capabilities and gaps.

As the analysis in Tables A.2.3 and A.2.4 and Figure 4.2 indicates, key needed OOS products are often similar across various decisions such as fisheries allocations, hatchery practices, and flow management, although the required timeframes and certain specific variables and locations may differ. For example, retrospective analysis of ocean conditions relevant to salmon survival and growth is a key product informing predictions of adult salmon abundance, fisheries allocations, and decisions about whether and how to revise hatchery practices. Similar data inputs could be used to produce predictions or analyses of ocean conditions and stock distribution patterns, which could in turn be used to improve decisions about the distribution of fishing effort.

Decisions involving responses to climate change and evaluating the success of habitat improvement programs require similar types of information but over longer-term decadal time scales. In contrast, decisions about river mouth breaching require real-time or near real-time ocean condition information at selected nearshore locations during key seasons.

Key existing OOS assets and gaps relative to meeting defined information needs are shown in the right-hand columns of Table A.2.4. Key existing assets that should be maintained to meet needs include:

- Oceanographic platforms, including moorings, gliders, and satellites
- Ocean condition indices and their foundation databases
- Multi-dimensional circulation and ecosystem nutrient-phytoplankton-zooplankton (NPZ) modeling programs
- Biological sampling programs relevant to salmon prey, including CalCOFI and NOAA Fisheries midwater trawls
- Salmon sampling programs, including Coded Wire Tags (CWT) and basic catch data

Gaps and needed improvements in observing system capabilities fall into the following categories:

- Model refinements, including improved assessments of key oceanic drivers of salmon survival and growth and coupling of physical and biological models
- Integration of climate change models with salmon models, and systematic monitoring of ocean climate change indicators such as warming, stratification, acidification, and effects on productivity
- Thorough short and long-term retrospective analyses of ocean condition and salmon data
- Longer-term Genetic Stock Identification (GSI) and acoustic tracking programs to assess migration and distribution of salmon young and adults
- Direct measurements of smolt survival when released under different ocean conditions
- Improved biological monitoring programs that can approach the spatial and temporal extent and resolution of physical oceanographic programs

As noted in Table A.2.4, efforts are underway to fill some of these gaps, although each one will require additional efforts. Specific recommendations and priorities related to identified gaps are addressed further in Section 4.6 below.

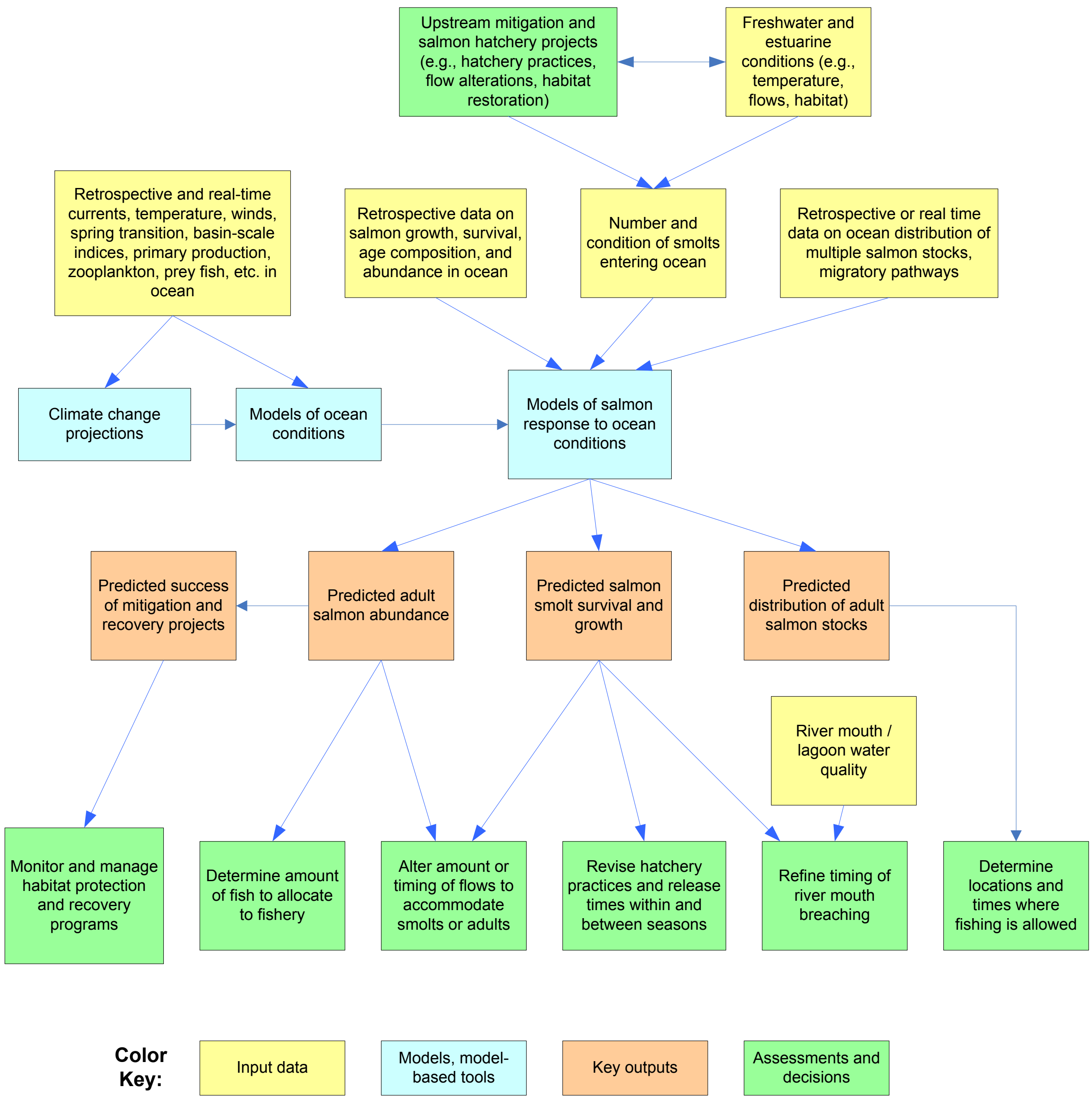


Figure 4.2. The data inputs, models, and model-based tools needed to produce the key information outputs and assessments required for decision making related to salmon recovery. Multiple decisions flow from four primary information outputs. Additional details on management decisions, needed products, key inputs and models, existing assets, and gaps are provided in Appendix A2.3 and A2.4.

4.5 Salmon recovery institutional issues

It is important to recognize the institutional issues that must be resolved if salmon management decisions are to benefit from OOS information and related technical capabilities. As noted in Section 2.0 (Institutional Issues), institutional and technical/scientific issues must be addressed together and this is nowhere more important than in salmon management. Interviews with managers indicated that currently there is virtually no use of ocean data in key salmon management decisions. Managers often tended to view the ocean as a "black hole" (their words), stating that they understood it was an important part of the salmon life cycle but knew very little about basic processes occurring there. They sometimes expressed a fundamental skepticism about the utility of complex ocean models and their predictions, in part because of lack of knowledge about the ocean but also because of previous problems they had experienced with applying complex salmon models and predictions in upstream settings.

> **Building Blocks for Predictive Models**
>
> There are a few success stories that illustrate the potential of using ocean data to support California salmon management. Ocean data have been used since the 1980s in annual allocation decisions made for the coastal coho salmon fishery in Oregon, with varying degrees of success. Predictions of salmon abundance were based initially only on upwelling and sea surface temperature. Over time, research has improved the models to include a wider range of inputs and conditions. A new salmon forecasting model approved by the PFMC in 2010 incorporates sea surface temperature, upwelling, timing of spring transition, sea surface height, salmon spawners, and several large-scale oceanic and atmospheric indices (Rupp et al. 2010). Scientists have also used shifts in the species composition of oceanic copepods to further refine predictions of Oregon Chinook and coho.
>
> In California, the Monterey Bay Aquarium Research Institute (MBARI), NOAA Fisheries, and their colleagues are developing more complex forecasting models for Central Valley and Klamath River Chinook. These models, funded by the National Aeronautics and Space Administration (NASA) and OPC, utilize a variety of physical, chemical, and biological variables that define the underlying mechanisms driving oceanic processes. They also aim to develop interactive tools to evaluate the impacts of alternative management decisions regarding fisheries, water flows, hatcheries, and other factors when applied under various predicted ocean conditions. In the near future, these models should be able to identify which ocean variables are the key drivers for salmon production and provide forecasts of salmon survival and growth that can be considered in various decision processes in California for both marine and upstream freshwater environments.

4.5.1 Institutional traditions

A number of managers noted that salmon management is encumbered with many institutional traditions that may be resistant to change and that will impede efforts to utilize OOS information more broadly. One unfortunate tradition is the lack of regular, effective communication and coordination between the marine community and the salmon recovery community focused on upstream issues. While this has improved somewhat in recent years, it remains difficult for managers and scientists working in these different areas to collaborate effectively, both within as well as between agencies. In addition, some groups resist incorporating ocean data into the salmon decision process because they fear it may detract from the focus on critical upstream issues.

In many cases there are also traditional management policies or practices that must be modified in order to incorporate ocean information in decision-making processes. Such modifications are likely to be complex and contentious, as with all aspects of salmon management. The examples below are illustrative but certainly not exhaustive.

The PFMC, its staff and committees are generally aware of the potential for incorporating ocean data and projections into decision making related to salmon, including the ocean indices used in determining Oregon's Coho catch limits and the Chinook salmon forecasting models currently under development for California by Monterey Bay Aquarium Research Institute (MBARI), NOAA Fisheries, and colleagues (see text box above). However, several steps would be required, once such forecasts are refined, to move away from the established procedure of setting California's salmon catch limits based on the numbers of returning jacks. Technical teams, managers, and key stakeholders would first need to understand and accept the validity of the forecasts, and they are likely to be initially skeptical due to the inherent complexity of the topic, unfavorable past experiences with models, and concerns about a reduced focus on upstream impacts. Overcoming this skepticism will likely require sustained interactions and discussions between scientists and managers, as well as a joint review of the success of ocean condition forecasting over several years, before it could be formally incorporated into decision making. New data sources and models would need to be similarly reviewed and approved by several of PFMC's technical committees and major changes would require approval by the Council itself.

4.5.2 Challenges in upstream settings

Modifying institutional practices to better use ocean data in decision making becomes more challenging in upstream settings such as hatchery management and river restoration efforts. A fundamental understanding of the inherent variability of ocean conditions and the importance of a variety of healthy stocks that enter the ocean at different times of the year is key to developing policies that would reduce the volatility of salmon returns from year to year. However, hatcheries currently emphasize monoculture production of fall run Chinook to provide for a large ocean harvest of this particular stock; shifting to a more diverse production strategy that includes late fall, winter, and spring run fish would require addressing a series of political, policy, logistical, and economic issues.

Even for fall run Chinook, using data on ocean conditions to adjust hatchery production numbers or spring release times to optimize survival would require changes in policy and practice. Currently, the target salmon production numbers and release times for hatcheries often remain the same from year to year, regardless of the capacity or productivity of the ocean. These targets are typically based on dam mitigation agreements and stakeholder fishing goals and are subject to NOAA Fisheries Biological Opinions, making them relatively inflexible over short time scales. In addition, moderately long lead times would be needed to prepare hatchery operations for significant changes in target numbers or release times.

Even if parties were willing to move from relatively static to more dynamic production targets, there is as yet no technical basis for doing so, because there has been no discussion or agreement about how best to adapt hatchery production in response to specific ocean conditions. Such an agreement would depend on explicit goals for salmon, e.g., maximize ocean harvest, maximize wild stocks, enhance diversity. Such goals would need to be defined and alternative management responses evaluated for scenarios when predicted or measured ocean conditions are poor or strong. The critical first step in this process would be to demonstrate a clear connection between predictable ocean conditions and salmon survival and growth, a fundamental aim of the forecasting efforts currently underway. If successful, these efforts could use ocean information to increase the survivability of hatchery and/or natural fish and increase diversity among stocks, and thereby provide a basis for the parties involved (state and federal agencies, hatcheries, scientists, stakeholders) to consider a range of abundance, diversity, and release targets in the future.

Significant institutional challenges also confront attempts to incorporate ocean data or forecasts into other types of coastal and upstream decisions, including rivermouth breaching, flow management, and predicting and tracking the success of salmon restoration or mitigation efforts. For example, including ocean information in decisions on managing water flows for salmon would require a plan defining the best flow response for outmigrating smolts if ocean conditions were strong or poor, or the best flow response if predicted numbers of returning adults was large or small. However, water flows are obviously also influenced by a broader array of existing factors, including urban, agricultural, and other environmental uses, existing agreements and standards, system design, and logistics. These issues are managed by a complex array of agencies, stakeholders, and processes; decisions are influenced by institutional traditions and environmental, economic, and social conflicts across a broad physical and political landscape. Thus, initial efforts to link ocean conditions and water flow management might be feasible in smaller coastal river systems where these factors are more manageable.

4.5.3 Opportunities for improved salmon management

Although there are many institutional challenges to incorporating OOS information into salmon management, there are also many opportunities to build upon. The ocean is widely acknowledged as a critical component of the salmon life cycle, and the 2008/2009 population crash heightened managers' interest in ocean conditions. There are strong terrestrial science capabilities in key management agencies, a factor that should facilitate understanding of ocean science if communication is increased between marine and terrestrial scientists. Also, an active and engaged suite of ocean scientists are eager to apply their information to salmon management and recovery, and a wide array of ocean data, indices, and modeling efforts are available that should prove useful for salmon management. These factors, together with enhanced institutional coordination and communication, can provide a foundation for more fully integrating OOS into salmon decision making in a variety of habitats. Clear examples showing how OOS information could improve upstream decisions by accounting for oceanic variation would be helpful in building this foundation. We outline an approach to building on these opportunities and addressing the challenges involved in the next section.

4.6 Salmon recovery recommendations

As noted above in Section 4.4 (Salmon information needs) and in more detail in Table A.2.4, there are a variety of specific ocean observing platforms, programs, and models that should be sustained, expanded, or created to provide basic information related to salmon recovery. These include various oceanographic platforms for tracking physical and chemical variables, circulation and ecosystem models, and basic biological sampling programs. Beyond that, we highlight additional priority recommendations needed to fully and effectively utilize these data and information products.

4.6.1 Strengthen short-term salmon modeling efforts

Effective salmon hindcast, nowcast, and forecasting models that incorporate ocean conditions will be important for fisheries management and for improving upstream decisions related to hatcheries and water flows. Developing these models will require continued support of ocean condition and salmon modeling efforts focused on the time interval from when smolts enter the ocean to the migration of adults upstream, with integrated linkages to upstream conditions and management activities (see text box above). Stronger involvement of decision makers at state and federal agencies will also be needed to increase their understanding and to ensure that the models and results are relevant to their needs. In addition, once these modeling efforts identify the key drivers of ocean conditions most relevant to salmon, state and federal agencies and CeNCOOS should work together to ensure that long-term data collection on these key drivers is sustained.

4.6.2 Develop longer-term salmon ocean forecasts with upstream linkages

Forecasts of ocean conditions and salmon abundance at medium (1-10 years) and long (10-50 years) term time scales will be essential to decisions related to climate change impacts or adaptations. Ocean forecasts over these longer time scales will also be important to effectively predict and evaluate the success of critical upstream mitigation and habitat restoration projects. The foundation for such extended forecasts is development of a robust long-term retrospective analysis and the integration of salmon forecasting models with climate models. It will also require communication with upstream managers and scientists to build understanding of how ocean variation can positively or negatively impact the success of mitigation and restoration projects. The multi-agency San Joaquin River Restoration Program, which is focused on restoring Chinook salmon to the river below Friant Dam near Fresno, has initiated efforts to include ocean conditions in their project evaluations, although with a relatively limited set of ocean indices to date (SJRRP 2009). Broader development and testing of models to account for ocean variation in various mitigation plans and restoration success tracking will be important to expand and enhance the success of such efforts. Without incorporation of oceanic variability it will remain difficult to predict or evaluate the true impact of mitigation or restoration efforts on salmon population recovery.

4.6.3 Enhance biological monitoring and data access

In addition to existing physical and chemical oceanographic sampling programs, biological data collection programs should be strengthened to improve their spatial and temporal extent and resolution. This includes enhanced measurements of lower trophic levels including salmon prey and young salmon via improvement and expansion of automated techniques such as acoustic tracking or image analysis. For adult salmon, estimates of stock distribution and abundance would benefit from longer-term GSI programs, expansion of age-composition analysis using CWT, and interpretation of these data relative to oceanographic conditions and processes. Observing system organizations such as CeNCOOS should play an expanded role in improving automation and integration of biological measurements and data access that is currently scattered among a variety of programs, similar to the role they have served for physical and chemical oceanography. This would facilitate more successful coupling of physical-biological models in salmon forecasting and in broader ecosystem management efforts.

4.6.4 Conduct pilot projects to link ocean information and hatchery releases

Decisions regarding hatchery practices such as optimal release times and biodiversity enhancement measures among stocks would benefit from a stronger understanding of the relationship between release times and salmon survival and growth. This understanding would be enhanced by development of a pilot project in which hatcheries worked together with ocean scientists to release and track survival of smolts over a range of months and ocean conditions. This project could examine responses to varying ocean conditions both within and between stocks. Such a project would further inform salmon forecasting models, encourage hatchery managers to consider and plan for using ocean information, and provide an opportunity to evaluate related logistical and policy issues.

4.6.5 Conduct pilot projects to use ocean information in river mouth breaching decisions

Incorporation of ocean information into decisions about the optimal timing of river mouth breaching could be facilitated by initiation of pilot projects in two to three diverse locations adjacent to proposed breach areas. Existing decision processes primarily consider environmental conditions inside the lagoon and risk of flooding in deciding breach timing. Pilot projects should test the feasibility and utility of incorporating basic measurements of ocean conditions relevant to smolt survival and growth, such as temperature and productivity. Information on tides and waves that may influence the breaching decision should also be included.

4.6.6 Overcome institutional barriers to integrating ocean data into decision making

Prior to new pursuit of the technical recommendations outlined above, a broad approach to addressing institutional impediments will be needed to more effectively integrate science and management of salmon affecting all their life stages and habitats. Such an approach could lead to more effective integration of ocean data into a variety of decisions, and could also provide impetus for a broader integration of science and management across the multitude of ocean, delta and riverine habitats that are critical to salmon population recovery.

The priority recommendation for salmon is to develop an interagency approach to incorporating ocean information into the diverse array of decisions outlined above, and to improve the overall integration between ocean and upstream science and policy. This could best be accomplished by development of a designated agency liaison and interagency committee. The liaison position could be appropriately incorporated under the Ocean Science Trust/Ocean Protection Council and be a component of two prioritized topics in OPC's Five Year Strategic Plan, land-sea interactions and sustainable fisheries. The position would coordinate and oversee a variety of implementation steps, including:

- Initiating, establishing and coordinating an interagency subcommittee under the auspices of OPC focused on use of ocean data in salmon decisions and linking the science and management needs of ocean, estuary and river salmon programs. The committee should include members of state agencies that play key roles in salmon recovery and related issues, including CDFG, Coastal Conservancy, DWR, State Water Board, Delta Conservancy, key federal partners such as NOAA Fisheries and USFWS, and CeNCOOS.
- Developing and implementing a targeted "Ocean 101" roadshow to key salmon management agencies and committees to increase understanding of ocean processes and their role in salmon life history, survival, growth and population recovery, interpret ocean information relevant to their management decisions, and lay the groundwork for future use of products and models.
- Organizing two-day workshops to bring together ocean/river/estuary scientists and managers to focus on sharing scientific information and related opportunities for more integrated management across salmon life cycles.
- Serving as an ongoing liaison between ocean scientists and agencies to fully understand and refine management science needs, develop targeted products, conduct appropriate training and improve products as needed over time.
- Identifying, tracking and, where appropriate, coordinating ocean scientists' participation in key salmon review and planning processes upstream, e.g. Hatchery Review Process, Delta Stewardship Council and Science Board, etc.
- Assisting in interagency coordination for pilot projects such as those identified above for hatcheries and river mouth breaching

Development of such a position or contract would be very inexpensive compared to many other types of statewide expenditures for salmon and OOS in general. It would also leverage and integrate the resources expended in separate river, estuary and ocean programs. It may also be possible to develop a shared position and co-sponsorship of the interagency committee with NOAA Fisheries to share costs and further solidify a state-federal partnership. This effort could also be incorporated into OPC's work with Oregon and Washington under the West Coast Governor's Agreement, since salmon are a regional resource affected by broad-scale processes in the California Current.

This work could potentially be conducted solely by an interagency committee provided that support staff time was available from each agency, in the event that no funds for a targeted liaison position were available. However, in our experience such efforts do not succeed without a dedicated leader and staff time that is wholly focused on the coordination effort, to guide and leverage committee actions and ensure implementation of the suite of recommendations noted above. Developing and carrying out a strong vision to address the gap between the ocean and upstream components of salmon management and science will be a key step in effective and timely salmon recovery.

5.0 Ocean Renewable Energy

Overview – Wave energy conversion (WEC) is the primary type of ocean renewable energy being considered in California. No WEC projects have yet progressed through permitting to implementation in California, or anywhere in the U.S. Nevertheless, it appears that the major issues in decision making about siting and permitting relate to the prediction, assessment, and management of projects' potential environmental and socioeconomic impacts.

Environmental impacts – WEC projects can potentially impact the coastal ocean environment in a number of ways. These impacts are due to reductions in wave energy and other changes to the wave field, to the physical presence of project infrastructure, and to project operations.

Ocean renewable energy management and decision framework – The regulatory framework for ocean renewable energy is daunting and complex and involves numerous federal and state agencies.

Ocean renewable energy information needs –There are three categories of decisions related to continued development and implementation of ocean renewable energy: resource assessment and energy plant operations, technology development, and environmental impact assessment. Government's primary emphasis is on the environmental impact assessment process for leasing, permitting, and licensing. The highest priority concerns are effects on migratory species, effects of an altered wave field, and spatial management to reduce use conflicts. Existing capabilities that must be maintained, and in some cases improved or expanded, include wave buoys and wave models, passive acoustic monitoring, marine spatial planning tools, high spatial resolution bathymetry surveys, measurement of ocean conditions from a variety of platform types, and biological survey and tagging programs. Gaps that must be filled include: improved tools for estimating how WEC will alter incoming wave fields; validated nearshore wave, circulation and sediment transport models; a more inclusive marine spatial planning tool; knowledge of marine wildlife migratory pathways at relevant locations and spatial scales; models of organisms' behavioral responses to changes in ocean conditions and sound; and validated sound propagation models and maps of ambient noise.

Ocean renewable energy institutional issues – Largely because ocean renewable energy development is at a relatively early stage, the management frameworks, agency expertise, databases, and assessment tools needed for effective and efficient decision making are not fully developed and readily available.

Ocean renewable energy recommendations – We recommend that the state improve its capability to evaluate the appropriate application of, and output from, WEC / wave interaction models and nearshore wave models that will be used to predict WEC project impacts, and that it build on existing capabilities to develop coordinated spatial planning tools and datasets to provide the capacity to identify and evaluate potential use conflicts. In addition, we recommend developing a validated sound propagation model and map of ambient underwater noise for state waters.

NOTE: Please see Appendix 2, Tables A2.5 and A2.6, for the detailed analysis of decision information needs and OOS capabilities on which the following discussion is based.

5.1 Ocean renewable energy issue overview

The State of California in 2011 established (through enactment of SBX1 2) the requirement that one-third of the electrical power sold in California be derived from renewable sources by 2020. The requirement is based on goals established earlier in Executive Order S-14-08 to decrease dependence on fossil fuels. California and other coastal states are pursuing renewable energy sources at sea as well as more traditional sources (e.g. solar, wind, geothermal, biofuels) on land. Because California has over 1200 kilometers of coastline and the majority of its population lives within coastal counties, the potential of the ocean as an energy source is very attractive in spite of the numerous technical and environmental challenges involved.

Five forms of ocean renewable energy, also known as offshore or marine renewable energy, are actively being pursued for potential commercial use around the world, with Europe leading the way in most respects. Bedard et al. (2010) offer a brief overview of the present state of all five of these renewable energy technologies. As Table 5.1 illustrates, four of the five are either not suitable for California or are far from being economically feasible in this locale. We therefore focused our attention on hydrokinetic energy systems.[4]

Table 5.1. Summary of the status in California of the five forms of ocean renewable energy.

Form of energy	Status
Ocean thermal energy conversion	Ocean conditions off California are not suitable
Tidal barrages[5]	Tidal conditions in California are not suitable
Salinity gradient power	Technology needs considerable further development for economic feasibility
Offshore wind energy	While this technology is in use in Europe, and projects are under development in other countries and off the U.S. East Coast, California's narrow continental shelf would require complex floating platforms in deeper water, and the most suitable wind resources are not near available transmission infrastructure
Marine hydrokinetic energy	Planning at more advanced stage in California

The management and decision context for renewable ocean energy continues to develop and there is some uncertainty about specifics of the permitting and licensing processes because no project in California has progressed through permitting and implementation. Nevertheless, it appears that the major issues in decision making about siting and permitting relate to the prediction, assessment, and management of projects' potential environmental impacts.

[4] Marine hydrokinetic energy systems generate electricity directly from the flow of water (i.e. kinetic energy) in ocean currents or from surface waves by harnessing their kinetic and/or potential energy (due to the change in sea level height associated with the wave).

[5] Tidal barrages, also known as tidal impoundment, convert tidal potential energy, i.e. the change in sea level height due to the tides, to electrical power.

5.2 Ocean renewable (hydrokinetic) energy characteristics and impacts

The Electric Power Research Institute (EPRI) (2007) has estimated that the U.S. "wave and current energy resource potential that could be credibly harnessed is about 400 TWh/yr or about 10% of national energy demand." Wave energy conversion (WEC) is the main hydrokinetic source being considered for California[6]. Wave energy projects are also actively being pursued in Oregon and Hawaii. Using data from ocean observing systems, the California Energy Commission's Public Interest Energy Research program (PIER 2007) estimated the deep water wave energy resource off California at about 38 GW and based on wave conditions, bathymetry, technical considerations regarding spacing of WEC devices and arrays, and proximity to the transmission grid, shipping lanes, and marine protected areas, judged that perhaps 20% of this shows promise for development. The Energy Commission reports in its more recent renewable energy strategic plan that the technical potential for wave and tidal technologies is nearly 33,000 megawatts (California Energy Commission 2011). The efficiency with which wave energy can be converted to electrical power depends on the type of device and the wave conditions (e.g. Previsic 2010). Efficiency estimates vary widely (from 3% to over 90%), but even assuming a moderate 15% conversion efficiency, wave energy could provide more than 1 GW of power, equivalent to about 3.5% of California's 2006 electricity usage.

Implementing new energy sources is a long and difficult process, as the Cape Wind project off Massachusetts clearly shows. As with offshore wind, WEC project developers must deal with funding uncertainties, technological and logistical challenges, complex regulatory processes, and potential environmental impacts. For WEC, the numerous types of devices available, many of which are still undergoing development and testing, may complicate the environmental assessment and review process. Because the technologies have never been deployed on a large commercial scale and have only been tested in a few limited pilot studies and small-scale applications, it may be necessary to adopt an adaptive management approach that involves ongoing environmental monitoring. The challenges involved in conducting environmental impact assessments and the uncertain scope of environmental monitoring requirements have contributed to the halting progress toward the implementation of wave energy in California. Over the last few years, several WEC projects were proposed off California but by July 2011 all of them were either canceled or on hold awaiting further funding or other developments.

OOS could potentially inform the development of WEC in a number of ways. In addition to resource assessment as noted above, technology development and project operations also require knowledge of wave height, period, and direction, and the temporal variability of the wave field, as well as other environmental parameters. Perhaps most importantly, OOS might help in addressing potential environmental impacts during project planning, permitting, operations, and decommissioning.

There are many types of WEC devices, including ones designed to be installed very close to shore and others to be moored offshore. The DOE Marine and Hydrokinetic Technology database (http://www1.eere.energy.gov/windandhydro/hydrokinetic/listings.aspx?type=Tech) lists over 100 different wave energy technologies. Most of the discussion in California has concerned devices (Figure 5.1) that would be moored well offshore of the surf zone. All WEC devices reduce wave amplitude, or height, since energy is being withdrawn from the wave field. The reduction in wave energy, the physical presence of the devices and any associated infrastructure, and the installation, operation, and dismantling could potentially result in a number of environmental impacts. These have been enumerated and

[6] There are a limited number of locations in California where tidal in-stream energy conversion (TISEC), another type of hydrokinetic energy, might be feasible. Along the U.S. West Coast, the majority of TISEC project planning has been in Washington State, but Federal Energy Regulation Commission (FERC) issued one preliminary permit in California to Golden Gate Energy Company on Feb. 4, 2010. The potential environmental impacts associated with TISEC are in many ways similar to those for wave energy except that TISEC results in weakened tidal currents rather than smaller wave heights.

discussed in a number of workshops and reports (e.g. Aqua-RET 2008, Boehlert and Gill 2010, EMEC 2008, EPRI 2004, Kramer et al. 2010, and Nelson et al. 2008) and are summarized in Table 5.2.

