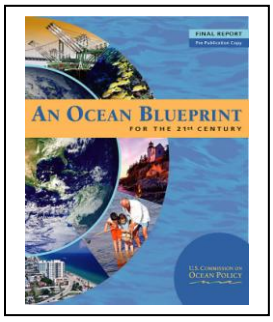
NATIONAL WATER QUALITY MONITORING COUNCIL
Working Together for Clean Water
NWQMC

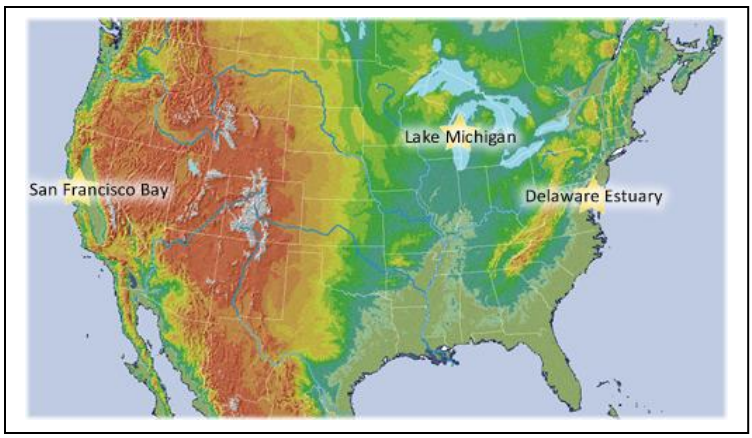
Integrated Land-to-Sea Assessments and the National Water Quality Monitoring Network for U.S. Coastal Waters and Tributaries ("Network")

Demonstrations of integrated land-to-sea assessments in San Francisco Bay, Lake Michigan, and Delaware Estuary provide critical information about the health of our oceans and coastal ecosystems and inland influences on coastal waters for improved resource management (http://acwi.gov/monitoring/network/index.html).



These assessments support concepts that were laid out in a *National Water Quality Monitoring Network for U.S. Coastal Waters and their Tributaries* (or "Network") that was designed by the Council and more than 80 stakeholders in response to a recommendation by the U.S. Commission on Ocean Policy in 2004 in *An Ocean Blueprint for the 21st Century*.

The Network is, in reality, comprised of a "network of networks" and represents an integrated, multidisciplinary, and multi-organizational approach that leverages diverse sources of data and information; augments existing monitoring programs; and links observational capabilities. These networks include federal agencies, the Integrated Ocean Observing System (IOOS) (http://ioos.gov/), and regional associations representing a broad community of users, including coastal and inland states, tribes, researchers, and non-governmental organizations (http://usnfra.org/).

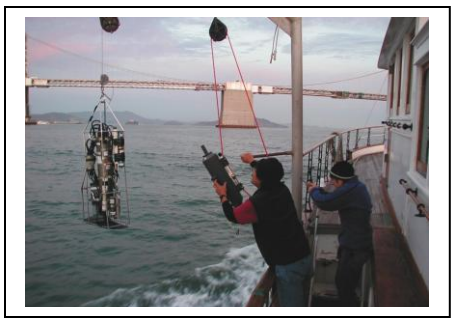


Since 2007, Network concepts have been piloted and implemented in San Francisco Bay, Lake Michigan, and Delaware Estuary. Gap analyses and new monitoring have been funded by USGS in the three areas in support of the Ocean Research Priorities Plan, as well as through partnerships with local, state, regional, and federal organizations. The activities are coordinated with key organizations and IOOS regional associations, including the Delaware River Basin Commission and Mid-Atlantic Coastal Ocean Observing Regional Association (MACOORA); Great Lakes Commission and Great Lakes Observing System (GLOS); and the San Francisco Estuary Institute and Central and Northern California Ocean Observing System (CenCOOS).

