PUBLIC HEALTH WORKSHOP REPORT
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PUBLIC HEALTH RISKS:
COASTAL OBSERVATIONS FOR DECISION-MAKING

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Public Health Risks: Coastal Observations for Decision-Making

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EXECUTIVE SUMMARY

While the oceans provide resources critical to human survival and well-being, they also pose dangers, including exposure to aquatic toxins and pathogens. Burgeoning development along our coasts increases the risks of exposure from point and non-point discharges of human and animal wastes, non-point inputs of anthropogenic nutrients, and vulnerability to coastal flooding. Managing and mitigating human health threats requires better knowledge and sustained monitoring of the links between ocean processes and health, especially the risks encountered from recreational use of waters and the consumption of shellfish. Public health risks from these human uses can and should be assessed in a more timely fashion and predicted with greater accuracy. Decisions are severely hampered by *a lack of accurate and timely data and information.*

Monitoring techniques and requirements for estimating the risks of exposure to pathogens and toxins are in critical need of upgrading. The most commonly used indicator of human health risks in shellfish today is the concentration of fecal coliform bacteria. *Escherichia coli* is the specific bacterial indicator for fresh water and *Enterococcus* for salt water. Although these organisms are relatively easy to measure:

1) they do not indicate concentrations of other microbial pathogens, or their risk to humans;
2) it can take up to 48 hours to obtain results, during which aquatic concentrations and associated risks can change;
3) they do not predict health risks from microbes in the water body or when toxins are accumulated by seafood.

As a result, health risks are at times unacceptably high, a situation that is not known until the risk has passed. Conversely, beaches and shellfish beds may be closed longer than warranted, causing unnecessary economic losses. Newer methods have the potential to overcome these shortcomings in terms of both accuracy and timeliness.

Toxins produced during harmful algal blooms also present serious risks, and understanding, assessment, and prediction of these phenomena are very limited. By combining surveys of waterborne pathogens and toxic algae with measurements of environmental parameters (marine meteorology, water temperature and salinity, ocean color, surface currents, and waves) and models of coastal circulation, changes in risk can be detected more rapidly and predicted with greater accuracy. The U.S. is now in the process of designing and implementing an Integrated Ocean Observing System to provide data and information to meet seven societal needs, one of which is to reduce public health risks from exposure to waterborne pathogens, harmful algae and their associated toxins, and contaminated fish. Specifically, the IOOS will collect information on variations in physical, chemical, and biological parameters across time and space for incorporation into models that provide timely and reliable information to risk assessors and managers.

This report summarizes the findings, conclusions, and recommendations of a three-day workshop titled "Public Health Risks: Coastal Observations for Decision Making" held January 23-25, 2006, in St. Petersburg, Florida. A representative group of public health officials, coastal zone managers, and oceanographers from all regions were tasked by organizers with the following goals:

1. *Identify decision processes and critical information gaps experienced by coastal public health officials that could be filled by the Integrated Ocean Observing System, with a specific focus on reducing the risk of illness or injury from direct human exposure to coastal waters from:*
   a. *Microbial pathogens*
   b. *Marine biotoxins and harmful algal blooms (HABs)*
   c. *Emerging coastal public health threats*

(Note that effects of contaminated fish and shellfish were not chosen as a separate category, although it was acknowledged at the workshop as a risk that warrants further attention.)

2. *Identify coastal water quality information needed to make more timely public health, closure or advisory decisions through the use of predictive models and improved monitoring techniques, including data and information that will improve local and regional models used to predict risk of water (marine)-borne diseases.*

3. *Prioritize data and information parameters required to fill the above gaps.*

4. *Develop a mechanism to maintain the involvement of this community (managers, public health officials, and oceanographers) in efforts to ensure the timely flow of accurate, integrated and sustained ocean and coastal data and information for public health benefit.*

Workshop participants concluded that an Integrated Ocean Observing System (IOOS) is critical to improving the ability of decision-makers to manage and mitigate public health threats more effectively. To achieve these goals, participants agreed that the IOOS must:

- Increase the accuracy and timeliness of estimates of the concentration and distribution of waterborne pathogens, toxic algae, and their toxins. Identify more accurate indicators of risk and improve measurement techniques to reduce time lags between sample collection and the availability of results. Molecular, optical, and hybrid methods should be considered.

- Conduct more near-shore sampling, including measurements of waterborne pathogens, toxic algae and their toxins, at times and locations that match the measurements of environmental parameters that determine their survival rates and distributions
- Increase environmental observations (e.g., vector winds, temperature, salinity, waves, and currents) on time and space scales relevant to the population dynamics of waterborne pathogens and harmful algae by deploying adaptive sensing platforms near HAB hot spots and nutrient sources, combined sewer outfalls, and other point and non-point contamination sources as appropriate
- Support improved utilization of near real-time multi-sensor satellite data and products for public health applications (e.g., detection & fate and transport of pollutants/pathogens, blooms) and develop new and improved remote sensing capabilities and derived, user-driven, information products (e.g., water quality assessments - proxies & indicators to support beach closure decisions)
- Implement national standards and protocols for biological, chemical, and physical data measurements, data management and communications, and modeling
- Conduct baseline assessments and connect environmental and epidemiological databases to improve risk assessment capabilities
- Specify chemical, physical, and biological data requirements for predicting the development of HABs and their trajectories
- Develop and validate coupled physical-pathogen transport models for nowcasting risks and forecasting changes in risks with known accuracy
- Develop and improve near-shore circulation models that link land-based inputs and near-shore processes with better offshore boundary conditions. Incorporate pathogen and algal biology into these models.
- Provide the data and information needed to quantify relationships between changes in land use and land-based inputs to coastal waters and changes in public health risks
- Support the development of methods for real-time, *in situ* detection measurements of microbial indicators or pathogens for more accurate and timely warnings and advisories for closing and opening beaches and shellfish beds
- Foster cooperation and collaboration among research disciplines, e.g., between medical practitioners and ocean scientists

In order to effectively carry out these recommendations, the participants also emphasized the need for:

- A new paradigm of coordination among public health and environmental protection officials, living resource and coastal zone managers, and oceanographers and coastal hydrologists to develop an IOOS that meets their collective needs
- More effective use of the internet and other electronic media to transmit relevant data to public health officials so that they can issue timely warnings to the public
- Stronger stakeholder coordination and use of IOOS Regional Associations to help identify regional needs, train users, and guide the integration of public health requirements into the IOOS. Participation of coastal managers, public health practitioners, and stakeholders responsible for beach and shellfish management in the Regional Associations.

IOOS development is driven by the data and information needs of user groups. The above recommendations provide guidelines for developing an IOOS that meets the data and information needs of decision makers responsible for minimizing health risks from waterborne pathogens and toxic algae. A mature IOOS will allow managers to anticipate risk instead of react to it. Critical decisions that apply to closures and openings of beaches and shellfish beds can be based on real-time health risk assessments, timely predictions of changes in risk, and detailed knowledge of human risk pathways. Ultimately, the IOOS will unite experts in a common decision framework and provide for a smooth flow of health-based information to the public.

In 2000 Congress passed the BEACH Act, which created the EPA Beaches Program to strengthen beach standards and testing activities, provide faster laboratory test methods, predict pollution, invest in epidemiological and methods research, and inform the public. EPA was also specifically tasked with identifying new indicators for pathogens for recreational water (new bacteria criteria). Once completed, states will be required to adopt the new standards and procedures. Recommendations from the workshop confirm the importance of EPA's present work to carry out the BEACH Act.
(See www.epa.gov/waterscience/beaches/)

INTRODUCTION

In 1998, Congress called for the development of an Integrated Ocean Observing System (IOOS) for the oceans and the nation's coastal waters (including the Great Lakes) to provide data and information needed to address seven societal goals:

(1) Improve predictions of climate change and weather and their effects on coastal communities and the nation;
(2) Improve the safety and efficiency of maritime operations;
(3) More effectively mitigate the effects of natural hazards;
(4) Improve national and homeland security;
(5) Reduce public health risks;
(6) More effectively protect and restore healthy coastal ecosystems; and
(7) Enable the sustained use of ocean and coastal resources.[1]

Plans for the IOOS are being developed under the auspices of the National Oceanographic Partnership Program (NOPP), established by law in 1997 to facilitate interaction among federal agencies, academia, and industry; to increase visibility for ocean issues on the national agenda; and to achieve a higher level of coordinated effort among the broad oceanographic community.[2] One of NOPP's four main goals is the creation of a sustainable IOOS. The need for such a system for the public good was underscored by the U.S. Commission of Ocean Policy in its report "An Ocean Blueprint for the 21st Century," which cited a lack of sufficient attention devoted to the links between the ocean and human health.[3] The group stressed the importance of reducing the negative health impacts of marine microorganisms caused by harmful algal blooms, marine bacteria and viruses, contaminated seafood, and global climate change. In addition to expanded research, it called for improved methods for monitoring and identifying pathogens and chemical toxins in ocean and coastal waters and in organisms.

Just as the National Weather Service continuously monitors meteorological variables for weather forecasting, the IOOS must engage in sustained observations, data management and modeling to provide data and information needed to achieve its stated goals. In short, the IOOS must routinely, reliably and continuously acquire and disseminate data and information on past, present, and future states of the oceans, the nation's coastal waters, and the Great Lakes. Although each societal goal has unique requirements for data and information, many shared data and information needs can be addressed through an integrated approach to environmental observations, data management and modeling.

It is important to emphasize that the IOOS must be user-driven in order to provide data and information in forms and at rates required by decision makers. To this end, Ocean.US, the federal interagency office for coordinating the implementation of the IOOS, conducted a series of workshops and conferences that led to the First IOOS Development Plan released in early 2006. The plan recommends an initial IOOS that addresses all of the societal goals except reducing public health risks. A major objective of this workshop was to fill this gap – to bring the oceanographic and public health communities together to specify observing system requirements that must be met to lessen the risk of marine toxins and pollutants from point and non-point inputs to coastal waters.

The Beaches Program, established by the BEACH (Beach Environmental Assessment and Coastal Health) Act of 2000, is the primary nation-wide program for monitoring human pathogens in coastal recreational waters. In October 2004 the Environmental Protection Agency (EPA), which administers the Program, organized a National Beaches Conference to provide a forum for learning about beach health initiatives across the country; presenting new methods, indicators, and modeling techniques; identifying beach health needs; discussing priorities for short-term and long-term actions; and recommending protocols and procedures to encourage greater consistency among jurisdictions.[4] Participants at the Conference recognized the potential mutual benefits of incorporating activities conducted under the Beach Act into the IOOS and called for collaboration. In addition, the National Oceanographic Partnership Program's Ocean Research and Resources Advisory Panel urged the National Oceanic and Atmospheric Administration (NOAA) to improve coordination with health agencies at its June 2005 meeting and endorsed a workshop to address public health issues. A number of other federal agencies have responsibilities for health-related coastal research and monitoring, including the National Aeronautics and Space Administration (NASA), the National Science Foundation, the U.S. Geological Survey, the National Institutes of Health, and the Centers for Disease Control and Prevention.