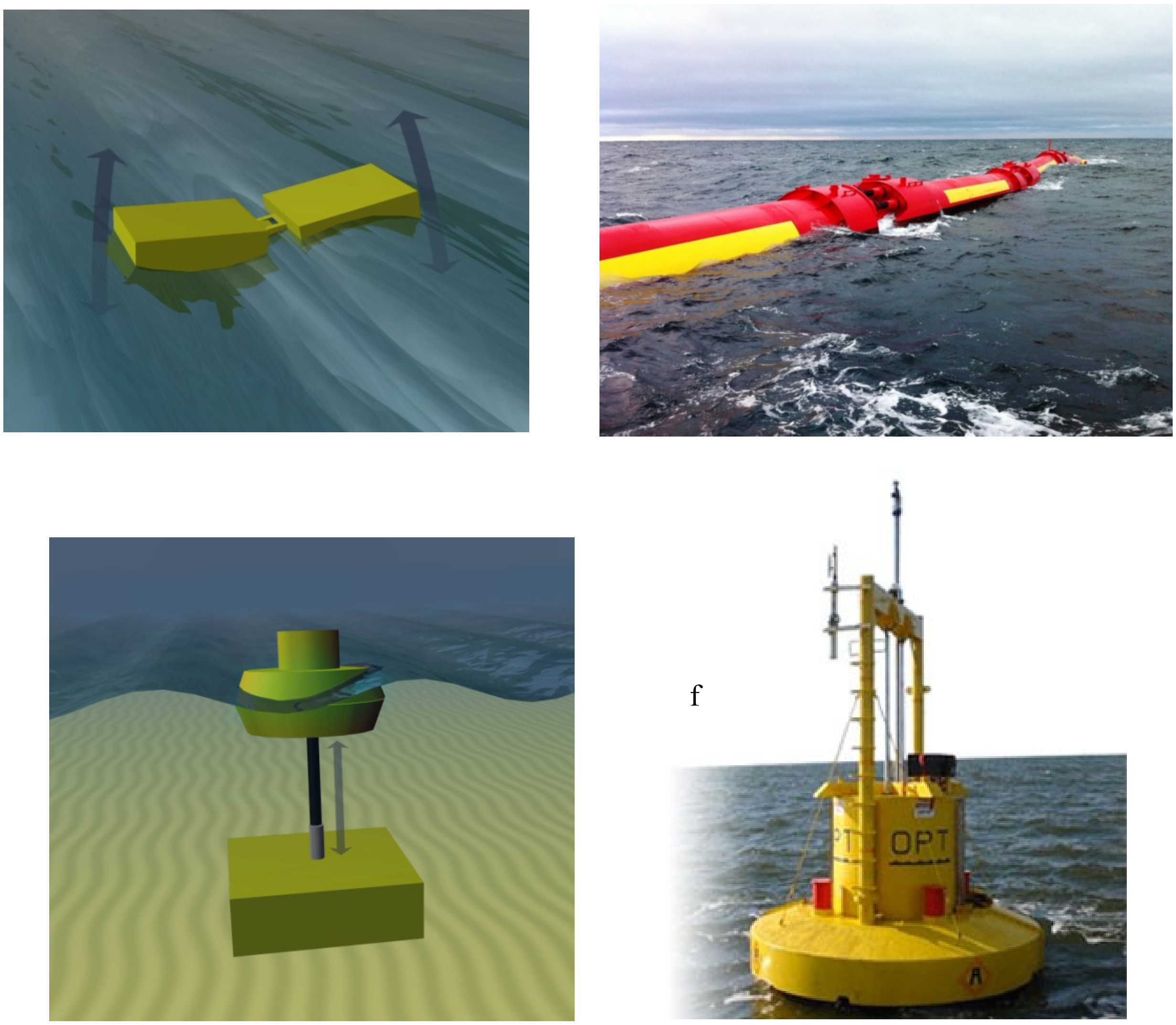


Figure 5.1. Hydrokinetic Energy Converters – Examples. Schematics (Aquaret 2011) and examples of two types of wave energy converters are shown: attenuators (Pelamis Wave Energy Converter, top right) and point absorbers (Ocean Power Technologies' PowerBuoy, bottom right). "Attenuators are floating devices that are aligned perpendicular to the waves. These devices capture energy from the relative motion of the two arms as the wave passes them." "Surface point absorbers are floating structures that can absorb energy from all directions. They convert the motion of the buoyant top relative to the base into electrical power." (Aquaret 2011).

Table 5.2. Possible environmental and ecological effects that could result from WEC projects[7].

Environmental Stressor	Possible Environmental Effects
Energy extraction	• Reduced wave heights • Altered distribution of wave energy vs. frequency • Reduction in turbulence and mixing
Physical presence of WEC devices and associated infrastructure	• Wave diffraction or reflection • Changes to near-field currents and/or turbulence (e.g. scouring and/or eddies produced; local changes in stratification) • Entanglement of wildlife in mooring and transmission lines, or in marine debris entangled in project infrastructure • Substrate for biofouling organisms • Fish aggregation • Marine mammal haul-out sites • Bird roosting sites • Increased predation due to the three preceding effects • Shell mounds beneath infrastructure • Benthic disturbance due to undersea cables • Alteration of sediment transport and deposition
Moving parts in WEC devices Vessel traffic	• Entrapment, entanglement, or striking of wildlife
Increased underwater noise during project installation, operation, and/or maintenance	• Acoustic disturbances to marine life, particularly marine mammals
Chemicals (e.g. hydraulic fluid) discharged during operations or maintenance	• Toxicity to marine and/or bird life
Electromagnetic fields associated with electricity generation and transmission	• Attract or repel marine life, • Affect marine wildlife's navigational ability (e.g. elasmobranches)
Lights on surface structures	• Disorientation and mortality of seabirds • May also affect pinnipeds and fish
Reduced public access Restriction of some other uses	• Reduction in fishing or other human activities could have ecological consequences

Arrays of WEC devices can diffract and reflect surface waves, which along with the extraction of energy, can alter the amplitude, direction, spatial distribution, and spectral content of the surface wave field. These changes to the wave field could impact nearshore currents and sediment transport (both alongshore and cross-shore), and consequently spatial patterns of sediment size distribution, beach profiles, and coastal geomorphology, including harbor and estuary entrances. Should these changes occur, they could affect navigation (e.g. entering a harbor could be easier if wave heights were reduced) and marine

[7] Note that socioeconomic and other issues not directly related to OOS are not included in Table 5.2. These other issues include things like the visual impact of structures, possible interference of mooring and anchorage lines with commercial and sport-fishing, possible threat to navigation from collisions due to the low profile of the wave energy devices above the water making them undetectable either by direct sighting or by radar, and re-routing of ship traffic. A number of socioeconomic variables, such as tourism, available fishing grounds, recreational opportunities, are likely to be affected by the impact on environmental variables that are listed in Table 5.2, e.g. fish distribution, wave height.

recreation, including surfing. Changes to the surface wave field could also affect mixing and stratification, and turbidity and underwater light levels. Any or all of the above, as well as other effects of a reduction in wave energy, such as the ability of waves to deliver food to sessile organisms and disperse larvae, could possibly influence the abundance and distribution of marine species, particularly in the nearshore.

Other environmental stressors (Table 5.2) not specifically associated with changes to the surface wave field, either individually or in combination, could result in changes in the marine environment and in the disturbance or destruction of marine and/or bird life and/or marine habitat. For instance, migration routes could be influenced by the mere presence of large WEC farms and the produced noise. Benthic habitat could be altered by scour around hard structures or cables, by the introduction of shell mounds produced by maintenance activities and by physical disturbance or increased turbidity that might be produced by cable laying or anchor installation.

5.3 Ocean renewable energy management and decision framework

The management framework for WEC projects continues to develop and remains in some degree of flux because no project has yet progressed completely through the permitting and implementation process.

5.3.1 Policy, planning, and research

Both the federal and state governments have an interest in promoting the development of ocean renewable energy sources. A number of federal and state agencies, as well as non-governmental organizations, track the progress of ocean renewable energy projects and participate in and/or sponsor research to advance development of this energy source.

At the national level, the Department of Energy (DOE) plays a major role in policy, planning, and research, particularly through the following programs and laboratories:

- The Wind and Hydropower Technologies Program focuses on increasing the development and deployment of reliable, affordable, and environmentally responsible wind and water power technologies through a variety of research and development activities. It also maintains a searchable database of hydrokinetic projects
- The National Renewable Energy Laboratory is dedicated to the research, development, commercialization, and deployment of renewable energy and energy efficiency technologies
- The Pacific Northwest National Laboratory and Sandia National Laboratories study the environmental effects of marine hydrokinetic and offshore wind energy

NOAA's Office of Ocean and Coastal Resource Management provides national leadership, strategic direction and guidance to state and territory coastal programs, and may provide guidance in siting energy facilities. NOAA's Coastal Services Center has participated in developing tools to facilitate the planning, siting, and permitting of ocean renewable energy projects.

The California Energy Commission is the state's primary energy policy and planning agency. It supports public interest energy research, and renewable energy by providing market support to existing, new, and emerging renewable technologies. The Energy Commission also certifies specific projects as eligible for California's Renewable Portfolio Standard. Only certified projects can claim the generated electricity is from renewable energy sources.

5.3.2 Core agency responsibilities

Producing electricity from ocean energy sources is a new industry, with no commercial projects yet operating in the U.S. The regulatory framework is daunting, complex, and rapidly evolving and involves numerous federal and state agencies (Pacific Energy Ventures 2009).

Under the Energy Policy Act of 2005 (and subsequent directives and clarifying memoranda of understanding) the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE, formerly the Minerals Management Service) has leasing authority for both hydrokinetic and offshore wind projects on the Outer Continental Shelf (OCS), i.e. greater than three nautical miles from shore off California (Frank 2010). They also have primary regulatory authority (which differs from leasing authority) for offshore wind projects on the OCS. BOEMRE will work with the Federal Energy Regulatory Commission (FERC, see below) and the Renewable Ocean Energy Action Coordination Team, established by the West Coast Governors Association, to coordinate development and oversight of renewable energy development activities proposed along the West Coast (BOEMRE 2011). BOEMRE has not yet received any lease requests for renewable energy projects off the West Coast.

Under the Federal Power Act, and an MOU with BOEMRE, the FERC has primary regulatory authority for hydrokinetic projects in both state waters and on the OCS, including licensing, inspecting and overseeing such projects (Konnert 2010). The FERC will not accept a license application for OCS projects until the applicant has a lease from BOEMRE. FERC is also the lead agency for National Environmental Policy Act (NEPA) analysis, which would involve consultation with NOAA Fisheries, USFWS, CCC, Bay Conservation and Development Commission (BCDC), and/or National Marine Sanctuaries, depending on project location. USACE authorization, in the form of a Clean Water Act Section 404 permit, would be needed for any dredging associated with a WEC project, and a River and Harbors Act Section 10 permit for any structures placed in navigable waters.

In addition, state agencies would play the following roles:

- The SLC leases state lands, including ungranted tide and submerged lands
- SLC would generally be the lead agency for CEQA review for projects or parts of projects in state waters
- SLC would consult with CDFG regarding impacts on living resources
- The State Water Board issues 401certification under the Clean Water Act
- The CCC issues permits for coastal facilities and ensures federal permitting actions are consistent with the federally approved California Coastal Management Plan
- The CPUC regulates private electric companies operating in California

5.3.3 Permitting and licensing procedures

Hydrokinetic projects in state waters can, but are not required to, apply for a Preliminary Permit from FERC, A Preliminary Permit gives the permit holder site priority for up to three years while determining project feasibility, but does not authorize construction or operation. The Preliminary Permit application and requirements are quite rudimentary, which reflects the exploratory nature of this phase of project development. Preliminary Permits have been granted for wave energy projects in southern, central, and northern California (FERC 2011, http://elibrary.ferc.gov/) (Figure 5.2). For projects on the OCS, FERC stopped issuing Preliminary Permits as of April 9, 2009; BOEMRE limited leases now serve a similar purpose.

Figure 5.2. Location of the nine Preliminary Permits (two at Fort Ross) issued by FERC as of March 28, 2011 for WEC projects in California. Not all are still active.

A Federal Hydroelectric License is needed to construct and operate a hydrokinetic facility for the purposes of producing and transmitting electric power (hydrokinetic facilities without the electrical power takeoff components may operate without the FERC license). There are currently no licensed marine hydrokinetic projects in the U.S and only the Reedsport wave energy project in Oregon has a license application pending, using the traditional licensing process. In 2008, FERC added a new licensing option called a Pilot Project License intended to expedite the license application process for short-term (up to five years) projects intended as testbeds.

Only one hydrokinetic energy project in California has gone beyond the exploratory Preliminary Permit stage. On March 1, 2010, Pacific Gas & Electric (PG&E) submitted a Draft Pilot License Application[8] for the Humboldt Wave Connect project, the first wave energy project to use FERC's Pilot Project License process. However, in early November 2010, PG&E announced they would not proceed with this license application, with the result that no ocean renewable energy project in California has gone beyond what is known as the pre-filing stage (i.e. the license application has not been submitted). Contributing to PG&E's decision was that while the Pilot Project License process reduces FERC's requirements relative to those

[8] This step formally kicks off the process for state and federal agencies to review and comment on the project, although in the Humboldt WaveConnect case, there was extensive discussion among the proponent, stakeholders, and agencies prior to the application submission.

for a full-scale commercial license, it does not reduce the environmental review and adaptive management plans that other agencies require to meet their mandates. The resulting high costs relative to the length of the project, and the short time scale of the Pilot Project License process proved to be incompatible with private investment funding.

5.4 Ocean renewable energy information needs

At this relatively early stage of WEC development, there are three categories of decisions related to continued development and implementation, with government's primary emphasis on the environmental impact assessment process for leasing, permitting, and licensing (see Figure 5.3 for the data inputs and key outputs that inform environmental assessment):

- Resource assessment and energy plant operations
- Technology development
- Environmental assessment, with the three highest priority concerns[9] identified as:
  - Effects on migratory species
  - Effects of an altered wave field
  - Spatial management to reduce use conflicts

Table 5.2 summarizes additional environmental concerns and Table A.2.5 provides a detailed overview of the specific management questions, and ocean information and OOS products and product needs in each of these decision categories. Table A.2.6 then matches these decisions and information needs with a more detailed description of current observing system capabilities and gaps.

Wave Energy Resource Assessment

Assessments of available wave energy resources are a key prerequisite for project planning and development. This is no longer a pressing need because such assessments have successfully been completed using data from ongoing OOS programs. Specifically, wave data from NDBC and CDIP buoys have been invaluable in evaluating the economic and technical feasibility of harvesting wave energy along the California coast. These data have been used extensively by project proponents, as well as by EPRI, which has provided maps of wave energy density along the U.S. coast and estimates of the amount of energy that could be produced from this resource (Hagerman and Bedard 2003, Previsic and Bedard 2007). O'Reilly (2010) states that there is likely enough wave energy almost anywhere off California to be able to employ WEC devices. CDIP historical, nowcast, and forecast wave products for the coast of California (www.cdip.ucsd.edu), are useful not only for wave energy efforts in terms of resource assessment, project operations, and environmental impact, but also for a variety of other ocean uses.

[9] At the time of the interviews, none of the agencies had ever proceeded all the way through the licensing approval process, so there may be some evolution of their major concerns and requirements as they evaluate future projects.

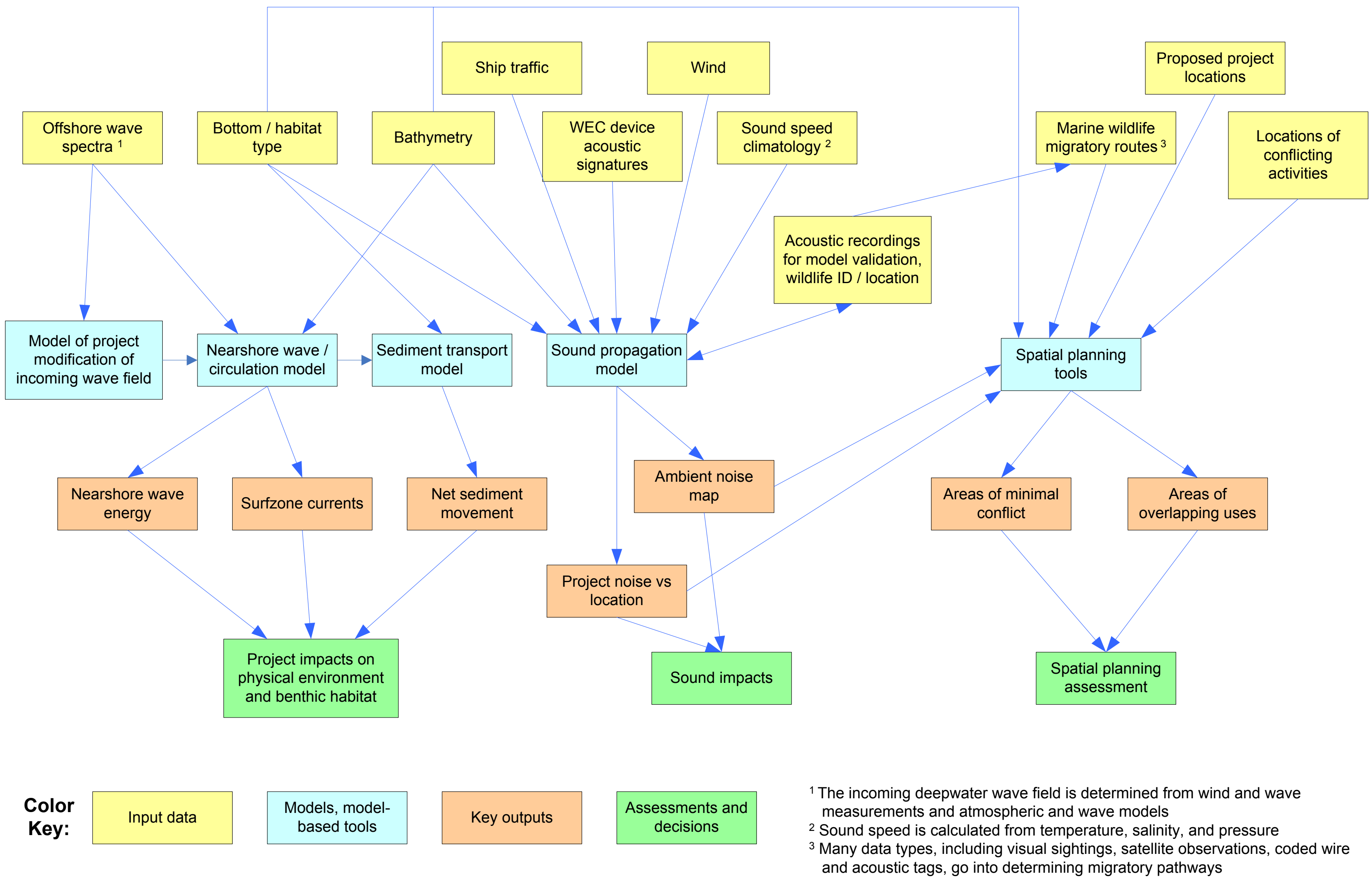


Figure 5.3. This figure demonstrates how ocean data, models, and tools can inform key aspects of environmental impact assessment and consequent permitting, licensing, and leasing decisions for ocean renewable energy projects. Measurements and predictions of changes to wildlife behavior and location are not included due to lack of space.

5.4.1 Migratory species

Interviewees cited issues involving the location and behavior of migratory species as one of the two highest priority environmental concerns related to WEC projects. Required information includes wildlife distribution, migratory pathways, whether they would be harmed by the WEC devices, and whether WEC project infrastructure would alter either their behavior or distribution. Improved understanding of how species' habitat use varies with changing oceanographic conditions would provide useful background information for evaluating potential WEC impacts. Causes for concern are listed in Table 5.2.

There are presently a number of programs associated with OOS that provide information about migration paths and, in some cases the abundance, of migratory species. These include the NOAA Fisheries and CalCOFI ship surveys and the Tagging of Pacific Predators (TOPP) and Pacific Ocean Shelf Tracking (POST) tagging programs. Unfortunately, these existing assets suffer from one or more of the following issues, thus reducing their usefulness for forecasting and evaluating WEC impacts:

- Spatial resolution is too coarse
- Sampling locations do not overlap with proposed WEC projects
- Data formats are not compatible with geospatial planning tools being used in ocean energy management
- Inconsistency among databases in terms of metadata and quality control

Presently, OOS in California are not involved in any systematic program of underwater sound measurements. However, as part of Navy-funded programs that are in general separate from OOS, and that provide only limited data access, there are acoustic monitoring assets that can hear underwater marine wildlife. These, also, are not necessarily in locations that are optimum for marine hydrokinetic energy issues.

Finally, while many oceanographic variables are measured by OOS, scientific knowledge is not yet sufficiently developed to make useful forecasts of wildlife locations and behaviors based on oceanographic conditions.

5.4.2 Altered wave field

The second high priority environmental concern was the potential effects of wave energy farms on sediment transport and benthic habitat. The altered wave field resulting from the presence of wave energy devices could conceivably modify sediment transport, benthic habitat, coastal geomorphology, water quality (including turbidity and oxygen concentration), and nearshore communities (Nelson et al. 2008; Komar et al. 2007).

Understanding and predicting how WEC devices, either in isolation or in an array, will affect the surface wave field involves fitting together three kinds of information. The first is information about the incoming wave field impinging on the WEC devices. CDIP provides this information for the entire coast of California (see text box above).

The second is to determine how the interaction with WEC devices will modify the wave field. Wave height will be reduced because energy is being withdrawn from the wave field. However, the amount of reduction, which wave periods and directions will be most affected, how waves will be diffracted, and whether they will be reflected, are all functions of the background wave environment and the specific type of WEC device, as well as the number and spacing of the devices. While some general parameters are known, there are very few specifics available, and models are under development to help answer these questions. Ultimately, wave measurements, including on the lee side of wave energy projects, will be needed to help validate such models, but the small spatial scale required for such measurements is probably inconsistent with present OOS capabilities. HF radar, used to measure surface currents, has some capability to provide information about the surface wave field but is too coarse a measurement to capture the likely perturbations caused by even large WEC projects.

The final type of information needed to assess WEC impacts on the wave field is what happens after waves have passed through the WEC array and are progressing towards, and then impacting, the shoreline. Circulation and sediment transport in the nearshore zone are largely, although not exclusively, a function of the incoming wave field. There are a number of numerical models available for predicting how waves are modified as they propagate through shallow water to shore, as well as the nearshore currents (e.g., alongshore transport, rip currents) that result from breaking waves. Such nearshore wave models require high spatial resolution bathymetry in order to achieve reasonable accuracy and CDIP has applied such models only experimentally due to the costs of validation on the needed small spatial scales. Sediment transport models driven by nearshore wave and circulation models can be used to predict changes in sediment distribution, beach slope, and coastal geomorphology.

5.4.3 Spatial management

A third major concern is the need to visualize environmental and human use as data layers in relation to relevant legal jurisdictions and proposed WEC project boundaries. WEC energy projects could conflict with sensitive habitats such as kelp beds, rocky substrates, marine protected areas, or ASBSs, and with an array of human uses such as shipping, fishing, and surfing.

The Multipurpose Marine Cadastre (MMC) covers all U.S. waters and is widely used for this sort of spatial analysis, although it is limited because it focuses primarily on legal and administrative boundaries. The MMC was originally developed by BOEMRE, NOAA, USFWS, in partnership with OPC and the Coastal Conservancy, to support wave energy development.

Given the limitations of the MMC, there is currently no state sanctioned marine spatial planning (MSP) tool for use in California, although several recent efforts (including two OPC projects in early 2011) have focused on defining capabilities needed to meet California's needs. In addition, the California Natural Resources Agency and the Resources Legacy Fund sponsored development of MarineMap, a spatial planning tool used to support development of marine protected areas in state waters. MMC and MarineMap share important similarities, although MarineMap includes many additional data types related to biological, physical, and geological oceanography that are applicable to ocean renewable energy planning and permitting. While MarineMap does not extend into the OCS, and does not cover the entire California coastline, all WEC projects proposed to date are located along areas of the coast covered by MarineMap. Despite this, neither agency staff involved in ocean renewable energy nor project proponents were aware of MarineMap as a potentially useful tool for planning and permitting, a significant knowledge gap given the significant amount of effort and funding invested in its development.

5.4.4 Key information needs

Table A.2.5 lists the specific and detailed management questions and information needs associated with each decision category. These information needs are then matched with a more detailed description of observing system capabilities and gaps in Table A.2.6. The important outcome of this process is the definition (in the right-hand columns of Table A.2.6) of key existing system assets and gaps needed to fulfill the information requirements for each management decision and/or question. Figure 5.3 demonstrates how ocean data, models and tools can inform key aspects of one of the major categories of decision making -- environmental impact assessment.

Existing capabilities that could contribute to identified management decisions include:

- CDIP and NDBC wave buoy networks and the wave models that use these data
- Central and southern California passive acoustic monitoring of marine mammals
- MMC and MarineMap spatial planning systems
- High spatial resolution bathymetry surveys
- Measurement of basic oceanographic conditions from satellites, buoys, gliders, and other assets
- NOAA Fisheries and CalCOFI biological surveys
- TOPP and POST tagging programs

Gaps in observing system capabilities that must be filled to address identified management questions fall into the following major categories:

- Inputs for nearshore wave and circulation models, e.g., measurements or valid estimates of the wave field inshore of WEC projects and nearshore high-resolution bathymetry and bottom type
- Validated nearshore wave, circulation, and sediment transport models
- A fully functional MSP tool, perhaps achievable through expansion and integration of MMC and MarineMap
- Marine wildlife migratory pathways at WEC project scales
- Models of organisms' behavioral responses to changes in ocean conditions and underwater sound
- Passive acoustic monitoring for validation of sound propagation models and marine mammal behavioral models
- Electromagnetic field measurements to assess effects on marine organisms

5.5 Ocean renewable energy institutional issues

Section 2.0 (Institutional Issues) described overarching adjustments to the existing institutional framework needed to ensure that ocean observing capabilities are well matched to management decision-making needs. In addition, there are features of the existing management system specific to ocean renewable energy that limit the effective use of some types of ocean observing products. To a large extent, these stem from the fact that ocean renewable energy development is at a relatively early stage and that ocean information, in general, is poorly organized and integrated compared to its terrestrial counterparts. As a result, the management frameworks, agency expertise, databases, and assessment tools needed for effective and efficient decision making are not fully developed and readily available.

Making full use of the information products described in Figure 5.3 and Table A.2.6 would be enhanced by:

- Improving the capacity of State agency staff to run and/or evaluate output from the models that will be used to assess WEC project impacts for environmental impact reports and other planning processes
- The development of coordinated spatial planning tools that build on existing capabilities and that provide the capacity to identify and evaluate potential use conflicts
- Parallel improvements to data management and data integration capabilities needed to support comparable spatial planning and impact assessment statewide

These issues are addressed in greater detail in the recommendations section below. However, one way that state and federal agencies can foster renewable energy development would be to facilitate the collection of environmental information needed for the permitting process. Some such efforts are underway. The federal government is funding a number of studies to shed light on environmental effects of marine renewable energy devices, for example a DOE study of marine wildlife interactions with such devices. DOE has focused on migratory species on the OCS, but since all marine hydrokinetic projects will have at least some elements (such as cables) in state waters, the inner continental shelf under state jurisdiction must also be addressed. Other entities have (e.g. European Marine Energy Centre), or are planning (e.g. Northwest National Marine Renewable Energy Center), marine hydrokinetic energy device test sites. Oregon also has a public-private partnership, the Oregon Wave Energy Trust (OWET), dedicated to "supporting responsible development" of wave energy in that state (http://www.oregonwave.org/). Such basic information gathering and assessment could be expanded with leadership from key state agencies.

Government agencies may also help improve the efficiency of developing individual project environmental studies and data collection. While federally- and state-supported OOS cannot, and probably should not, meet all the project-specific needs proponents usually address, OOS can provide longer-term and larger-scale context for these projects. Perhaps CeNCOOS and SCCOOS could play a coordinating role among federally- and state-funded and local project-specific data collection efforts so that data could be combined into products useful for both the agencies and project proponents. The RAs might also produce those combined products. California and federal agencies may project proponents and operators to follow certain data collection and management protocols for project specific monitoring that meets agency mandates.

State support, perhaps from the State Water Board or the California Resources Agency, or the CPUC, for providing some of the data needed for project environmental assessments will help to attract and foster development of ocean renewable energy. In addition, given the uncertainty surrounding the environmental impacts of WEC devices, state involvement of this kind will also help to reduce environmental harm. Information that is comparable across projects, validated, broadly coordinated, and widely accessible will support the adaptive management approaches needed to continually assess the environmental effects of WEC projects and modify or even discontinue them if necessary.

If these institutional issues are not addressed, the combination of economic factors and regulatory mandates for increased production of energy from renewable sources may support the continued development of renewable ocean energy resources anyway. However, recent experience that has seen many projects either canceled or delayed also suggests that state action of the sort suggested here and in the recommendations below could create an improved atmosphere for development by addressing major issues and impediments identified in this evaluation.

5.6 Ocean renewable energy recommendations

As noted above in Section 5.4 (Ocean Renewable Energy Information Needs) and in more detail in Table A.2.6, there are a variety of specific ocean observing platforms, programs, and models that should be sustained, expanded, or created to provide the information needed for siting, permitting, and managing WEC projects. From among these, we highlight the priority recommendations that would enable OOS to better support wave energy development. Recommendations focus primarily on underwater noise and acoustic monitoring, wave and nearshore modeling, and marine spatial management.

5.6.1 Develop a map of ambient underwater noise

Passive acoustic measurements are useful for identifying and locating wildlife, particularly marine mammals, through their vocalizations, and are also necessary to validate sound propagation models that can be used to quantify both ambient background and project-related noise. WEC project developers, the US Navy, IOOS, and California's CeNCOOS and SCCOOS should collaborate to produce a statewide ambient noise and sound propagation model. An ambient noise and sound propagation model would:

- Produce validated estimates of project-related sound levels as functions of frequency and location
- Provide larger-scale and longer-term context for comparing project noise to ambient noise
- Aid in acoustic tracking of marine mammals

Such a model would also be useful in assessing the noise impacts of a variety of ocean activities in addition to those from renewable energy projects. Presently, there is no "map" of ambient underwater noise for California state waters, and decisions regarding noise effects are made on a project-by-project basis with no adequate way to reliably compare projects to the ambient background or to assess cumulative effects. Given that WEC projects have been considered for much of California's coast, developing a statewide map of ambient noise could require only a marginal increase in effort compared to that needed to support planning and permitting for WEC projects. This expanded scope could lessen the cost for each partner by attracting additional partners.

The components needed for an ambient noise and sound propagation model are:

- Ship traffic
- Wind
- Sound speed climatology
- Bathymetry
- Bottom type
- Acoustic spectra for model validation

Several of these components already exist or are in the process of being created. The Automated Information System (AIS) provides real-time information about ship type and location, with data available through CeNCOOS and SCCOOS for the most heavily trafficked areas of the California coast. Wind data from buoys, satellites, and models are also available through the two RAs. Sound speed climatologies (or the data from which to calculate them) are available through various online databases. The California Seafloor Mapping Project is collecting bathymetry and backscatter data, from which bottom type may be determined, for all of California's state waters. Further offshore, bathymetry at adequate resolution can be obtained from a number of sources. Bottom type may be available through US Navy databases (although Department of Defense information may be difficult to obtain) or other sources. Acoustic spectra for model validation are currently available for one site off central California and multiple sites in southern California waters.