Integrated assessments in San Francisco Bay, Lake Michigan, and Delaware Estuary are successfully using new technologies, such as real-time monitoring with sensors and autonomous underwater vehicles (AUVs), along with more traditional monitoring. The assessments are helping to improve estimates of oceanic and land-based inputs of sediment, nutrients, and contaminants to U.S. coastal waters and estuaries, and improving assessments on the sources, amounts, timing, and severity of natural and anthropogenic stressors on coastal ecosystems. Findings will be useful to compare responses of different estuarine and coastal waters to these stressors, which help to facilitate water-management decisions in other U.S. waters.

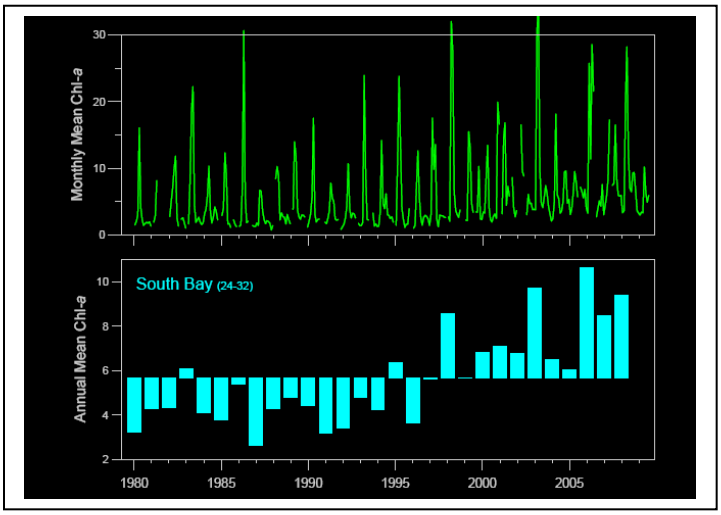
Highlights on selected nutrient issues and ongoing monitoring in the three Network areas are below. For more detailed information, photos, graphics, and contacts for these areas, as well as information on integrated assessments in other coastal areas, access: (http://acwi.gov/monitoring/network/index.html).

San Francisco Bay—Long-term, integrated, and multi-organizational studies conducted over 40 years in San Francisco Bay—known as the longest sustained program of research and observation in a U.S. coastal ecosystem—help resource managers and resource protection agencies understand the response of the Bay's aquatic community to the combined effects of climate variability, urbanization, changes in the hydrologic system, and the introduction of nutrients, organic contaminants, and trace elements.



Hydrologists collect water samples for analysis of long-term trends in nutrients, dissolved oxygen, chlorophyll a and other constituents in San

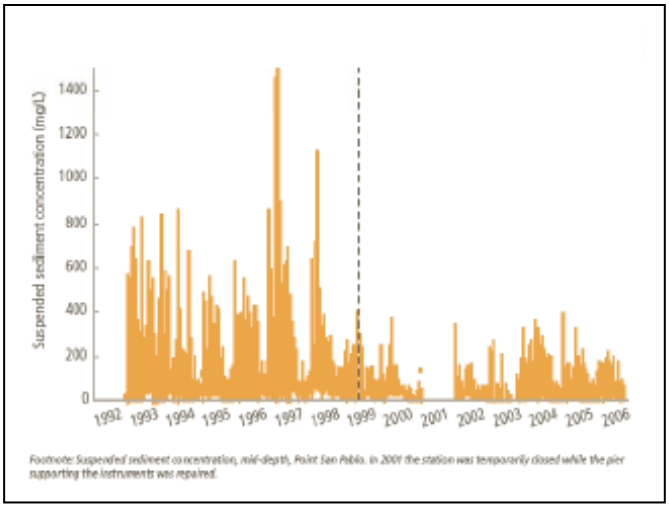
San Francisco Bay has historically been resilient to degradation from nutrient enrichment and not known for hypoxia or harmful algal species as found in other areas, such as Chesapeake Bay. This is despite the fact that San Francisco Bay, like Chesapeake Bay and other large estuaries, has elevated nutrient loadings. One manifestation of the resilience in San Francisco Bay has been relatively low concentrations of chlorophyll *a* (an indicator of phytoplankton biomass). Concentrations of chlorophyll *a*, however, have been increasing steadily since 1999.