[1] Ocean.US, 2006. *The First U.S. Integrated Ocean Observing System (IOOS) Development Plan,* Publication No. 9, 86 pp. (http://www.ocean.us/documents/docs/IOOSDevPlan_low-res.pdf)
[2] www.nopp.org
[3] U.S. Commission on Ocean Policy, 2004. *An Ocean Blueprint for the 21st Century.* Final Report, Washington, D.C. (www.oceancommission.gov)
[4] U.S. Environmental Protection Agency. Proceedings of the 2004 National Beaches Conference, March 2005. EPA-823-R-05-001. (http://www.epa.gov/waterscience/beaches/meetings/2004/index.htm)

NOAA and EPA engaged these agencies in a dialogue to consider the inclusion of health risk assessment in the IOOS. The first step was a workshop organized to assess the needs for coastal observations requirements for improved for decision-making, held January 23-25, 2006, in St. Petersburg, Florida. A steering committee of senior officials from NOAA, EPA, and other agencies worked for one year to develop and refine the goals and agenda of the workshop (see Appendix A) and to select over 75 decision-makers and scientists from county, state, and federal agencies, non-profit organizations, and academia. The list of participants is given in Appendix B. The steering committee recognized that many disciplines need to be involved. Initial attention would be given to water-borne microbial pathogens and harmful algal blooms, both of which present a possible risk of illness from direct exposure. Though some regions (e.g., Great Lakes) face unique water quality issues, all can learn from one another. Expected outcomes of the workshop were:

- A blueprint for ocean and coastal observations for public health – relevant findings of this workshop and guidance for IOOS.
- A description of one or more pilot projects for developing or testing new products or information, with performance metrics identified. Such a description could be used by NOPP agencies in considering options for IOOS pilot projects.
- Recommendations for next steps, responsibilities, and pathways for ongoing communication.

This report presents the results of the workshop, its conclusions, recommendations, and topics for suggested pilot projects.

I. Public Health and the Coasts: 21st Century Challenges

Human health and the oceans are indelibly linked. Oceans cover roughly 70% of the planet, provide critical sources of dietary protein, and generate services that include tourism, recreational opportunities, and employment. Coastal activities contribute $117 billion and 2 million jobs to the U.S. economy alone—a reflection of their economic importance.[5] According to the initial conclusions of a 2005 NOPP study to estimate the economic benefits of regional observing systems, IOOS data and information could result in increased annual revenues from beach recreation (due to fewer lost days and improved safety) by $94 million in California and $50 million in Florida alone.[6]

But even as the oceans sustain human life and contribute to our economy, they also pose numerous health threats. In many areas, storms, coastal erosion, and flooding have become more intense, producing significant economic, ecological, and human health impacts. Many cities, especially older cities, have combined storm water and sewer drainage systems that discharge bacteria and other pollutants into streams, rivers, and coastal estuaries during heavy rains. Bacterial pathogens from sewage and fecal matter pose human health risks from consumption of contaminated shellfish, and from contact with contaminated waters.[7] Toxic algae also threaten humans through similar routes of exposure, and evidence suggests these threats too may be rising.

A. Coastal Development

A key factor exacerbating ocean-borne health risks is coastal development. Coastal counties cover less than 20% of U.S. land area, but they account for more than half the nation's population. Seventeen of the 20 fastest growing counties in the United States border the coast.[8] Studies have shown that when pavement covers at least 10% of watershed acreage, nearby rivers and streams become degraded. These systems funnel oil, nutrients, and other pollutants directly into coastal estuaries. Sewage discharges also contain nutrients that can promote the growth of algae, including harmful species.[9] The result of current trends in coastal development is an increasing number of people interacting with the coast and deteriorating water quality conditions.

[5] National Ocean Economics Project, www.oceaneconomics.org
[6] Kite-Powell, H.L., C.S. Colgan, K.F. Wellman, T. Pelsoci,, K. Wieand, L. Pendleton, M.J. Kaiser, A. G. Pulsipher, and M. Luger, 2005. *Estimating the Economic Benefits of Regional Ocean Observing Systems*. Woods Hole Oceanographic Institution, Technical Report WHOI-2005-03, 128 pp.
[7] Dorfman, M. Testing the Waters 2005: A Guide to Water Quality at Vacation Beaches. New York, N.Y: Natural Resources Defense Council, 2005.
[8] Crossett, K.M., T.J. Culliton, P.C. Wiley, and T.R. Goodspeed. 2004. *Population Trends along the Coastal United States: 1980-2008*. National Oceanic and Atmospheric Administration, NOAA's National Ocean Service, Special Projects: Silver Spring, MD.
[9] National Research Council. *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution*. Washington, DC: National Academy Press, 2000.

TABLE 1 – Estimated Annual Economic Impacts From Harmful Algal Blooms In The U.S.[10]
(Estimate for 1987-1992, reported in 2000 dollars)

	LOW	HIGH	AVERAGE
Public Health	$18,493,825	$24,912,544	$22,202,597
Commercial Fisheries	$13,400,691	$25,265,896	$18,407,948
Recreation & Tourism	-	$29,304,357	$ 6,630,415
Monitoring and Management	$ 2,029,955	$ 2,124,307	$ 2,088,885
TOTAL	$33,924,471	$81,607,104	$49,329,845

B. Toxic Algae

People are typically exposed to HAB toxins when they eat contaminated fish and shellfish.[11] Toxins released to the air by mechanical processes such as breaking waves can also be inhaled, triggering asthma reactions in susceptible people, in addition to a variety of respiratory and eye pathologies. Illnesses produced by HAB exposure include several "shellfish poisoning syndromes," each named according to its individual symptoms; i.e. paralytic shellfish poisoning (PSP), neurotoxic shellfish poisoning (NSP), and amnesic shellfish poisoning (ASP), among others. Dermal contact and dermal absorption are also of concern.

A report produced by the Ecological Society of America, the Harmful Algal Research and Response National Environmental Science Strategy,[12] concludes that HAB outbreaks are increasing worldwide, both in ocean and in freshwater systems. Accurate descriptions of the rate of increase are not available due to a lack of data concerning HAB abundance and distribution. Although harmful algal species occur naturally in aquatic systems, human activities—including sewage discharge, agriculture, and ballast water discharge—appear to be increasing the frequency with which they affect human health. Conservative estimates indicate that harmful algal blooms cost the nation's fishing and tourism industries $50 million annually.[13] Table 1 lists estimated ranges of impacts by sector.

C. Pathogens from Sewage and Animal Fecal Matter

Concentrations of pathogens in coastal waters are increasing.[14] As noted above, discharge from land-based human activities becomes more pronounced as coastal areas become more crowded. Other sources of fecal matter besides humans include birds, dogs, wildlife and agricultural sources located in upstream reaches of a given watershed.

Fecal matter discharged into coastal waters via sewage provides a key route of exposure to pathogenic viruses that sicken bathers and shellfish consumers.[15] The discharge of viruses in treated sewage is not directly regulated; it is regulated indirectly by monitoring bacterial indicators, i.e. *Enterococcus* and *E. coli,* which reliably correlate with the presence of fecal matter, including viral contamination. The correlation between these indicators and the occurrence or abundance of human pathogens is not well known. Storm water discharges alone often contain high counts of indicator bacteria. Disease outbreaks from human exposure to partially treated or untreated sewage occur every year. The most common viral pathogens in coastal waters include enteroviruses, hepatitis A viruses, Norwalk viruses, reoviruses, adenoviruses, and rotoviruses. These organisms produce a range of asymptomatic to severe gastrointestinal, respiratory, and eye, nose, and skin infections. Studies have shown that viral pollution in coastal waters can pose substantial human health risks. However, the relationships

10 Anderson, D.M *et al*.
11 *Ibid*.
12 (HARRNESS, 2005; Harmful Algal Research and Response National Environmental Science Strategy 2005-2015. Ramsdell, J.S., D.M. Anderson, and P.M. Glibert, (Eds.), Ecological Society of America, Washington, DC,96 pp. (www.whoi.edu/redtide/nationplan/2005nationalplan.html)
13 Anderson, D.M., P. Hoagland, Y. Kaoru, and A.W. White, 2000. *Estimated annual economic impacts from harmful algal blooms (HABs) in the United States*. Woods Hole Oceanographic Institution, Technical Report WHOI-2000-11, 96 pp.
14 Dorfman, M. 2005.
15 Wade, T.J., R.L. Calderon, E. Sams, M.Beach, K.P. Brnner, A.H. Williams, and A.P. Dufour. 2006. Rapidly Measured Indicators of Recreational Water Quality Are Predictive of Swimming-Associated Gastrointestinal Illness. *Environmental Health Perspectives,* 114 (1).24-28.

between the presence of viral pathogens and the risk to humans is poorly understood, largely because methods for accurately detecting both bacteria and viruses in aquatic systems are not available. Likewise, the occurrence of viral pathogens in marine waters is not well characterized, principally because scientific studies in this area remain limited.

> ***Almost all coastal states monitor beach water quality by measuring levels of certain indicator bacteria. However, studies have shown that the presence or absence of these indicator species does not provide information about all possible threats. In particular, concentrations of marine viruses are not well characterized by indicator bacteria levels. Another problem with using microorganisms as indicators of contamination is the lag time between sample collection, test results, and public notice. During this time swimmers continue to be exposed to the contaminated water.***
>
> **U.S. Commission on Ocean Policy, An Ocean Blueprint for the 21st Century, Final Report**

D. Impacts of Global Warming

Of all the coastal threats facing the public, those produced by global warming could be the most catastrophic. According to NASA's Goddard Institute for Space Studies, 2005 was the warmest year in recorded human history (Figure 1). Current models suggest that mean global temperatures could rise five to eight degrees Celsius by 2100, generating impacts that include sea-level rise, expanded habitats for pathogenic microbes, coastal erosion, flooding, and more destructive weather patterns. Models endorsed by the Intergovernmental Panel on Climate Change predict sea levels could rise up to one meter by the end of the century as a consequence of climate change. Models that assume substantial melting of ice sheets in Greenland, the Arctic, and the Antarctic predict up to a six-meter rise in sea level over the same time frame, dramatically altering coastlines as we know them today.[16]

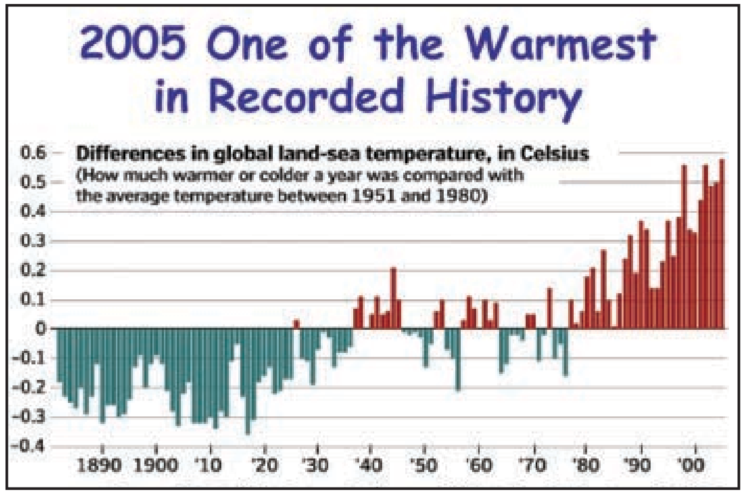


Figure 1: Chart based on data issued by NASA's Goddard Institute for Space Studies (Source: Warren Washington)

Impacts of such environmental changes are broad and substantial. Warming waters promote the growth of pathogens and expand the areal extent of their distribution. The increased frequency and severity of storms, predicted by climatologists, will promote flooding that exacerbates the input of contaminants from land-based sources and increases exposure risks. For instance, the tropical bacterium that causes cholera, known as *Vibrio cholerae,* thrives on warm, nutrient-laden water. Rising sea-surface temperatures, combined with added nutrients flushed into the sea by extreme storms, create optimal conditions for the microbe's survival. Recent studies show the severity of cholera outbreaks in Bangladesh correlate with El Niño weather patterns produced by Pacific Ocean warming. Scientists now believe that global warming could expand the microbe's habitat, driving it towards more temperate regions, including the coastal United States.[17]

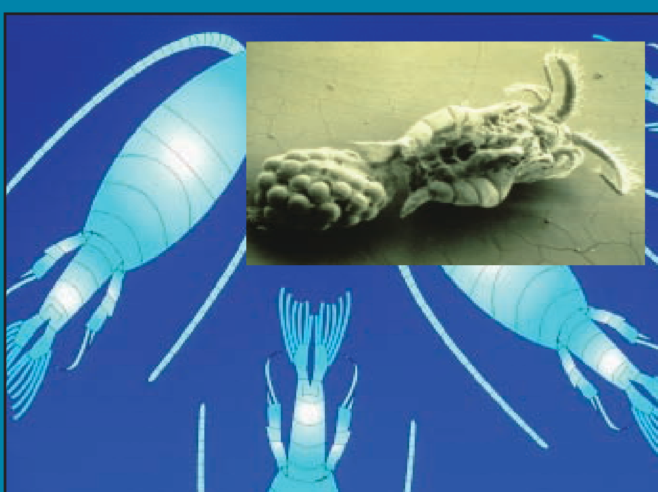
16 Hansen, J.E., "Is There Still Time to Avoid Dangerous Anthropogenic Interference with Global Climate?", Presentation on December 6, 2005 at the American Geophysical Union, San Francisco, CA (http://www.giss.nasa.gov/~jhansen/keeling/keeling_talk_and_slides.pdf)

17 Colwell, R.R.. 1996. Global Climate and Infectious Disease: The Cholera Paradigm. Science, 274 (2795): 2025-2031.

<u>The Cholera Paradigm</u>

Cholera is an example of a health risk that can be mitigated by an integrated observing system. A "systems" approach is essential because of the complexity of *Vibrio cholerae.* Water is a carrier (thus, the term "waterborne disease") but it is also a reservoir since *V. cholerae* live inside copepods, which serve as the disease vector. Warm water and low salinity encourage *V. cholerae.* Increased outbreaks have been inked to the global El Niño phenomenon in both Peru and the Bay of Bengal. Scientists have shown that remote sensing of sea surface temperatures can be the basis for an early warning system of cholera risk and are developing models capable of predicting outbreaks locally.