The number of acoustic data records for model validation could be enhanced by project-specific monitoring required as part of the permitting process. For example, it is likely that WEC projects would be required to provide estimates of their device and other project noise and to employ passive acoustic monitoring for marine mammals in their project areas. Such project-related monitoring should coordinate with and build upon existing US Navy-sponsored passive acoustics monitoring programs that include partners such as the Naval Postgraduate School, SIO, and NOAA Fisheries, all of whom have ties to CeNCOOS and/or SCCOOS. Because of IOOS's interest in expanding its acoustic and biological monitoring capabilities, California should take the initiative to develop a collaborative state and federal pilot project to examine the effect of noise on marine mammals, perhaps using NOAA's Stellwagen Bank passive acoustic monitoring project as an analogy (http://stellwagen.noaa.gov/science/passive_acoustics_noise.html).

In addition to providing some required system components, California should consider assigning the RAs core responsibility for acting as a data repository and/or data server for acoustic data, provide data integration by creating products combining acoustic data from multiple sources, and combine acoustic and other types of oceanographic data to correlate the location of marine mammals to oceanographic conditions. NOAA Fisheries' Pacific Fisheries Environmental Laboratory currently conducts such studies with satellite data for a variety of species tagged by the TOPP program. The same techniques could be applied to using acoustics to locate wildlife of concern. Such analyses could be expanded to locate wildlife in relation to subsurface features as measured by repeated glider transects. Products of this type would be useful to ocean renewable energy projects if the presence or abundance of species could be tied to oceanographic factors that could be monitored or, better yet, predicted. In addition, by relating the location of wildlife to the ambient noise spectra, it may be possible to select preferable WEC project areas in part by identifying areas that are avoided by certain types of wildlife based on the area's acoustic signature.

5.6.2 Improve tools for modeling WEC impacts on waves and nearshore conditions

WEC farms could potentially impact coastal geomorphology, benthic habitat, and human uses along and near the shoreline. The state should ensure the development and implementation of models needed to predict these and other potential impacts related to the modification of the wave field by a WEC project. This will require tools that produce reliable estimates of the incoming wave field, the modification of the wave field by WEC devices, and the nearshore currents associated with the modified wave field. The CDIP, which provides nowcasts and forecasts of the incoming wave field offshore of California, meets a part of this need and should be continued.

Current estimates of the efficiency of WEC arrays (i.e., how much energy these arrays can extract from the incoming wave field) are highly uncertain, yet reliable measures of efficiency are key to estimating both environmental effects and the amount of electrical power that can be generated. California should place a high priority on obtaining and providing better information about energy conversion efficiency, because investment in, and siting and permitting of, WEC projects is critically dependent on this knowledge. California should therefore monitor developments in wave / WEC device interaction studies, including engineering, modeling, and measurement activities. While we are not recommending that California, or the RAs, engage directly in research in such interactions, we do recommend that California be ready, at the appropriate time, to ensure that suitable models of wave / WEC interactions are applied in making environmental impact assessments.

5.6.3 Improve California's capacity to evaluate WEC projects

At present, there appears to be very limited expertise within state agencies to evaluate the effects of WEC-modified wave fields on the nearshore region. State agency staff do not have the expertise required to either conduct their own modeling studies or to adequately evaluate the information supplied by project proponents. We therefore recommend that state agencies enhance their knowledge of nearshore dynamics and nearshore wave models, perhaps through one of the following avenues: sharing expertise among agencies, hiring consultants, using expert panels, training, or other activities organized by the RAs. (see Section 2.2 for additional discussion of communication and training). We also recommend that California identify a validated and accepted suite of models to be used to evaluate at least the physical effects of the altered wave field, much as dilution modeling of effluent discharges is conducted by State Water Board staff using a model approved by the U.S. Environmental Protection Agency (USEPA).

5.6.4 Develop spatial management tools to resolve use conflicts

Federal agencies primarily use the MMC for offshore energy planning while California has used MarineMap for marine protected area planning. The OPC has co-convened the California Coastal and Marine Geospatial Working Group and has recently initiated two projects to formally designate tools for ocean renewable energy planning. We recommend that California continue its efforts with the goal of achieving relevant MSP tool consolidation and/or interoperability. This would avoid the self-defeating inefficiency associated with developing different MSP tools for different ocean management needs.

We also noted that there are a number of overlapping databases for living marine resources (e.g. OBIS-SEAMAP, CalCOFI DataZoo, PaCOOS West Coast Habitat Portal) and that the same data may be treated differently in different databases. Many of the providers of these data are RA partners and they may be able through the regional associations to provide guidance regarding the proper use of migratory species data. Coordinated datasets on the movements of migratory species would be an invaluable aid in WEC project impact assessments.

Finally, we recommend that, should ambient underwater noise maps be developed, they be introduced as a data layer into MSP tools.

5.6.5 Reduce institutional impediments

The path to an operational, or even a pilot, marine hydrokinetic project is long, involved, and expensive. As a result, many potential project developers have bowed out, or put their projects on hold, for lack of funds. We recommend that California improve its ability to attract ocean renewable energy projects by taking actions, such as those described above, that will reduce individual project costs related to environmental baseline and monitoring studies. This will require a more fully developed state policy that, among other things, prioritizes and integrates the recommendations listed above.

6.0 Decision Information Needs: Harmful Algal Blooms (HABs)

Overview – HABs are widespread and have been increasing in frequency in California's coastal waters. They affect human and wildlife health, degrade water quality, and impact coastal economies. The California Department of Public Health (CDPH) conducts a successful program to monitor for and mitigate the health impacts of blooms, although its capacity to do so is limited by the absence of more comprehensive monitoring and forecasting tools.

HAB characteristics – HABs are the blooms of a variety of algal species that produce a number of different toxins or produce negative impacts. There are four major types of poisoning events that have been documented in California, some of them fatal to humans and/or wildlife. Paralytic shellfish poisoning (PSP) is the most common human health impact. Some types of HABs are more common than others, although new types of HAB species have recently occurred in California and these patterns may be changing.

HAB management and decision framework – The primary HAB management framework is CDPH's collaborative monitoring and management program that includes mandatory shellfish inspections, volunteer phytoplankton monitoring, annual recreational harvest quarantines, and a system of alerts to local managers. There are no water quality regulations targeting HAB toxins, although one TMDL in northern California focuses on microcystin toxin in the Klamath River. The possibility that anthropogenic nutrient discharges could be stimulating HABs is a concern for coastal managers because of the large costs of removing nutrients from discharges. HABs can cause economic impacts on the shellfish industry, which must cease harvesting during blooms, and on desalination plants, which may have to shut down during blooms.

HAB information needs – Information needs are very similar for all management areas and focus on the ability to reliably monitor and forecast HAB events. This will require improvements to monitoring networks and methods, our understanding of the relative roles of natural and anthropogenic nutrients in stimulating blooms, modeling tools needed for forecasting blooms, and the ability to deliver information to managers to support immediate response and long-term planning.

HAB institutional issues – The CDPH program has successfully protected human health for several decades. However, there are strains on CDPH due to limited resources. The primary focus on human health has created gaps in HABs management for other purposes. Developing an operational HAB observing system will require maintaining effective partnerships and identifying the lead entity (or entities) if the program's scope expands beyond human health. This entity should improve research coordination and develop protocols for moving research results to operational capabilities. The economic value of a HABs observing system should be evaluated before embarking on further system development.

HAB recommendations – Key recommendations include continuing technology development, implementing a statewide HABs observing system, developing forecasting models, and building an early warning system with both technical and institutional components. In addition, data management capabilities should be improved and support for core research should be continued.

NOTE: Please see Appendix 2, Tables A2.7 and A2.8, for the detailed analysis of decision information needs and OOS capabilities on which the following discussion is based.

6.1 HAB issue overview

Harmful algal blooms (HABs) occur in almost all aquatic environments from open seas to freshwater lakes worldwide. They adversely affect human and marine wildlife health and coastal economies by producing marine toxins that can cause illness and mortality, degrade water quality, disrupt food webs, shut down aquaculture operations, and interfere with desalination facility operations. It is unclear what causes HAB events, but they are increasing in frequency in many parts of the world and particularly along the west coast of North America, where true red tides[11] have also become more frequent. Both the West Coast Governors' Agreement on Ocean Health's Action Plan (Gregoire et al. 2006) and the California Ocean Protection Council's Five-Year Strategic Plan (OPC 2006) call for improved HAB monitoring and forecasting capabilities to protect coastal resources, businesses, and public health.

Four major illnesses caused by algal toxins have been documented in California (Table 6.1), although California, like all other states, regulates only two toxins for public health, paralytic shellfish poisoning (PSP) toxins and domoic acid. The California Department of Public Health (CDPH) conducts a successful monitoring program for these toxins, based on sampling sport and commercial shellfish year-round. Commercial shellfish operations may be required to suspend harvesting and sales when toxins are present. CDPH also quarantines sport harvesting of mussels from May 1 through October 31, the period when mussels are most likely to accumulate PSP toxin. Despite the increase in the incidence of HABs, there have been no reported human cases of Amnesic Shellfish Poisoning (ASP) or PSP from consuming regulated commercial seafood in California. Any recent illnesses due to PSP are recreational victims who ate untested shellfish taken during the quarantine period. State budget shortfalls have made it difficult for CDPH to expand its capabilities to cover additional marine biotoxins and funding for CPH's existing monitoring is under pressure even while the threat from HAB events is on the rise.

In addition to its human health threat, domoic acid poisoning (DAP) has been linked to thousands of marine mammal and sea bird mortalities along the California coast since 1991 and a toxic bloom of *Pseudo-nitzschia* in the San Pedro Channel/Long Beach Harbor area had some of the highest concentrations of domoic acid recorded from natural coastal ecosystems. Finally, high biomass loads from blooms can significantly impact desalination operations by fouling filtration equipment and forcing plant shutdowns.

While the current monitoring and management system functions effectively to protect human health, other risks, such as to water quality, wildlife health, and coastal businesses are sometimes less well managed. In addition, the lack of a reliable forecasting ability prevents proactive responses to active blooms and forestalls planning to mitigate HAB effects over the long term, for example, with more informed facility siting decisions.

A coordinated and comprehensive network of ocean observations could support a number of key outcomes and solutions for HABs management, including:

- More robust models
- Detailed, accessible databases which can be easily interrogated
- Better forecasting to provide timely detection and warnings of toxic HABs
- Better mitigation strategies
- Improved risk management
- More accurate and understandable information to underpin business, regulation, and policy decisions

[11] A red tide is a bloom of dinoflagellates that causes reddish discoloration of coastal ocean waters. A red tide that occurred in Monterey Bay in 2007 was caused by *Akashiwo sanguinea*.

6.2 HAB characteristics

California's coast is unique relative to other U.S. regions impacted by HABs because its coastal waters are largely dominated by upwelling in the California Current System. Upwelling brings nutrients to the ocean surface, often in higher levels than from anthropogenic sources, and stimulates the growth of marine algae. The characteristics of the marine phytoplankton community typically change seasonally, although there is a great deal of variability related to winds, currents, and location along the California coast. Of particular concern are the potentially severe health impacts to humans, the large extent of wildlife mortalities, and the apparent recent increase in the frequency of blooms and the appearance of HAB species not previously seen in California.

Table 6.1. Marine planktonic species occurring along the west coast of the U.S. that are potential concerns for public health (adapted from Caron et al. 2010). Only two, the saxitoxins and domoic acid, are regulated by CDPH. In addition, domoic acid also poses significant risks to fish, birds, and marine mammals.

Plankton species	Toxin(s)	Poisoning event	Effects
Dinoflagellates *Alexandrium spp*	Saxitoxins (STXs)	Paralytic Shellfish Poisoning (PSP)	Human • Gastro-intestinal symptoms • Paralysis • Death Ecosystem • Marine mammal mortalities
Diatoms *Pseudo-nitzschia spp*	Domoic acid (DA)	Amnesic Shellfish Poisoning (ASP)	Human • Gastro-intestinal symptoms • Neurologic symptoms • Death Ecosystem • Marine mammal mortalities • Bird mortalities
Dinoflagellates: *Lingulodinium polyedrum* *Gonyaulax spinifera* *Protoceratium reticulatum*	Yessotoxins (YTXs)		Human and ecosystem • None reported
Dinoflagellates *Dinophysis spp* *Prorocentrum spp*	Okadaic acid (OA) Dinophysistoxins (DTXs) Pectenotoxins (PTXs)	Diarrhetic Shellfish Poisoning (DSP)	Human • Gastro-intestinal symptoms Ecosystem • None reported

Paralytic shellfish poisoning toxins occurred in detectable amounts in shellfish in nearly all months for all Californian coastal counties in 2009 (Langlois 2009) with the highest concentrations centered on Marin County. Most large-scale outbreaks of PSP toxicity occur in the summer and fall during the annual recreational mussel harvest quarantine period and usually move northward over time (Langlois 2001). In the typical pattern, dinoflagellate blooms (*Alexandrium catenella*) are first detected along the open coast during relaxation of upwelling and can then be transported into bays and estuaries and into the nearshore zone during favorable winds (Langlois 2009). While documented poisoning outbreaks have affected only humans, there is some concern about potential impacts on wildlife. Because these neurotoxins are found in seafood species throughout California at several times of year, there is a need for year-round monitoring.

Amnesic shellfish poisoning is caused by diatoms of the genus *Pseudo-nitzschia* which occur in all California waters, although the concentrations of the neurotoxin domoic acid vary greatly according to season and latitude. Algal blooms tend to occur when upwelling conditions are weak. Because the degree of toxicity varies among diatom species, algal cell counts alone are not a good indicator of toxicity. While there have been no confirmed cases of human mortality in California due to domoic acid, it is a significant threat to marine wildlife (see text box). The first documented toxic event of marine wildlife on the U.S. west coast occurred in Monterey Bay in September 1991. Such events often occur over very large areas for extended periods of time and they are becoming more frequent and severe (Trainer et al. 2007). It is not clear what environmental conditions trigger diatoms to produce domoic acid, although many potential causative factors, including anthropogenic changes to coastal water chemistry (e.g., increased nutrient loading) have been suggested.

Understanding a Massive Fish Kill

On Tuesday, March 8, 2011, King Harbor in the City of Redondo Beach a massive mortality event killed several million Pacific sardines (http://www.sccoos.org/data/habs/news.php). Sensor packages in and around the harbor showed extremely low levels of dissolved oxygen in the harbor, which were unquestionably the immediate cause of the mortality event. It is possible that the large numbers of fish entering the harbor depleted the oxygen or that there was an influx of coastal water with low oxygen concentrations.

Because HAB toxins are often associated with large-scale fish kills, researchers evaluated the potential for such a link in this case. Continuous sensors in the harbor showed low chlorophyll concentrations in the period leading up to the fish kill, showing that high algae concentrations and/or toxins in the harbor were not the direct cause of the event. However, sardines had high levels of domoic acid in their guts and an offshore survey on March 9 found high levels of domoic acid in the plankton. This suggests that the sardines ingested the toxin offshore. The toxin may have contributed to the swimming behavior that caused the large concentration of sardines in the harbor, where their large numbers depleted dissolved oxygen levels.

This event and the attempt to understand its cause(s) illustrates the value of a monitoring network that collects real time and near real time data, along with the ability to quickly mobilize to collect additional information during and immediately after a HAB-related event. The knowledge needed to effectively target such data collection efforts is derived from ongoing research into the causes and dynamics of HAB events.

King Harbor, Redondo Beach, CA (Photo source: KCAL News)

Other toxic species. Although the dinoflagellates that produce yessotoxins and the toxins responsible for diarrhetic shellfish poisoning (DSP) occur in California waters, their toxins are not regularly monitored and there have been no documented cases of either human illnesses or wildlife deaths associated with either type of toxin.

Newly occurring HAB species have apparently been increasing along the U.S. west coast. For example, blooms of an emerging potentially toxic organism, *Cochlodinium* sp, have been reported off central California; massive blooms of the dinoflagellate *Akashiwo sanguinea* are common in coastal waters of southern and central California and have recently been the cause of seabird mortality. Microcystins, produced by cyanobacteria in fresh water, have long been considered a public health issue in rivers, lakes, and reservoirs, but have recently become a concern in coastal marine environments. They have been detected off the mouth of the Klamath River, at the ocean edge of San Francisco Bay, and in the discharges of three rivers to the Monterey Bay National Marine Sanctuary, where they were linked to the deaths of 21 sea otters.

6.3 HAB management and decision framework

The diversity in blooms and their impacts present a significant challenge to managers of coastal resources threatened by HABs. The strategies needed to protect public health and minimize ecosystem and economic losses may vary considerably among locations and HAB types, and no single agency has the combination of expertise and management responsibility needed to fully address the HABs challenge.

A number of management strategies to reduce HABs impacts are applicable to four major decision categories related to:

- Public health
- Water quality

- Marine wildlife surveillance and rescue
- Coastal business operations, primarily aquaculture and desalination

For each decision category, managers could utilize one or more strategies aimed at mitigation, prevention, or control. **Mitigation** strategies include monitoring, modeling and forecasting, early detection or warning systems, and public information dissemination and education. **Prevention** strategies that attempt to avoid the occurrence of toxic blooms are not well developed, in large part due to poor understanding of the immediate causes of toxic blooms. **Control** strategies are the most challenging and controversial and include mechanical, chemical, and biological control methods. However, many such control methods have been rejected due to their effects on ecosystems, high costs, or limited effects on target organisms. The CDPH has focused almost exclusively on mitigation strategies in each of the following decision categories, based on a combination of precautionary management and leveraging its own efforts through collaboration with other volunteer monitoring networks.

6.3.1 Public health

The CDPH Marine Biotoxin Monitoring Program began in the early 1930s in response to the recognition that PSP was a serious health risk and includes:

- Testing shellfish from commercial growing areas
- Shellfish monitoring along the coast
- Coordination of a volunteer-based marine phytoplankton sampling network
- Mandatory reporting of any known or suspected case of PSP or DAP to health authorities and CDPH
- An annual quarantine of sport-harvested mussels from May 1through October 31 along the entire California coastline to prevent PSP
- Public education and health alerts

Commercial shellfish growers submit samples for PSP testing to CDPH from their shellfishing beds at weekly intervals, year-round, during all harvesting periods. All harvesters and growers of bivalve shellfish must also obtain a certificate from the CDPH, based on these test results, prior to harvest. In addition, California's county environmental health departments submit sentinel mussel samples from their regions once or twice per month for testing and this monitoring is augmented in some areas with samples collected by the CDPH, the CDFG, and various other participants. The CDPH manages this program with a staff of four people responsible for classifying commercial shellfish growing areas statewide. Commercial shellfish harvesting operations can be shut down when toxins are present.

Sampling and testing shellfish is the only method currently approved by the Food and Drug Administration and CDPH, other than case reporting, to verify and document PSP or DAP activity. While there is no systematic monitoring of toxins in seawater, shellfish toxin levels are assumed to provide a rough representation of toxins in the upper water column over seasonal and annual scales. Additional sampling may be triggered by reports of marine mammal strandings if animals exhibit symptoms consistent with DAP. An important logistical constraint on testing programs is that the current methods used to detect the toxins responsible for PSP and DAP are time consuming and expensive.

A volunteer-based Phytoplankton Monitoring Program (Figure 6.1) was implemented in 1993 in response to the large-scale 1991domoic acid outbreak in Monterey Bay and involves over 80 participants statewide, including management agencies, shellfish growers, and citizen volunteers. Monitoring sites include all commercial shellfish growing areas and numerous coastal sites. This statewide program enables early detection of toxic blooms, which allows CDPH to focus efforts such as additional sampling and analytical support in the affected area.

Figure 6.1. Example monitoring results for the third week of April, 2011, for the volunteer toxic phytoplankton monitoring program. This map displays relative abundance of *Pseudo-nitzchia*, responsible for domoic acid, and *Alexandrium*, responsible for the PSP toxins. (source: http://www.cdph.ca.gov/HealthInfo/environhealth/water/Pages/Toxmap.aspx)

The annual harvesting quarantine applies only to recreational harvesting of mussels, which both accumulate and eliminate PSP toxins faster than most other shellfish. Mussels are a high-priority health risk because they are commonly eaten without removing the digestive organs, where the toxins may concentrate. The timing of the quarantine can be adjusted based on monitoring results and the quarantine can also be extended to all bivalve shellfish if unsafe levels of toxins are detected.

CDPH's warnings, quarantine information, and health advisories are the most common source of HAB information for coastal managers. In contrast, monthly and annual monitoring program reports are most valuable for retrospective analysis and for providing a statewide context for assessing toxin levels and impacts. However, it is important to recognize that the CDPH monitoring programs are limited to nearshore sites and that toxin contamination in more pelagic or benthic organisms is not monitored currently. Any expansion of California's aquaculture enterprises to offshore sites would require an increase in the spatial coverage of current CDPH monitoring.

6.3.2 Water quality

There are no state or federal regulations that address potential water quality impacts of HABs. However, in 1998, USEPA included freshwater cyanobacteria and their toxins on the first Candidate Contaminant List on the basis of their potential public health significance. In 2008, the State Water Board and USEPA included microcystin toxin on California's 2006 Clean Water Act Section 303(d) List "as an additional cause of impairment" of a segment of the Klamath River. As a result, California was required to develop a TMDL and account for all sources of the pollutants that caused the water to be listed.

While HABs are a natural occurrence, the recent increase in their frequency has raised concerns that anthropogenic influences, particularly nutrient discharges to the coastal zone, are a contributing factor. At present, there is scientific consensus that nutrient loading and HABs are linked (Heisler et al. 2008; Anderson et al. 2008), but direct evidence for specific sites in California is difficult to come by (Kudela et al. 2008). However, if further research shows that such nutrient loading contributes significantly to harmful algal blooms, POTW and stormwater discharges may come under increasing pressure to reduce nutrient loads. Stricter regulations on effluent quality that would require costly nutrient removal are among measures mentioned by public officials. For example, installing tertiary treatment capacity for all POTWs discharging to the coastal zone would require extremely large initial capital costs, along with increased operating costs (e.g., 40 – 50% increase in energy consumption (M/J Industrial Solutions 2003)).

6.3.3 Marine wildlife surveillance and rescue

A significant challenge facing the marine wildlife rescue community is the optimal deployment and coordination of limited assets during large-scale toxic events and strandings. In addition, rescue centers wish to avoid releasing rehabilitated wildlife when blooms may be imminent. Such centers typically rely on direct communication with CDPH and its network of partners for information on HAB conditions.

However, to the extent that decisions about potential risk depend on data from mussel tissue monitoring, there are concerns about the number of cases where extremely high DA toxin levels in other marine organisms correspond with low toxin levels in sentinel mussels. For example, a massive mortality of California sea lions along the central California coast in May and June 1998 corresponded with a *Pseudo-nitzschia australis* bloom observed in the Monterey Bay region (Scholin et al. 2000). High levels of DA from the bloom were detected in planktivorous fish, including the northern anchovy. In contrast, mussels collected during the DA outbreak contained no or only trace amounts of. Therefore, solely monitoring mussel toxicity may not necessarily provide adequate warning of DA entering the food web at levels sufficient to pose risks to marine wildlife and perhaps humans.

6.3.4 Coastal business operations

The potential direct economic impact of PSP and DAP to California's commercial shellfish industry, which had total sales of over $16.4 million in 2008, is loss of income due to closures, shellfish mortalities, and consumer avoidance. Indirect impacts, such as reduced investment, are also costly. Early HABs detection allows shellfish growers to make timely decisions (e.g., rapid harvesting) to minimize damage. In addition, historical information supports strategic decisions about placement of new growing locations.

Algal blooms can have significant negative impacts on desalination facilities employing reverse osmosis. Over 20 large desalination facilities along the California coast have been initiated or proposed in the past ten years. Large and rapid increases in organic load and biomass in the intake water can lead to increased use of chemicals as well as fouling of pretreatment filtration membranes (Caron et al. 2010). For example, extreme red tides in the Middle East have caused plants to suspend operations (Lauri et al. 2010). Early HABs detection would allow desalination facilities to adjust operations to avoid shutdowns and reduce maintenance costs.

Algal toxins pose a second threat to desalination operations. Studies are ongoing to determine the effectiveness of pretreatment and treatment technologies for removing HAB toxins. For example, a pilot plant study in Santa Cruz, CA showed that a toxin analog, kainic acid, could be detected in polished drinking water after spiking the desalination train to simulate a very moderate bloom event. More intensive treatment (i.e., reverse osmosis) is effective at removing domoic acid and saxitoxins (Lauri et al. 2010), but its effectiveness at removing other toxins under operational conditions is unclear.

6.4 HAB information needs

As briefly described in the preceding section, there are four categories of decisions related to HABs that could potentially utilize OOS information, including:

- Human health protection, not only for PSP and DAP, but also for new or emergent HAB toxins and related threats
- Marine wildlife protection, including endangered species, at the individual and population level, and protection of ecosystem health
- Water quality, specifically the regulatory implications of HABs on POTW and riverine / estuarine discharges of nutrients and harmful algae or toxins
- Economic impacts to marine aquaculture and desalination operations as well as to recreational use of the coastal zone

The principle response of both public agency and private managers to threats posed by HABs has been mitigation (as opposed to prevention or control), or "…minimizing HAB impacts on human health, living resources, and coastal economies when they do occur…" (NOAA 2001).

An effective mitigation strategy will require the capacity to reliably monitor and forecast HAB events, which will involve improvements to:

- The ability to detect HAB species and HAB toxins
- The understanding of relative contributions of natural and anthropogenic factors to HAB formation and duration
- The capability for short-term (48 – 72 hour) and long-range (monthly to seasonal) HABs forecasting
- HAB information delivery

Table A.2.7 provides a detailed overview of the specific management questions, and ocean information and OOS products and product needs in each of these decision categories. Table A.2.8 then matches these decisions and information needs with a more detailed description of current observing system capabilities and gaps. The important outcome of this process is the definition (in the right-hand columns of Table A.2.8) of key existing observing system assets and gaps needed to fulfill the information requirements for each management decision and/or question. Figure 6.2 illustrates the data inputs and model outputs fundamental to these decisions and capabilities.

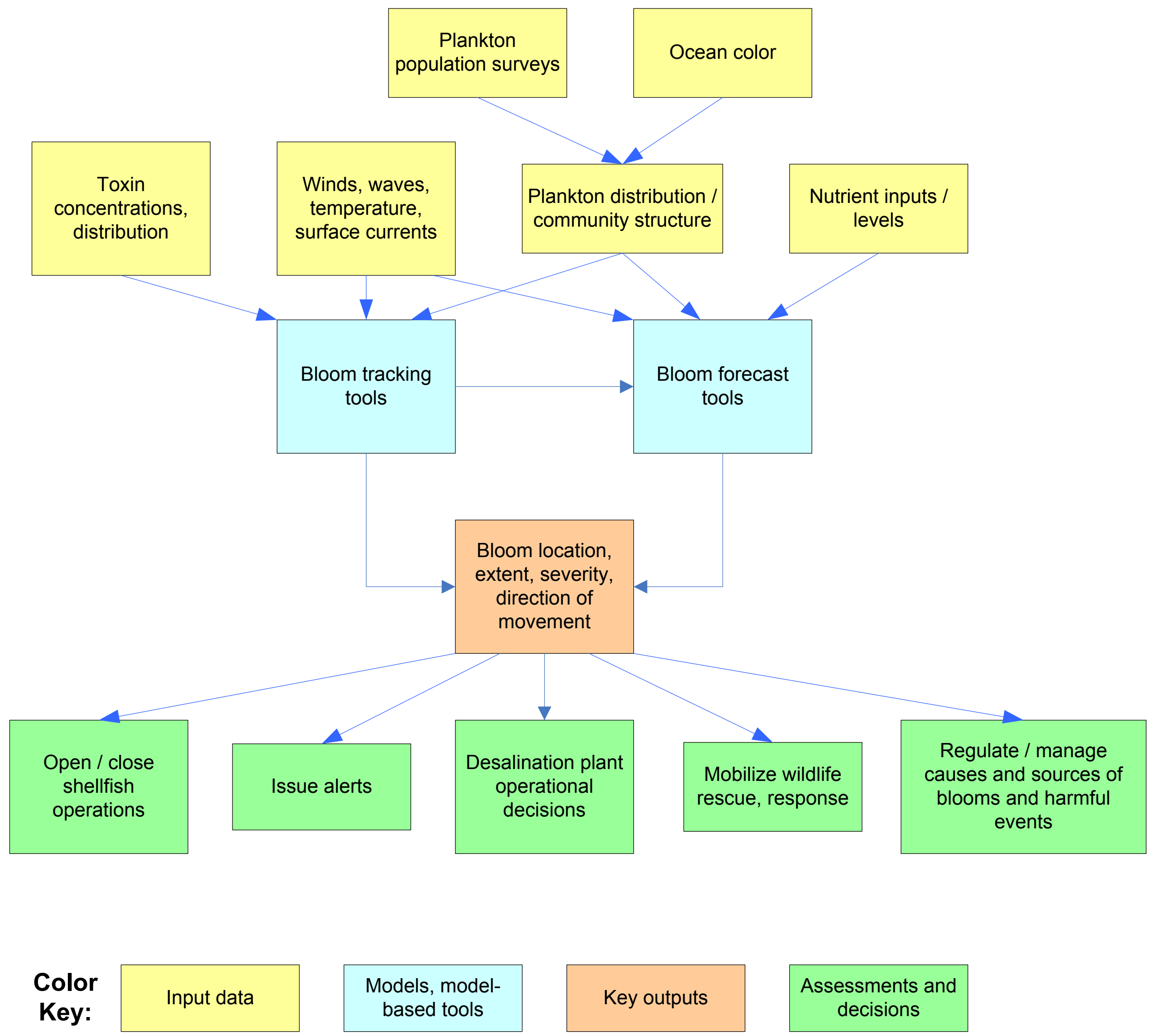


Figure 6.2. A schematic illustration of how ocean data, models, and tools can inform key aspects of decision making related to HABs. Note that multiple decisions flow from one primary set of information outputs.