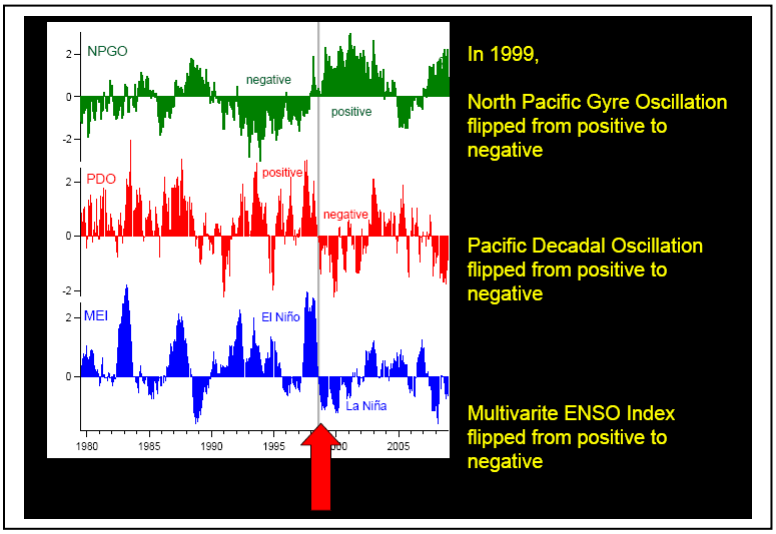


Chlorophyll a (an indicator of phytoplankton biomass) has been increasing since 1999. Conditions in San Francisco Bay may therefore reflect a reduced resilience to nutrient degradation, hypoxia, and harmful algal species.

Three possible reasons may explain the increases in chlorophyll *a* over the last 10 years. First, water clarity is increasing because turbidity is decreasing, which allows increased phytoplankton growth. Turbidity is decreasing in part because of human activities related to damming and flood control and continued depletion of the erodible pool of sediment dating back to the Gold Rush. Second, chlorophyll *a* is increasing in the Pacific Ocean so that the ocean is now a major source of photoplankton biomass to San Francisco Bay. Third, clams, which are a major consumer of phytoplankton, have decreased because of exceptionally large increases in clam predators beginning around 1999, including the English sole, Dungeness Crab, and Bay Shrimp (http://www.pnas.org/cgi/reprint/104/47/18561).

Decreases in suspended sediment since 1999 are evident in the time series of data from a station in Point San Pablo. Most sites monitored by USGS show similar decreases. Decreasing turbidity is leading to increasing phytoplankton biomass in San Francisco Bay.





The large physical and biological shifts described above occurred in San Francisco Bay after a dramatic shift in the ocean currents/atmospheric circulation system in 1999, signaled as sign reversals of the Pacific Decadal Oscillation and North Pacific Gyre Oscillation. These natural oscillations drive changes in climate, and along with human activities (such as related to damming of rivers) are leading to degradation of biological communities and water quality.

Lessons learned from the integrated assessments in San Francisco Bay: (1) Biological communities and water quality are influenced by both human activities (i.e. damming rivers that reduce sediment supply and turbidity) and natural climatic oscillations; (2) Estuaries are influenced by their connectivity to the oceans (not just watersheds and terrestrial connections); and, (3) Long-term climatic cycles (20 to 30 years) can have large impacts on estuaries, oceans, and coastal ecosystems.

The increase in water clarity and nutrient loadings in San Francisco Bay are likely to persist, leading to continued phytoplankton abundance. Management of nutrients and development of nutrient criteria are now critical for a Bay that historically was resilient. Continued monitoring and tracking of nutrients, sediment, and phytoplankton abundance is needed in this dynamically changing ecosystem to help forecast future effects of climatic change on water quality and biological communities in the coastal zone.

Network activities have been ongoing in San Francisco since 2007, funded by USGS in support of the Ocean Research Priorities Plan, as well as through partnerships with local, state, regional, and federal organizations. Highlights include: (1) nutrient monitoring at selected sites to continue tracking nutrient loadings to the Bay; (2) monitoring and assessment of the composition of the phytoplankton community (including the presence and threat of harmful algal species); and, (3) real-time monitoring for suspended sediment and quantification of the suspended-sediment flux to the Bay. Data are managed and made available through a public, web accessible database containing more than 40 years of water-quality data. Statistical tools and guides are being developed to analyze time series of water quality, extract trends and significance levels, and assess seasonal and long-term patterns of variability, which will be useful to other water-quality monitoring programs across the Nation.