The cholera paradigm also points to the need for a global ocean observing system. Firstly, complex environmental patterns interact on a global scale. Secondly, the worldwide movement of people and goods is increasing exponentially. International travel, which accelerates the transmission of infectious disease, has increased to almost 500 million international arrivals per year. The World Health Organization reported 120,000 cases of cholera and over 3700 deaths in 2002.[18]



This tiny shrimp-like creature harbors V. cholerae, particularly around the egg sac and, to a lesser extent, the mouth. This animal lives in rivers and salt or brackish waters, and travels with currents and tides. (Source: Dr. Rita Colwell)

Rising sea levels resulting from climate change could also produce numerous health threats, including saltwater intrusion and contamination of fresh drinking water supplies; expanded habitats for mosquito-borne vectors, including the parasite that causes malaria; increased storm surges and coastal damage; changes in agriculture and food production; biodiversity losses; and damage to coral reefs—which in addition to providing key ecological services also dampen wave energy and thereby protect coastal communities in the tropics.

Rising coastal populations, combined with the dynamic factors that affect coastal water quality, intensify needs for comprehensive, state-of-the-art monitoring strategies to assess health risks from ocean water exposure. The Integrated Ocean Observing System is the framework for developing these tools. In addition to reducing health risks by enhancing predictive capabilities, the IOOS will also improve efforts to monitor the success of efforts to reduce threats at their sources.

II. The Integrated Ocean Observing System (IOOS) and Public Health

A. Design and Current Focus

Achieving the seven goals of the IOOS requires a system that efficiently links observations, data management, and modeling to provide required data and information on local to global scales, e.g., from the local scale of beaches and shellfish beds to the global scale of an El Niño event. Thus, IOOS architecture is being designed to address two major challenges: (1) Efficiently integrate observations, data telemetry, data management and communications, modeling, and analysis to rapidly generate reliable quality-controlled data and information, and (2) Develop an integrated hierarchy of observations, data management, and modeling that links local, regional and global scales of variability and change.

The IOOS is a tool that can be used to address environmental problems in an ecosystem context. Using the example of agriculture practices, figure 6 depicts the pressures, changes, impacts, and responses caused by certain practices.[19]

[18] World Health Organization, 2004. Using Climate to Predict Infectious Disease Outbreaks: A Review. WHO/SDE/OEH/04.01. Geneva, 55 pp.
[19] An Implementation Strategy for the Coastal Module of the Global Ocean Observing System. GOOS Report No. 148; IOC Documents Series No. 1217, UNESCO 2005.

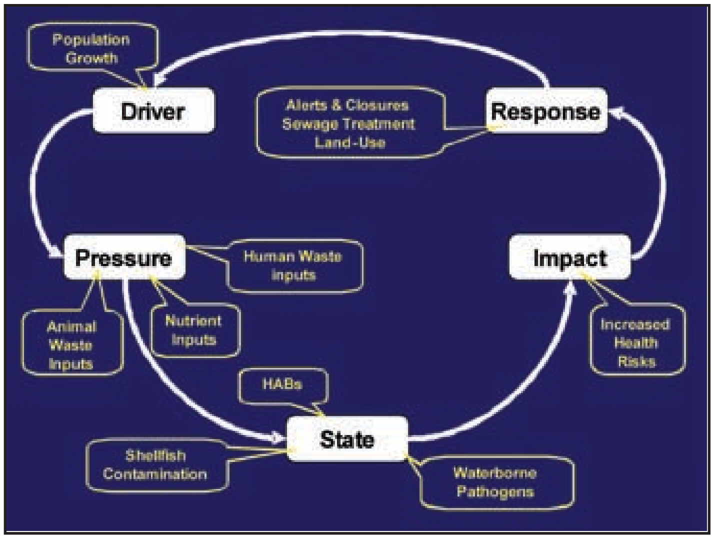


Figure 2: Schematic of Driver-Pressure-State-Impact-Response model. The Driver-Pressure-State-Impact-Response (DPSIR) model provides a framework for linking environmental changes to socio-economic systems across the land-sea interface. Drivers describe large-scale patterns of human activities (e.g., population growth and associated increases in agriculture and release of feces and nutrients). The resulting pressure is in the form of increases in inputs of nutrients, animal wastes and human wastes which change the state of coastal marine ecosystems by causing harmful algal blooms, contaminating shellfish beds, and increasing concentrations of waterborne pathogens, all of which increase human health risks (impacts). Responsible government agencies respond by issuing alerts, closing beaches and shellfish beds, and managing the drivers to reduce or control inputs (pressures). The IOOS contributes data and information needed for more rapid detection and timely predictions of pressures, changes in state, and the impacts of such changes.
(Source: Tom Malone)

Observations and data telemetry consist of global and coastal components with the latter consisting of a National Backbone and regional coastal ocean observing systems embedded in it. The recently approved First IOOS Development Plan addresses the use of existing assets to improve estimates of sea surface meteorological conditions and changes in the geophysical and ecological states of pelagic and benthic environments (Figure 3 lists examples of pertinent IOOS measurements). Data management and modeling are IOOS integrators that cut across the IOOS at all scales. However, the plan does not address IOOS requirements for better detection and prediction of phenomena that affect public health. See www.ocean.us for a more detailed description of the IOOS.

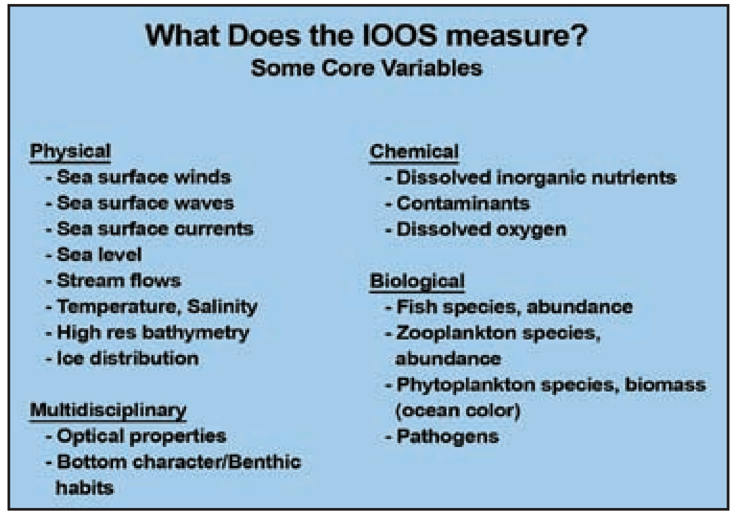


Figure 3: Examples of Core Variables Measured by IOOS.
(Source: Dr. Mary Altalo)

B. Challenges of Developing an IOOS that Addresses Public Health Needs

There are many challenges to building an IOOS that will serve to minimize human health risks. Important needs include:

- Specification of data and information requirements for public health elements of the IOOS;
- Timely exchange of reliable data and information among federal and state agencies;
- Improving near-shore observations in terms of the variables measured, increasing the time-space resolution of measurements, and measuring biological-chemical-physical variables at the same times and places;
- Integrating land use data with ocean data;
- Reducing the time lag between sample collection and the dissemination of results;
- Improving hydrodynamic models of near-shore coastal waters;
- Improving models of particle transport and microbial population dynamics in near-shore coastal waters;
- Developing data assimilation techniques for chemical and biological variables required to initialize and update model predictions;
- Coupling biological and physical models to improve predictions (hindcasts, nowcasts and forecasts) of public health risks (e.g., more accurate and timely estimates of the distribution and concentration of waterborne pathogens, toxic algae, and their toxins); and
- Achieving these objectives cost-effectively.

Appendix C lists examples of present IOOS activities that support public health risk forecasts and assessments. The ultimate challenge, and crucial task of the IOOS, is to promote the coordination of these often disparate efforts to maximize the return on present investments in infrastructure and identify and fill gaps in order to achieve a comprehensive system.

III. Findings

A. Present Decision Processes

1. Beach Management

Across the country, there were nearly 20,000 days of closings and advisories at ocean, bay, and Great Lakes beaches in 2004, an increase of nine per cent over the previous year. This change can be explained, in part, by expanded monitoring. According to EPA's 2004 Swimming Season Update, an increase of 1717 beaches reported information to EPA.[20] Scientists expect the trend toward more beach closure days to continue, but concede that interpretation of water quality data and statistics is complicated. Since the passage of the BEACH Act, there has been more data collection and hence a greater degree of water quality awareness, particularly with regards to fecal pollution. And because of the economic impact of beach advisories and closings on the surrounding community, there is greater effort put into identifying and eliminating sources of pollution.

Concerns of the Great Lakes
Great Lakes waters have a special importance---their use as drinking water for 40 million U.S and Canadian residents. The 94,000 square miles of lakes supply 56 billion gallons a day for municipal, agricultural, and industrial use. A total of 14% of the beaches monitored on the Great Lakes were closed 10% of the time in 2002. In Michigan beach closures increased 174% from 2003 to 2004, the likely result of increased monitoring, due to better awareness of existing problems.[21]

Beach management decisions can be divided into three categories:

a. Immediate decisions to open, close, or re-open a beach for swimming, or to issue an advisory or warning.
b. Longer term decisions to determine priority areas and strategies for remediation and the spatial scale of those actions
c. Problem identification and characterization designed to track the source of a problem, its fate and transport, and the gradients of contamination in time and space

Health departments base decisions to open or close beaches on two kinds of data: 1) observations such as the presence of medical waste or obvious bacteria scum; or 2) measurements of bacterial indicators. The most common indicators—namely fecal coliforms such as *Enterococci*, a gram positive intestinal microbe used for sea water testing, and *Escherichia coli,* a freshwater indicator—require up to 48 hours to culture in the laboratory, a significant barrier to real-time water quality assessments. Although coliform is the easiest bacterium to measure, the data do not indicate the source of contamination (e.g., human or animal). What's more, these indicators often do not reflect the actual risk of exposure to the pathogen itself; they merely indicate the presence of fecal matter, either human or animal. There is recent evidence that both *Enterococci* and *E. coli* can grow in sand, providing recharge sources for these indicators.[22] It is unknown whether associated pathogens also grow in sand. High indicator levels identified during sampling may therefore either over or underestimate health risks.