6.4.1 Detecting HABs and toxins

An effective HAB detection system has several components that must provide the information needed to answer the following questions:

- What is the distribution of potentially toxic algae and their toxins?
- Where do the early warning signs of HABs occur?
- Once HABs occur, what is their likely intensity, trajectory, and duration?

Characterizing the distribution of potentially toxic algae and toxins requires that both be measured on the same time frame. Neither indicator alone enables definitive conclusions because each algal species' toxicity may vary and the presence of algae does not always indicate toxicity. Further, sampling must include both shore-based and offshore stations because nearshore blooms are not always associated with offshore blooms, and vice versa; samples from shore-based stations are representative of conditions up to only two to five km from shore. Thus, the existing shore-based network (CDPH stations, SCCOOS pier stations, research stations in central California) should be expanded with moorings up to 15 km offshore in northern California and up to 20 km offshore in the Southern California Bight. This degree of coverage will improve the characterization of HABs' extent and increase the chances that blooms will be detected in their early stages.

However, existing monitoring, based on direct sampling and analysis methods (e.g., laboratory identification of algae species and toxins), is not adequate to detect both algae and toxins on the same time frame or to sample an offshore network of stations at reasonable cost. An effective HAB detection system should therefore include *in situ* methods that can support remote, real time monitoring. Such methods are under development but have not yet reached the operational stage. These include the Environmental Sample Processor, developed by MBARI, which detects water-borne microorganisms, their genes, and gene products. Molecular probescan simultaneously detect a variety of harmful algae and their toxins. Solid Phase Adsorption Toxin Tracking (SPATT) is another promising technology.

Detecting the early warning signs of HABs not only depends on algae and toxin data from the network of shore-based stations and offshore sensors described above, but also requires information about the oceanographic conditions and processes that are most conducive to HABs. There are a number of OOS assets that produce important pieces of this picture, including NOAA's NDBC (sea state and ocean meteorology), the ROMS model (nowcasts and forecasts of surface currents), and the periodic Southern California Bight regional monitoring program (coastal processes that affect nutrient budgets and HABs).

Taken together, these tools would provide the basics of a capability to identify conditions characteristic of the early stages of a bloom. However, not all are fully developed (e.g., the offshore network) and they have not yet been integrated into an operational detection system, in part because the dynamics of HAB formation are still only poorly understood.

Tracking HABs' intensity, trajectory, and duration is an important aspect of managers' ability to mitigate HAB effects, for example by adjusting shellfish or desalination plant operations. Forcing by wind and water currents is a dominating factor in bloom transport and surface current data obtained from the California Coastal Ocean Currents Monitoring Program's (COCMP) HF radars are important for determining bloom trajectories.

Optimal sensor location will maximize the amount of collected information by exploiting synergy with existing observational networks, reducing redundancy, and minimizing development and operational costs for the network. Recent work by Frolov and coworkers has shown that a network of seven offshore moorings would be able to detect 60% of HABs in the Southern California Bight, with sampling every one or two weeks throughout the year. In central and northern California, weekly sampling would need to be increased to twice-weekly sampling during the periods of HAB events. Further work is required to validate the proposed optimal design.

6.4.2 Understanding HAB dynamics

Understanding the relative contributions of natural and anthropogenic factors to HAB formation, severity, and extent (Figure 6.3 provides one example) is crucial for designing and implementing sound management practices and regulatory actions related to HABs (e.g., decisions about controls on nutrient discharges). This will require studies of the coastal processes that affect nutrient budgets and HABs, focusing on:

- The relative contributions of major nutrient sources such as upwelling, POTW discharge, atmospheric deposition, and terrestrial coastal runoff
- The spatial and temporal patterns of plankton blooms
- The specific water quality conditions and nutrient sources associated with bloom events

Such studies have begun to be implemented in southern California, particularly as part of the Southern California Bight Program led by SCCWRP. SCCOOS assets and expertise are an integral part of this ongoing effort. Data from the SCCOOS pier network and gliders is combined with data from offshore ship surveys during HAB events and is being coordinated with the forecasting efforts described below. The Bight Program studies are a model for the sort of broader-scale studies that must be expanded to other regions of California.

Figure 6.3. Aerial photograph of the August 2010 Tetraselmis bloom off San Diego County in southern California. (source: Charles J. Smith)

6.4.3 Forecasting HAB events

Coastal managers have great interest in developing the capability to forecast HAB events. Short-term forecasts (48 – 72 hours) of bloom severity, trajectories, and duration for specific sections of the coast would enable proactive management intervention such as resource allocation, health advisories, or shellfish bed closings. Longer-term forecasts would enable strategic planning such as facility siting or revisions to policies controlling contributing factors such as possibly nutrients from discharges.

Reliable forecasts of HAB events will require linking descriptions of ocean circulation, produced by the ROMS, or other circulation, model, with a biogeochemical / ecosystem model that generates nutrient fields and forecasts of plankton population dynamics. Two recent efforts focused on developing and testing forecasting models of *Pseudo-nitzschia* blooms and domoic acid concentration in the Santa Barbara Channel (Anderson et al. 2009) and in Monterey Bay (Lane et al. 2009). The OPC has recently funded an effort to integrate these models with ROMS (Kudela 2009), test and expand the models in other regions, initiate a similar modeling effort for PSP, and use field monitoring to validate the model results. If successful, this effort could provide the basis for a statewide forecasting capability that would enhance the value of a range of OOS data.

6.4.4 Information delivery

HABs monitoring and research produce a wide range of relevant information for managers and other audiences, who identified two basic types of information and delivery mechanisms. The first is real time alerts of expected problems such as the presence of toxin or toxic species, contaminated shellfish, or marine wildlife strandings. Managers currently prefer to obtain such alerts directly from CDPH or local researchers through simple email messages. This capability could be improved by automating the alert process, based on comparison of monitoring data to agreed-on thresholds.

The second type of information is more complete historical HABs and oceanographic information suitable for retrospective analyses, e.g., location, duration, trends of HAB events over longer time periods. Data of this type are available on the CDPH, CeNCOOS, and SCCOOS websites and the websites' utility could be improved by including tools for specific kinds of retrospective analyses. In addition, California Harmful Algal Bloom Monitoring and Alert Program (HABMAP), established in 2008, provides a basic framework to facilitate information exchange among researchers and managers.

6.4.5 Key information needs

California has built or is beginning to build the foundations for the HAB monitoring system described above. However, achieving a sustained operational capability will require maintaining certain existing assets, developing new monitoring and modeling tools, and integrating these into a coordinated observing system.

Key existing capabilities that should be maintained to fully address management questions include:

- CDPH's statewide shellfish and phytoplankton monitoring networks
- Pier-based observations, supported by the two RAs, of real time temperature, salinity, sea level, and chlorophyll, combined with laboratory measurements of nutrients, algal species, and domoic acid
- Periodic Bight Programs (1994, 1998, 2003, 2008) that provide large-scale monitoring coverage of the Southern California Bight and the infrastructure for investigating the coastal processes that affect nutrient budgets and HABs
- The HF radar system and the ROMS model that support trajectory forecasts

Gaps in observing system capability that must be filled to fully address management questions fall into the following major categories:

- Offshore moorings in both northern and southern California, up to 15 and 20 km offshore, respectively, with the number of moorings and monitoring frequency refined through an optimization study
- Improved technology to enable remote, *in situ*, integrated detection and identification of algae species and toxins
- Better understanding of the dynamics of HAB formation to support early warning based on specific patterns and thresholds of ocean condition
- Continued research into the potential role of anthropogenic nutrient discharges in HAB formation
- Development of a linked circulation and biogeochemical / ecosystem model that would forecast HAB events based on physical (e.g., temperature, upwelling), chemical (e.g., nutrients), and biological (e.g., plankton species and density) parameters
- Increased automation of the HAB alert system
- Improved web-based tools for retrospective analysis of HAB events and trends

6.5 HAB institutional issues

Despite CDPH's small size, its monitoring and management program has been largely successful in protecting public health for the past three decades, in part due to its success in establishing extensive volunteer networks for shellfish and phytoplankton sampling. However, there are strains in this system stemming from the limited resources available to some partners (e.g., county health departments) and the high cost of current laboratory identification methods for algae and toxins. In addition, there are gaps in capability due to the program's primary focus on human health and the lack of a comprehensive monitoring and forecasting capability. These issues must be addressed if management decisions are to benefit fully from the types of OOS information described above. Some of these are specific to the HAB issue and others (e.g., improved data management) reflect the overarching concerns described in Section 2.0 (Institutional Issues).

Development of an operational HAB observing system depends on:

- Maintaining and enhancing the existing environment for partnership among the wide variety of participants in existing monitoring, research, and management efforts. This may require restructuring if new observing tools become available and/or if the scope of the system expands beyond its current focus on human health
- Identifying the lead entity (or entities) if the program's scope expands significantly beyond human health to include water quality, wildlife impacts, and/or coastal businesses
- Better coordinating research projects to improve their focus on priority questions and their relevance to eventual operational capabilities
- Developing protocols for transitioning research results to an ongoing operational capability
- Expanding and improving data management tools that enable efficient access to data from all relevant sources, data integration and analysis, and production of needed alerts, reports, and other products
- Assessing the economic value of the HAB observing system, since an operational system will require investment and no additional NOAA funding should be expected

If the HAB observing system is not developed, then the existing system would most likely continue in operation. Human health would continue to be protected, as evidenced by CDPH's long record of success in this area; as stated above, this would not support or improve better management of ecosystem and wildlife health. However, without a forecasting capability, the system would continue to depend on real time reports from its monitoring network and would have little if any anticipatory capacity. The absence of a forecasting ability would also prevent either short- or longer-term planning by shellfish growers, desalination plant operators, or POTW managers. Finally, without a forecasting capability, and the research it would be based on, it will not be possible to answer questions about the potential role of anthropogenic nutrient discharges in stimulating HABs.

6.6 HAB recommendations

The highest priority for most HAB responders is the development of a regional operational HAB forecast system that would provide both short- (hours to days) and longer-term (months to years) forecasts. Short-term forecasts can provide information about bloom sources, triggers, trajectory, duration, and toxicity. This will help to alert agencies, wildlife rescue groups, businesses, and individuals to prepare for and respond to HABs and alleviate their effects. Longer-term forecasts can inform management decisions about the need to reduce nutrient loads, where to site aquaculture operations or desalination plant intakes, or how to optimize monitoring efforts.

An operational HAB forecast system will require addressing the following recommendations, which are similar to those put forward at the West Coast Governors Association HAB Summit in 2009. However, securing the needed investment may depend on establishing the true costs of HABs on California's economy and the value of HAB forecasts to diverse stakeholders. As Section 6.5 (HAB Institutional Issues) shows, the current system of monitoring combined with precautionary management appears to adequately fulfill management needs to protect human health, although there are unmet needs related to water quality, marine wildlife, and coastal business. We therefore recommend a careful assessment of the economic costs and benefits of developing and deploying a HAB forecast system, including its monitoring, data management, and communication components.

6.6.1 Continue technology development

The most important operational methods for identifying harmful or toxic algal species and their toxins are applicable only in the laboratory. California should collaborate with and help coordinate efforts to develop *in situ* methods that could provide real time detection of harmful and toxic algae (e.g., the Environmental Sample Processor) and their toxins (e.g., SPATT for PSP toxin and domoic acid). However, these and other advanced technologies will require field performance and cross-method comparisons before they can be adopted into routine monitoring programs. California should therefore form partnerships with organizations such as the Alliance for Coastal Technologies to conduct third-party evaluation of such sensors to inform decisions about the choice of operational monitoring methods.

6.6.2 Implement a statewide HABs observing system

Existing OOS include aspects that are directly relevant to HAB forecasting. California should build on these to design and implement a statewide HABs observing system with the following components:

- The existing HAB monitoring network as a backbone
- An expanded pier-based monitoring network in the CeNCOOS region to match that in the SCCOOS region
- The addition of HAB-specific sensors (see Section 6.6.1 above) to other long-term monitoring networks (e.g., the Bight Program in southern California, CCLEAN in central California)
- The use of remote sensing platforms, such as COCMP's HF radars, which can provide surface current information needed to forecast bloom trajectories
- Additional monitoring effort (e.g., fixed sites for tracking trends, transects, *in situ* sensors) in undersampled areas such as the nearshore zone where cyanobacteria and microcystins enter the ocean as well as further offshore

The design of the statewide HAB observing system should be optimized to ensure that monitoring and other related efforts are allocated in terms of relative risk and need for information, using one or more methods currently available for evaluating the benefits of adding new observing capacity to existing systems.

6.6.3 Develop operational HAB models

California should encourage and coordinate the development of forecasting models that can forecast HABs in a cost-effective and timely manner. The OPC has funded a project to extend earlier research efforts in Monterey Bay and the Santa Barbara Channel by linking the ROMS circulation model with a biogeochemical / ecosystem model, an important step in developing a HAB forecasting capability. If this pilot project is successful, California should support its extension to other regions of California, particularly the Southern California Bight.

6.6.4 Build a HABs early warning system

California HABMAP is a grassroots effort, with support from OST and NOAA, that has made considerable progress in coordinating HAB monitoring and building the foundation for an early warning system. This has included building trust with key audiences and identifying the core elements of a risk communication strategy (e.g., threshold values to trigger alerts). California should help provide additional support to HABMAP to refine its risk communication methods and develop prototype and operational information products. An active and effective HABMAP will provide the basis of the communications component for the operational HAB observing system called for in Section 6.6.2.

6.6.5 Improve data management capabilities

California's two RAs, SCCOOS and CeNCOOS, have begun a collaborative effort to establish an online HAB Information System to store information provided by all parties involved in HAB monitoring and research on the occurrence and impacts of marine and brackish water harmful algae. California should encourage and support the continued development of this system to ensure that it:

- Includes data from both university-based monitoring and research efforts as well as from CDPH's monitoring programs
- Is fully compatible with other state information management initiatives
- Includes links to other useful data such as relevant oceanographic conditions and nutrient loading, as well as larger information systems such as the Harmful Algal Information System currently being developed by the United Nation's Intergovernmental Oceanographic Commission.

6.6.6 Support core research

Increased nutrient loading from human activities is often cited as one reason for the increase in frequency, duration, and harmful properties of HABs, with POTWs facing greater scrutiny as a major source of nutrients discharged to the coastal ocean. Because nutrient controls would be extremely costly, California should support research into the potential role of anthropogenic nutrients in HABs. Examples of ongoing research include the OPC-funded Southern California Bight Nutrient Loading Study and the Bight '08 Water Quality project which includes over 60 agency partners. An important research emphasis should be the development and application of models capable of resolving the role of different nutrient sources in upwelling systems such as coastal California. Because of its large store of oceanographic data and its substantial research capacity, such research should focus on the southern California Bight.

6.6.7 Improve the institutional setting for HAB research and management

Implementing the recommendations described above will require a more robust and well defined institutional framework for HAB research and management. A lead entity should be defined to ensure that efforts related to water quality, wildlife impacts, coastal business are adequately coordinated and that useful partnerships are developed and maintained. In addition, the effective application of new tools will require protocols for determining when and how these should transition from research to operational phases.

7.0 Decision Information Needs: Oil Spills

Overview – Petroleum hydrocarbons enter the marine environment from natural seeps and as the result of crude oil extraction, refining, transportation, distribution, and consumption. Offshore oil operations in California include 23 platforms in federal and nine platforms and related facilities in state waters. California is home to three of the five busiest ports in the country and approximately 260 million barrels of crude oil and refined products are transported by tankers along the California coast each year. Tankers, container ships, and other vessels have been the source of the majority of oil spills in California in recent years. Spills in waterways and from offshore oil platforms are the next largest source of California spills. The quantity of each spill is usually small, with over half involving less than ten gallon and about 90% less than 100 gallons. Since the 1969 Santa Barbara spill, annual spill volumes have been dominated by accidents.

Oil spill characteristics – A variety of physical, chemical, and biological processes change the composition and environmental impacts of spilled oil, ultimately producing floating tar lumps and dissolved and particulate hydrocarbon materials that either remain in the water column or are deposited on the sea floor, beaches, and shorelines. Spilled oil can impact wildlife and habitats through physical damage and toxic effects. The severity of the environmental consequences will depend on the specific spill conditions, such as the type and amount of oil, weather conditions, habitat where the spill occurred, and effectiveness of response methods.

Oil spill management and decision framework – The Office of Spill Prevention and Response (OSPR), in the California Department of Fish and Game (CDFG), is the lead state agency charged with oil spill prevention, response, and natural resource restoration in the marine environment. In California, the Incident Command System (ICS) is the designated organizational structure that coordinates agencies responding to an oil spill. The ICS is managed by the Unified Command (UC), which is comprised of a designated official of the US Coast Guard (USCG), OSPR, and the responsible party (oil spiller). The UC makes all decisions on response operations with the USCG making final decisions. Each UC member has its own scientific team and NOAA's Office of Response and Restoration (OR&R), assists the Federal On-Scene Coordinator (FOSC) and UC in coordinating scientific activity.

Oil spill information needs – Emergency managers need information on spill location, size and extent in three dimensions (surface and subsurface), direction and speed of oil movement, and predictions of oil drift and dispersion to limit the damage by a spill and facilitate cleanup efforts. Real-time data on current profiles (surface to bottom), wave energy, suspended sediment concentrations, detailed bathymetry, seafloor sediment characteristics, and sediment transport patterns and rates are needed to validate or calibrate models (both computer and conceptual), direct sampling efforts, and predict the behavior and fate of submerged oil. Data needs for modeling dispersants and oil spills include composition and properties of spilled oil, and data on the effectiveness of dispersants.

Oil spill institutional issues – Funding for OSPR's statewide spill programs comes out of the Oil Spill Administration Fund (OSPAF). Projected budget shortfalls would force OSPR to cut back on its preparedness for responding to a catastrophic spill. Unresolved technical and institutional concerns combine to limit the use of HF radar data and data products in oil spill trajectory modeling.

Oil spill recommendations – We recommend establishing and/or expanding efforts for long-term monitoring of vulnerable components of ecosystems likely to be exposed to petroleum releases; developing protocols to improve input of real-time data (e.g., HF radar) directly into OR&R's trajectory modeling; and developing more effective autonomous methods for subsurface sensing and tracking.

NOTE: Please see Appendix 2, Tables A2.9 and A2.10, for the detailed analysis of decision information needs and OOS capabilities on which the following discussion is based.

7.1 Oil spill issue overview

While diverse, the sources of petroleum input to the sea fall into three major groups, extraction, transportation, and consumption (e.g., urban runoff from automobiles; two-cycle recreational boat engines). Each of these poses some risk of oil release and the risk rises with the amount of petroleum involved. Once oil is spilled into the ocean, environmental damage is almost certain, with potentially severe and long-lasting biological, economic, political, cultural, and/or social impacts. Against this background, the goals of oil spill management are to:

- Protect human life
- Prevent or mitigate environmental damage by
    - Keeping oil away from sensitive habitats
    - Applying cleanup techniques that enhance recovery where oil does contact sensitive habitats

Oil spills in the marine environment occur irregularly and range in size from small spills associated with in-port shipping activities to large open sea events associated with oil tanker and other cargo ship accidents and oil well blowouts. Other potential risks include oil transport by pipeline and offshore oil and gas exploration. In California:

- Offshore oil operations occur at 23 platforms in federal waters (> 5 km from shore) and nine platforms and related facilities in state waters (< 5 km), all in southern California (Figure 7.1). Federal offshore tracts produced 66,400 barrels (bbl) (11,000 m^3) of oil per day in November 2008, all of which was sent to shore by pipeline. Tracts in state waters produced 37,400 bbl (5,900 m^3) of oil per day
- The ports of Los Angeles, Long Beach, and Oakland are three of the five busiest ports in the U.S., with traffic dominated by tankers, container ships, and other large vessels. Tankers annually transport approximately 260 million bbl of crude oil and distillates (e.g., gasoline) along the California coast. Individual container ships can carry upwards of one million gallons of heavy fuel oil
- Tankers, container ships, and other vessels have been the source of the majority of oil spills in California in recent years. The quantity of each spill is usually small, with over half involving less than ten gallons and about 90% less than 100 gallons. Since the 1969 Santa Barbara spill, annual spill volumes are dominated by accidents, i.e., the 2007 *Cosco Busan* spill (53,569 gallons), the 1990 T/V American Trader spill (397,000 gallons) and the 1987 M/V *Pac Baroness* spill (339,000 gallons)were the source of 364 of the 1,099 oil spills in California in 2007. For example, in November 2007, the container ship M/V *Cosco Busan* struck the Bay Bridge in San Francisco Bay, California, releasing 58,000 gallons of fuel oil
- Spills in waterways and from offshore oil platforms are the next largest source of California spills

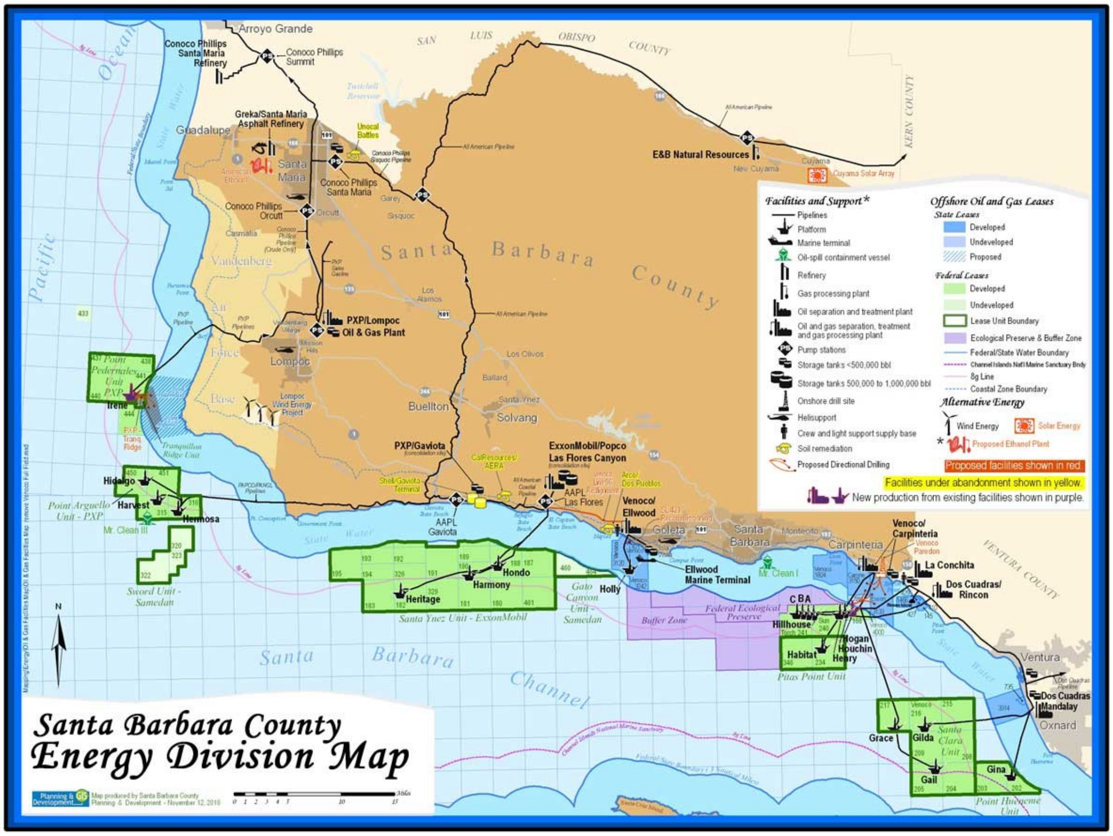


Figure 7.1. Offshore oil production and transport facilities in Santa Barbara County.

7.2 Oil spill characteristics

Spilled oil is transported, and its composition and character altered, by a variety of physical, chemical, and biological processes in the ocean. Response plans depend heavily on site-specific modeling predictions of spill behavior. Chemical dispersants change the relative importance of these processes, affecting both the fate and the subsequent ecological effects of spilled oil. It is thus important to understand the transport and fate of oil both with and without dispersant use.

7.2.1 Behavior of oil in the marine environment

Oil or petroleum products spilled on water undergo changes in physical and chemical properties that are termed "weathering" (Figure 7.2) Weathering begins immediately after oil is released into the environment and its speed varies greatly but is usually highest immediately after the release. Weathering's duration and end result depend on the properties and composition of the oil itself, characteristics of the specific spill, and environmental conditions.

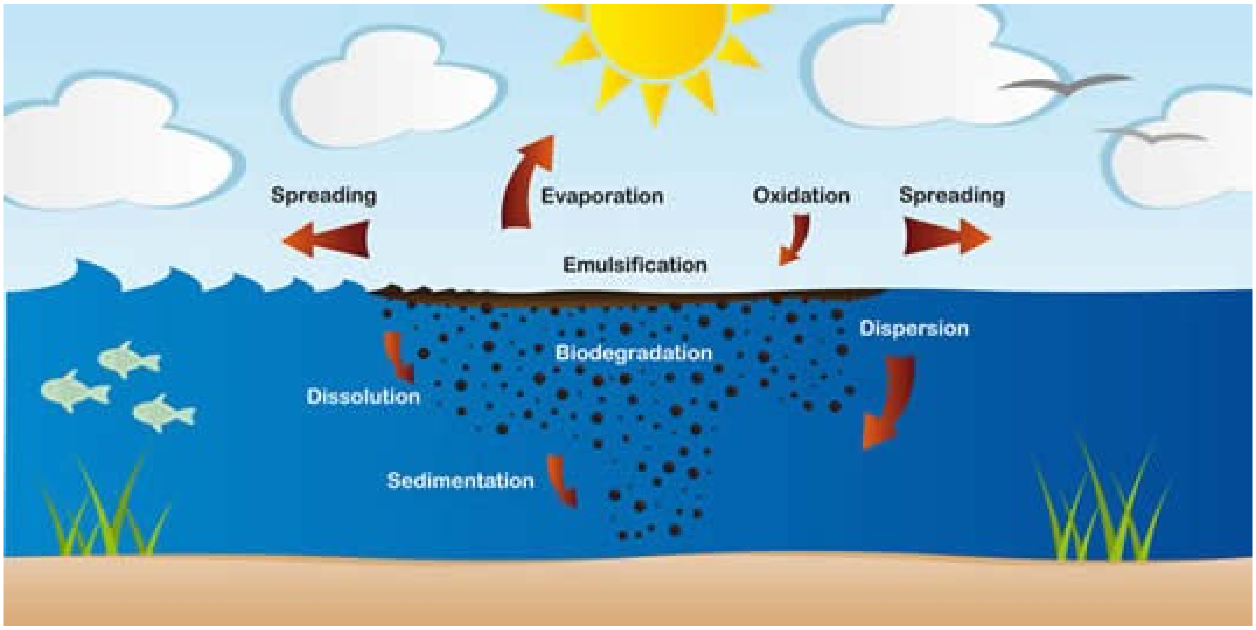


Figure 7.2. Fate of oil spilled at sea showing the main weathering processes (source: http://www.itopf.com/marine-spills/fate/weathering-process/).

Spreading. The speed at which oil spreads over the ocean surface is controlled by oil viscosity and the surface tension of water, along with temperature, surface currents and waves, tides, and wind speed. At first forming a continuous layer as thin as 1 mm or less, a slick will, after a few hours, begin to break up and, under the influence of winds, wave action and turbulence, form narrow bands parallel to the wind direction.

Evaporation. During the first several days after a spill, the lighter components of the oil will evaporate. The percentage evaporated will depend on the relative proportion of light or volatile (e.g., gasoline, kerosene, diesel oils) versus heavier (e.g., heavy fuel oil) compounds. Evaporation can increase as the oil spreads and with rougher seas, high wind speeds, and/or high temperatures.

Dispersion. Waves and rough seas can cause lighter oils to break up into droplets of varying sizes. Smaller droplets tend to remain suspended in water while larger ones will tend to rise back to the surface, where they may either coalesce with other droplets to reform a slick or spread out to form a very thin film. The addition of chemical dispersants accelerates dispersion.

Emulsification. Emulsification results from physical mixing by turbulence at the sea surface that causes sea water droplets to become suspended in the oil. Emulsification increases the pollutant volume by a factor of three or four and slows other dispersal and weathering processes. Emulsified oil can thus persist in the marine environment for more than 100 days.

Oxidation. Oils react chemically with oxygen in a process promoted by sunlight, although, even in strong sunlight, thin films of oil oxidize at no more than 0.1% per day. While the final products of this process are usually more soluble in water, it can also lead to the formation of emulsions or tarballs.

Sedimentation / sinking. In shallow waters of the coastal zone where particulates are abundant and water is subjected to intense mixing, 10 – 30% of oil spilled may adsorb onto suspended material and deposit to the bottom. In deeper areas remote from shore, sedimentation of oil (except for the heavy fractions) is an extremely slow process and can involve biosedimentation, absorption of emulsified oil by plankton and other organisms. Suspended oil and its components may undergo intense chemical decomposition and microbial degradation in the water column. However, once oil reaches the sea bottom, decomposition rates of any oil buried on the bottom abruptly drop and oxidation processes slow, especially under anaerobic conditions. Oil stranded on sandy shorelines often becomes mixed with sand and other sediments and may sink to the bottom when washed off the beach back into the sea.

Microbial degradation. The fate of most petroleum substances in the marine environment is ultimately defined by microbial transformation and degradation. The degree and rate of hydrocarbon biodegradation depend in part on their molecular structure. Microbial decomposition rates usually decrease as structural complexity and molecular weight increase. The most important environmental factors influencing hydrocarbon biodegradation include temperature, nutrient and oxygen concentrations, and the species composition and abundance of oil-degrading microorganisms. Because of the complexity of these factors and the variability of oil composition, it is extremely difficult to compare and interpret available data about the rates and degree of oil biodegradation in the marine environment.

Aggregation. Spilled oil can aggregate into petroleum lumps, tar balls, or pelagic tar and all these forms occur in the open ocean and coastal waters as well as on beaches. The chemical composition of oil aggregates varies, but its base most often includes asphaltenes (up to 50%) and high-molecular-weight compounds of oil's heavy fractions.

Combined processes. Spreading, evaporation, dispersion, emulsification, and dissolution are most important during a spill's early stages. Oxidation, sedimentation, and biodegradation are more important over time and determine spilled oil's ultimate fate. Simple models, based on oil type, have been developed to predict changes in oil over time. Although these models are not precise, they can provide clues about whether the oil is likely to dissipate naturally or whether it will reach the shoreline. This information can be used by spill responders to decide upon the most effective spill response techniques and whether such techniques can be initiated quickly enough to be effective.