Major partners:

- San Francisco Estuary Institute
- Regional Monitoring Program for Water Quality in the San Francisco Estuary
- Point Reyes Bird Observatory;
- Sun Microsystems
- Central and Northern California Ocean Observing System (CENCOOS)
- California Coastal Conservancy
- South Bay Salt Pond Restoration Project
- California Department of Fish and Game
- California Coastal Conservancy
- University of Washington
- Georgia Tech
- University of California
- National Science Foundation National Center for Ecological Analysis and Synthesis
- U.S. Fish and Wildlife Service (FWS)
- U.S. Geological Survey (USGS)
- National Oceanography and Atmospheric Administration (NOAA)
- U.S. Bureau of Reclamation

Web access:

- http://sfbay.wr.usgs.gov/access/wqdata/index.html
- http://sfbay.wr.usgs.gov/sediment/cont_monitoring/

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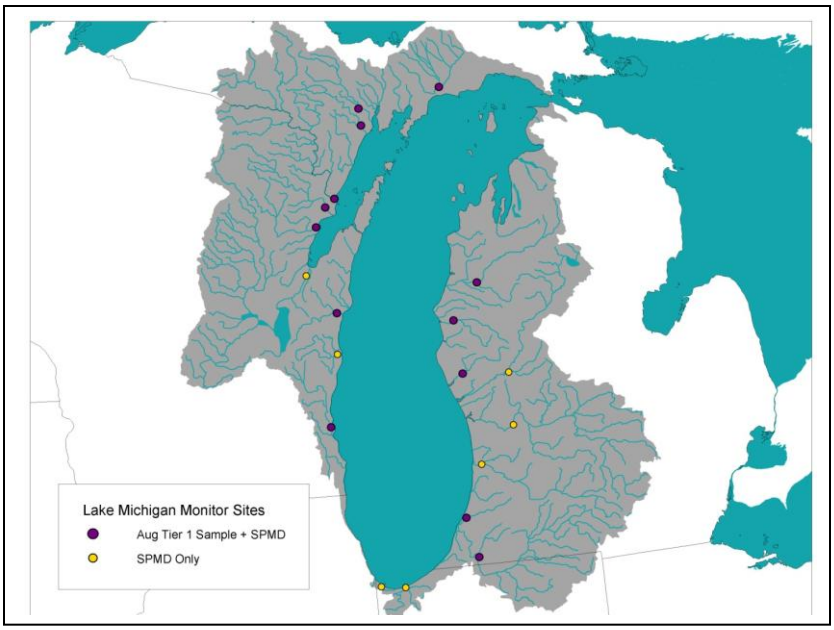
Lake Michigan is the sixth largest lake in the world and the only Great Lake entirely within the U.S. Projections are that by 2030 development in the watershed around surrounding southern Lake Michigan will grow by nearly 40 percent and the population will increase by 2 million, subjecting the area with water-supply and water-quality challenges.

Hydrologists prepare to measure streamflow at the mouth of the Milwaukee River before it enters Lake Michigan.

Major management issues in Lake Michigan and the surrounding watersheds relate to sustaining beneficial uses through continued remediation in ten "Areas of Concern" that are experiencing degradation of benthos, impaired food webs because of invasive species, restricted water supplies, loss of habitat (especially coastal wetlands), elevated nutrient loadings and undesirable algae, and beach closings because of potential pathogenic organisms. Lake Michigan has relatively long water retention that makes it particularly susceptible to pollutant buildup. This has led to several fish consumption advisories because of mercury and legacy toxic chemicals, such as polychlorinated biphenyls (PCBs), polychlorinated aromatic hydrocarbons (PAHs), flame retardants, DDT and other organochlorine pesticides.