[20] EPA, 2005. EPA's Beach Program: 2004 Swimming Season Update, EPA 823-F-006, July 2005, Washington, D.C.
[21] http://www.epa.gov/greatlakes/
[22] Whitman, R.L. and M.B. Nevers, 2003. Foreshore sand as a source of *Escherichia coli* in nearshoure water of a Lake Michigan beach, *Appl Environ Microbiol,* 69(9), 5555-5562.

Existing indicators allow decision makers to merely react to detected risks instead of anticipating risks and preparing for them in advance. In the time it takes to obtain indicator test results, coastal pathogens can disperse or accumulate, in accordance with wind, currents, rain, and many other variables. Meanwhile, beach managers and swimmers alike have little knowledge about the real nature of a pathogen threat before cases of illness begin to appear. To improve decisions, observations of health threats need to be more site-specific, timely, and provide information as to the cause of the health problem.

Epidemiological data gaps also impede efforts to track illnesses resulting from exposure to beach contamination, which further limits opportunities for informed, health-based decision making. Lack of epidemiological data limits the ability of policy makers to assess adequacy of current microbial indicators at predicting health risk and presence of pathogens.

Moreover, inadequate monitoring affects longer-term beach management decisions. For example, because of long time lags between sample collection and laboratory results, beaches are regularly closed after they should be, and are kept closed longer than needed, thereby reducing the recreational value of the beach unnecessarily.[23] In addition, without sufficient data, managers cannot identify the sources of bacterial pollution and HABs, nor can they make informed decisions about where to apply limited resources for remediation.

Another consideration in the decision-making process is jurisdictional differences. Many beaches are situated in more than one governmental jurisdiction, which can exacerbate the beach closure decision-making process. Policies also vary from state to state suggesting a need for a regional approach to both the science and management of these areas. Reliable scientific data regarding the identification of contaminant sources and any links to watershed use, land patterns, epidemiological studies, and health outcomes can be used to support resolution of conflicts and ensure greater consistency in advisories and closings.

Newer methods have the potential to improve these problems. New indicators or sets of indicators which are correlated to health effects would improve reliability and certainty of beach advisories or closures. More rapid analysis techniques of any chosen indicator(s) will allow more real time decision making.

An Example in San Diego

A coastal observing system off San Diego has been established to centralize water quality data as well as surface currents, satellite images, bathymetry, weather data, and historical data for use by public health officials in an effort to identify sources of pollutants and track their movement on a 24-hour basis. The project began in 2001 with support from the State of California and the City of Imperial Beach and has contributed to more accurate and timely notifications of local problems. Termed the San Diego Coastal Ocean Observing System, it is an example of the benefits of integration among types of data, public agencies, and scientific disciplines. (www.sdcoos.org/)

2. Shellfish Bed Management

Shellfish bed managers face similar problems. Decisions to open or close shellfish beds contaminated by fecal matter and HABs ultimately lie with state health agencies and sampling data supplemented by local fish and wildlife departments. While testing water samples for the fecal coliform indicator is mostly done using the multiple tube fermentation method, to obtain HAB toxin data, biologists prepare shellfish extracts and test them using methods geared towards specific types of contamination.[24] Testing for domoic acid, for instance, relies on analysis using high-performance liquid chromatography. In another key test for brevetoxin, biologists inject mice with shellfish extracts and record how long it takes for the animals to die. The resultant "mouse units" are converted to units used in regulatory standards for shellfish management decisions.

The HAB Bulletin

The Gulf of Mexico Harmful Algal Bloom bulletin was developed by NOAA in partnership with several state and local agencies.[25] The bulletin supplies information on the location, extent, and potential for development or movement of *Karenia brevis* blooms. The forecasting system relies on satellite imagery, field observations, and buoy data to provide the large spatial scale and high frequency of observations required to assess bloom location and movements. Conditions are posted to a web page twice a week during the HAB season. Additional analysis is included in the HAB Bulletin that is provided to state and local resource managers in the region. (www.csc.noaa.gov/crs/habf.)

[23] Kim, J.H. and S.B. Grant, 2004. Public Mis-notification of coastal water quality: a probabilistic evaluation of posting errors at Huntington Beach, California. *Environ Sci Tech,* 38(9), 2497-2504.

[24] CENR, 2000. National Assessment of Harmful Algal Blooms in U.S. Waters, National Science and Technology Council Committee on Environment and Natural Resources, Washington, DC.

[25] Stumpf, R.P., M.E.Culver, P.A. Tester, M. Tomlinson, G.J. Kirkpatrick, B.A. Pederson, E. Truby, V. Ransibrahmanakul, and M. Soracco, 2003. Monitoring *Karenia brevis* blooms in the Gulf of Mexico using satellite ocean color imagery and other data, *Harmful Algae* 2, 147-160.

These tests provide estimates of human toxicity from eating contaminated shellfish, but they cannot predict contamination in advance. Prediction requires more information, such as detailed knowledge of HAB sources and antecedents, the environmental factors that promote HAB growth, and the physical processes that carry HABs towards shellfish beds and fisheries. Without sufficient monitoring, greater knowledge of HAB ecology and its links to land use and human health remains elusive. Monitoring deficiencies also impede knowledge of new HABs emerging in U.S. waters, including highly toxic varieties such as *Pseudo-nitzschia, Pfiesteria, Karlodinium, and Aureococcus*. Evidence suggests changing environmental conditions, including nutrient loading and eutrophication, promote the influx of new HABs.[26] But their identification could also reflect increased awareness and scrutiny arising in response to outbreaks elsewhere.

B. The Vision for Observations and Predictions

How can the IOOS best provide data and information for more effective and efficient public health decisions? The IOOS can provide advance warning of events by providing environmental data at the spatial and temporal scales needed to link sources of contamination to human health risk (Figure 4). For immediate beach closure decisions, requisite data must include measurements of pathogen indicators collected several times per day at near-shore locations. For longer term events, such as cholera outbreaks, the appropriate data will describe environmental factors that predict their occurrence. For both immediate and long-term decisions, IOOS data will contribute to the development of models that predict where these events may occur and how they may be transported. An effective IOOS will provide a framework for data sharing between agencies, and also link observations to health and epidemiology data, in part by increased collaboration with local health departments.

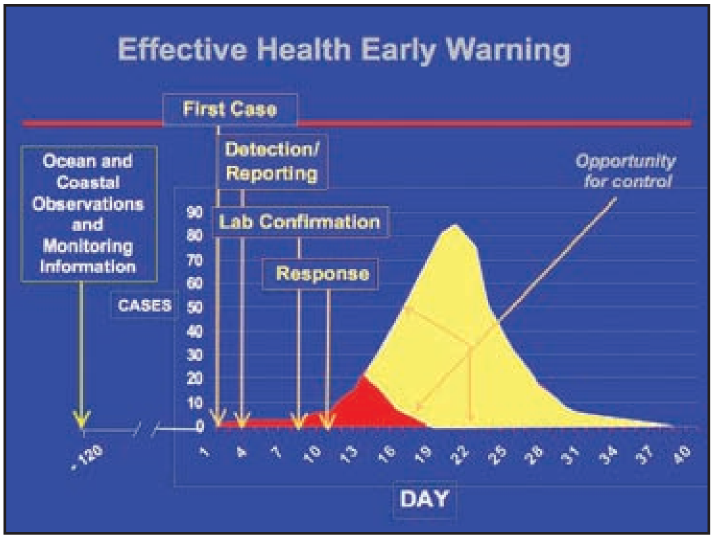


Figure 4: Ocean observations can improve the response time of the health community by providing them with advance warning of the environmental conditions that may lead to an event. Faster response will result in an improved opportunity to control the risk and fewer people may be affected. (Source: Juli Trtanj)

Several commonalities that would improve decision-making for all types of health decisions were recognized:

- Coastal data now collected by multiple agencies and archived in disparate locations should be integrated to allow for use in both management decisions and research.
- Physical, biological, chemical, and epidemiological data are needed *on a sustained basis.*
- Those data must be temporally and spatially compatible
- Models that couple land and near shore features are needed to understand the effect of land use, including pollutants, on coastal water quality.
- Models that link biological and physical data, in addition to shore-based and near-shore processes, are needed to understand the initiation and transport of biological events. Ultimately, models should possess scale-up capabilities, such that researchers can continually add new data and information as it becomes available.
- Analytical methods are frequently too slow to result in timely management decisions.
- Adaptive, flexible data platforms, accessible to a wide range of users, would improve the database. Emphasize placement of sampling devices near contamination sources and HAB initiation sites.

[26] National Research Council, 2000.

Workshop participants pointed to the need to incorporate multilayer integration, based on both automated satellite sensing and near-shore buoy based monitoring. The basic framework should be augmented with additional field sampling for HABs and pathogens. Illness surveillance must include case demographics (and populations sensitive to outbreaks), environmental information, exposure information, signs and symptoms, and follow-up. In addition, illness outbreaks must be followed up with retrospective studies that link early cases to environmental data. Figure 5 shows components of an effective early warning system.

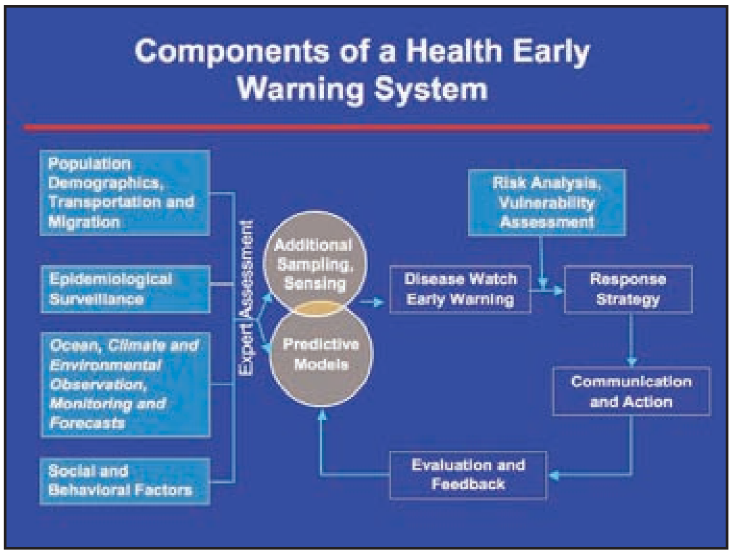
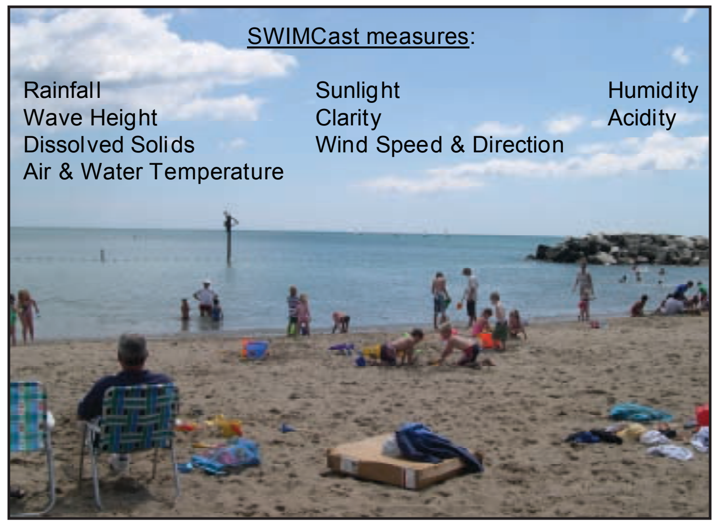


Figure 5: A health early warning system will integrate assessments from a variety of disciplines to monitor and predict an event. The warning system will provide information for consideration in risk assessments to develop mitigation and control options and communicate the recommended actions. (Source: Juli Trtanj)

1. Recreational Beaches

The optimal IOOS for beach management will improve the accuracy and precision of health-based decision-making. Workshop participants agreed that the IOOS will provide better understanding and assessment of the fate and transport of sewage plumes. They also emphasized needs for coupled models that integrate near-shore processes with terrestrial features, such as combined sewer overflows and non-point pollution sources. The optimal IOOS would imbed sensors near pathogen sources and in surf zones, which are poorly characterized and understood now. It would also measure physical forces that govern the transport of contaminants, including parameters such as volume stream flow, tides, wave height, and water temperature. Ideally, IOOS measurements would be delivered to centralized database accessible to a wide range of users.