7.2.2 Oil spill dispersants

Natural dispersion cannot be relied upon to disperse most oil spills, especially as oil weathers, its viscosity increases, and the rate of natural dispersion is greatly reduced. Dispersion can be enhanced with chemical dispersants, with the goal of transferring oil from the water surface into the water column by generating larger numbers of small oil droplets. These smaller droplets are more likely to remain suspended in the water column, rather than combining into larger droplets that would float back to the water surface and reform into surface slicks.

Evaluating the environmental trade-offs associated with dispersant use is one of the most difficult decisions oil spill responders and natural resources managers face during a spill. Rather than reducing the amount of oil entering the environment, dispersants change the chemical and physical properties of oil, which changes its transport, fate, and potential effects. Dispersants reduce the potential that a surface slick will contaminate shoreline habitats or come into contact with birds, marine mammals, or other wildlife at the surface or on the shore. On the other hand, dispersants increase the potential exposure of water-column and benthic species to spilled oil. Decisions to use dispersants therefore involve complex trade-offs which involve consideration of the type of oil spilled, the volume of the spill, sea state and weather, water depth, degree of turbulence, and at-risk habitats and species.

7.2.3 Environmental impacts of oil spills

The effects of petroleum hydrocarbons in the marine environment can be either acute or chronic. Acute toxicity is the immediate short-term effect of a single exposure to the oil. Chronic toxicity is either the effects of long-term and continuous exposure to oil or the long-term sublethal effects of acute exposure. Ecological effects of oil are a function of factors such as oil type, release rates, fate processes, and distribution of biological resources. It is difficult to generalize impacts on marine resources because of the wide range of exposure pathways and species sensitivity. Oil can kill marine organisms or reduce their fitness through sublethal effects. Spills also can damage the structure and function of marine communities and ecosystems.

Coastal managers must assess the potential damage at the level of individuals, populations, and communities within the complex spatial and temporal extent of the spill. Determining impacts' significance may be more important than determining their spatial extent and persistence. For example, damage to a large area is more significant than damage to a small area of similar habitat. However, if the small area contains a highly valued resource, damage can be of greater significance than damage to a much larger area that may have less of these valued resources.

The observational framework for quantifying impacts involves determining differences based on sets of observations at impacted and non-impacted areas, or at one or a series of sites where before-and-after impact observations can be made.

7.3 Oil spill management and decision framework

The lead state agency charged with marine oil spill prevention and preparedness, response, and natural resource restoration in California is the Office of Spill Prevention and Response (OSPR) in CDFG. OSPR is the only state agency in the U.S. with combined regulatory, law enforcement, pollution response, and public trust authority in coastal waters. Funding for OSPR's spill-related activities is provided by the Oil Spill Administration Fund (OSPAF). In addition to OSPR, key roles are filled by:

- SLC, which adopts rules and regulations for marine terminals to minimize the possibilities of an oil discharge. Following a spill, the SLC assists OSPR in determining the cause and amount of the spill and examining the effectiveness of regulations and spill prevention programs
- CCC, which participates in efforts to improve oil spill prevention and response; reviews and comments on oil spill related regulations and contingency plans; and consults on the design, planning, and operation of wildlife rehabilitation facilities
- SWRCB and its nine Regional Water Quality Control Boards, which provide CDFG with technical assistance on water quality impacts and set sediment cleanup limits at spill sites

Twenty-two state agencies (Table 7.1) share some responsibilities for oil spill prevention and response. The State Interagency Oil Spill Committee (SIOSC), chaired by the OSPR Administrator, with co-chairs from SLC and CCC, provides liaison among these agencies, federal and local agencies, and public and private organizations engaged in oil pollution prevention and control. SIOSC coordinates day-to-day procedures, prepares and updates the California Oil Spill Contingency Plan, and provides guidance and state input to the Regional Response Team, the Federal on Scene Coordinator, and the State Agency Coordinator in an oil spill emergency. At the local level, Harbor Safety Committees at five major ports develop safety plans to reduce spill risk in and around ports.

At the federal level, the U.S. National Response Team (NRT) is activated when an oil spill exceeds the response capability in the region where it occurs; happens in more than one region; or involves a substantial threat to the public health or welfare of the U.S, the environment, or substantial amounts of property. The NRT includes 16 Federal departments and agencies; its actions are guided primarily by the National Oil and Hazardous Substances Pollution Contingency Plan. In California, the key agencies for oil spill preparedness and response include the US Coast Guard 11th District; NOAA and in particular, the Office of Response and Restoration (OR&R), U.S.EPA, BOEMRE, and the USFWS.

Table 7.1 State agency members of SIOSC.

- Office of Emergency Services
- State Lands Commission
- State Water Resources Control Board
- Department of Justice
- California Highway Patrol
- California National Guard
- Department of Conservation (Division of Oil & Gas)
- Department of Fish and Game
- Department of Transportation
- Department of Health Services
- Bay Conservation and Development Commission
- Department of Parks and Recreation
- Department of Water Resources
- Department of Forestry
- State Fire Marshal
- Regional Water Boards
- California Resources Agency
- California Office of Environmental Affairs
- California Conservation Corps
- Department of Agriculture
- California Coastal Commission
- Office of Environmental Health Hazard Assessment

7.3.1 Oil spill preparedness

California's Oil Spill Contingency Plan, created by OSPR in 2003, reflects pre-planning at different levels of risk and addresses sensitive resources, priorities for protection and cleanup, logistics appropriate to local and seasonal conditions, storage and disposal options, and command and control. The overall plan includes area contingency plans (ACP) that include specific local information and integrate and coordinate participants' response at manageable regional scales. California's two agencies with Coastal Zone Management ACT (CZMA) review authority, the CCC and the San Francisco Bay Conservation and Development Commission (BCDC), help ensure that the ACPs are consistent with California's coastal zone policies. California has also used the Net Environmental Benefit Analysis (NEBA) approach (Schallier et al. 2004) to assist in selecting the spill response option(s) with the lowest overall negative impact on the environment. For example, NEBAs helped designate pre-approval zones for dispersant use in federal waters.

7.3.2 Oil spill response

In California, the Incident Command System (ICS) (Figure 7.3) is the required structure for organizing spill response efforts. The ICS integrates policies, procedures, personnel, facilities, communications, and equipment into a common organizational structure. It is managed by the Unified Command (UC), which, for oil spills in California's coastal zone, includes a designated official of the US Coast Guard (USCG), OSPR, and the Responsible Party (oil spiller). The UC makes all decisions on oil spill incident operations and the On-Scene Coordinator, usually an OSPR warden for California, directs and coordinates all efforts at the scene. Each UC member has its own scientific experts. In cases where the USCG provides the Federal On-Scene Coordinator, the National Contingency Plan specifies that the Scientific Support Coordinator be a representative of the NOAA NOS Office of Response and Restoration, Emergency Response Division. These designated responsibilities and relationships play an important role in decisions about the use of OOS assets in spill planning and response.

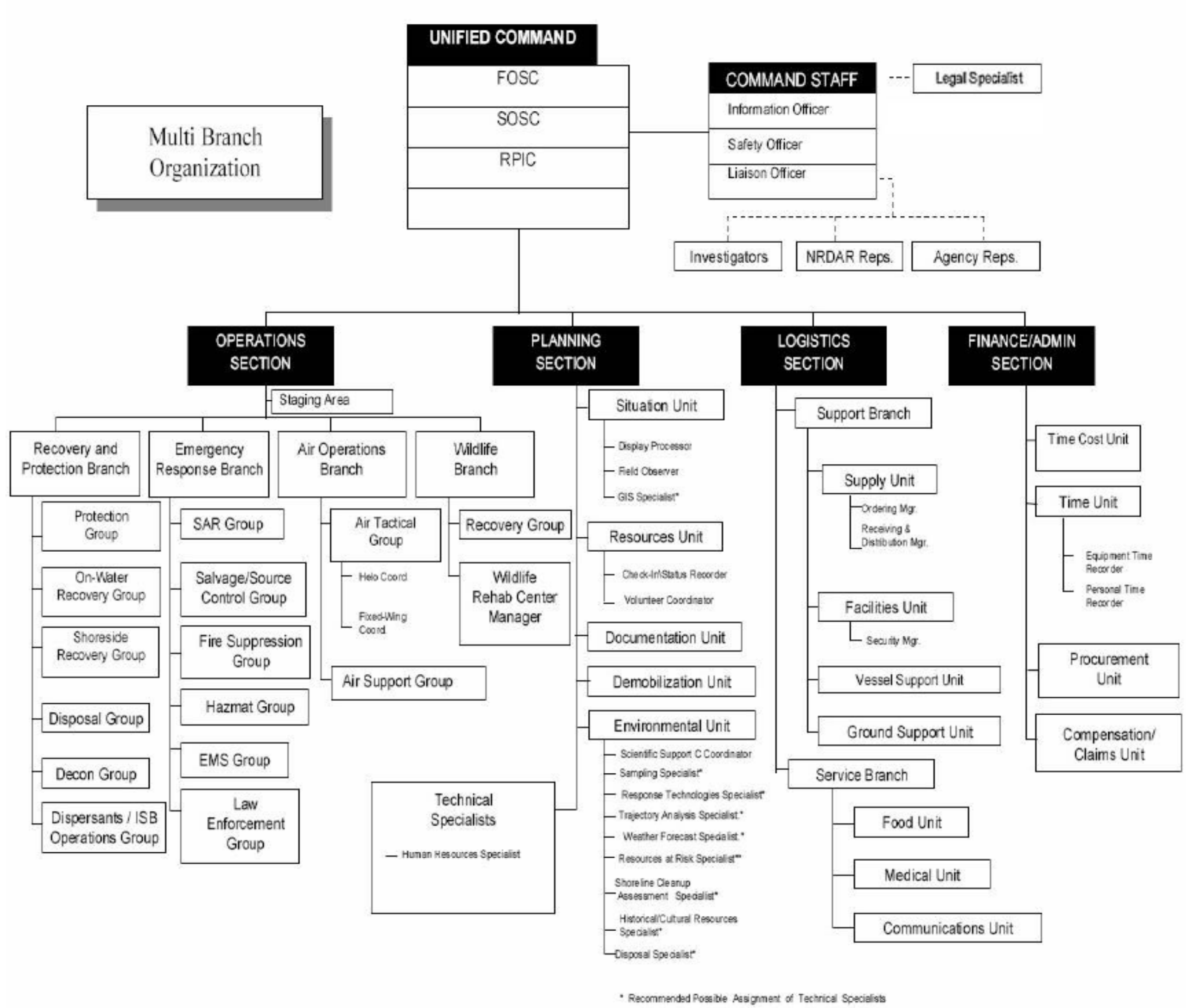


Figure 7.3. Incident Command System for oil spills (source: OSPR 2010).

7.3.3 Damage Assessment

The Natural Resources Damage Assessment (NRDA) process, authorized by the Oil Pollution Act of 1990 (OPA), allows affected states and the federal government to determine levels of harm and appropriate remedies. As the trustee for California, OSPR would manage the NRDA assessment to address California's interests through the process's three phases:

- Preassessment, to evaluate the extent, severity, and duration of impacts from the oil spill
- Restoration planning, to determine the appropriate type and scale of restoration actions, based on the determination of damage
- Restoration implementation, which includes not only conducting corrective action, but also monitoring activities

7.4 Oil spill information needs

There are five key questions that structure the information needed for decision making about oil spill planning, response, and damage assessment:

- What got spilled?
- Where will it go?
- What will it hit?
- How will it hurt?
- What can be done about it?

Table A.2.9 provides a detailed overview of the specific management questions and ocean information and OOS products and product needs in each of these decision categories. Table A.2.10 then matches these decisions and information needs with a more detailed description of current observing system capabilities and gaps. The important outcome of this process is the definition (in the right-hand columns of Table A.2.10) of key existing observing system assets and gaps needed to fulfill the information requirements for each management decision and/or question.

For operational decision making during active spill response, data needs include the nature of the spilled oil and its weathering over time, local environmental conditions, spill trajectory, assessment of the impact on natural resources, and selection of the most effective clean up technologies. These data and information needs can be grouped into basic observations and the models used to assimilate and integrate those data into usable information products. Figure 7.4 illustrates the data inputs and model outputs fundamental to these decisions and capabilities.

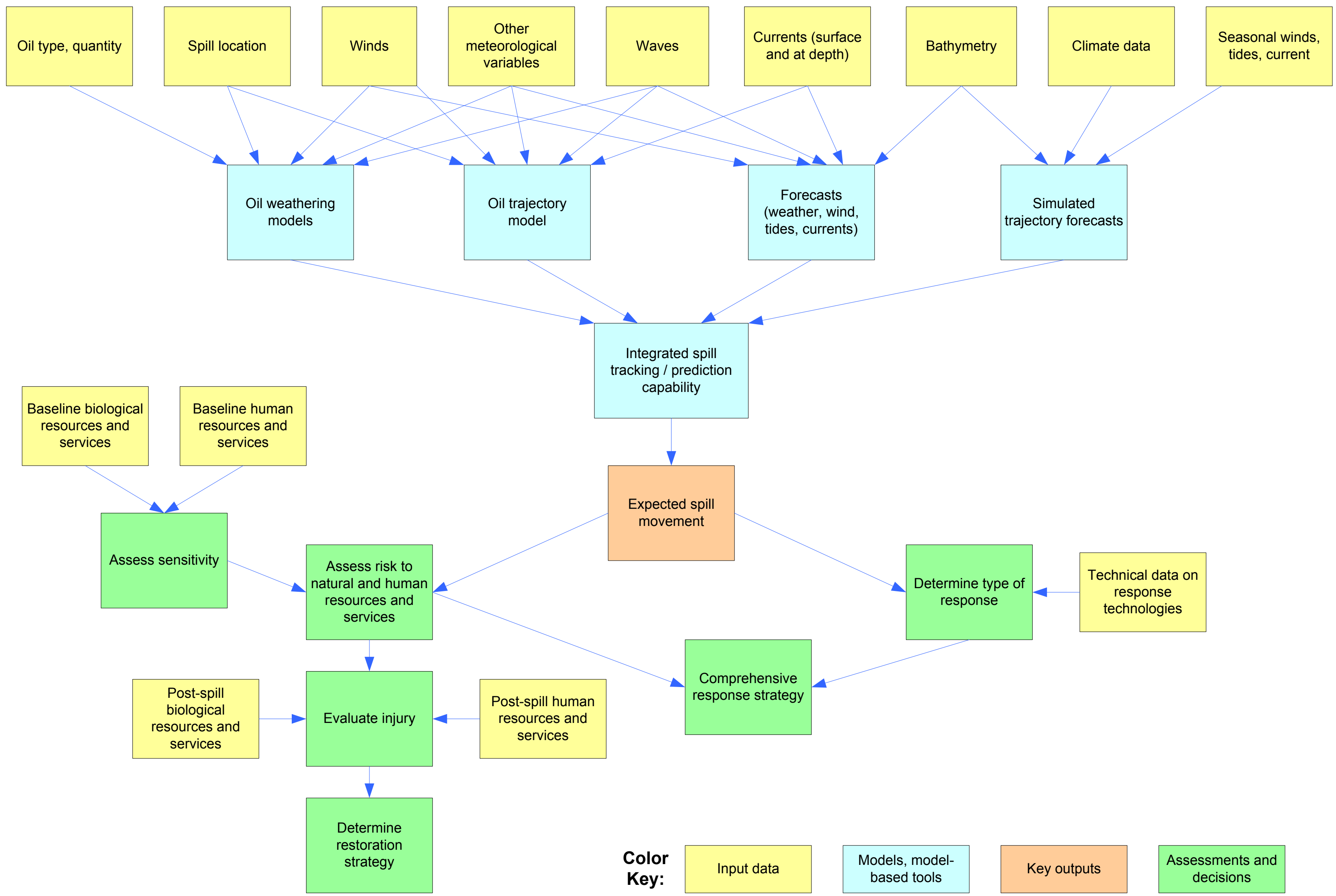


Figure 7.4. A schematic illustration of how ocean data, models, and tools can inform key aspects of decision making related to oil spills. Note that multiple decisions flow from one primary information output.

7.4.1 Observations

Oil characterization. Predicting spill behavior and impacts and choosing response methods depend on timely information about the characteristics of the spilled oil. NOAA's OR&R maintains the ADIOS2 (Automated Data Inquiry for Oil Spills) database, which includes estimates of the physical properties of different types of oils and products. These data are used in the ADIOS2 oil weathering model (see below) which provides quick estimates of changes in spilled oil's properties.

Spill characterization. Spill response managers must direct sampling efforts and validate or calibrate models used to predict spilled oil's behavior and fate. Needed information includes the location of the spill, environmental conditions at the spill site (e.g., wind, currents, sea state), and the dimensions and drift of the oil slick.

A variety of observing technologies are available for reconnaissance to determine spill location and the extent of contamination. Visual observations from the air are the simplest and most common method, but are limited to favorable sea and atmospheric conditions and cannot be used in rain, fog, or darkness. Remote sensing from aircraft to detect surface oil includes infrared (IR) video and photography, thermal infrared imaging, airborne laser fluorosensors, optical sensors, and synthetic aperture radar (SAR). SAR sensors can provide data under poor weather conditions and during darkness. Optical and SAR sensors can also be deployed from satellites, although the operational use of satellites for spill response is limited by low spatial resolution, slow revisit times, and delays in receiving processed images.

Spill characterization also requires real-time data on current profiles (surface to bottom), wave energy, and meteorological conditions, especially wind intensity and direction. Monitoring submerged oil requires data on suspended sediment concentrations, detailed bathymetry, seafloor sediment characteristics, and sediment transport patterns and rates. A complete and detailed inventory of OOS capabilities and assets is provided in the OSPR 2010 Best Available Technology Prevention/Mitigation Focus Group Report (OSPR 2010). Key OOS capabilities and assets listed include (

- NOAA NOS Physical Oceanographic Real Time System (PORTS®)
- Coastal Data Information Program (CDIP)
- The California Coastal Ocean Currents Monitoring Program (COCMP) (HF radar)
- Buoys, shore stations, and satellites for measuring winds.
- Acoustic doppler current profilers and autonomous underwater vehicles for measuring underwater currents

PORTS® is operational in Los Angeles-Long Beach Harbor and San Francisco Bay and provides real-time water levels, currents, salinity, water temperature, and meteorological parameters, including winds, atmospheric pressure, and air temperature. Tidal measurements from NOAA National Water Level Observation Network (NWLON) stations were a key component of the trajectory forecasts of the M/V *Cosco Busan* oil spill in San Francisco Bay in November 2007.

The CDIP buoy network provides near real-time wave observations and forecasts. Forecasts of wave heights are critical for predicting spill trajectories. CDIP is operated by the Ocean Engineering Research Group (OERG), part of the Integrative Oceanography Division (IOD) at Scripps Institution of Oceanography (SIO). There are 24 stations currently operational in California. Observation-based products include real-time predictions of regional swell heights and combined sea-and-swell conditions near harbors. Five-day swell forecasts are also available (http://cdip.ucsd.edu).

COCMP, the statewide network of 54 HF radar sites, was initiated in 2002 through voter approved funding. Harlen et al (2010) provides an overview of the fundamentals of HF radar operation and applications. Briefly, HF radars provide a means for mapping fields of surface current speed and direction by using by measuring the Doppler shift between a transmitted radio signal and its return signal reflected off of ocean waves. COCMP employs the CODAR system, which is a direction finding HF-radar that uses a single transmit antenna and a single receive antenna. Each COCMP site can measure currents from just beyond the surf zone out to 150 kilometers offshore. Real-time surface wave and current maps can be incorporated with OSPR's integrated on-scene GIS products to assist in predicting spill trajectories and developing response strategies.

Sources of real-time wind measurements include NOAA NDBC weather buoys, shore-based weather station networks operated by numerous agencies, and Synthetic Aperture Radar (SAR) imagery. SAR images have been acquired over the oceans on a continuous basis for nearly 20 years. Their high resolution and large spatial coverage make them a valuable tool for measuring ocean surface winds, and are now believed to be accurate within a 2-3 m/s in the wind speed range 0-20 m/s. However, the overpass schedule of the satellite limits the use of SAR for measuring rapid changes in wind speed and direction.

Measuring underwater currents is critical to understanding the fate of oil from a spill. Current speed and direction at various depths are obtained with Acoustic Doppler Current Profilers (ADCPs), which can be mounted on the ocean floor or on a surface buoy. Autonomous underwater vehicles (AUVs) and gliders represent an advanced IOOS capability with a great deal of potential application to monitor oil spills. AUVs are fast, highly maneuverable vehicles driven by propellers and steered with moveable fins. Gliders are a type of AUV that uses small changes in its buoyancy in conjunction with wings to move throughout the water column without propellers. They were used extensively during the BP Oil Spill Response to locate and track oil at various levels in the water column, as well as on the water's surface. In addition to sensing oil in the water, AUVs also can be equipped with sensors to collect data on temperature, salinity, currents, and density that can help predict transport of subsurface oil.

Damage assessment. Data needs for an NRDA include the extent of shoreline oiling and the degree of oiling for each habitat type, e.g., intertidal, near-shore subtidal, and shoreline (marshes, mudflats, beaches), and the distribution of wildlife strandings (marine mammals, birds, fish, and shellfish), and any human recreational impacts.

7.4.2 Models

Model simulations of spill transport, fate, and biological effects are useful for risk assessment, contingency planning, response, and NRDAs. Models may be applied to investigate a single spill event, to evaluate the probable consequences of a hypothetical spill, or to determine impacts of a worst-case spill scenario. There are two types of oil spill models:

- Stochastic models, which are probability models for response planning, risk assessment, and environmental impact assessments
- Deterministic models, which provide oil spill trajectory and fate predictions for actual spills or exercises

The two types of models differ not only in purpose but in their data requirements and timeframes. Stochastic models use large amounts of historical data and produce output intended to support decision making during preplanning efforts. Deterministic models are typically used to meet immediate oil spill response needs, produce outputs in hours, and may be rerun many times as the spill progresses.

One stochastic model is NOAA's Trajectory Analysis Planner (TAP II), which helps assess potential threats of possible spills in a given region by estimating probabilities of oil reaching specific sensitive areas in a particular timeframe. TAP II is available for San Francisco and San Diego Bays but cannot be used in the event of an actual spill because real world conditions may not be well represented in the background statistics.

A number of deterministic models are available to guide response to actual spills. However, the operational use of these models is challenging because it requires the timely acquisition of numerous input parameters and the availability of high quality forecast data, specifically for winds and currents. Such data may need to be refreshed frequently because oil can move quickly and cover large areas.

The initial products provided by NOAA OR&R to help guide oil spill response include:

- Weather forecasts
- Tide, wave, and current forecasts
- Oil fate information
- Initial trajectory report (NOAA OR&R, 2002)

Weather forecasts are obtained twice a day from the National Weather Service Forecast Office responsible for the spill area and provided by OR&R to ensure that the forecast used for trajectories and field operations are consistent. An in-house tide model based on the National Ocean Service tide tables provides forecast tide heights and currents. Predictions of oil fate are generated by the NOAA ADIOS2 model, which includes components to estimate the effects of common cleanup techniques and environmental processes such as sedimentation. The initial trajectory report uses this information to provide an estimate of the time scale of the spill, how far it can be expected to move, and which areas are threatened downcurrent and downwind.

If the initial trajectory report indicates that the oil will be a threat to resources over a time span of 24 hours or more, then NOAA's General Operational Modeling Environment (GNOME), a 2-dimensional trajectory model, is set up and run. The core idea of an oil spill trajectory model is relatively straightforward; given the local atmospheric forcing, ocean currents, oil properties and spill location, integrate the currents forward in time to predict the future locations of the oil. GNOME employs a combination of the two accepted methods for modeling the movement of an oil spill on water: Eulerian and Langrangian. The latter method also can track oil weathering. GNOME is structured to accept inputs from a variety of data sources and models. GNOME's outputs consist of digital maps and 2-dimensional visualizations, including a "best guess" trajectory indicating the most likely movement path of the spill with concentric zones of low, medium, and high surface oil density, along with a contour representing a 90 percent confidence boundary. After making a GNOME trajectory forecast, NOAA usually gathers information on the actual movement and positions of the oil from overflights and other filed observations. These observations are used to recalibrate the GNOME output, and an updated trajectory can be generated after reinitializing the oil distribution to the field observations. This forecast/observation/hindcast mode is then repeated on a 12- to 24- hr cycle for as long as necessary.

GNOME estimates trajectories using a combination of information on ocean winds, currents, tides, and oil characteristics. Accurate modeling of surface currents depends greatly on the effective description of the wind, which is variable in space and time. In the past, the standard approach was to use observed wind statistics and stochastic methods to generate multiple wind field scenarios. GNOME can use wind information from a time series of observations at a point. However, due to the sparseness of offshore wind data, modeled winds are commonly used to derive ocean currents.

Ocean currents can be obtained either by direct measurement or from models. In the past, it was difficult to get current measurements at more than a few points, and the high variability of currents in space and time made the use of direct measurement impractical for tracking the oil for extended periods. One exception is the use of HF radar systems, which can measure surface currents over large areas. While short-term current forecasts based on statistics of recently measured currents and estimated tidal currents may be generated from the HF radar measured currents, atmospheric models would be needed to forecast future wind-driven currents to generate prospective spill trajectories several days into the future. In scenarios where surface currents depend on more than just wind and tidal forcing, or where subsurface current predictions are also needed, full hydrodynamic models with appropriate forcing and inputs would be needed to produce currents for trajectory models.

The GNOME modeling framework requires ocean surface current data in a particular version of the NetCDF file format. Garfield et al (2009) worked closely with NOAA OR&R to create and test a tailored NetCDF file format for importing HF radar-derived surface current mapping data into GNOME. Each NetCDF file had a 72- hr time series of surface currents created from 1) hourly data for the past 48 hours and 2) a 24-hr forecast based on the mean currents and tidal currents calculated over the recent past measurements.

Another challenge in applying HF data for operational oil spill tracking is the need to fill gaps in the data sets, both in space and time. Because the behavior of GNOME, such data gaps are treated as zero velocity locations, which would cause computed trajectories to erroneously stop at those locations. This issue can be solved by applying and validating current estimation interpolation techniques to fill the gaps, such as Open Modal Analysis (Kaplan and Lekien, 2007) or Optimal Interpolation (Kim et al., 2008).

Trajectory models of surface and subsurface slicks cannot evaluate the extent of biological impacts. Applying information on estimated spill size and spill probability to potential biological impacts is difficult because of the many factors involved, e.g., type, rate, and volume of oil spilled, oceanographic conditions; quantity of submerged oil, composition of the oil at the time of shoreline or habitat contact; and toxicity. The greatest uncertainty in modeling biological impacts is the estimation of the probability of an animal being oiled and dying as a result. Oils contain a complex mixture of thousands of hydrocarbons that undergo varying weathering processes and have differential fates, and it is not practical to track the fate of individual compounds that are toxic to organisms. Once mortality is estimated, population modeling of biological impacts is well developed. The primary limitation on population modeling is the availability of data for estimating population parameters.

7.5 Oil spill institutional issues

While the technical aspects of dealing with an oil spill are clearly important, the effectiveness of spill response ultimately depends on involved organizations' ability to organize and implement the various aspects of the response. This is complicated by the necessity for integrating data inputs and analysis outputs from multiple sources and for negotiating compromises among different organizational missions in a complex and dynamic decision environment. Achieving and maintaining this ability requires leadership by an experienced regulatory agency with adequate funding and the capacity to coordinate multiple participants. However, OSPR, the lead agency for California, is facing increased budget shortfalls due to a depleted OSPAF. Recent budget projections from the California Department of Finance indicate that the OSPAF will be deficient $2.3 million for 2011-12, $11 million for 2012-13, and $18 million for 2013-14, which will most likely lead to cuts in OSPR's programs (AB 1112 Bill Analysis, May 27, 2011).

Each member of the UC has their own scientific experts; OSPR does not model or project oil spill trajectories and defers to NOAA for such modeling. External, local data on the nature and extent of the spill is frequently integrated into GNOME runs as it becomes available to NOAA &R spill trajectory analysts. Near real-time ocean currents data are critical to trajectory forecasts, and California's network of HF radars offers a significant asset for oil spill response. HF radar data allows inclusion of the spatial current variability in the track computation with a high temporal resolution. This is particularly important for California's coast where the currents exhibit a large spatial variation imposed by tides, winds, large scale circulation, and topography. However, although HF radar technology has been used for ocean surface current measurements for over 30 years and NOAA has no formal restrictions on the use of HF radar data products in the GNOME trajectory model, it was not until the Safe Seas 2006 Oil Spill Response Exercise in the San Francisco Bay area that HF radar data were directly accessed for GNOME. While this exercise provided a foundation for the acceptance of HF radar data as input to GNOME by NOAA's oil spill trajectory modelers, Garfield and colleagues (2008) believe routine adoption of HF radar data in response protocols will depend on HF radar being available nationally with adequate coverage and sustained operational support for this application.

7.6 Oil spill recommendations

At a minimum, we recommend maintaining OSPR's unique capabilities for oil spill prevention, response, and restoration capabilities, as well as the existing network of OOS assets that provide needed data inputs to the spill tracking and forecasting tools needed to manage the immediate spill response. We also recommend enhancing California's ability to determine impacts and track recovery by expanding monitoring in selected regions with a greater risk of oil spills and/or impacts (e.g., ASBS areas). The Deepwater Horizon oil spill in the Gulf of Mexico highlighted significant gaps in understanding of the behavior of subsurface plumes and the ability to track and forecast their movement. California should coordinate and leverage its funding decisions with all key federal stakeholders (NOAA, BOEMRE, USCG, USGS) as well as industry on research and development targeted at more effective autonomous methods for subsurface sensing and tracking of undersea oil spill plumes, multi-dimensional spill modeling, updated environmental sensitivity indices, and oil toxicity on key species. Further, we recommend that California address the need for an oil spill biological effects model for use in both risk and NRDA assessments. The model should consider acute and chronic exposure, direct impacts, sublethal effects (e.g., reduced growth or reproductive success), and population and ecosystem effects.