Elevated nutrient loadings from point and nonpoint sources of pollution from agricultural and urban land and the atmosphere are resulting in excessive growth of algae and other nuisance plants (eutrophication). Phosphorus has been identified as the primary nutrient of concern and hence "targets" for phosphorus loads were established in the 1970s and 1980s through Great Lake Water Quality Agreements. Subsequent actions resulted in decreased phosphorus loadings that have reduced eutrophication in the open lake. Since 1980, phosphorus loadings to Lake Michigan have remained below the targeted loads. Eutrophication issues, however, such as related to nuisance growth of cladophora, now occur in some nearshore areas and embayments. Continued monitoring and tracking of nutrient sources and loads from the upstream watersheds and water quality in the nearshore are therefore critical.

Network activities have been ongoing in Lake Michigan since 2007, funded by USGS in support of the Ocean Research Priorities Plan, as well as through partnerships with local, state, regional, and federal organizations. A major activity involves monitoring of flow and concentrations of nutrients and other constituents at 20 sites. Such monitoring enables direct assessment of about 70 percent of total inflow to Lake Michigan; provides information for key geographic and potential pollution-source areas that have not been previously monitored; and, helps to more comprehensively track loadings from the watersheds to the near-shore environments and Lake Michigan. In addition, Semi-Permeable Membrane Devices (SPMDs) have been deployed at the 20 sites to assess potential toxicity from hydrophobic organic contaminants, such as PAHs and DDT.



Monitoring at 20 sites helps to track nutrient loadings and other constituents from watersheds to Lake Michigan. Semi-Permeable Membrane Devices (SPMDs) have been deployed to assess potential toxicity from hydrophobic organic contaminants, such as DDT and other organochlorine pesticides and polychlorinated biphenyls (PCBs).

Semi-Permeable Membrane Devices (SPMDs) are passive samplers for assessing trace levels of hydrophobic organic contaminants and are designed to mimic biological membranes, such as the gills of fish.

Beginning in 2010, Network monies also support implementation of automated underwater vehicles (AUVs) in tributary mouths in the Milwaukee harbor environments and the bay of Green Bay. This innovative, real-time technology produces continuous high-resolution data for chlorophyll *a*, temperature, conductivity, dissolved oxygen, pH, turbidity, and blue-green algae; provides side scan sonar images of the lake or river bottom; and profiles water velocity. The continuous data are integrated with field chemistry samples to develop baseline water-quality monitoring surveys, and mapping of bathymetry, point and non-point sources, and substrate. The AUV technology also will be tested as a possible mechanism to track plumes from tributary mouths through embayments and into the nearshore.

***Automated underwater vehicles (AUVs) are used in the bay of Green Bay and the Milwaukee harbor environments, and produce a continuous stream of high-resolution data for chlorophyll a, temperature, conductivity, dissolved oxygen, pH, turbidity, and blue-green algae. (Note:* AUVs, such as the YSI Ecomapper shown above, are available from a variety of manufacturers.)**

Network data are integrated in a data-management and web services system that is coordinated through the Great Lakes Restoration Initiative. In addition, Network-supported efforts and information contribute to the Near Shore Monitoring Plan of the Lake Michigan Monitoring Coordination Council (LMCC). This Plan describes coordinated monitoring and assessments for tributaries, embayments, and near-shore environments, which will help to track nonpoint sources of nutrients, pesticides, and heavy metals to near-shore environments. In addition, this information will enable evaluation of the health of coastal ecosystems and changes over time, all of which will provide information necessary for managers to make informed decisions, adapt their actions as needed, and assure effective stewardship of Lake Michigan.