SWIMCast: An Example in the Great Lakes
Managers in Lake County, Illinois, have developed an *E. coli* prediction system that has dramatically increased the speed and accuracy of beach closure decisions. The system, called SwimCast, uses meteorological equipment to monitor a beach's environment, such as air temperature, wind speed and direction, water temperature and clarity, sunlight, and wave heights—all factors that can hinder or encourage the growth of *E. coli.* A model has been developed that is 87% accurate in predicting concentrations of *E. coli* in real time. SwimCast is in use at two beaches to supplement the established monitoring programs.[27]



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Satellite remote sensing data can provide valuable synoptic information on the fate and transport of pollutant/pathogen laden sewage/runoff plumes. However, greater efforts need to be made to link remote sensing data providers and analysts with public health end users and decision-makers (e.g., beach postings/closures) to facilitate information exchange. Pilot projects (discussed in Section 6 below) can help facilitate this effort. New and improved remote sensing capabilities are also necessary to better support user information needs.

The IOOS will augment current methods for analyzing indicator bacteria with rapid test methods that provide real-time results. Workshop participants emphasized that these tools should be automated and faster, more accurate, and less expensive than the testing methods used today. They may include antibody "dipsticks" that measure bacterial toxins; Quantitative Polymerase Chain

[27] NOAA, 2005. High-tech monitoring improves timeliness of Illinois beach closures, *Coastal Services,* 8(1), 6.

Reaction (QPCR) -based methods for rapid microbial detection based on RNA and DNA; RAPTOR--- portable fiberoptic biosensors that detect microbiological and chemical analytes in water; and shoreline sampling buoys that provide continuous water quality measurements in near shore areas. Improved sampling designs that dictate precisely where measurements should be taken could also facilitate real-time knowledge of health threats. In addition, the IOOS must incorporate improved risk assessment procedures and links with epidemiology. Finally, methods for delivering real-time water quality information to the public must also be developed.

Benefits Of The IOOS To Beach Management
- **Clean beaches re-opened sooner due to rapid identification of improved conditions**
- **Ability to remediate sources of contamination and mitigate problems**
- **More cost-effective monitoring**
- **Improved risk assessments**

2. Shellfish Bed Management

The National Shellfish Sanitation Program gives criteria for monitoring seafood safety but implementation varies widely among states, with some incorporating new scientific data more readily than others. Although many states have programs that predict fecal contaminants and anticipate closures triggered by local rainfall or river stage upstream, many responses are reactionary rather than predictive, and outbreaks are not recognized quickly enough.

Concerns include:
- Sewage viral and bacterial contamination
- HABs: PSP and NSP, with indications that other pathogens are emerging
- *Vibrio vulnificus, Vibrio parahaemolyticus, Vibrio cholerae*
- Contaminant spills
- New, unidentified pathogens

Workshop participants identified several shellfish bed management decisions that could be enhanced by the IOOS. They include:
- How to structure and schedule monitoring of shellfish beds in federal waters more effectively
- How to determine if shellfish beds have been affected by additional contaminants, including viruses and/or toxic pollutants
- When to open or close a shellfish bed
- When to embargo a harvest
- Determination of optimal temporal and spatial boundaries during harvest seasons

For shellfish management, forecast models are needed that incorporate rainfall; land use; estuarine circulation; real-time salinity, temperature, and currents; and turbidity. Real-time temperature data is particularly critical for predicting pathogen survival. Special attention must be directed towards the identification of *Vibrio vulnificus*. This bacterium, which increases in number in warmer air and water temperatures, is the most common cause of death from seafood consumption. Required observations include real-time air and water temperature and sea surface salinity, which can also aid efforts to predict *V. parahaemolyticus* abundance and associated risk. *In situ* measures can fill sampling gaps from satellite-based remote sensing, which generally can not presently effectively resolve or discriminate the characteristics and properties of near shore waters. New and improved capabilities are needed from both satellite and suborbital platforms.

The IOOS needs to consider all benthic seafood products in order to improve shellfish bed management, including crabs and filter feeders. Adaptive sampling—based on risk predictions rather than regulatory requirements—will enable more efficient use of sampling and analytical resources. Sampling schemes should not be limited to shellfish contamination outbreaks. Shellfish bed closures should incorporate risk forecasts which will, in turn, limit reactive responses. In the long run, improved ocean observations will help managers focus monitoring strategies and more clearly identify risk potentials, with a goal of *adaptive closing* of shellfish beds rather than reacting to problems already in existence. Early warnings will reduce costs to industry as well as save lives.

Benefits Of The IOOS To Shellfish Management
- **Contaminated shellfish beds closed before pathogen or toxin exposure can occur due to accurate assessment of health risk. Clean shellfish beds re-opened sooner due to rapid identification of improved conditions**
- **Economic gains due to improvements in management of shellfish resources**

3. Approaches to New and Emerging Threats

New and emerging threats facing coastal waters have potentially enormous economic impacts as well as health risks.[28] Threats include:

- Unknown HABs delivered by ballast waters
- Gene-transfer in coastal waters and the evolution of new HAB species and other microbes
- New toxic and pathogenic organisms (and moving from the traditional host)
- Natural disasters, such as storms, earthquakes, and volcanoes
- Rising sea level and resulting dislocations
- Zoonotic microbial pathogens transferred to the oceans by pets, domesticated animals, and terrestrial wildlife
- Chemical releases

It is difficult to manage what is not known. Workshop participants noted that the IOOS will help decision-makers respond more effectively to poorly characterized threats. By contributing to baseline monitoring, IOOS can help detect emerging threats either directly, by early detection of environmental anomalies and monitoring of sentinel animal species, or indirectly, by detecting changes in the combination and impact of multiple ecosystem stressors (e.g., warmer sea surface temps, accompanied by increased coastal development and nutrient loads, and marine animal illness). However, the emphasis needs to be on prevention and mitigation of impacts.

Decisions concerning emerging threats fall into three categories:

a. **Preventive Actions:** Create risk profiles at different scales (similar to those developed by the insurance industry); assess health risks from seafood consumption, and issue warnings and advisories to the public.
b. **Diagnostic Actions:** Use screening tools to rule out known threats; and hindcast for better understanding of the effects of ecosystem dynamics, climate, etc., on public health
c. **Treatment Actions:** Allocate resources for research, management and response in order to identify and prepare for emerging threats that may be local to global in scale.

A prerequisite to good decisions is a better understanding of baseline conditions and present genetic diversity. Using IOOS data, products can be generated that integrate a variety of types of coastal data. The IOOS will also collect additional baseline data that can feed into models that couple land and near-shore features. Although the potential problems are complex, and specific threats may not be readily predictable, the *conditions* that promote the growth of toxins and pathogens can be predicted with sufficient data. Additional knowledge, based on data products, will allow researchers to evaluate the importance of various indices, to improve sampling schemes, and to identify potential hazards, as yet unknown. A goal is to develop the most cost-effective indicators for the *ecosystem* and correlate those with health data.

Participants emphasized that early warnings of environmental anomalies or changes exhibited by sentinel species can afford more threat response options. Public health practitioners need to be educated on how to identify and respond to risks indicated by these early warnings. Participants also noted the importance of training young scientists to build the capacity to undertake the breadth and depth of research required. And considering the breadth and depth of potential threats, the importance of outreach and workforce development cannot be overestimated.

Examples of Emerging Issues and Possible Measurement Time Scales

- New/toxic Pathogens	- Seasonal/monthly and adaptive sampling
- Global Contamination (e.g., mammals with high levels of DDT)	- Surveillance, long-term monitoring
- Food Web Disturbance	- Surveillance/monitoring of food web
- Global Climate Change	- Seasonal/monthly over the long-term
- Extreme Weather	- Real-time
- Coastal Development	- Long-term
- Biothreats- intentional and Unintentional	- Surveillance/real-time

[28] For a discussion of the challenges of studying emerging infectious diseases, see Wilcox, B.A. and R.R. Colwell, 2005. Emerging and reemerging infectious diseases: biocomplexity as an interdisciplinary paradigm, *EcoHealth*, 2(4), 244-255.

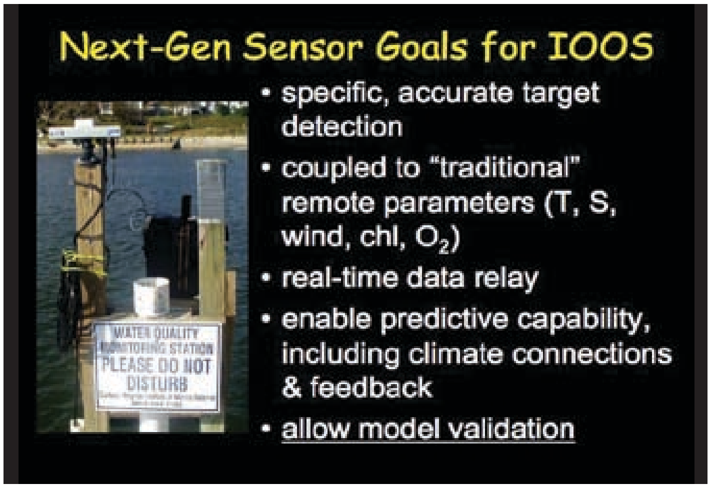
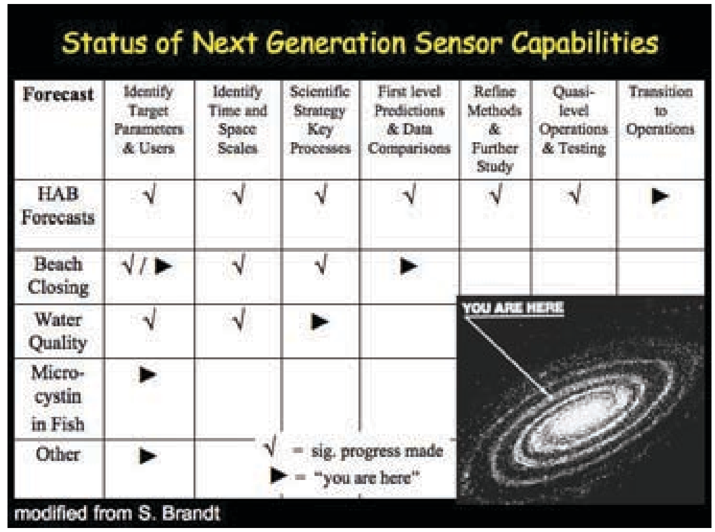


Figure 6: The goal of next-generation sensors is to make environmental monitoring faster, easier, cheaper, more accurate, and more automated. (Source: Kelly Goodwin)



Forecast	Identify Target Parameters & Users	Identify Time and Space Scales	Scientific Strategy Key Processes	First level Predictions & Data Comparisons	Refine Methods & Further Study	Quasi-level Operations & Testing	Transition to Operations
HAB Forecasts	√	√	√	√	√	√	►
Beach Closing	√ / ►	√	√	►			
Water Quality	√	√	►				
Micro-cystin in Fish	►						
Other	►						

Figure 7: The chart represents a rough outline of the operational use of "next-generation" sensors. Progress in developing, deploying, and integrating new sensors varies by region of the country and by target. For example, satellite imagery has advanced understanding and assessment of *K. brevis* in the Gulf of Mexico and has lead to synergistic implementation of new in situ sensor platforms, but satellite remote sensing is not effective in all regions or for all targets. (Source: Kelly Goodwin and Steve Brandt)

4. Technology Considerations

A variety of tools can be used to assess pathogens and toxins, and technology is changing rapidly. The IOOS must accommodate new technology as it becomes available in order to achieve public health goals. Promising approaches allow for rapid detection of targets of interest, such as HAB species, Enterococci, *E. coli*, human pathogens (protists, bacteria, and viruses), toxins, and source tracking markers. Some new methods base identification on molecular signatures, including DNA, RNA, and immunological markers.[29] Some molecular detection approaches have already been deployed on *in situ* sensing platforms, including the Monterey Bay Aquarium Research Institute's Environmental Sensing Platform, and the University of South Florida's Autonomous Genosensor.[30] In some cases, IOOS observations may be generated from rapid laboratory methods, handheld biosensors, or dipstick-type methods, particularly for threats occurring in the very near shore or aquaculture products. Continued support for technology research and in these areas is needed and the transfer to incorporate next generation technology into operational use was stressed.