We recommend that OPC initiate an effort to improve the use of remote sensing data, particularly HF radar data, in trajectory modeling. OPC should facilitate activities among NOAA OR&R, OSPR, and COCMP researchers to promote the routine use of HF radar data and products directly in GNOME. This should begin with discussions to identify, articulate, and summarize the requirements related to this potential GNOME enhancement. These requirements should then be validated to ensure that they match GNOME user needs, and test runs performed to conduct a systematic verification/validation using simulations and field studies with quantifiable metrics.

8.0 OOS Assets Needed For Multiple Management Areas

Overview – Several OOS assets provide essential information for multiple management areas and strengthening and maintaining their operational status will be critical for improving OOS' relevance and applicability to the five management areas. In addition, several technical recommendations cut across multiple management areas and are equally critical for improving OOS' broader relevance and applicability. We recommend that the state work with the RAs and other partners to:

Develop a long-term commitment to modeling efforts – Three dimensional circulation models such as ROMS and ecological NPZ models of biological productivity are funded by a fragmented set of grants managed through an informal set of arrangements. We recommend more reliable state funding that would provide significant dividends because of the broad applicability of these modeling tools. We also recommend creation of a more stable, long-term operational capability that is less dependent on the continued involvement of a few critical individuals.

Link nearshore and offshore circulation models – Models of circulation in nearshore and offshore zones are distinct and rely on different data inputs. In addition, nearshore circulation models suffer from data gaps that hamper their development and application. Many applications, such as discharge plume and spill tracking, rely on the ability to link these separate models as water moves back and forth between the two zones. We recommend that nearshore and offshore models be functionally linked and that key data gaps be filled.

Rigorously evaluate HF radar applications – HF radar provides data that are useful in many management applications, although its more widespread use has been limited by a number of technical and institutional constraints. We recommend a one-to-two-year rigorous evaluation of HF radar's applicability to specific management decisions, an effort that should include focused efforts to identify and then resolve or validate these constraints. In addition, state funding agencies should develop realistic expectations about HF radar's applicability, based on more complete understanding of the technology's strengths and limitations.

Integrate diverse (biological, chemical, and physical) data and products – OOS and the RAs are perceived as focusing primarily on physical and chemical data. Biological data are not well integrated with physical and chemical data, limiting the ability to conduct more comprehensive analyses. In addition, biological sampling tools are only beginning to utilize methods that permit collection of continuous data on finer spatial and temporal scales. We recommend the state promote enhanced data access and integration tools, improved sampling methods, and training of state managers and scientists in OOS tools. The RAs could play a key role in all three efforts.

NOTE: Please see Appendix 2, Tables A2.11a and A2.11b, for the detailed analysis of decision information needs and OOS capabilities on which the following discussion is based.

The preceding chapters identified OOS assets that could help fill management information needs related to water quality, salmon recovery, renewable ocean energy, harmful algal blooms, and oil spills. Table A.2.11 lists these assets, their applicability to specific issues and product needs, and describes basic technical characteristics such as measured variables and spatial and temporal coverage and resolution. Table A.2.11 also shows that many OOS assets contribute to more than one of the SCOOP management areas. These key OOS assets are currently funded by a variety of federal, state, and private sources, and strengthening and maintaining their operational status will be critical for improving OOS' relevance and applicability to the five management areas. In addition, several technical recommendations cut across multiple management areas and are critical to improving OOS' relevance and utility. We recommend that California work with the RAs and other partners to:

- Develop a long-term commitment to existing modeling efforts
- Link nearshore and offshore circulation models
- Rigorously evaluate HF radar applications
- Integrate diverse (biological, chemical, and physical) data and products

8.1 Develop a long-term commitment to existing modeling efforts

There are two types of models that produce key inputs to decision-making capabilities for several management areas, but that are currently supported by an insecure mix of funding sources and staffing policies. Resolving these problems will require sustained funding, a 24/7 operational infrastructure, and a long-term staffing policy.

Multi-dimensional circulation models, such as the ROMS, are an important component of modeling efforts for all five management areas and were also used in planning California's network of marine protected areas. They create retrospective and real-time analyses, as well as forecasts of ocean currents, temperature, and salinity by integrating into a numerical model data inputs (e.g., temperature, currents, winds) obtained from OOS platforms such as satellites, gliders, moorings, and HF radar antennae (Table A.2.11).

Ecosystem Nutrient-Phytoplankton-Zooplankton models describe processes related to primary and secondary productivity and can be expanded to include higher trophic levels such as fish. When linked to multi-dimensional circulation models, they provide coupled physical / biogeochemical / ecosystem models used to investigate relationships among ocean conditions, biological responses to ocean condition, and ecosystem behavior. Further refinement of such linked models would significantly improve predictions related to salmon recovery and HABs.

Development and application of these models in California is currently funded by a varying and fragmented set of grants from federal, state, and private sources. This approach limits models' sustainability and accessibility to users, thus slowing the development of targeted applications. We recommend a sustained, long-term effort to develop a fully operational, linked circulation and NPZ model for California, one that does not rely on new individual grants from disparate sources each year. An investment of approximately $200,000 per year would provide significant returns because these modeling tools are a core component of many other product needs. This cost is an estimate for providing operational stability and continuity for the existing models.

We recommend that California, federal agencies and the RAs partner to develop a stable funding mechanism for these models, for example as has successfully been done with CDIP. This funding would enable partners to derive a much greater return on investments in the array of OOS assets that provide inputs to the models. In addition, these partners should investigate options for implementing a sustainable, long-term, 24/7 operational setting for these models. The existing ROMS and NPZ models are critically dependent on a few key individuals and they lack both the surrounding infrastructure and a long-term succession plan for eventual operations without these individuals. Any consideration of potential operational settings should recognize that the academic settings where these models may be developed may not be ideal for supporting high reliability, long-term, 24/7 operations.

8.2 Link nearshore and offshore circulation models

Successfully predicting and tracking discharge plumes, distribution of young salmon entering the ocean, impacts of renewable energy devices, and oil spills depends on understanding nearshore circulation patterns and their linkages to offshore circulation. However, the linkage between nearshore[12] and offshore circulation models has not been fully developed. We therefore recommend a targeted effort to develop a linked set of nearshore and offshore circulation models at key locations along the coast.

Presently, circulation in nearshore and offshore regimes is simulated with distinct models that use different sets of data inputs and different physics. Nearshore models have data (e.g., high spatial resolution bathymetry) and validation (e.g., at small spatial scales) requirements that can be both challenging and costly to fulfill. As a result, no nearshore circulation models are being run routinely for management use throughout California. However, several nearshore modeling and monitoring efforts have been undertaken for research or to address short-term and/or site-specific management questions.

The linkages between nearshore and offshore circulation models (e.g. ROMS), which generally operate in depths greater than about 10 m, are not as well developed as the models separately, although some progress has been made at linking them (http://tinyurl.com/6jovy6g, Warner et al. 2008). Thus, there is no routine capability, for example, to track discharge plumes or spills as they move offshore or into the nearshore zone, nor to predict the distribution of young salmon as they enter the ocean and pass through the nearshore zone.

We therefore recommend that the state evaluate the existing capabilities of nearshore circulation models and their linkages to offshore circulation models to identify specific requirements for meeting state needs. State agencies should help guide and inform development of these linked models at priority locations along the coast, building on the specific management decisions and product needs identified in Tables A.2.1 – A.2.10.

8.3 Rigorously evaluate HF radar applications

California has made significant investments in the application of HF radar technology to measure surface currents and is evaluating options for future funding and development of this capability. While HF radar data are used in a number of applications, they have not been used as widely as possible due to a number of technical and institutional constraints. We therefore recommend a short (one to two years) period of additional funding during which the technology's utility would be more rigorously evaluated. We also recommend that state funding agencies become more familiar with the technology's capabilities and limitations, as a basis for developing realistic expectations about HF radar's utility.

Surface currents measured by HF radar are used to support decision making in several of the issues we examined. For example, they are used to track discharges in southern California, as an informal data source in oil spill response, and are assimilated into ROMS models to improve their accuracy for a number of other uses. However, significant gaps remain in the full application of HF radar current measurements to management areas, including oil spill response, salmon forecasting efforts, and tracking discharge plumes in diverse locations. While California's initial focus on achieving a fully operational system has been successful, many managers remain unaware of the technology, its current uses, and its potential application to a broad range of management decisions.

We recommend California provide one to two years of additional funding to enable a rigorous evaluation of HF radar's utility, based on clear goals and metrics of success related to specific, high-priority

[12] Nearshore circulation models as used here are also commonly called surfzone models.

management decisions (e.g., discharge plume tracking, oil spill response). This evaluation should be accompanied by an initial, concerted effort to more fully identify and then either resolve or validate impediments that have limited HF radar's acceptance and application. For example, we recommend a professionally facilitated workshop with oil spill modelers and responders to identify and address barriers to the full and routine official use by federal and state agencies of HF radar-measured currents in spill nowcasts and forecasts. Another workshop should bring together salmon managers, biologists, and modelers, while a third would convene discharge agencies, water quality regulators, and modelers.

We also recommend that state funding agencies develop realistic expectations about HF radar's utility, based on a more complete understanding of the technology's strengths and limitations. High frequency radar can provide continuous observations of surface currents over a large spatial area, and can inform estimates of circulation close to shore to the extent that the larger scale circulation drives the flow nearshore. However, HF radar cannot be used to make direct current measurements very close to shore. Most HF radar antennae installations in central and northern California are medium- or long-range, providing spatial resolution on the scale of 2 – 3 or six km, respectively. High frequency radar installations in southern California provide resolution of 1 – 1.5 km and short range systems with 0.4 km resolution are installed around San Francisco Bay. Because the system cannot produce reliable current estimates from any cell that includes land, the spatial resolution limits how close to shore current measurements can be made. In addition, because the system functions by combining measurements from two or more antennae, no, or only poor, current estimates are produced near long, straight segments of coastline. However, where high resolution antennae are installed around curved coastlines, such as in San Francisco and Monterey Bays, or on the mainland and offshore islands, such as in the Southern California Bight, HF radar can provide current measurements within a kilometer or so of shore. Understanding the strengths and limitations of the technology will be important in establishing a realistic set of expectations to support decisions about the role of HF radar in meeting a range of statewide management needs.

These three elements (evaluate utility; identify, where possible, resolve impediments to full use of the data; develop realistic expectations) should be combined at the end of the one to two year funding period as the basis for an independent review to assess 1) whether HF radar can adequately meet management needs, and 2) whether the system should be supported by ongoing, sustained funding. This final assessment should also consider whether potential savings could be obtained by omitting stations on California's north coast if available funding is not sufficient to operate the system statewide.

8.4 Integrate diverse information and products

OOS and the RAs are still viewed by many as primarily focused on physical and chemical oceanographic variables such as currents, temperature, salinity, and nutrients. OOS assets that address biological data on living resources often do so on more limited spatial and temporal scales and the data produced is not well integrated with physical and chemical information. We recommend that biological data be more fully integrated with physical and chemical data in order to support more robust decision making for key management areas. This would pay dividends for all five management areas we examined, as well as for many other ecosystem management areas. More specifically, we recommend:

- Continue developing systems and tools that integrate physical and chemical oceanographic data, including dynamic displays of temporal variation, with the GIS-based displays that are more commonly used for static biological data. Incorporate these integrated databases into decision support tools used in marine spatial planning
- Improve and expand the technology, monitoring, and data access systems for OOS biological data. Unfortunately much biological data are still collected by traditional monitoring programs that are scattered, small-scale, and labor-intensive, with limited data access that does not enable direct links to

OOS physical or chemical data. Over the long term, RAs could play a key role in developing methods to expand and integrate OOS biological data collection via acoustics, tagging, image analyses, genetic sampling, tracers or other techniques. The role could also include supporting progress towards more automated and widespread sampling programs and would be similar to the role the RAs have played in automating physical monitoring. The coordinated analysis and display of biological data with other types of oceanographic data would have applications to all five management areas evaluated here and to many other ecosystem management concerns as well

- Conduct training and education workshops for agency managers and scientists on OOS data and tools. Many state agency managers and scientists who work on coastal and marine issues are trained as biologists and lack familiarity with many physical and chemical aspects of oceanography, as well as with the data analysis and visualization tools common in these areas. Such training could help agency staff better understand and utilize the various types of OOS data and products

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Appendix 1 – Information Resources

Name	Organization
State Agencies	
Scott Barrow	California Department of Fish and Game
Chris Beegan	State Water Resources Control Board
Jon Bishop	State Water Resources Control Board
Robin Blanchfield	California Coastal Commission
Michael Bowen	California Coastal Conservancy
Clifford Dahm	Delta Stewardship Council
Mark Delaplaine	California Coastal Commission
Alison Dettmer	California Coastal Commission
Steve Edinger	Office of Oil Spill Prevention and Response, CDFG
Laura Engeman	Ocean Protection Council
Leslie Ewing	California Coastal Commission
Vicki Frey	California Department of Fish and Game
Jack Gregg	California Coastal Commission
Dominic Gregorio	State Water Resources Control Board
John Hintgten	California Energy Commission
Randy Imai	Office of Oil Spill Prevention and Response, CDFG
Jerry Johns	California Department of Water Resources
Mike Kane	California Energy Commission
Kenneth Koyama	California Energy Commission
Robin Lewis (ret.)	Office of Oil Spill Prevention and Response, CDFG
Alice Low	California Department of Fish and Game
Tom Luster	California Coastal Commission
Amber Mace	California Ocean Protection Council
Jon Marshack	California Water Quality Monitoring Council
Dean Marston	California Department of Fish and Game
Skyli McAffee	California Ocean Science Trust
Melissa Miller	California Department of Fish and Game
Judd Muskat	Office of Oil Spill Prevention and Response, CDFG
Cy Oggins	State Lands Commission
Joe O'Hagan	California Energy Commission
Bill Orme	State Water Resources Control Board
Melodie Palmer-Zwahlen	California Department of Fish and Game
Kevin Shaffer	California Department of Fish and Game
Val Termini	California Coastal Conservancy
Marija Vojkovich	California Department of Fish and Game
Karen Worcester	Central Coast Water Quality Control Board
Julie Yamamoto	Office of Oil Spill Prevention and Response, CDFG
Vanessa Zubkousky	California Department of Public Health
Federal Agencies	
Christopher Barker	NOAA/ORR/ERD
Hoyt Battey	US Department of Energy
Erik Bjorkstedt	NOAA Fisheries
Stephen Bowler	Federal Energy Regulatory Commission
Jocelyn Brown-Saracino	US Department of Energy
Ann Bull	Bureau of Ocean Energy Management, Regulation and Enforcement
Yi Chao	Jet Propulsion Laboratory
Robert Clark	US Fish and Wildlife Service

Sahrye Cohen	US Army Corps of Engineers
Andrea Copping	US Department of Energy
Kerri Danil	NOAA Fisheries
Monica DeAngelis	NOAA Fisheries
Jennifer Ewald	Bureau of Ocean Energy Management, Regulation and Enforcement
John Field	NOAA Fisheries
Terry Fleming	US EPA, Region IX
Carlos Garza	NOAA Fisheries
Simon Geerlofs	US Department of Energy
Churchill Grimes	NOAA Fisheries
Scott Hamelberg	US Fish and Wildlife Service
Jack Harlan	Integrated Ocean Observing System , NOAA
John Haskins	Elkhorn Slough National Estuarine Reserve
Mark Helvey	NOAA Fisheries
Maurice Hill	Bureau of Ocean Energy Management, Regulation and Enforcement
Laura Hoberecht	NOAA Fisheries
Kenneth Hogan	Federal Energy Regulatory Commission
Bridget Hoover	Monterey Bay National Marine Sanctuary
Peter Lawson	NOAA Fisheries
Steve Lindley	NOAA Fisheries
Jaron Ming	Bureau of Ocean Energy Management, Regulation and Enforcement
Hassan Moustahfid	Integrated Ocean Observing System, NOAA
Michael O'Farrell	NOAA Fisheries
David Panzer	Bureau of Ocean Energy Management, Regulation and Enforcement
Frank Schwing	NOAA Fisheries
Richard P. Stumpf	National Ocean Service, NOAA
Marc Suddleson	National Ocean Service, NOAA
Shelly Tomlinson	National Ocean Service, NOAA
Chuck Tracy	NOAA Fisheries
David White	NOAA Fisheries
Brian Wells	NOAA Fisheries
Gerald Wheaton	Office of Coast Survey, NOAA
David Woodbury	NOAA Fisheries
Chris Yates	NOAA Fisheries
Local Agencies	
Akin Babatola	City of Santa Cruz
Mas Dojiri	City of Los Angeles
Joe Gully	Los Angeles County Sanitation Districts
Wendy Enright	City of San Diego
Harriet Hill	Humboldt County
Paul Kelley	California Association of Water Agencies
Phil Lauri	West Basin Water Municipal Water District
David Manning	Sonoma County Water Agencies
Joe McCullough	Los Angeles County
Steve Peters	Santa Cruz County
Barbara Pierson	City of Watsonville
Martha Ramirez	Ventura County
George Robertson	Orange County Sanitation Districts
Alex Steele	Los Angeles County Sanitation Districts
Cordel Stillman	Sonoma County Water Agency
Private Entities and NGOs	
Matthew Armsby	Center for Ocean Solutions

Michelle Berman	Santa Barbara Museum of Natural History
David Bitts	Pacific Coast Federation of Fishermen's Association
Robert Blair	Pacific Gas and Electric
Meg Caldwell	Center for Ocean Solutions
Francisco Chavez	Monterey Bay Aquarium Research Institute, CeNCOOS
Elizabeth Copper	Avian Research Associates
Greg Dale	Coast Seafood Co.
Karen Garrison	Natural Resources Defense Council
Frances Gulland	The Marine Mammal Center
Dane Hardin	Applied Marine Sciences
David Hokanson	Trussell Technologies, Inc.
Meredith Howard	Southern California Coastal Water Research Project
Paul Jacobson	Electrical Power Research Institute
Sharon Kramer	H.T. Harvey
Ryan Luster	The Nature Conservancy
Wendy Millet	The Nature Conservancy
Nick Nezlin	Southern California Coastal Water Research Project
Doug Obegi	Natural Resources Defense Council
Linda Sheehan	California Coastkeeper
Paul Siri	Ocean Science Applications
Brandon Southall	Southall Environmental Associates
Bill Sydeman	Farallones Institute
Brad Warren	Sustainable Fisheries Partnership
Steven Weisberg	Southern California Coastal Water Research Project
Ian Wren	San Francisco BayKeeper
Universities	
Jack Barth	Oregon State University
David A. Caron	University of Southern California, SCCOOS
Melissa Carter	Scripps Institution of Oceanography
Ching-Sang Chiu	Naval Postgraduate School
Christopher Costello	UC Santa Barbara
Carolynn Culver	California Sea Grant Program
John Dorsey	Loyola Marymount University
Toby Garfield	San Frarnciso State University, CeNCOOS
Bob Guza	Scripps Institution of Oceanography
John Hildebrand	Scripps Institution of Oceanography
Christine Kreuder Johnson	UC Davis
Burton Jones	University of Southern California, SCCOOS
Raphael Kudela	UC Santa Cruz, CeNCOOS
John Largier	UC Davis Bodega Marine Laboratory, CeNCOOS
Will McClintock	UC Santa Barbara
Corey Olfe	Scripps Institution of Oceanography, CDIP
Tuba Oshan-Haller	Oregon State University
Bill O'Reilly	Scripps Institution of Oceanography
Jeff Paduan	Naval Postgraduate School
John Richards	UC Santa Barbara
Jason Smith	Moss Landing Marine Laboratories
Eric Terrill	Scripps Institution of Oceanography, SCCOOS
Bob Twiss	UC Berkeley Emeritus
California OOS	
Lisa Hazard	SCCOOS
Heather Kerkering	CeNCOOS

Steve Ramp	CeNCOOS
Julie Thomas	SCCOOS, CDIP
Tom Wadsworth	CeNCOOS

Appendix 2 - Observing System Requirements and Capabilities

Discharges requirements, capabilities, and gaps

Table A.2.1. Information needs associated with discharge-related management decisions. Each higher-level decision category in column 1 is broken down into several subsidiary management decisions and management questions in column 2, each with its own set of information needs. These information needs are matched with more detailed observing system capabilities and gaps in Table A.2.2.

Decision category	Management decision or activity	Ocean information needed for decisions	Decision makers	Information product	When required
1. POTWs / stormwater - Open / close swimming beaches	Open and close swimming beaches on a daily basis to reduce the risk of exposure to water-borne pathogens	Do the concentrations of indicator bacteria and/or pathogens exceed AB411 standards and/or levels that indicate an unacceptable risk of exposure or illness?	Public health departments and Regional Water Boards, supported by POTWs and stormwater programs	Exceedances of AB411 regulatory standards at swimming beaches	Daily and as near to real time as possible
2.	Close swimming beaches after sewage spill or large runoff event	Where are plumes? Are they now hitting beaches or will they in the near future (hours)?	See row 1	Location, direction, speed, and dispersal of plume	As near to real time as possible immediately after event
3.	Open swimming beaches after sewage spill or large runoff event	Where are plumes 48 - 72 hours after the spill or runoff event? Are they either far enough away or dispersed enough that it is safe to reopen beaches?	See row 1	Location, direction, speed, and dispersal of plume	As near to real time as possible for period 48 - 72 hours after spill or runoff event

Decision category	Management decision or activity	Ocean information needed for decisions	Decision makers	Information product	When required
4.	Rate swimming beaches in terms of their overall relative exposure to discharge plumes	Which beaches present the greatest risk of exposure to pathogens, based on their relative exposure to discharge plumes? What is the probability that plumes will hit specific beaches over specified time periods (e.g. summer swimming season, year)?	Public health departments, Regional Water Boards, and public interest groups, supported by POTWs and stormwater programs	Probability distribution of POTW and stormwater plumes over seasonal and annual time scale.	Annual report
5. POTWs / stormwater – Prioritize discharges and problems; manage, evaluate efforts to maintain / improve water quality	Prioritize individual discharges and categories of discharge in terms of their relative contribution to different types of impact, based on plume extent, persistence, and overlap with other plumes Prioritize problem areas based on plume extent, persistence, and overlap with other plumes	What is the individual and cumulative extent of discharge plumes?	Public health departments and Regional Water Boards, supported by POTWs and stormwater programs	Probability distribution of POTW and stormwater plumes over seasonal and annual time scale.	Annual report
6.	Prioritize discharges and their relative contribution to problem areas in water column based on levels and loads of contaminants Develop and implement TMDLs and similar programs	What is the spatial and temporal distribution of water borne pollutants in discharge plumes?	Regional Water Boards, supported by POTWs and stormwater programs	Probability distribution of dissolved pollutant levels over seasonal and annual time scales	Annual report
7.	Manage compliance with permit conditions Track success of management actions	Do pollutant concentrations in discharge plumes exceed Ocean Plan and other regulatory standards?	See Row 5	Regulatory exceedances based on comparison of plume concentrations to Ocean Plan and other standards	Annual report
8.	Prioritize discharges and their relative contribution to problem areas based on eutrophication	Are nutrients in discharge plumes contributing to plankton blooms, particularly of toxic or otherwise harmful	See Row 6	Estimates of the degree to which nutrients increase the growth	Annual report

Decision category	Management decision or activity	Ocean information needed for decisions	Decision makers	Information product	When required
	Develop and implement TMDLs and similar programs	species?		rates of plankton	
9. Desal plants - Manage operations	Suspend or restrict operations when probability of fouling by plankton is high	When are plankton blooms above a critical threshold density occurring, or likely to occur, in the vicinity of plant intakes?	Plant managers	Real time monitoring and near real time predictions of occurrence, location, and density of plankton blooms	Continuous, updated hourly
10. Desal plants – Assess impacts	Assess impacts of saline discharge plume	Where are plumes? Are they affecting marine resources?	See row 9	Probability distribution of plume location over seasonal and annual timeframe	Annual report
11.	See above	Does the salinity of the discharge plume exceed Ocean Plan and other regulatory standards?	Regional Water Boards, supported by plant managers	Ongoing monitoring of the distribution of salinity levels in the area around the plant discharge	Annual report

Table A.2.2. Detailed observing system capabilities and gaps matched with the discharge-related decisions and information needs identified in Table A.2.1.

Management decision or activity	Information product	Product components and key inputs	Location, coverage, resolution	Key existing assets	Gaps / needs / notes
1. Open / close swimming beaches on daily basis	Exceedances of AB411 regulatory standards	Measurements of indicator bacteria, preferably rapid indicator method	Daily in AB411 season, less in non-swimming season, at swimming beaches, systematic coverage with additional focus on sources (storm drains, rivers, likely spills, inshore of POTW plumes)	County and permittee beach sampling programs	Improved rapid indicators to compensate for long lag time with traditional indicators; implementation methods that address rapid indicators' strict logistical requirements
2. Close swimming beaches after sewage spill or large runoff event	Location / direction of plume immediately after event	Nearshore current direction and especially speed (because it tells managers whether the spill is likely to spread or remain localized), based on offshore waves, nearshore wind, nearshore bathymetry	Continuous, updated hourly, in immediate areas of likely spills based on facility location, past history; mostly at / near POTW facilities	Offshore waves, nearshore wind; temperature, salinity; nearshore bathymetry in some locations; nearshore current models, plume models	Nearshore bathymetry and wind in all key locations, near shore current models validated for key locations;, coordination among development efforts and process for validating / implementing desired model(s)
3. Open swimming beaches after sewage spill or large runoff event	Transport / location of plume at 48 - 72 hours	Nearshore - offshore mixing and transport of discharge, based on Row 2 plus offshore currents	Continuous, updated hourly, in coastal zone 10 kms up- and downcoast of key locations	Row 2 plus HF radar and 3-dimensional offshore current models	Row 2 plus improved HF radar spatial coverage, vertical profiles of temperature, salinity (for density) and current at spill locations, integrated offshore and nearshore current models
4. Rate swimming beaches	Probability distribution of plumes over seasonal / annual time scale	Row 3 for all POTW and major stormwater discharges	Continuous, updated hourly, in coastal zone where discharges are a concern	See Row 3	Row 3 plus vertical current profiles at all major discharges
5. Assess plume impacts based on extent	See Row 4	See Row 4	See Row 4	See Row 3	See Row 4

Management decision or activity	Information product	Product components and key inputs	Location, coverage, resolution	Key existing assets	Gaps / needs / notes
6. Assess plume impacts based on dissolved pollutant distribution	Probability distribution of dissolved pollutants	Row 4 plus loadings of water-borne pollutants from offshore and near shore plumes; 3 D distribution of pollutant concentrations in water column	Continuous, updated hourly for plume models, episodic for pollutants, in coastal zone where discharges are a concern	Row 3 plus POTW effluent monitoring, stormwater mass loadings monitoring for water borne fraction	Row 4 plus loadings from river and creek discharges
7. Determine regulatory exceedances	Regulatory exceedances in plume	Pollutant concentration estimates	See Row 6	See Row 3	Row 4 plus adapt regulatory standards to accommodate river and creek discharges and model estimates
8. Assess plume impacts due to nutrient enrichment	Estimated contribution of discharge plumes to plankton blooms	Row 6 specifically for nutrients	See Row 6	Row 6 plus plankton bloom (NPZD) modeling efforts (see HABS)	Row 6 plus plankton bloom modeling needs for HABS
9. Desal plants - manage operations	Prediction of plankton blooms above a particular threshold	See HABS	Continuous, updated hourly, in an area 10 km around desal plant location	Row 6 plus plankton bloom modeling efforts (see HABS)	Row 6 plus plankton bloom modeling needs for HABS
10. Assess plume impacts of desal plants due to saline discharge	Probability distribution of plume locations over seasonal / annual periods for each plant	See Row 2	See Row 9	See Row 3	See Row 3
11. See above	Estimated regulatory exceedances from comparison of salinity in plume to background as defined in permits	Salinity measurements	See Row 9	Depending on location, pier stations, glider measurements, etc.	Row 3 plus monitoring arrays around desal plants

Salmon recovery requirements, capabilities, and gaps

Table A.2.3. Information needs associated with salmon recovery-related management decisions. Each higher-level decision category in column 1 is broken down into several subsidiary management decisions and management questions in column 2, each with its own set of information needs. These information needs are matched with more detailed observing system capabilities and gaps in Table A.2.4.

Decision category	Management decision or activity	Ocean information needed for decision	Decision makers	Information products	When required
1. Fishery management	Allocate catch to fishery for coming season, based on estimated adult stock and conservation objectives in Fishery Management Plan (FMP) and Biological Opinion	How many adult salmon will return upriver to spawn next year (estimated escapement)?	PFMC, NMFS, CDFG	Ocean conditions relevant to salmon survival and growth over past 2 years, particularly for first months after smolts arrive in ocean Predicted abundance of adult salmon for coming year	Annual summary at year-end Lower priority to have outyear predictions
2.	Develop Biological Assessment and Biological Opinion required by ESA Estimate bycatch of listed salmon species by other fisheries; establish catch limits	Where are adult salmon in the ocean during fishing season? How will commercially fished and listed species overlap in space and time?	NMFS	Migratory pathways of individual stocks during spring and summer Predicted distributions based on ocean conditions	Periodic (5 years) summaries to support Biological Opinions on listed stocks
3.	Estimate optimal allocation of fishery in space and time to meet conservation objectives and minimize bycatch of listed species	Where are adult salmon in the ocean during fishing season? How will commercially fished and listed species overlap in space and time?	PFMC, Salmon Advisory Committee, NMFS, CDFG	Migratory pathways of individual stocks during spring and summer Predicted distributions based on ocean conditions	Annual summary at year-end
4.	Alter in-season fishing to respond to changed ocean conditions and better meet conservation, bycatch, economic goals	How does the distribution of various salmon stocks respond to changing ocean conditions during the fishing season?	PFMC, NMFS, CDFG	Short term predictions (weeks-months) and/or real-time data on ocean conditions that impact salmon distribution Predicted distributions of mixed stocks during open season	Weekly during spring and summer

Decision category	Management decision or activity	Ocean information needed for decision	Decision makers	Information products	When required
5.	Incorporate key ocean conditions into an Ecosystem Based Fishery Management Plan, an umbrella plan for existing FMPs	What are the short-term status and long-term trends in climate and ocean conditions? What are salmon's trophic interactions and habitat use?	PFMC, NMFS, CDFG	Annual Status of the Ecosystem report to PFMC that includes ocean conditions Ecosystem-based predictions useful in risk assessments and to establish harvest policies	Annual summary at year-end
6. Hatcheries	Plan hatchery production and release dates for coming year to enhance survival and meet target abundance goals for hatchery and wild salmon	What will be the capacity of the ocean to sustain smolts next year? When will spring ocean conditions be best for survival and growth of smolts?	USFWS, CDFG, NMFS	2 week - 18 month forecast of spring ocean productivity indices Historical relationship between indices and growth / survival of smolts.	Annually in fall, 1 year prior to planned spawning Annually in spring prior to release
7.	Identify new hatchery practices to buffer stocks from variable ocean conditions by enhancing genetic and life history diversity	What is the variability in ocean conditions over time? How does that variability impact survival and growth of various salmon runs? How would expanding hatchery release times across a range of ocean conditions impact smolt survival and abundance?	CDFG, USFWS, NMFS	Retrospective (10 – 20+ yrs) analysis of ocean condition indices relevant to salmon, including inter- and intra-seasonal time scales Correlation of ocean variability with success of salmon runs as assessment of synchronous release strategy Results of pilot project to assess effect of varying hatchery release dates on survival and abundance under different ocean conditions	Once for analyses and pilot project
8. Water flow	Estimate flows necessary for adequate returns of adults upstream during spawning season	What is the number of salmon likely to return at various times of year? How should flow be altered depending on returning number of salmon?	DWR, USBR, Delta Stewardship Council, local water agencies, NMFS	Ocean conditions relevant to salmon survival and growth over past 2 years, particularly for first months after smolts arrive in ocean Prediction of abundance of adult salmon for coming year	Annual summary report by year-end. Lower priority to have outyear predictions.