Major partners:

- Great Lakes Commission
- Great lakes Restoration Initiative
- Lake Michigan Monitoring Coordination Council
- Green Bay Metropolitan Sewerage District
- Milwaukee Metropolitan Sewerage District
- Wisconsin Department of Natural Resources
- University of Wisconsin Water Institute
- Great Lakes Regional Research and Information Network
- Great Lakes Environmental Research Laboratory (NOAA)
- Great Lakes Observing System (GLOS)
- U.S. Environmental Protection Agency (EPA)
- U.S. Geological Survey (USGS)

Web Access:

Lake Michigan Monitoring Coordination Council:
http://wi.water.usgs.gov/lmmcc/
Great Lakes Restoration Initiative: http://www.epa.gov/glnpo/glri/

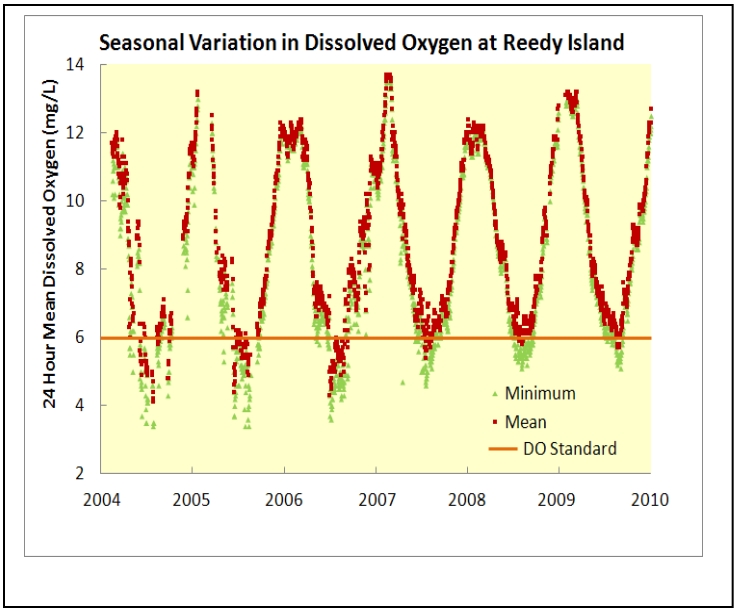
Contacts: Kevin Richards, krichard@usgs.gov (608) 821-3861, Charlie Peters, capeters@usgs.gov (608) 821-3810, and John Hummer, jhummer@glc.org, (734) 971-9135

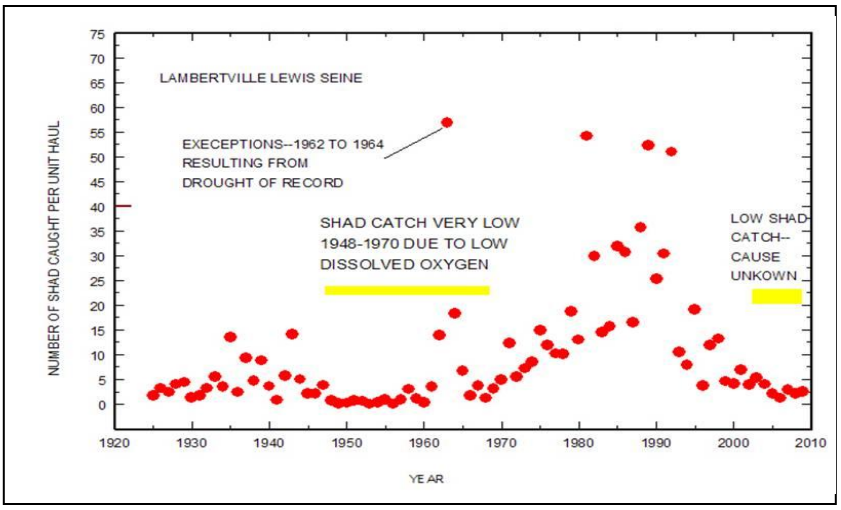
Delaware Estuary—The Delaware Estuary drains more than 13,000 square miles and consists of an 85-mile long tidal freshwater river and a 48 mile long bay. The tidal freshwater river provides drinking water to millions of people, but is susceptible to contamination from urban and agricultural sources. Transported sediments can clog shipping channels, and often carry persistent legacy contaminants, such as polychlorinated biphenyls (PCBs) that can contaminate fish and create disposal problems when dredged.