Near real-time data from earth observing satellites, particularly ocean color observations, can be useful for detecting, characterizing, and tracking plumes as well as some types of harmful algal blooms. Remote sensing provides the broader synoptic view that places in situ measurements in context. However, current remote sensing assets are generally limited in their ability to provide adequate coverage or resolution (spatial, temporal and/or spectral) of near shore waters. Moreover, remote sensing is not currently effective in regions with high cloud cover or for organisms that do not contain photopigments.[31] New and improved dedicated coastal remote sensing capabilities are needed.

Combining remote sensing capabilities with in situ observations is a powerful synergistic approach for long-term monitoring of the environmental conditions that may lead to public health threats. In addition to molecular signatures, detection approaches for HABs include technologies that measure photopigments, toxins, or visual identification. Real-time data from earth observing satellites such as ocean color sensors are useful for detecting and characterizing some types of harmful algal blooms. Additional sensing platforms, including gliders and adaptable moorings placed near HAB initiation sites, could be deployed to study the initiation and transport of HAB events. Evidence suggests that in some cases, HAB events can initiate offshore at depth under calm conditions, and then be transported to the surface by coastal upwelling, while in other cases, initiation sites occur closer to

[29] Rose, J.B. and D. J. Grimes. 2001. Reevaluation of Microbial Water Quality: Powerful New tools for Detection and Risk Assessment, American Academy of Microbiology, Washington ,D.C.
[30] Alliance for Coastal Technologies, 2005. Genetic Sensors for Environmental Water Quality. Workshop Proceedings. ACT-05-01. St. Petersburg, FL.
[31] DiGiacomo, P.M., L. Washburn, B. Holt, and B.H. Jones, 2004. Coastal Pollution Hazards in Southern California observed by SAR Imagery: stormwater plumes, wastewater plumes, and natural hydrocarbon seeps, *Marine Pollution Bulletin* 49, 1013-1024.

shore. Additional monitoring is needed to shed light on environmental HAB antecedents, and the physical factors that transport HABs, particularly in near-shore areas where shellfish beds and fisheries are vulnerable. Indeed, technology for HAB detection and forecasting is already moving from research into operations. An effective IOOS will link with global monitoring programs such as the Global Ocean Observing System to survey the sources, as well as the fate and transport processes that move pathogens and harmful species from one region to another.

Further, greater efforts are needed to link technology developers and analysts with end users and decision-makers; pilot projects can help facilitate this effort. In addition technology developers must be kept informed of DMAC hardware and software requirements to ensure effective real-time data relay and two-way communication and to ensure the successful incorporation of next-generation sensors into IOOS arrays

5. Data and Information Exchange Priorities

Ultimately, the IOOS must link coastal factors and health using two-way flows of information, such that IOOS data informs health responses, while health responses guide IOOS monitoring strategies. Under the BEACH Act grant program, coastal states and territories monitor for fecal indicators at selected beaches and, since 2004, report this information to EPA. The information is available to the public through a national website (Figure 8). Under the National Shellfish Sanitation Program (NSSP), NOAA has developed the Shellfish Information Management System (SIMS) which currently includes data and information on 8 of the 23 coastal shellfish producing states. EPA and FDA are collaborating with NOAA under the Subcommittee on Integrated Management of Ocean Resources (SIMOR) Work Plan (and seek to collaborate with others) on expanding and/or integrating SIMS. Under the National Water Quality Monitoring Network initiative, an inventory of monitoring programs is being conducted, which is a prerequisite to establishing the data exchange networks for developing a data base. There is substantial interest in assembling existing data and making the data accessible. Progress in developing the standards and protocols that facilitate data exchange is being made possible by the IOOS Data Management and Communications.[32]

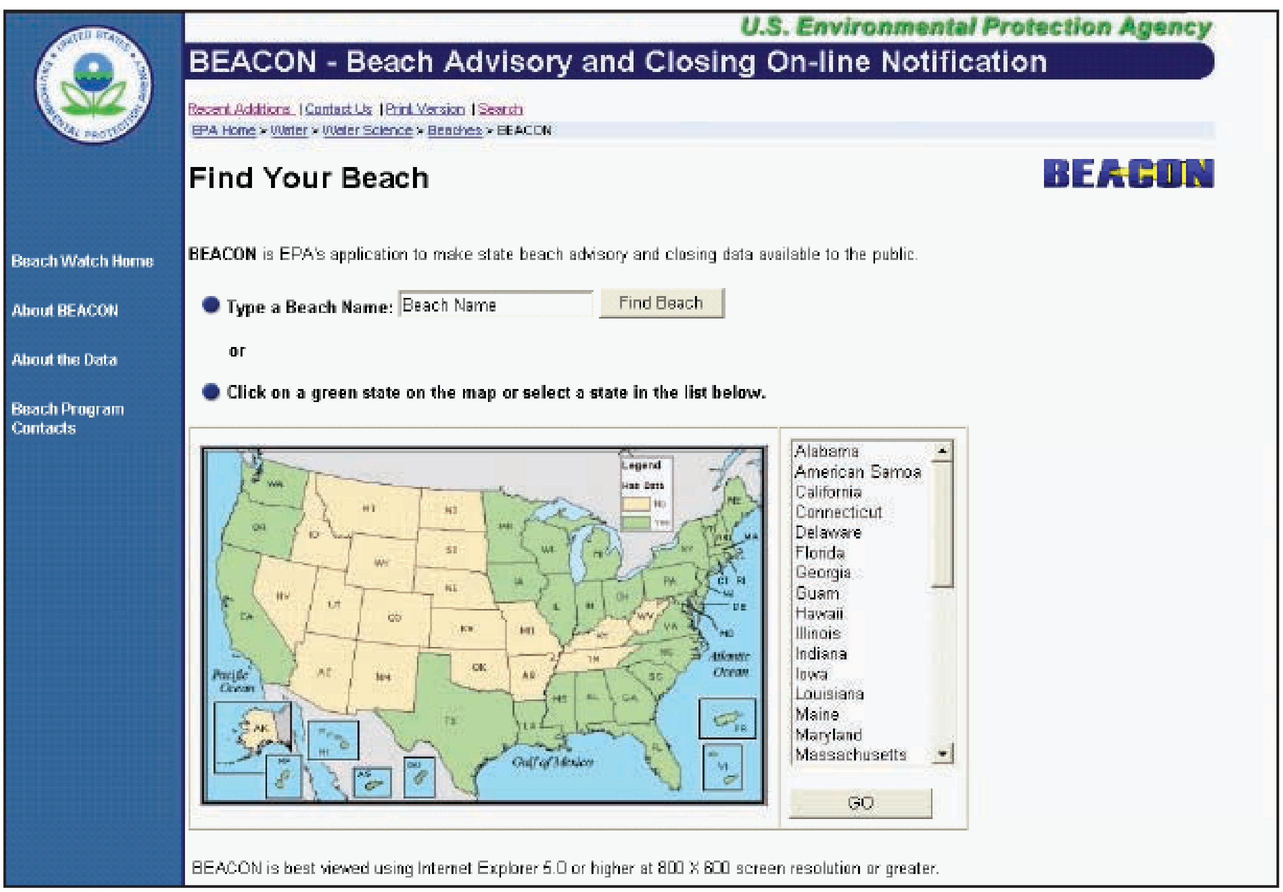


Figure 8: EPA web site where nation-wide beach advisory and closure information is available, based on data reported by states (http://oaspub.epa.gov/beacon/beacon_national_page.main)

32 See Ocean.US, 2005. Data Management and Communications Plan for Research and Operational Integrated Ocean Observing Systems, I. Interoperable Data Discovery, Access, and Archive http://dmac.ocean.us/dacsc/imp_plan.

To build the connections between ocean observations and public health data, priority items should focus on capacity building and dialogue between IOOS stakeholders, particularly data providers, and the health community. Specific activities may include IOOS-funded internships, multidisciplinary training at the university level, and educational programs for local health departments. The IOOS must also foster greater local collaboration—for instance between health experts, modelers, and beach management associations—to identify and meet regional needs. IOOS investigators could look for immediate opportunities to coordinate with ongoing epidemiology studies, or studies being proposed.

Workshop participants repeatedly emphasized the need for user-friendly systems to manage IOOS data and information. These systems should be easily accessible to a wide range of user groups, including researchers, decision-makers, and the public. IOOS systems must provide easy access to archived data on disease outbreaks and documented risk factors, in order to facilitate retrospective studies. Finally, real-time IOOS information on water quality must be delivered in rapid, accessible formats to the public, either through networked beachside warning systems or through television, radio, and the Internet.

6. Proposed Pilot Projects

An important next step in articulating observing system requirements and demonstrating the potential for the system is to conduct pilot projects. Participants were asked to identify possible projects that would enhance IOOS capabilities, or demonstrate how the IOOS can help meet health goals. Participants stressed that pilot projects should possess a few common characteristics:

- Have a high probability of success
- Build off existing systems, datasets, and monitoring programs
- Demonstrate the benefits of data integration
- Have strong support from local public health and environmental agencies
- Have the support of public officials responsible for public health policy and/or decision-making.

In addition, pilot projects should do one or more of the following:

- Test and validate new sampling devices and models
- Provide capacity for retrospective analysis
- Be capable of iterative processes and on-going support and analysis
- Function with geographic information systems
- Provide training modules designed for local groups
- Have applicability to broad geographic areas
- Use flexible designs

Two broad areas were identified as high priorities: (1) Testing and validating of sensors and models for rapid identification of health threats and (2) data management and information delivery. In regard to the latter, the need for more effective data management and information delivery was repeatedly emphasized. More rapid access to data from different sources and the integration of these data to provide the kinds of information decision makers need are major challenges. Pilot projects that test standards and protocols for metadata and data discovery, browsing, transport and archival were recommended. Information must be available at rates and in forms needed by users from decision makers to the public at large. An iterative process was suggested whereby data providers and users work together on efforts to refine data products (information) in ways that meet the needs of decision makers.

Proposed pilot projects fell into three general categories, or a combination of them: (1) fate and transport of waterborne pathogens and toxins, (2) microbial and viral detection and assessment, and (3) links between developing an illness and coastal conditions at the time of exposure to the health risk.

Although beach and shellfish management concerns have similarities across the U.S., specific problems vary by region, especially with respect to harmful algal species and their toxins. Events that occur regionally include:[33]

- Northeast- Paralytic shellfish poisoning (PSP) caused by *Alexandrium sp.*
- Mid-Atlantic- PSP, *Vibrio* contamination, Dermo, brown tide
- Gulf of Mexico- Neurotoxic shellfish poisoning caused by *K. brevis*, *Vibrio* and other bacterial contamination
- Northwest- Amnesiac shellfish poisoning caused by domoic acid, paralytic shellfish poisoning, *Vibrio parahaemolyticus* and other bacterial and viral contamination spreading from increasing urbanization
- Alaska- PSP, ASP, possible enteric viruses, cadmium
- Pacific Islands- ciguatera toxin in fish
- Great Lakes - *Microcystis* blooms that produce potent hepatotoxins (microcystins)

Appendix D lists a number of topics proposed. Specific descriptions of projects were not elicited. This list is intended to give the reader examples of activities that should be considered by funding agencies, including the National Oceanographic Partnership Program.