Decision category	Management decision or activity	Ocean information needed for decision	Decision makers	Information products	When required
9.	Estimate flows necessary for adequate outmigration and survival of smolts	What will be the capacity of the ocean to sustain smolts next year? When will ocean conditions be best for survival and growth of smolts? How should flow be modified during outmigration in response to ocean conditions?	DWR, USBR, Delta Stewardship Council, local water agencies, NMFS	3 - 6 month prediction of spring ocean productivity indices Historical relationship between indices and growth / survival of smolts	Annual summary at year-end
10. Rivermouth breaching	Breach sandbars at rivermouth / lagoons to optimize survival and growth for outgoing smolts Balance flooding concerns	What are water conditions in estuary / lagoon and in adjacent nearshore ocean during outmigration? How will water conditions impact smolt survival?	CDFG, CCC, local water agencies, NMFS, USACE	Real-time or daily summaries of temperature, water quality, productivity Correlation between smolt survival and timing of entrance to ocean	Daily when breaching is considered
11. Climate change	Incorporate climate change into projections of salmon recovery in projects and plans, as required in many ESA consultations	How will climate change impact the drivers of salmon abundance and distribution, in both marine and terrestrial systems?	All involved federal, state, local agencies	Medium- to long-term (1 – 20 yrs) forecasts of changes in ocean condition indices and salmon abundance due to climate change	Once for broad summary As needed for project / plan approvals
12. Project success	Predict success, in terms of salmon population enhancement, of proposed habitat mitigation and infrastructure projects Predict success of NMFS Recovery Plans for listed salmon species	How will ocean conditions likely impact survival, growth and abundance of salmon? What are the baseline conditions for assessing project effects?	Delta Stewardship Council, water districts, NMFS, CCC, CDFG, local agencies, NGOs, NMFS	Multiyear (1 - 10 or 20 yr) forecasts of large-scale changes in ocean condition indices and salmon abundance Forecast analyses to account for variation in abundance due to non-project factors	Once at beginning of major planning efforts Annual updates to long-term forecasts
13.	Assess success, for approved projects, of mitigation measures and other efforts to enhance salmon populations Track success of Salmon Recovery Plans	How will ocean conditions likely impact survival, growth and abundance of salmon? What are the baseline conditions for assessing project effects?	Delta Stewardship Council, water districts, NMFS, Coastal Conservancy, CDFG, local agencies, NGOs	Retrospective (1 – 10 yrs) analysis showing proportion of variation in salmon abundance attributable to ocean conditions Integrate to provide broader context for evaluations of success with other stages of life cycle.	Once for overall summary Annual updates

Table A.2.4. Detailed observing system capabilities and gaps matched with the salmon recovery-related decisions and information needs identified in Table A.2.3.

Management decision or activity	Information products	Product components and key inputs	Location, coverage, resolution	Key existing assets	Gaps / needs/ notes
1. Allocate catch to fishery for coming season	Ocean conditions relevant to salmon survival and growth over past 2 yrs, particularly for first months after smolts arrive in ocean	Historical ocean condition indices based on SST, winds, spring transition, primary production, zooplankton, prey fish	Big Sur to S. OR for past 2 yrs, esp. smolt habitat off San Francisco and Klamath, at eddy-scale 12.5 km or less	Satellites, moorings, gliders, ocean condition indices, CalCOFI, NMFS midwater trawls	Develop ocean condition indices most relevant to salmon Improved more automated data on lower trophic levels
a.	Predicted abundance of adult salmon for coming year	Correlation between indices and salmon growth, survival, abundance	Row 1, but for past 10 yrs	Catch data, Coded Wire Tag (CWT)	Expanded CWT program for age composition for Central Valley Chinook Constant fractional mark to assess wild vs hatchery stock Full Genetic Stock Identification (GSI)
b.		Predictive models of adult salmon abundance based on above plus number of smolts entering ocean	Row 1 plus upcoming yr	3D circulation models (ROMS), NPZD models (CoSINE), ocean condition indices	Expand ROMS to N. CA Link ROMS output to NPZD models and then to salmon abundance models, as initiated by MBARI/NMFS
2. Develop Biological Assessment, Biological Opinion	Migratory pathways of individual stocks during spring and summer	Retrospective analysis based on catch data, trawl surveys, acoustic data	Big Sur to S. OR for past 10 yrs, at 12.5 - 100 km scale	Catch data, CWT, GSI, POST acoustic line	2 additional yrs GSI data
a.	Predicted distributions	Forecasted distribution based on predicted ocean conditions, correlation with historical distribution	Big Sur to S. OR for next 1-5 yrs, at 12.5 - 100 km scale	See Rows 1 and 2	See Row 1
3. Estimate optimal fishery allocation	See Row 2	See Row 2	Big Sur to S. OR for next 3 - 9 months, at 12.5 - 100km scale	See Rows 1 and 2	2 additional yrs GSI data

Management decision or activity	Information products	Product components and key inputs	Location, coverage, resolution	Key existing assets	Gaps / needs/ notes
4. Alter in-season fishing to respond to changed conditions	Short term predictions and/or real-time data on ocean conditions that impact adult salmon distribution	Predictions or real-time data on currents, temperature, upwelling, fronts, productivity indices relevant to adult distributions	Big Sur to S. OR for next 1 week – 2 months, at 12.5 – 100 km scale	See Rows 1 and 2	Continued development of wind forecasts for next week to months
a.	Predicted distribution of mixed stocks during open season	Near real-time or recent data on distribution of mixed adult stocks in spring and summer based on catch and/or acoustic data	Big Sur to S. OR for next 1 week – 2 months, at 12.5 – 100 km scale, reported weekly	See Row 2 Successful use of GSI in Canada	See Row 3 Institutionalized GSI data collection by fishing fleet Expanded use of POST acoustic data for adults, with improved data turnaround
5. Incorporate ocean conditions into an Ecosystem Based Fishery Management Plan	Status of the Ecosystem Report	Ocean condition indices, ecosystem predictions, based on SST, winds, upwelling, primary production, zooplankton, prey fish, environ-mental variation	Big Sur to S. OR for past and upcoming year, at < 12.5 for indices relevant to survival /abundance, 12.5 - 100 km for distribution	See Row 1	Improved indices based on greater ecosystem understanding
6. Plan hatchery production and release dates	Forecast of spring ocean productivity indices Historical relationship between indices and growth / survival of smolts	Row 1 focused on smolts only	Row 1 focused on 2 weeks – 18 month forecast	See Row 1 NMFS project to model ocean predictions, flow modeling, hatchery release	Improved hatchery management practices to allow for variable release times
7. Identify new hatchery practices	Retrospective analysis of ocean condition indices relevant to salmon at within- and between-season scales Correlation of ocean variability with success of salmon runs as assessment of synchronous release strategy	Correlation between variation in ocean condition indices and historic and current smolt ocean arrival times, based on parameters in Row 6 Evaluation of synchronous hatchery releases and value of bet hedging	Big Sur to S. OR for past 10 – 20 yrs for ocean conditions, past 20 – 100 yrs for ocean arrival times	See Row 1 Klamath variation study MBARI/ NMFS retrospective analysis	Compilation and evaluation of existing data

Management decision or activity	Information products	Product components and key inputs	Location, coverage, resolution	Key existing assets	Gaps / needs/ notes
a.	Results of pilot project to assess effect of varying hatchery release dates on survival and abundance under different ocean conditions	Analysis of relationships among smolt release time, smolt survival / growth, and ocean conditions, based on parameters in Row 6 plus smolt recoveries	One – 2 yrs	See Rows 1 and 2	Pilot study measurements and analysis Mechanisms to modify hatchery practices
8. Estimate flows for returns	See Row 1, and a, b	See Row 1, and a, b	See Row 1, and a, b	See Row 1, and a, b	See Row 1, and a, b
9. Estimate flows for outmigration	See Row 6	See Row 6	See Row 6	See Row 6	See Row 6
10. Optimize breaching at river mouths	Real-time or daily water quality summaries Correlation between smolt survival and timing of entrance to ocean	Temperature, DO, water quality, productivity, tides, waves, smolt survival and timing	Big Sur to S. OR at near real-time, in lagoons and offshore of river mouths considered for breaching, at 1 – 20 km	Satellites, moorings, tide gauges, local water quality monitoring, lagoon sampling evaluated in some breaching processes, OOS data at some sites	Pilot project at several sites with diverse conditions, lagoon and OOS data as needed
11. Incorporate climate change into project planning	Forecasted changes in ocean condition indices and salmon abundance due to climate change	Retrospective analysis and hindcast of ocean conditions and salmon abundance based on parameters in Row 5 plus stock data	Big Sur to S. OR, next 1 – 20 yrs, based on last 10 – 50 yrs	See rows 1 and 2	Compilation and evaluation of existing data
a.		Climate change forecasts incorporated into ocean condition and salmon forecast models based on parameters in Row 11 plus temperature, season, acidification, sea level rise	Big Sur to S. OR, next 1 – 10 and 10 – 50 yrs	Climate projection models, preliminary salmon forecasting models	Integration of climate models with salmon forecasting models Systematic monitoring of ocean climate change indicators, including acidification
b.		Contribution of ocean variation to overall variation in salmon abundance, relative to other sources of variation based on parameters in Row 11 plus river and Delta flows, habitat changes	Big Sur to S. OR, with focus on project locations, next 1 – 10 and 1 – 50 yrs	Rows 1 and 2 plus river and estuarine sampling programs (DWR,DFG, USGS) Pending NMFS retrospective analysis	Long-term retrospective analysis Coordinated system to link ocean evaluations with multiple large water/habitat improvement projects affecting salmon

Management decision or activity	Information products	Product components and key inputs	Location, coverage, resolution	Key existing assets	Gaps / needs/ notes
12. Predict success of habitat mitigation and infrastructure projects	Multiyear (1 - 10 or 20 year) forecasts of large-scale changes in ocean condition indices and salmon abundance Estimates of roles of project and non-project factors in project success	See Rows 1, 11b	Big Sur to S. OR, with focus on project locations, next 1 – 20 yrs, based on last 1 – 10 yrs	Rows 1 and 2 plus river and estuarine sampling programs (DWR,DFG, USGS)	See Row 11 and a, b

Renewable ocean energy requirements, capabilities, and gaps

Table A.2.5. Information needs associated with ocean energy-related management decisions. Each higher-level decision category in column 1 is broken down into several subsidiary management decisions and management questions in column 2, each with its own set of information needs. These information needs are matched with more detailed observing system capabilities and gaps in Table A.2.6.

Decision category	Management decision or activity	Ocean information needed for decision	Decision makers	Information products	When required
1. Resource Assessment and Operations	Determine whether wave energy in a given locale is adequate for economical harvesting, and what type of WEC devices would work best for given wave environment Provide warnings of wave conditions which might affect operations	Wave energy (or height) as a function of wave period and direction, and how these vary over time	DOE, CEC, industry	Directional wave energy spectra Bathymetry (to extend information via models from measurement points to other locations)	Exact requirement unknown; but existing products are likely sufficient Observations every 30 min Hourly nowcasts Forecasts updated every 6 or 12 hrs
2. Technology development	Promote development and testing of WEC technology with in-water testing site	Environmental information to determine efficiency, durability, and environmental impact of WEC devices under known conditions	DOE, industry	Continuous wind, wave and water quality data Acoustic and EMF measurements Information on impacts on wildlife, including changes in animal behavior in the presence of WECs	Exact requirements unknown, but it is likely that some variables would need to be measured at least hourly
3. Permitting, leasing & licensing, Environment-al impact assessment	Determine compatibility of WEC with other uses to inform permitting / leasing / licensing decisions, including commercial, recreation and military activities Ensure consistency with state's Coastal Management Plan and issue permits Lease state lands	Location, relative to project location, of other potentially competing uses in the area	DOE, BOEMRE, CCC, SLC, CDFG	Geospatial data, preferably in formats compatible with multi-purpose marine cadastre, MMC, which defines area boundaries for activities potentially incompatible with WEC infrastructure	Starting in FY12, these data will be needed for national CMSP process Update annually if possible, or as uses change. 5-10 yr future horizon needed

Decision category	Management decision or activity	Ocean information needed for decision	Decision makers	Information products	When required
4.	Anticipate and evaluate impact on sensitive habitats to inform permitting / leasing / licensing decisions Ensure consistency with CMP and issue permits Lease offshore waters for hydrokinetic and wind projects Protect essential fish habitat Provide water quality certification	Location of ASBSs, sensitive habitats, and MPAs; species distributions, substrates and benthic habitat; essential fish habitat	CCC, BOEMRE, NMFS, SWRCB	Geospatial data that define the boundaries of sensitive habitats (preferably in format compatible with MMC)	5-10 yr planning Review annually
5.	Anticipate and evaluate impacts on marine mammals to inform permitting / leasing / licensing decisions Issue permits to "take" marine mammals by harassment Ensure consistency with CMP, issue permits Lease offshore waters for hydrokinetic and wind projects Licensing and lead CEQA and NEPA agencies Evaluate environmental impacts as part of DOE's market acceleration activities	Impact of project on marine mammals	NMFS, CCC, BOEMRE, SLC, FERC, DOE	Migratory pathways relative to project site Project-generated noise vs ambient background noise Information on changes in behavior or location of marine mammals due to project. May include passive acoustic monitoring, visual and tagging data etc.	Migratory pathways needed during EIR/EIS and permit review process. Real-time monitoring and data needed during construction, operation, and dismantling Based on changing oceanographic conditions, migratory path predictions may need to be updated
6.	Anticipate and evaluate impact on fish, birds, turtles, and other non-mammals to inform permitting / leasing / licensing decisions Administer incidental take provisions of CA Endangered Species Act Protect endangered species Licensing and lead NEPA agency DOE activities to facilitate permitting and licensing	Better understanding of pelagic fish, including fish eggs and larvae, invertebrate larvae Information about effect of project on predator-prey relations Predictions of location and behavior of migratory species including: sea turtles, birds, salmonids, ESA-listed species	CDFG, DOE, NMFS, FERC, BOEMRE	Distribution and abundance of wildlife, including COASST bird data and larval fish data, relative to predators, prey, and oceanographic variables Historical migratory paths Observations (visual, acoustic, satellite tracking, tagging etc.) of location and behavior of wildlife Models predicting locations of	Distribution and abundance data needed during EIR/EIS and permit review process. Real-time data may be needed during construction and dismantling phases Update distribution predictions based on knowledge of changing oceanographic conditions if relationships are known

Decision category	Management decision or activity	Ocean information needed for decision	Decision makers	Information products	When required
				wildlife based on oceanographic features, prey availability, avoidance behavior	
7.	Anticipate and evaluate impacts on water quality to inform permitting / leasing decisions	Impact of wave energy removal on water quality (including nutrient, oxygen, and chlorophyll levels)	SWRCB, DOE	Baseline environmental conditions, plus estimate of wave energy reduction effects on mixing	May need 2 yrs or more of data to establish baseline conditions
8.	Anticipate and evaluate impacts on sediment transport to inform permitting / leasing / licensing decisions, including potential effects of project-induced changes in sediment transport on essential fish habitat Facilitate permitting, licensing, and leasing in offshore waters	Impact of changes in wave field (e.g. damping and diffraction) on sediment transport and benthic habitat Geomorphic effects (erosion, deposition) for nearshore environments, including estuaries	DOE, CEC, FERC, BOEMRE, NMFS	Models and/or measurements of how WEC devices affect incoming wave field (attenuation, blocking, focusing) Coupled or linked wave-current-sediment transport models to enable comparison of baseline and altered wave fields on nearshore environments Capabilities to simulate effects of different types of WEC devices for specific projects and locations	Models needed in project planning and permitting / licensing phases Long-term measurements may be needed during operations to validate model results
9.	Determine impacts of cable burying and assess alternative cable routes to inform permitting / leasing / licensing decisions	Optimal cable routing Impacts of turbidity caused by cable burying	SLC, FERC, SWRCB	Bottom surveys Real-time currents	Information needed during project planning and construction phases

Table A.2.6. Detailed observing system capabilities and gaps matched with the ocean energy decisions and information needs identified in Table A.2.5.

Management decision or activity	Information products	Product components and key inputs	Location, coverage, resolution	Key existing assets	Gaps / needs / notes
1. Energy resource assessment (and operations)	Directional wave energy spectra	Wave height, period, and direction measurements at multiple locations Models to propagate wave information beyond measurement sites Bathymetry for models	Statewide, project site specific if needed for operations Several years' worth of historical data for resource assessment Real-time and forecasts if needed for operations	CDIP and NDBC wave buoys Spectral wave models	CDIP program meets need to characterize wave field impinging in WEC devices Large scale wave energy resource assessment has already been done
2. Energy technology development	Environmental data for technology development and assessment	Over-water wind speed and direction Electromagnetic field measurements to determine effects on fish Waves (see Row 1) Noise (see Row 7) Water quality (see Row 8a)	At site(s) where WEC devices are to be tested. One or two sites may be sufficient. While WEC devices are in water	Moorings, ship surveys, gliders	EMF measurements
3. Minimize competition with other resources, and minimize impact on sensitive habitats	Geospatial data on competing uses and sensitive habitats	Geographic coordinates outlining areas of competing uses (e.g. commercial and recreational fishing, recreational boating and surfing, military activity) and biological significance (e.g. MPAs, ASBS, essential fish habitat, kelp beds, rocky substrate)	Areas where WEC projects are considered (in state waters, where preliminary permits have been issued) Less than 1 km resolution Update annually	MMC includes legal and jurisdictional boundaries MarineMap includes many biologically significant data layers	MarineMap only includes state waters MarineMap has data layers useful for renewable energy planning, but data format must be compatible with MMC MarineMap uses open source Google software; MMC uses ESRI BOEMRE (a MMC developer) is looking at extending MMC to Google Earth
4. Protection of marine mammals and other wildlife.	Location of migratory species	Migratory pathways for marine mammals, sea turtles, seabirds, salmonids, and other protected fish; based on location (including depth or height) of species of interest as a function of season	Statewide, with project-scale specificity in areas where energy projects are being considered Spatial resolution needed for acoustic monitoring of	NMFS and CalCOFI surveys TOPP and POST tagging programs Central and southern CA passive acoustic monitoring	Need known migratory pathways in MMC-compatible format NMFS surveys are on very broad spatial scale, not specific to project sites

Management decision or activity	Information products	Product components and key inputs	Location, coverage, resolution	Key existing assets	Gaps / needs / notes
		Data inputs include acoustic monitoring, satellite and acoustic tags, visual spotting, net tows, etc.	marine mammals based on type of mammal and frequency of sounds made Seasonal resolution needed Update as significant new information added		Many overlapping databases (e.g. OBIS-SEAMAP, CalCOFI DataZoo, PaCOOS West Coast Habitat Portal) each with different strengths and weaknesses have these data
5.	Location of migratory species as function of time and oceanographic conditions	Dynamic updates and predictions of locations of marine mammals, sea turtles, seabirds, salmonids, other protected fish Dynamic predictions of where wildlife will be require relationships and models still under development, so exactly which types of oceanographic data will be needed are unknown at this time	In state and federal waters where projects are likely to occur, on project scale Sufficient coverage to understand how species use of habitat varies with changing ocean regimes	Satellites, moorings, gliders, circulation models, plus animal locations from assets listed in Row 4	Need to understand wildlife' behavior, including feeding and breeding Relationships between oceanographic conditions, animal behavior, and location are not sufficiently known to make useful forecasts. This is an area of active research.
6.	Changes in location or behavior of migratory wildlife and protected or commercially important species due to project	Visual, tag, and acoustic observations of wildlife in project area, including numbers of wildlife and feeding, haul-out, mating, and breeding behavior	In vicinity of proposed projects During planning, construction, and operational stages and after WEC devices are removed		Assets to address these questions will most likely be deployed as part of specific research projects, and/or by project developers and operators EMF measurements may be needed to analyze what causes changes in animal behavior
7. Protection of marine mammals and other wildlife	Noise levels	Ambient noise (or sound) levels, as a function of frequency, in absence of project Project-related noise levels as a function of frequency	Statewide, plus project site-specific Seasonally, since ambient noise levels depend on atmospheric and oceanographic conditions	High-frequency acoustic recording packages off Pt. Sur and southern California AIS ship tracking	Additional passive acoustic monitoring sites for model validation May be possible to develop first-order ambient noise and sound propagation model with ship tracking information and the few acoustic

Management decision or activity	Information products	Product components and key inputs	Location, coverage, resolution	Key existing assets	Gaps / needs / notes
					monitoring sites that exist in California
8. Environmental impact: anticipate and assess effect of WEC projects on wave field and subsequent impacts on:	Wave field with and without project infrastructure present	Models to propagate waves to WEC sites Models of wave / WEC device interactions Models to propagate waves in to shore Wave measurements (height, period, and direction) at multiple locations for model input and validation High resolution bathymetry from project site through the surf zone	Project site-specific Ongoing during assessment period for WEC device impacts and to validate models	Wave buoys and wave models (CDIP) to specify wave fields impinging on WEC devices from offshore	The wave / WEC device interaction piece is under development Need measurements to validate model results Nearshore wave / current / sediment transport models are not as well established as wave and current models used in deeper water
a. water quality	Water quality with and without project infrastructure present	Water quality data including: temperature, salinity, oxygen, nutrient and chlorophyll concentrations, turbidity	Project site-specific Throughout water column Time series (~2 yrs possibly) of environmental conditions prior to project implementation with continuation during construction, operation, and after removal	Moorings, ship surveys, gliders, pier stations	These data exist for a number of sites off CA, however the location of the sites are not specific to proposed projects
b. sediment transport and coastal geomor-phology	Sediment transport, with and without project infrastructure present	Distribution of sediment types Sediment transport model, needs waves and currents as inputs, could be coupled to wave and current models	Project site-specific Sediment-water interface May require long-term monitoring to assess whether small changes in the wave field result in sediment transport and beach morphology changes	High resolution bathymetry, bottom type	Agencies may need guidance on acceptable models Nearshore models heavily dependent on accurate fine spatial resolution time-dependent bathymetry
9. Habitat protection	Optimal cable routing	Bathymetry and bottom type	Project site-specific	High resolution bathymetry	

Table A.2.7. Information needs associated with harmful algal bloom-related management decisions. Each higher-level decision category in column 1 is broken down into several subsidiary management decisions and management questions in column 2, each with its own set of information needs. These information needs are matched with more detailed observing system capabilities and gaps in Table A.2.8.

Decision category	Management decision or activity	Ocean information needed for decisions	Decision makers	Information product	When required
1. Public health	Open/close commercial shellfish growing and harvesting / recreational shellfishing to assure that shellfish are safe for human consumption.	Do domoic acid and PSP toxin concentrations in shellfish exceed safe limits?	California Department of Public Health (CDPH)	Distribution and concentrations of DA and PSP toxin in shellfish, the distribution and relative abundance of *Alexandrium* and *Pseudo-nitzschia*	Twice weekly during active bloom events / once weekly during inactive bloom status.
2.	Issue public health advisories and warnings	Is there a threat to human health threat?	CDPH	Phytoplankton levels, community composition, presence of toxic species	Twice weekly during active bloom events / once weekly during inactive bloom status
3.		What areas are at risk and how long will the risk persist?	CDPH	HAB location, spatial extent, future movement and expected duration of bloom	Twice weekly during active bloom events / once weekly during inactive bloom status
4.	Focus and intensify sampling efforts	What is the probability of HAB formation at a specific location and time in order to adapt and increase effectiveness of sampling efforts?	CDPH	Physico-chem and biological ocean parameters; short term forecasts on changing ocean conditions that influence HAB formation	Daily and as near to real time as possible during active bloom events / once weekly during inactive bloom status
5.	Improve effectiveness of monitoring program and quarantine practices	What is the likelihood of HABs next year? Are current levels of monitoring adequate? Should closure/ quarantine practices be modified?	CDPH	Long-term time series of species composition and shifts in dominant groups (diatoms versus dinoflagellates). Long-term (seasonal/interannual, decadal) forecasts .	Spring and fall updates; annual
6. Marine wildlife health	Determine potential HAB impacts on living marine resources and ecosystems	Are animal mortalities due to HABs?	CDF&G, Marine Wildlife Rescue organizations (e.g., California Marine Mammal Stranding Network; Marine Mammal Center)	Strandings of birds, sea lions, dolphins, otters, etc. analyses of serum, urine, feces, stomach contents, kidney tissue	Real-time notification of strandings; bi-weekly updates of mortality.

Decision category	Management decision or activity	Ocean information needed for decisions	Decision makers	Information product	When required
7.	Focus watch efforts and recovery resources for rapid response to strandings	What is the probability of HAB formation in a specific location and time? What is current location, spatial extent, and future movement of bloom? When will the HAB dissipate?	CDF&G, Marine Wildlife Rescue organizations	Physico-chem and biological ocean parameters; short term forecasts on changing ocean conditions that influence HAB formation; HAB location, size and extent, and forecast (0-36h) of direction and speed of movement	Daily and as near to real time as possible during active bloom events / once weekly during inactive bloom status
8.	When to release wildlife back to environment	What are current phytoplankton levels and community composition? Are toxic species present? What is current location, spatial extent, and future movement of bloom? When will the HAB dissipate?	CDF&G, Marine Wildlife Rescue organizations	HAB location, size and extent, and forecast (0-36h) of direction and speed of movement; forecast of bloom dissipation	Daily during active bloom events / once weekly during inactive bloom status
9. Water quality	Should nutrient prevention/reduction/removal be required?	Have nutrients in discharge plumes changed the nature of plankton blooms or increased their frequency and/or severity?	Regional Water Quality Control Boards, POTWs	Historical records of HAB events; estimates of nutrients from discharge plumes to specific locations (hindcasts); long-term forecasts	Annual
10. Commercial aquaculture	Timing of product harvesting - when should product be harvested to avoid exposure?	What is the risk of shellfish beds being impacted by HABs?	Commercial shellfish growers	Short term predictions on changing ocean conditions that influence HAB formation; HAB location, size and extent, and forecast (0-36h) of direction and speed of movement; forecast of bloom dissipation	Daily during active bloom events / once weekly during inactive bloom status
11. Seawater Intake including desalination plants	Suspend or restrict seawater intake when probability of algal blooms high.	When are HABs likely to reach a threshold biomass level at or near seawater intakes?	Plant operators	Physico-chem and biological ocean parameters; short term predictions on changing ocean conditions that influence HAB formation; HAB location, size and extent, and forecast (0-36h) of direction and speed of movement; forecast of bloom dissipation	Daily during active bloom events / once weekly during inactive bloom status. Managers may want 72 hr notice.

Table A.2.8. Detailed observing system capabilities and gaps matched with the harmful algal bloom decisions and information needs identified in Table A.2.7.

Management decision or activity	Information products	Product components and key inputs	Location, coverage, resolution	Key existing Assets	Gaps/ Needs / notes
1. Open/close commercial shellfish growing and harvesting / recreational shellfishing	Distribution and concentrations of DA and PSP toxin in shellfish, the distribution and relative abundance of *Alexandrium* and *Pseudo-nitzschia*	DA, PSP concentration in mussel, oyster tissue. Cell counts of *Alexandrium* and *Pseudo-nitzschia*	CA coast. Include all commercial shellfish growers, µg toxin / g tissue (ppm)	CDPH biotoxin monitoring & phytoplankton monitoring networks; RA pier-based sampling.	Increased number of sample sites and frequency of sampling; rapid toxin detection methods
2. Issue public health advi-sories and warnings	Spatial distribution of phytoplankton levels, community composition, and presence of toxic species; future movement and expected duration of bloom	Currents, winds, SST, SSS, Chla, NO_3, PO_4, $Si(OH)_4$, ocean color; HAB abundance and DA conc; zooplankton, small and large detritus, dynamic phytoplankton carbon to chlorophyll ratio	CA coast, to 15 and 20 kms offshore, 1-4 km^2	CDPH biotoxin monitoring & phytoplankton monitoring networks. RA pier-based sampling. NDBC buoys, CDIP buoys, HF radar, gliders, satellites. Ocean condition indices. HABMAP alerts	Offshore sampling of phytoplankton and toxins; forecasts (0-36h) of direction and speed of bloom movement; statistical habitat models for Pseudo-nitzschia blooms & domoic acid concentration; NPZD biogeochemical model coupled to ROMS; model for dissipation of HABs
4. Focus and intensify sampling efforts	Physico-chem and biological ocean parameters; short term forecasts on changing ocean conditions that influence HAB formation	Currents, wind stress (Ekman transport), SST, SSS, Chla fluorescence	CA coast, to 15 and 20 kms offshore, 1-4 km^2	CDPH biotoxin monitoring & phytoplankton monitoring networks. RA pier-based sampling. NDBC buoys, CDIP buoys, HF radar, gliders, satellites. Ocean condition indices. HABMAP alerts	Offshore sampling of phytoplankton and toxins. forecasts (0-36h) of direction and speed of movement bloom; statistical habitat models for Pseudo-nitzschia blooms & domoic acid concentration; NPZD biogeochemical model coupled to ROMS; model for dissipation of HABs
5. Improve effectiveness of monitoring	Long-term time series of species composition and shifts in dominant groups (diatoms	Annual to decadal frequency, duration, and intensity HABs	CA coast	CDPH biotoxin monitoring & phytoplankton monitoring networks; RA pier-based	Offshore sampling of phytoplankton and toxins.

Management decision or activity	Information products	Product components and key inputs	Location, coverage, resolution	Key existing Assets	Gaps/ Needs / notes
program and quarantine practices	versus dinoflagellates). Long-term (seasonal/interannual, decadal) forecasts .			sampling. Ocean condition indices	
6. Determine potential HAB impacts on living marine resources, ecosystems	Strandings of birds, sea lions, dolphins, otters, etc. Analyses of serum, urine, feces, stomach contents, kidney tissue	Animal strandings; cell counts of Alexandrium and Pseudo-nitzschia in areas of strandings; toxin concentrations in animal tissue, body fluids, and stomach contents/feces	CA coast	Southwest Region Marine Mammal Stranding Network; CDPH biotoxin monitoring & phytoplankton monitoring networks	Offshore sampling of phytoplankton and toxins.
7. Focus watch efforts and recovery resources for rapid res-ponse to strandings	Short term predictions on changing ocean conditions that influence HAB formation; HAB location, size and extent, and forecast (0-36h) of direction and speed of movement	Currents, wind stress (Ekman transport), SST, SSS, Chla fluorescence	CA coast, to 15 and 20 kms offshore, 1-4 km^2	CDPH biotoxin monitoring & phytoplankton monitoring networks. RA pier-based sampling. NDBC buoys, CDIP buoys, HF radar, gliders, satellites. Ocean condition indices	Offshore sampling of phytoplankton and toxins; forecasts (0-36h) of direction and speed of movement bloom
8. When to return wildlife to environment	Short term predictions on changing ocean conditions that influence HAB formation; HAB location, size and extent, and forecast (0-36h) of direction and speed of movement; forecast of bloom dissipation	Currents, wind stress (Ekman transport), SST, SSS, Chla fluorescence	CA coast, to 15 and 20 kms offshore, 1-4 km^2	CDPH biotoxin monitoring & phytoplankton monitoring networks. RA pier-based sampling. . NDBC buoys, CDIP buoys, HF radar, gliders, satellites. Ocean condition indices	Offshore sampling of phytoplankton and toxins; forecasts (0-36h) of direction and speed of movement bloom
9. Should nutrient prevention, reduction, removal be required of POTW?	Historical records of HAB events; estimates of nutrients from discharge plumes to specific locations (hindcasts); Long-term forecasts	Continuous time-series SST, SSS, Chla fluorescence from piers. Nutrients from POTW effluents (Total N/ Total P, dissolved inorganic nutrients -ammonium, nitrate + nitrite, nitrite, phosphate silicate, particulate P and N, organic carbon, urea). HAB species counts *Pseudo-nitzschia,*	Southern California Bight (SCB), 1 km	RA pier-mounted sampling for continuous time series; Periodic SCCWRP Bight programs shipboard sampling; NDBC buoys –SST; USGS stormwater monitoring sites; satellite data: - JPL Remote Sensing; MODIS SST / Color; OCM Ocean Color;	Estimation the four principal nutrient sources to the Bight (atmospheric deposition, terrestrial runoff, upwelling, and POTW discharge); statistical habitat models for Pseudo-nitzschia blooms & domoic acid concentration; NPZD biogeochemical model

Management decision or activity	Information products	Product components and key inputs	Location, coverage, resolution	Key existing Assets	Gaps/ Needs / notes
		Alexandrium, L. polyedrum, P. dinophysis, A. sanguineum, C. phaeocystis		Optimally Interpolated SST; GOES hourly satellite images	coupled to ROMS
10. Aquaculture operations: timing of product harvesting - when should product be harvested to avoid exposure?	Short term predictions on changing ocean conditions that influence HAB formation; HAB location, size and extent, and forecast (0-36h) of direction and speed of movement; forecast of bloom dissipation	Continuous time-series SST, SSS, Chla fluorescence	Nearshore, in vicinity of shellfish beds, out to 15km	CDPH biotoxin monitoring & phytoplankton monitoring networks. RA pier-based sampling. . NDBC buoys, CDIP buoys, HF radar, gliders, satellites. Ocean condition indices	Offshore sampling of phytoplankton and toxins. forecasts (0-36h) of direction and speed of movement bloom; statistical habitat models for Pseudo-nitzschia blooms & domoic acid concentration; NPZD biogeochemical model coupled to ROMS, model for dissipation of HABs
11. Desalination plant operations: suspend or restrict seawater intake when probability of algal blooms high	Physico-chem and biological ocean parameters; short term predictions on changing ocean conditions that influence HAB formation; HAB location, size and extent, and forecast (0-36h) of direction and speed of movement; forecast of bloom dissipation	Continuous time-series SST, SSS, Chla fluorescence, total suspended solids	Nearshore, in vicinity of desal plant intakes, out to 20km	CDPH biotoxin monitoring & phytoplankton monitoring networks. RA pier-based sampling. . NDBC buoys, CDIP buoys, HF radar, gliders, satellites. Ocean condition indices	Offshore sampling of phytoplankton and toxins. Sampling near seawater intakes. Forecasts (0-36h) of direction and speed of movement bloom; Statistical Habitat Models for Pseudo-nitzschia blooms & domoic acid concentration; NPZD biogeochemical model coupled to ROMS, model for dissipation of HABs

Table A.2.9. Information needs associated with oil spill -related management decisions. Each higher-level decision category in column 1 is broken down into several subsidiary management decisions and management questions in column 2, each with its own set of information needs. These information needs are matched with more detailed observing system capabilities and gaps in Table A.2.10.

Decision category	Management decision or activity	Ocean information needed for decisions	Decision makers	Information product	When required
1. Oil spill preparedness	Determine where to focus prevention and response measures	Areas most susceptible to spills and that have high environmental and economic value and vulnerability	OSPR, CCC, BCDC (in SF Bay), SLC Marine Facilities Division, SWRCB, Area Planning Committees (APCs), NOAA, USFWS	Sensitive site locations: Shoreline Rankings, based on their sensitivity, the natural persistence of oil, and the expected ease of cleanup. Biological Resources, oil-sensitive wildlife, as well as habitats that either (a) are used by oil-sensitive wildlife, or (b) are themselves sensitive to spilled oil. Human-Use Resources, resources and places important to humans and sensitive to oiling, such as public beaches and parks, marine sanctuaries, water intakes, and archaeological sites (Muska, 2006)	Pre-spill
2.		Probabilities that a specific type of oil will move from a specified spill site to a designated target location	OSPR, NOAA OR&R	Historical (10yr) seasonal records of wind records, tidal currents, river flows, and wind-driven current patterns. Trajectory forecasts of large number of simulated spills. Weathering characteristics of oil used in simulations	Pre-spill
3.	Determine the fate and consequences of oil along a continuum of environmental conditions, from favorable to the worst case.	Adverse environmental conditions likely to occur, including timing, duration and frequency	OSPR, APCs, NOAA,	Climate and weather data Historical (10yr) seasonal records of wind records, tidal currents, river flows, and wind-driven current patterns	Pre-spill

Decision category	Management decision or activity	Ocean information needed for decisions	Decision makers	Information product	When required
				Trajectory forecasts of large number of simulated spills Weathering characteristics of oil used in simulations	
4.	Develop site specific spill response strategies	Available response options, conditions under which they can be used, and effectiveness	OSPR, APCs, Harbor Safety Committees, USCG	Response option technical data Physical constraints to mounting response (e.g., prevailing weather, site access)	Pre-spill
5. Oil spill response	Predict expected movement, behavior, and fate of spilled oil	Spill characteristics	USCG, OSPR	Oil quantity, type, composition and physico-chemical characteristics Weathering characteristics	Immediately
6.		Spill location, size, volume	USCG, OSPR	Aerial and satellite sensors, at sea surveys	Immediately and 1-2X daily thereafter.
7.		Likely path of spill	USCG, OSPR	Trajectory models Weathering models Real-time and forecasts of surface and water column currents, tides (if applicable), wind, and other weather Real-time waves	Day 1 and 1-2X daily thereafter.
8.	Determine what resources are at risk	At risk areas, resources	USCG, OSPR	Locations of marine wildlife and habitats that are in the area, in immediate danger or already impacted by the oil	Daily
9.	Determine type of response	Response options appropriate for the oil and conditions likely to be encountered	USCG, OSPR	Oil properties after weathering Metocean conditions Habitat type	Day 1, update as needed based on movement.

Decision category	Management decision or activity	Ocean information needed for decisions	Decision makers	Information product	When required
10. Damage assessment	Define "baseline" for natural resources and services that are likely to be or are anticipated to be injured (i.e., at risk) by oil spills	Status of the natural resources and services of concern	OSPR, other CDF&G, SCCC, WRCB, Regional and APCs, NOAA, DOI, USGS	Species richness, diversity, and abundance Natural variability of all populations in space and time Seasonal reproduction/ recruitment; feeding preferences, foraging ranges	Pre-spill
11.	Assess sensitivity	Mechanisms by which injury can occur	OSPR, other CDF&G, NOAA, DOI	Direct impacts- smothering, toxicity Indirect impacts- habitat loss, feeding or breeding disruption, loss of food sources	Pre-spill
12.	Evaluate and quantify potential injuries	Evidence indicating injury Potential degree and spatial and temporal extent of the injury Potential natural recovery period	OSPR, NOAA, USF&W	Documentation of wildlife and habitat conditions along spill trajectory	During spill and post-spill recovery
13.	Determine appropriate type and scale of restoration action.	Kinds of restoration actions that are feasible Capacity of replacement resources to provide the same type of services as those that were lost Opportunity for the replacement resources to supply the same type of services as those lost	OSPR, other CDF&G, NOAA, DOI	Ecological services include hydrological (floodwater storage, pollutant trapping),habitat/production (nutrient cycling, primary and secondary productivity) Human services include: recreational, commercial, cultural/historical, and passive use services.	During post-spill recovery

Table A.2.10. Detailed observing system capabilities and gaps matched with the oil spill decisions and information needs identified in Table A.2.9.

Management decision or activity	Information products	Product components and key inputs	Location, coverage, resolution	Key existing assets	Gaps / needs / notes
1. Determine where to focus prevention and response measures (Planning)	Sensitive site locations Impact probabilities	Inventories of shoreline types, biological resources, human-use resources Historical (10yr) seasonal records of wind, tidal currents, river flows, and wind-driven current patterns. Trajectory forecasts of large number of simulated spills. Weathering characteristics of oil used in simulations	CA coast	Shoreline Environmental Sensitivity Index (ESI), the CA Natural Diversity Data Base (CNDDB), coastal sensitive sites from the California statewide Area Contingency Plans (ACP) TAP II for San Francisco Bay and San Diego Bay ADIOS SINTEF oil weathering model GNOME	3-D circulation models for trajectories.
2. Determine the fate and consequences of oil along a continuum of environmental conditions, from favorable to the worst case.(Planning)	Trajectory forecasts of large number of simulated spills.	Climate and weather data Historical (10yr) seasonal records of wind records, tidal currents, river flows, and wind-driven current patterns. Weathering characteristics of oil used in simulations	CA coast	NOAA NWS, NCDC, NODC archives TAP II for San Francisco Bay and San Diego Bay ADIOS SINTEF oil weathering model GNOME	3-D circulation models for trajectories
3. Develop site specific spill response strategies (Planning)	Effectiveness of response technologies	Response option technical data. Physical constraints to mounting response (e.g., prevailing weather, site access)	CA coast	Coastal sensitive sites from the California statewide ACPs OSPR BAT reports	
4. Predict expected movement, behavior, and fate of spilled oil	Oil quantity, type, composition and physico-chemical characteristics, and	Laboratory analysis of oil Aerial and satellite sensors, at sea surveys Winds, currents, waves	Site of spill/discharge; potential impact area; km^2	OASIS & SINTEF oil weathering databases and models. GNOME	Technology/sensors to measure oil thickness Methodology for subsurface remote sensing

Management decision or activity	Information products	Product components and key inputs	Location, coverage, resolution	Key existing assets	Gaps / needs / notes
(Response)	weathering characteristics Location, extent, and quantity of spill Trajectory forecasts			Satellite and aerial remote sensors HF radar CDIP NOAA NWLON and PORTS NDBC Buoys	Submerged oil trajectory models
5. Determine what resources are at risk (Response)	Locations of marine wildlife and habitats that are in the area, in immediate danger or already impacted by the oil	Wildlife, intertidal, shoreline surveys	Potential impact area; km^2	Aerial reconnaissance OSPR GIS library	Biological impact model
6. Determine type of response (Response)	Oil properties after weathering Metocean conditions Coastal features and habitat types	Laboratory analysis of oil Real-time and forecast winds, currents, waves	Areas with sea surface and onshore oil	OASIS & SINTEF oil weathering databases and models. GNOME Satellite and aerial remote sensors HF radar CDIP NOAA NWLON and PORTS NDBC Buoys OSPR GIS library	
7. Define "baseline" for natural resources and services that are likely to be or are anticipated to be injured (i.e., at risk) by oil spills (Damage	Species richness, diversity, and abundance. Natural variability of all populations in space and time Seasonal reproduction/ recruitment; feeding preferences, foraging ranges.	Wildlife, intertidal, shoreline surveys Scientific literature	CA coast	OSPR GIS library	

Management decision or activity	Information products	Product components and key inputs	Location, coverage, resolution	Key existing assets	Gaps / needs / notes
assessment)					
8. Assess sensitivity (Damage Assessment)	Direct impacts- smothering, toxicity. Indirect impacts- habitat loss, feeding or breeding disruption, loss of food sources	Scientific literature	Organism and population level		
9. Evaluate and quantify potential injuries ((Damage Assessment)	Wildlife and habitat conditions along spill trajectory	Shoreline, intertidal, wildlife surveys - oiled marshes, oiled and dead wildlife, contamination of water bodies HC concentrations in water and sediment samples	Impacted areas	Aerial reconnaissance Wildlife recovery and rehabilitation networks	
10. Determine appropriate type and scale of restoration action. (Damage Assessment)	Before and after values of ecological and human services.	Ecological services include hydrological (floodwater storage, pollutant trapping),habitat/production (nutrient cycling, primary and secondary productivity) Human services include: recreational, commercial, cultural/historical, and passive use services.	Impacted areas	OSPR GIS library	

Table A.2.11a. Mapping existing OOS assets to information product needs for each management area. Abbreviations in the table include NCEP (National Centers for Environmental Prediction), MEI (Multivariate ENSO Index), BUI (Bakun Upwelling Index), CSMP (California Seafloor Mapping Program), CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization), SAR (Synthetic Aperture Radar), SCORE (Southern California Offshore RangE), AIS (Automatic Information Service), HARP (High-frequency acoustic recording package), TOPP (Tagging of Pacific Pelagics), CML (Census of Marine Life), WWIII (Wave Watch III), PORTS® (Physical Oceanographic Real-Time System).

	Asset[13]	SCOOP Issues	General Product Need	Variables[14]	Source	Location, Spatial Coverage / Resolution	Temporal Coverage / Resolution	Cost / Comments
1.	CDIP wave measurements and models (see Table A.2.11b)	Discharges Energy HABs Oil spills	Wave energy spectra	Wave energy as function of frequency and direction, significant wave ht, peak period and direction	CDIP, also uses NDBC buoys and NCEP WWIII model	6 deep water & 12 shallow water buoys off CA, plus 4-6 extras that get moved around; 4 NDBC buoys used	30 min data Hourly nowcasts Forecasts every 6 or 12 hrs	CDIP is supported by CA Dept. of Boating and Waterways and Army Corps of Engineers
2.	Gliders	Energy HABs Oil spills Salmon recovery	Circulation model Prediction of location of migratory species Environmental data for technology, development and assessment Water quality assessment Detection of submerged oil	Temperature, salinity, chlorophyll and CDOM fluorescence Depth-integrated currents (in near future)	SIO/IDG	CalCOFI lines 6, 80, 90; off Monterey, Pt. Conception, Dana Pt. 0-500 m depth 0-500 km offshore	2-4 months	$150K/glider, need ~2 gliders/line $110K/yr to operate one line continuously.

[13] e.g., platform, model, sampling program, instrument
[14] Other variables measured by this asset, but not identified as needed for SCOOP issue products, are not listed here.

	Asset[13]	SCOOP Issues	General Product Need	Variables[14]	Source	Location, Spatial Coverage / Resolution	Temporal Coverage / Resolution	Cost / Comments
3.	HF radar	Discharges HABs Oil spills	Real-time POTW and stormwater plumes, HAB, and oil location HAB and oil spill trajectories	Surface currents	SIO, NPS, BML, SFSU, Humboldt State	Whole state from coast out to ~ 130 km, with at least 6 km resolution	Hourly	~$3.6 M/yr to operate statewide system, including hardware replacement, data management, and technicians. In part OPC-funded. If higher spatial resolution is needed for N CA, then 4-5 additional antennae, at ~ $125K /antenna would be needed.
4.	High resolution bathymetry	Discharges Energy	Sediment transport Cable routing Nearshore circulation	Water depth; bottom type	CSMP	CA state waters		OPC funded
5.	MarineMap	Energy Oil spills	Geospatial data on sensitive areas	Legal and jurisdictional boundaries Use and environmental data	MarineMap consortia: UC Santa Barbara, Ecotrust, and The Nature Conservancy	State waters for one northern and one southern CA area		$230K to develop $400K/yr to maintain with science advisory team and analytics CA MarineMap work funded by MLPA initiative
6.	Multi-purpose moorings (e.g. MBARI OASIS moorings)	Discharges Energy HABs Salmon recovery	Vertical position of POTW and stormwater plumes in water column Ocean conditions influencing HAB formation, salmon prey availability Prediction of location of migratory species Environmental data for technology development and assessment Water quality assessment	Temperature, salinity, currents, fluorescence, wind stress, oxygen, other variables	MBARI	3 in or near Monterey Bay	10 min	$250K /mooring per year to operate. Initial procurement cost depends on instrumentation, but ~$200K is typical If for plume purposes only, and only temperature, salinity, velocity needed; may be less expensive

	Asset[13]	SCOOP Issues	General Product Need	Variables[14]	Source	Location, Spatial Coverage / Resolution	Temporal Coverage / Resolution	Cost / Comments
7.	NDBC moored buoys	Discharges Energy HABs Oil spills	Prediction of spill and discharge movements HAB trajectory	Wind Directional wave spectra Sea surface temperature	NOAA	Whole state	Hourly	Also see CDIP
8.	Nearshore wave and circulation model	Discharges Energy Oil spills Salmon recovery	Discharge plume and oil spill tracking Sediment transport Nearshore wave height	Alongshore currents in the surfzone	SCCOOS (Federson's surfzone model)	Currently in operational use for Huntington Beach and La Jolla areas		$1M to validate statewide In R&D status statewide Need site specific in-situ validation for nearshore currents product Same model is basis for inundation forecasts in Carmel Bay and nearshore wave heights being used in other product development efforts.
9.	NPZD model	Discharges HABs Salmon recovery	Coupled bio-physical models	Nutrients, phytoplankton, zooplankton, detritus	JPL, Univ. Maine	Linked to ROMS	Linked to ROMS	Likely similar to ROMS, but may require funds for field testing CoSINE NPZD models part of two recently funded projects-NASA salmon forecasting, HAB OPC forecasting; full development and ongoing use not included
10.	Ocean Condition Indices; e.g. MEI, BUI	HABs Salmon recovery	Forecasting models	Temperature, salinity, currents, winds	NOAA, NASA	Basin scale and west coast Resolution varies by index		

Asset[13]	SCOOP Issues	General Product Need	Variables[14]	Source	Location, Spatial Coverage / Resolution	Temporal Coverage / Resolution	Cost / Comments
11. Pier stations	Discharges Energy HABS	Water quality (WQ) Direction of spill and discharge movement (uses wind) HAB monitoring	Temperature, salinity, pH, turbidity plus oxygen, chlorophyll, wind at some stations Plankton concentrations	CSU, SIO, CeNCOOS, SCCOOS, Cal Poly, UCSB, USC, UCLA, MLML, UCSC	8 WQ stns between Trinidad and Long Beach, plus Scripps Pier (wind); HAB monitoring at 6 S CA piers plus Monterey and Santa Cruz wharves	Real-time; resolution on order of minutes for WQ Weekly data for HABs	
12. ROMS (see Table A.2.11b)	Energy HABs Salmon recovery	Coupled bio-physical models; Prediction of location of migratory species	Temperature, salinity, sea surface height, currents	JPL	Soon to be statewide with 3 km resolution; out to ~300 km from coast	Hourly, with 6-hourly data assimilation	$150K / yr COCMP contributed to development.
13. Satellites	Energy HABs Oil spills Salmon recovery	Position and size of blooms and oil slicks Ocean conditions influencing HAB formation and salmon prey availability Prediction of location of migratory species	Sea surface temperature, ocean color, wind	NOAA, NASA	Whole ocean Spatial resolution ~ 1 km, but depends on satellite and variable	Depends on satellite, variable, and weather ~1x/hr - 1x/day MODIS: 2300 km, 2x/day with 250 m horizontal resolution	National asset MODIS can't determine thickness of oil below sea surface; atmospheric haze and clouds can interfere with image data, making positive identification of a plume unreliable CALIOP capable of determining oil slick thickness, enabling quantification of spill with no interference from clouds Satellite-based SAR useful under low-to-moderate wind conditions.

Asset[13]	SCOOP Issues	General Product Need	Variables[14]	Source	Location, Spatial Coverage / Resolution	Temporal Coverage / Resolution	Cost / Comments
14. Ship surveys	Discharges Energy HABs Salmon recovery	Prey availability Location of marine mammals and other wildlife Prediction of location of migratory species Environmental data for technology development and assessment Discharge, water quality, and ecosystem assessment	Temperature, salinity, plankton, marine mammals, seabirds, benthic and fish communities, tissue contamination, other variables	CalCOFI; NMFS	Southern CA, central CA; ≤ 70 km (CalCOFI); statewide (NMFS)	2-4 times per year Annually for NMFS rockfish surveys	CalCOFI includes 9 nearshore SCCOOS stations. Other regional ship surveys conducted by Bight Program and CCLEAN
15. Water Level Stations	Discharges Oil spills	Prediction of spill and discharge trajectories	Water level, wind (at some stations)	NOS/NOAA	Whole state	6 min	
16. Beach sampling	Discharges	Degree of contamination and health risk	Bacterial indicators and pathogens	POTWs, stormwater, health depts	All swimming beaches; spatial intensity varies by location and season	Daily to weekly or less, depending on location and season	Rapid indicators can provide results more quickly but have sampling and analysis constraints
17. C-MAN stations	Discharges	Direction of discharge movement	Wind speed and direction	NOAA	At points along coast and islands	Hourly	
18. Effluent and dis-charge monitoring	Discharges	Discharge volume, levels and loads of contaminants	Flow, volume, constituent concentrations	POTW and storm-water monitoring programs	POTWs, river, stream, creek mouths	Ongoing and frequent for POTWs Selected storm events for stormwater programs	
19. AIS Ship tracking	Energy	Ambient noise	Ship type and position	CeNCOOS; SCCOOS	Pt. Arena - Pt. Conception and southern CA (nearshore)	Real-time; continuous	

	Asset[13]	SCOOP Issues	General Product Need	Variables[14]	Source	Location, Spatial Coverage / Resolution	Temporal Coverage / Resolution	Cost / Comments
20.	HARPs	Energy	Ambient noise Location of marine mammals	Underwater sound / noise	NPS, SIO	Pt Sur, S CA	Pt Sur HARP turned around at 6 mon intervals Data from SCORE is real-time.	~ $50K / HARP Instruments and data collection are primarily Navy funded. Raw data from SCORE is classified. Data is not currently integrated with OOS data. Proposals in response to recent RFPs may take steps in that direction.
21.	MMC	Energy	Geospatial data on competing uses	Mostly legal and jurisdictional boundaries Some environmental data	NOAA	All U.S. waters		Developed for offshore energy planning; includes state and offshore waters
22.	TOPP	Energy	Location of migratory species	Location of a variety of tagged wildlife; some other data available from some types of tags	TOPP	Worldwide	Archival, pop-up and satellite tags used; the last conveys data in near real-time via satellite	TOPP is a CML project
23.	Phytoplankton sampling	HABs	Distribution and relative abundance of Alexandrium and Pseudo-nitzschia	Alexandrium and Pseudo-nitzschia cell counts	CDPH	139 sites statewide	Weekly	Volunteer network
24.	Shellfish sampling	HABs	Biotoxin presence	Domoic acid PSP concentration	CDPH	77 sites statewide	Weekly	

	Asset[13]	SCOOP Issues	General Product Need	Variables[14]	Source	Location, Spatial Coverage / Resolution	Temporal Coverage / Resolution	Cost / Comments
25.	Aircraft	Oil spills	Locations of marine wildlife relative to oil Location, condition and oil thickness estimate Input and validation data for oil spill trajectory forecast models	Visual observation of wildlife Spectrometer measurements High Spectral Resolution Lidar (HSRL)	CDG aircraft, NASA aircraft	Statewide	Variable Near real-time	State and national assets NASA Airborne Visible /Infrared Imaging Spectrometer (AVIRIS)
26.	PORTS®	Oil spills	Prediction of oil spill trajectory	Wind, waves, currents, water level, SST, conductivity	NOS/NOAA	SF Bay; Long Beach / Los Angeles	6 min	At LA/LB: wind speed and direction & misc met At SF Bay, also currents; SST and waves from CDIP buoys
27.	Fish tagging	Salmon recovery	Abundance and distribution estimates	Fish location, age composition	CDFG, POST, NMFS	CWT covers Central and N CA POST line Pt Reyes	CWT--spring and summer	
28.	Genetic catch sampling	Salmon recovery	Species and run-specific salmon distribution and migration	Salmon genetic ID Link to location and temperature, currents, ocean condition indices	CA Salmon Council (fishing organization), NMFS	Central and N CA -- sample each PFMC management area	Spring and summer	$150K (if fishery is open and fishermen collect samples) Much more expensive to do if fishery is closed and must be conducted via chartered vessels

Table A.2.11b. Examples of OOS models or programs that rely on multiple assets for inputs and/or consist of multiple capabilities. Abbreviations in the table that are not previously defined include JAXA (Japan Aerospace Exploration Agency) and WRF (Weather Research & Forecasting).

Capability		Component	Platform (or model)	Variables	Source	Location, spatial coverage	Temporal resolution	Needs and gaps
1.	ROMS (circulation model)	Data assimilation	Satellite	Sea surface temperature	NOAA, NASA, ESA, JAXA	Whole ocean; 1 km resolution	Temporal repeat varies depending on the satellite; uses all data available within a 6 hr window	
2.		Data assimilation	Gliders	Temperature, salinity, depth-integrated currents (in near future)	SIO/IDG	CalCOFI lines 6, 80, 90; off Monterey, Pt. Conception, Dana Pt. 0-500 m depth; 0 - 500 km offshore	2 – 4 months	More lines, especially north of San Francisco, and along shore, would help constrain model
3.		Data assimilation	HF radar	Surface currents	SIO, NPS, BML, SFSU, Humboldt State	Whole state from coast out to ~ 130 km; 1-km for short range, and 6-km for long-range	Hourly	Entire CA coastline covered with at least low spatial resolution (6 km). If higher spatial resolution is needed for N CA, then 4-5 additional antennae, at ~ $125K/antenna would be needed.
4.		Data assimilation	Moorings	Temperature, salinity	MBARI	3 in or near Monterey Bay	10 minutes	Need at least one permanent mooring in the southern California
5.		Atmospheric forcing	COAMPS® for CeNCOOS region and WRF model for SCCOOS region	Wind stress, surface heat flux	NRL for CeNCOOS and JPL/UCLA for SCCOOS	3-4 km	Hourly	No high resolution atmospheric model available for whole state. Can't get wind stress curl well enough with NCEP North American 12 km spatial resolution model.

Capability		Component	Platform (or model)	Variables	Source	Location, spatial coverage	Temporal resolution	Needs and gaps
6.		Boundary conditions	Large scale data assimilating model	Temperature, salinity, sea surface height, currents	JPL	Covers whole U.S. West Coast out to 300-500 km, with 15 km resolution	Hourly, with 6-hourly data assimilation	Depends on proposal cycle, no sustained funding to maintain a long-term operation
7.		24/7 model nowcasts and forecasts	ROMS	Temperature, salinity, sea surface height, currents	JPL	Currently 1-km for southern California, and 1.5-km for MB; soon to be statewide with 3 km resolution; out to 300 km from coast	Hourly, with 6-hourly data assimilation	Depends on proposal cycle, no sustained funding to maintain a long-term operation
8.	CDIP (wave ht, period, dir)	Wave measure-ments used for Refraction model forcing, assimilation, and validation	Directional wave buoys	Wave energy as function of frequency and direction, significant wave ht, peak period and direction	CDIP, NDBC	6 deep water and 12 shallow water buoys off CA, plus 4-6 extras that get moved around; 4 NDBC buoys used	30 minutes	Outer buoys are used for swell models, inner ones for sea and swell
9.		Wave model used to force Refraction model	WaveWatchIII	Swell ht, period, and direction	NOAA / NCEP	World ocean	4 times per day	Used as input to CDIP forecasts
10.		Regional wave model	Refraction	Significant wave ht, peak period and direction	CDIP	Statewide; 100 m resolution	Hourly nowcasts; forecasts every 6 or 12 hrs	Swell only (periods > 8 s) for outer continental shelf and S CA Bight Sea and swell (2-30 s periods) for region from 15 m depth - 10 km offshore
11.		Surfzone wave model	Federson	Nearshore waves, alongshore current	CDIP	Limited; case by case basis		Still experimental; needs validation
12.		Bathymetry				Need ~100m resolution		