[33] CENR, 2000.

7. Outreach, Education, and Coordination

Greater knowledge, better assessments, and more accurate forecasting of potential health problems will be worthless without effective response capabilities. To achieve response readiness, first, a new paradigm of cooperation is needed among states and local governments, academia, federal agencies, industry, and non-profit organizations. At present, most state and local agencies do not have the resources for comprehensive coastal monitoring. Increased coordination must also occur among those responsible federal agencies, particularly, among the EPA Beaches Program, the NOAA Oceans and Human Health Initiative, the National Science Foundation, the National Aeronautics and Space Administration, the Center for Disease Control and Prevention, the National Institute for Environmental Health Sciences, the Food and Drug Administration's Office of Seafood, and the U.S. Geological Survey.

Workforce development is another priority that needs to be addressed. Research disciplines that have not traditionally worked together need to acknowledge mutual needs, collaborate, and train one another. Education and training in areas such as data management, modeling, and risk assessment are critical to ensure future capacity to sustain and benefit from the IOOS. [34]

Regional Associations (Figure 9), set up to implement the coastal component of the IOOS, can assist greatly with outreach and education by serving as an access point and actively engaging the public health community and the general public. The public's awareness of coastal health risks is generally poor. Communication to the general public by federal, state, and local agencies must increase, in order to raise the level of knowledge. Without sustained knowledge, mitigation and response efforts cannot be effective.

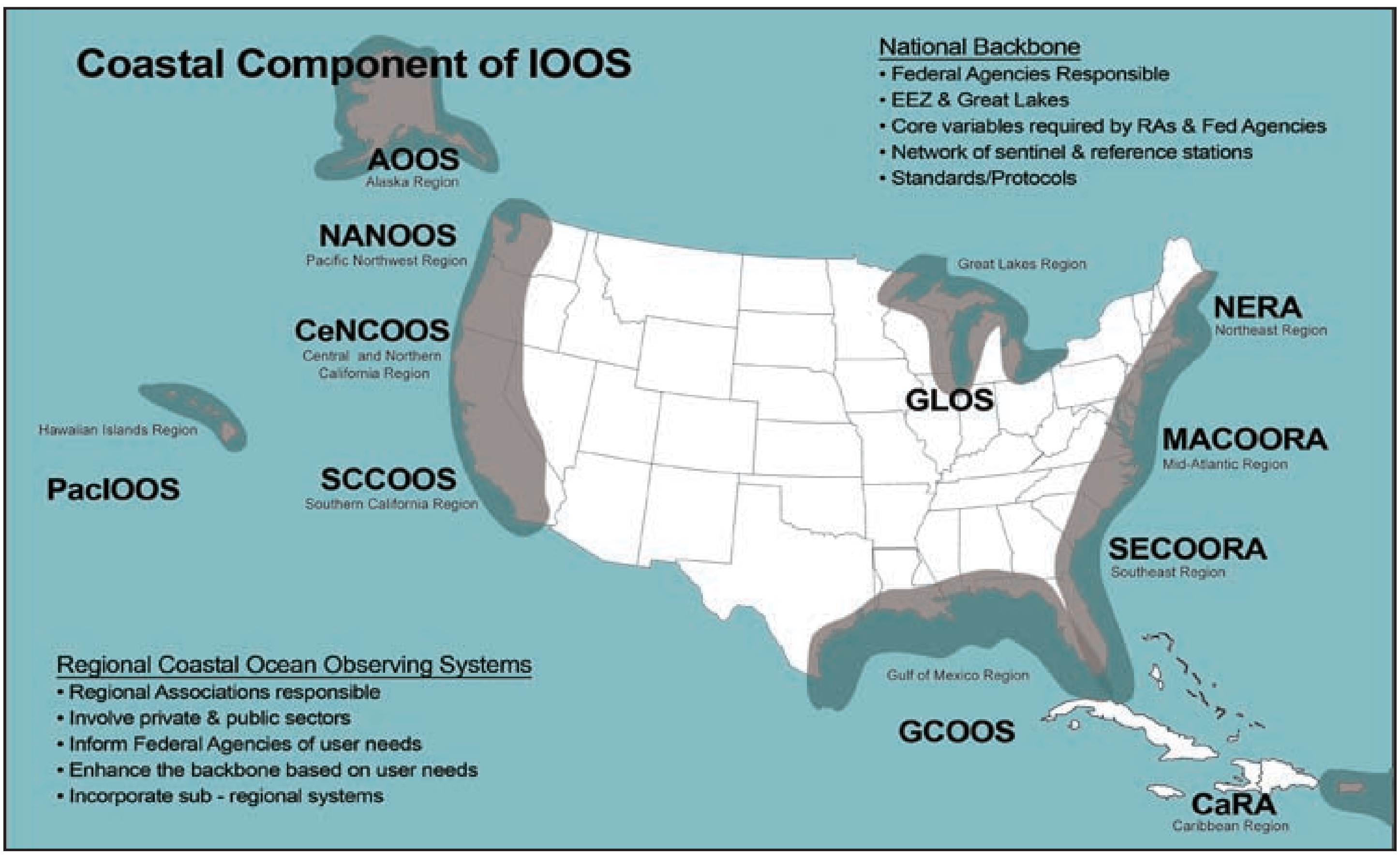


Figure 9: IOOS Regional Associations are responsible for providing data for region-specific needs and for engaging regional data providers and users in the development of IOOS.

AOOS- Alaska Ocean Observing System, **NANOOS**- Northwest Association of Networked Observing Systems, **CeNCOOS**- Central and Northern California Ocean Observing System, **PacIOOS**- Pacific Islands Integrated Ocean Observing System, **SCCOOS**- Southern California Coastal Ocean Observing System, **GLOS**- Great Lakes Observing System, **GCOOS**- Gulf (of Mexico) Coastal Ocean Observing System, **NERA**- NorthEast Regional Association, **MACOORA**- Mid-Atlantic Coastal Ocean Observing Regional Association, **SECOORA**- SouthEast Coastal Ocean Observing Regional Association, **CaRA**- Caribbean Regional Association

[34] For a discussion of IOOS education plans including workforce needs, see Promoting Lifelong Ocean Education: Using the Integrated Ocean Observing System (IOOS) to Shape Tomorrow's Earth Stewards and the Science and Technology Workforce, Ocean.US Publication No. 4, 2004. (http://www.ocean.us/node/205)

IV. Conclusions and Recommendations

Participants identified a wide range of opportunities for linking IOOS capabilities and health. Ideally, the IOOS will provide new data and integrate existing data to help focus scarce monitoring resources, identify emerging threats, assess climate impacts on public health, and determine the likelihood of beach and shellfish bed contamination. The IOOS will enable decision-makers to be proactive in their approach to resource management. More effective, focused monitoring will reveal minimize risks, and predict ecological changes that affect where people live, work, and recreate. Not insignificantly, the IOOS can improve beach closure and advisory decisions, which may allow beaches to be open for greater periods for recreation, resulting in local economic benefits.

But numerous challenges remain. Observation capacities now are poorly suited to coastal areas where health impacts are most often realized. Significant research is needed to bridge land-based, near-shore, and ocean dynamics in ways that allow for more accurate monitoring and risk prediction. In addition, IOOS links with the health community are now tenuous at best. Specialists in earth observations and health work in disparate fields, with different research cultures. Uniting them in a common IOOS framework will require new avenues for dialogue, and accessible formats for collecting and sharing data and information. This broad imperative has its roots at regional and local levels. To advance IOOS health goals, stakeholders must engage local groups and individuals and leverage regional advances towards national objectives.

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The recommendations comprise a strategy for linking the IOOS to health decisions:

- Increase the accuracy and timeliness of estimates of the concentration and distribution of waterborne pathogens, toxic algae, and their toxins. Identify more accurate indicators of risk and improve measurement techniques to reduce the time between sample collection and the availability of results. Molecular, optical, and hybrid methods should be considered.

- Make more inshore measurements and measure indicators of and/or the concentration of waterborne pathogens, toxic algae and their toxins, at the same times and sites as measurements of environmental parameters that determine the survival rates and distributions of waterborne pathogens and toxic algae.

- Implement national standards and protocols for measurements, data management and communications, and modeling.

- Record environmental observations (e.g., vector winds, temperature, salinity, waves, and currents) on time and space scales relevant to the population dynamics of waterborne pathogens and harmful algae by deploying adaptive sensing platforms near HAB hot spots and nutrient sources, combined sewer outfalls, and other point- and non-point contamination sources as appropriate.

- Improve the reliability of epidemiological data linking exposure to illness.

- Specify chemical, physical, and biological data requirements for predicting the development of HABs and their trajectories.

- Develop and validate coupled physical-pathogen transport models for nowcasting risks and forecasting changes in risks with known accuracy.

- Develop and improve near-shore circulation models that link land-based inputs and near-shore processes with better offshore boundary conditions. Incorporate pathogen and algal biology into these models.

- Support improved utilization of near-real time multi-sensor satellite data and products for public health applications (e.g., detection & fate and transport of pollutants/pathogens, blooms) and develop new and improved remote sensing capabilities and derived, user-driven, information products (e.g., water quality assessments - proxies & indicators to support beach closure decisions).

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- Provide the data and information needed to quantify relationships between changes in land use and land-based inputs to coastal waters and changes in public health risks.

- Develop methods for real-time, *in situ* detection measurements of microbial indicators or pathogens for more accurate and timely warnings and advisories for closing and opening beaches and shellfish beds.

In order to effectively carry out these recommendations, the participants also emphasized the need for:

- A new paradigm of coordination among public health and environmental protection officials, living resource and coastal zone managers, and oceanographers and coastal hydrologists to develop an IOOS that meets their collective needs.

- More effective use of the internet and other electronic media to transmit relevant data to public health officials so that they can issue timely warnings.

- In addition to promoting stronger national stakeholder coordination, use IOOS Regional Associations to help identify needs, entrain users, and guide the integration of public health requirements into the IOOS. Increase participation by coastal managers, public health practitioners, and stakeholders responsible for beach and shellfish management in the Regional Associations.

Appendices

APPENDIX A

AGENDA
Public Health Risks: Coastal Observations for Decision Making
January 23 - 25, 2006
St. Petersburg, FL

Monday, January 23rd

8:30 a.m.	**Welcome**	Rita Colwell
8:45 a.m.	**Global and Regional Climate Change: Present and Future**	Warren Washington
9:30 a.m.	**Climate Change, Long-term Observations, and the Impacts to Public Health**	Rita Colwell
10:00 a.m.	**Introduction to the Integrated Ocean Observing System**	Mary Altalo
10:30 a.m.	*Break*	
10:45 a.m.	**Linking Monitoring to Decision-Making for Public Health**	Shannon Briggs Cindy Heil Lorrie Backer
12:30 p.m.	*Lunch brought in*	
1:30 p.m.	**Observations and Models: Capabilities and Possibilities**	Steve Weisberg
1:40 p.m.	Capabilities and potentials of applicable technology 1. Sensors 2. Remote sensing 3./4. Models	Kelly Goodwin Paul DiGiacomo Richard Whitman Tony Busalacci
3:10 p.m.	*Break*	
3:30	**Ocean Observations and the Public Health Model System – Vision**	Juli Trtanj
3:45	Break-out 1: **Improving Public Health Decisions with an Ocean Observation System** Group A1, A2: Monitoring for Management of Recreational Beaches Group B1, B2: Monitoring and Surveillance of Emerging Health Group C1, C2: Monitoring for Management of Shellfish Harvesting Areas	Charge to the WGs – Paul Sandifer Group Leads A1. Joan Rose A2. Barbara Kirkpatrick B1. Jill Stewart B2. Mary Gant C1. Mark Luther C2. Jan Newton Group Coordinator: Muriel Cole
5:00 p.m.	Review Tomorrow's Agenda	
5:30 p.m.	Adjourn for the Day	

Evening Reception at Pier Aquarium hosted by Alliance for Coastal Technologies

Tuesday, January 24th

8:30 a.m.	Review Day 1	Paul Sandifer
8:45	Reports out Break-out 1	Paul Sandifer/ Group Leads
9:45 a.m.	Case Study: **Ecosystem-based Management of Public Health Risks**	Eric Terrill
10:05 a.m.	Break Out 2 : **Designing an Ocean Observation System to Support Public Health Decisions**	Charge to the WGs – Steve Weisberg
	Group A1, A2: Monitoring for Management of Recreational Beaches Group B1, B2: Monitoring and Surveillance of Emerging Health Group C1, C2: Monitoring for Management of Shellfish Harvesting Areas *Break as needed*	Break-out Group Leads A1: Lorrie Backer A2: Donna Francy B1: Lora Fleming B2: David Rockwell C1: David Heil C2: Vera Trainer Group Coordinators A: Beth Leamond B: Juli Trtanj C: Mary Culver
12:00 p.m.	*Lunch*	
1:00 p.m.	Reports from Break-out 2	Steve Weisberg/ Group Leads
2:15 p.m.	**Challenges of Integration and Implementation: Lessons Learned and Future Directions**	Joan Rose
2:45	*Break*	
3:00 p.m.	Break-out 3: **Defining the Next Steps**	Charge to the WGs – Tom Malone
	Groups D1, D2: Research Needs Groups E1, E2: Information Delivery Groups F1, F2: Data Management	Break-out Group leads D1: Rachel Noble D2: John Stegeman E1: Lynn Schneider E2: Usha Varanasi F1: Steve Brandt F2: Steve Williams Group Coordinators: D: Beth Leamond E: Mary Culver F: Muriel Cole
5:00 p.m.	Adjourn for the day	

Dinner at the Yacht Club

Wednesday, January 25th *(end at 12:00)*

8:30 a.m.	Recap previous day	Tom Malone
9:00 a.m.	Report Out – Break out 3	Tom Malone/ Group Leads
10:00 a.m.	**Synthesis of Recommendations –**	Joan Rose/Break-out Leads/Agency Leads
11:15 a.m.	**Next Steps**	
12:00 p.m.	Adjourn	

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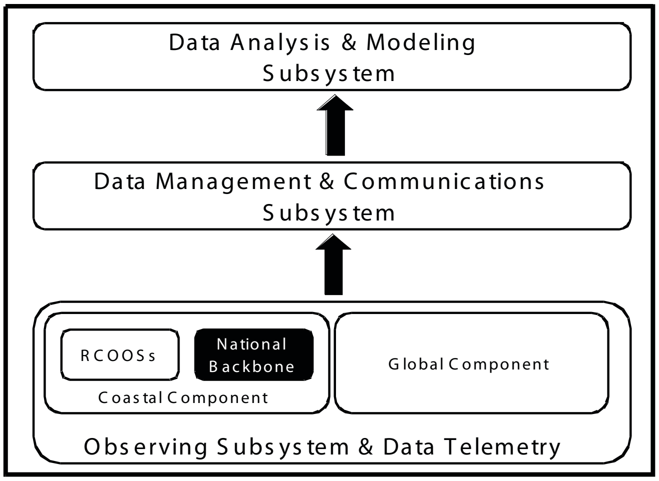
APPENDIX C - Public Health Needs Now Monitored By The IOOS National Backbone



The IOOS is an "end-to-end" system that efficiently links three subsystems (observations and data telemetry, data management and communication, and data analysis and modeling) for the provision of data and information required to address the seven societal goals. The "National Backbone" is a suite of operational observing elements, both *in situ* and remote sensing programs, that monitor core marine variables. The Backbone is supplemented, along the coasts, by Regional Coastal Ocean Observing Systems (RCOOSs).

Below is a synthesis of present National Backbone activities, listed by the agency funding the effort, that support the detection of waterborne microbial pathogens and prediction of changes in human health risks.

Purpose	Core Variable	EPA	NOAA	US Geological Survey	US Army Corps of Engineers	NASA	State Agencies
Risk Assessment	HABs	NEP[1], NCAP[2]	NCAP, NERRS[3]			MODIS[4], SeaWiFS[5]	X
	Bacterial pathogens	Beaches					X
Prediction of Risk	Sea surface winds	NEP	C-MAN[6], NWLON[7], NDBC[8], PORTS[9], NERRS, CoastWatch			QuikScat[10]	
	Surface runoff			Stream gauging, NSIP[11], NASQAN[12]			X
	Salinity	NEP	LMR-ES[13], PORTS, NERRS, NDBC, C-MAN				X
	Sea Surface Temperature	NEP	NDBC, CoastWatch, C-MAN, NWLON, PORTS, LMR-ES, NERRS, AVHRR[14]			MODIS, TMI[15]	X
	Water level		NWLON, PORTS	NSIP, GSN[16]		Altimeters	
	Surface waves		NDBC		CFDC[17]		
	Currents		NDBC, PORTS, NCOP				
	Nearshore bathymetry		Hydrographic survey, Coastal mapping, Topographic change mapping	Coastal change mapping	Hydrographic survey, Shoreline mapping		X
	Dissolved nutrients	NEP, NCAP	LMR-ES, NERRS, NCAP, Habitat Assessment				X
	Dissolved oxygen	NEP					X
	Optical properties	NCAP	NCAP, CoastWatch, NERRS			MODIS, SeaWiFS	

1 NEP - National Estuary Program
2 NCAP - National Coastal Assessment Program
3 NERRS - National Estuarine Research Reserve System
4 MODIS - Moderate Resolution Imaging Spectroradiometer
5 SeaWiFS - Sea-viewing Wide Field-of-view Sensor
6 C-MAN - Coastal-Marine Automated Network
7 NWLON - National Water Level Observation Network
8 NDBC - National Data Buoy Center (moored meteorological sensors, DART mooring systems)
9 PORTS - Physical Oceanographic Real-Time System
10 QuikScat - Quick Scatterometer Mission
11 NSIP- National Streamflow Information Program
12 NSQAN- National Stream Quality Accounting Network
13 LMR-ES - Living Marine Resources-Ecosystems Survey
14 AVHRR – Advanced Very High Resolution Radiometer (on Geostationary Operational Satellite)
15 TMI - Tropical Rainfall Measuring Mission Microwave Imager
16 GSN - Global Seismographic Network
17 CFDC - Coastal Field Data Collection

APPENDIX D

Examples Of Specific Pilot Project Topics Proposed

Detection Of Pathogens And Toxins

- Risk assessment of *Vibrio vulnificus* in oysters from the Gulf of Mexico, using real-time environmental data
- Evaluation of capabilities of "plug-in" pathogen and toxin sensors for ease of deployment, stability, and comparability with existing technology and measurements
- Demonstration of the benefits of using the Quantitative Polymerase Chain Reaction (QPCR) molecular biology technique for rapid detection of pathogens
- Augmentation of programs to identify *Vibrio parahaemolyticus* in locations of known occurrence (Prince William Sound, AK, Hood Canal, WA, Delaware Bay, NJ, Great South Bay, NY) in order to describe the factors responsible for its occurrence and virulence

Fate And Transport Of Pathogens And Toxins

- 1) Retrospective analysis to identify health outcomes in relation to *Karenia brevis* harmful algal bloom dynamics in Florida and the Gulf of Mexico using integrated health and environmental data, and 2) Autonomous sampling in conjunction with models to improve HAB alerts
- Investigation of the transport and persistence of domoic acid on the Washington State coast
- Linkage of simulation model with sediment transport modeling in Tomales Bay, California, leveraging ongoing research to improve shellfish bed management.
- Data collection over one-two years using current meters; high frequency radar; conductivity, temperature, and depth profiles;, acoustic Doppler current profilers; water level measurements; and other sensors to validate the models of *Karenia brevis* distribution in Charlotte Harbor Bay, Florida
- Demonstration of the end-to-end capabilities of the IOOS at a "high-problem, high-use" beach in the Great Lakes region
- Evaluation of the effects of hypoxia on methylation of mercury and possible contamination of fish and shellfish
- Coupling of land-use with near-shore and lake models for better pathogen monitoring schemes and quantitative microbial risk assessments in the Great Lakes
- Assessment of aquatic-based threats to coastal Texas from *Karenia brevis* blooms and V*ibrio vulnificus* using the Texas Coastal Ocean Observing Network
- Evaluation of links between oceanographic processes and the accumulation of cadmium in Pacific shellfish
- Preparation of a genomic profile of an environment to address mass movement of pathogens, incursion of species, and effects of population changes

Health Risk Assessments

- Linkage of epidemiological studies with environmental data being collected by the Southern California Coastal Ocean Observing System or other regional observing system
- Comparison of shellfish closure and harvesting data and BEACH data for the Gulf Coast to identify any correlation and thus determine the feasibility of public health decisions made jointly for shellfish and recreational beaches
- Determination of relationship between holding ponds and shellfish bed closures through the use of measurements and models using GIS
- Demonstration of methods of determining and communicating a "hot spot" situation that requires rapid notification of an event to various agencies and the public
- Leveraging of public health grants to include remote sensing in models of health impacts
- Integration of epidemiological studies with present sensor capabilities in a select region having a population with common exposure and common complaints

APPENDIX E- Acronym Listing

ASP	Amnesic Shellfish Poisoning
BEACH	Beach Environmental Assessment and Coastal Health
CTD	Conductivity Temperature Depth
DMAC	Data Management and Communications
DNA	Deoxyribonucleic Acid
DPSIR	Driver-Pressure-State-Impact-Response
E.Coli	*Escherichia coli*
EPA	Environmental Protection Agency
FDA	Food and Drug Administration
GIS	Geographic Information System
HAB	Harmful Algal Bloom
IOOS	Integrated Ocean Observing System
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NOPP	National Oceanographic Partnership Program
NSP	Neurotoxic Shellfish Poisoning
NSSP	National Shellfish Sanitation Program
PSP	Paralytic Shellfish Poisoning
QPCR	Quantitative Polymerase Chain Reaction
RNA	Ribonucleic Acid
SC	Steering Committee
SIMOR	Subcommittee on Integrated Management of Ocean Resources
SIMS	Shellfish Information Management System
STORET	STOrage and RETrieval

APPENDIX F - List of Ocean.US Publications completed

Report No. 1 - Building Consensus: Toward an Integrated and Sustained Ocean Observing System, May 2002
Report No. 2 - An Integrated and Sustained Ocean Observing System for the United States: Design and Implementation, May 2002
Report No. 3 - Regional Ocean Observing Systems, an Ocean.US Summit, March 2003
Report No. 4 - Proceedings of the National IOOS Education Workshop, March 2004
Report No. 5 - Proceedings of the Regional Organization Workshop March 2004
Report No. 6 - Data Management and Communications Plan for Research and Operational Integrated Ocean Observing Systems: Interoperable Data Discovery, Access, and Archive, March 2005
Report No. 7 - Surface Current Mapping in U.S. Coastal Waters: Implementation of a National System, June 2004
Report No. 8 - Proceedings of the First Annual IOOS Development Workshop, August 2004
Report No. 9 - First Integrated Ocean Observing System (IOOS) Development Plan, January 2006
Report No. 10 - NOPP Economics Report: Estimating the Economic Benefits of Regional Ocean Observing Systems
Report No. 11 - Global Ocean Observing System:
U.S. National Implementation and Planning Activities and Highlights,
April 2005
Report No. 12 - Proceedings of the Second Annual IOOS Development Workshop, May 2005
Report No. 13 - Technical Workshop: Application of Iridium Telecommunications to Oceanographic and Polar Research