Nutrient runoff and discharges to the estuary create persistent low dissolved oxygen and the potential for damaging algal blooms. Up until the late 1970s, low dissolved oxygen was prevalent in the estuary, such as in vicinity of Philadelphia, creating anoxic dead zones that affected local aquatic species and migratory fish, such as shad. Over 40 years of monitoring data show improvements in water quality and ecological indicators, including increasing dissolved oxygen, decreasing concentrations of PCBs, and restored fin fish populations. These improvements are attributed to water-quality regulations and bans on contaminants of concern since the 1970s. Improvements over the last 10 to 20 years have been less dramatic and there is concern that conditions may still be harmful to humans and aquatic life.

Hydrologists deploy real-time continuous monitors for turbidity, dissolved oxygen, specific conductance, and other parameters, which help to measure vertical profiles and monitor daily and seasonal variations and trends.

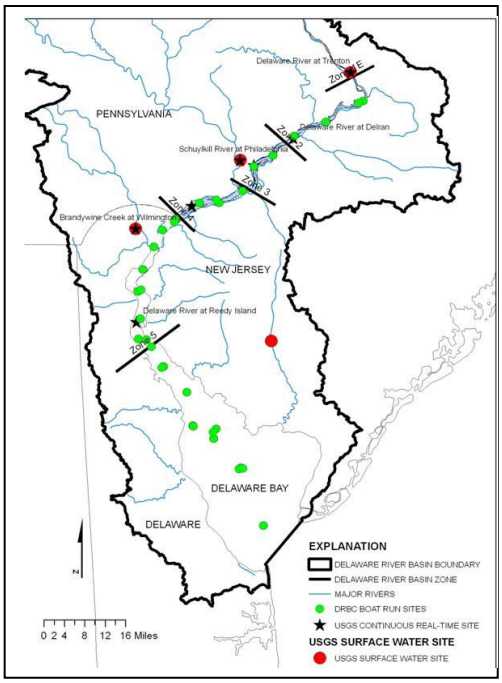
Continuous data for dissolved oxygen on the Delaware River at Reedy Island Jetty in Delaware show levels below the 24-hour mean criteria (orange line) established by the Delaware River Basin Commission. Most regions of the estuary currently meet the established water-quality criteria. However, ongoing real-time monitoring demonstrates that low sags in dissolved oxygen still occur during certain times of the year, such as in the summer. Ammonia may be a lead factor in reducing dissolved oxygen in the estuary. Low dissolved oxygen can be harmful to certain species and research suggests that the established water-quality goals for dissolved oxygen may not protect important species in the estuary, including current and candidate threatened and endangered species, such as the Atlantic sturgeon. Continued management of dissolved oxygen and development of criteria for nutrients are therefore needed to protect living resources in the Delaware Estuary.





Initial rebound in shad fishery in 1980's and 1990's is attributed to improved levels of dissolved oxygen in the estuary. Reasons for the decline since that time are uncertain.

The Network has served as a catalyst for prioritizing issues and strategies within the basin. Highlights include nutrient monitoring at four head of tide tributaries that contribute over 90 percent of the flow to the Delaware Estuary. Dissolved oxygen, nutrients, and other constituents are monitored eight times each year at over 20 locations from the mouth of Delaware Bay to the head of tide as part of a boat run. The continuous monitoring network, which measures dissolved oxygen, pH, temperature, conductance, and turbidity in real time, has been enhanced in areas of major drinking water intakes in the upper estuary and at existing mid-estuary locations where the role of turbidity in limiting algal growth is uncertain. Data are made available through a public web page linking data and information from a multitude of partners. Real-time data are linked to Delaware River Basin Commission (DRBC) Water Quality Criteria and disseminated to stakeholders using automated software applications and email notification, which allows managers to respond to water issues in real time.



Despite relatively high nutrient loadings to Delaware Estuary, which are comparable to those of the adjacent Chesapeake Bay, algal blooms are not as prevalent in the Delaware Estuary as in Chesapeake Bay. Monitoring and assessments are ongoing to help explain the relatively unique response in the Delaware Estuary, and the importance of factors such as stratification in the bay, high turbidity in the tidal river, and a high flush rate in limiting accumulation of algal biomass.

Future plans involve development of an eutrophication model by the DRBC to help clarify the role of ammonia in reducing oxygen in the estuary. Air and water monitoring and modeling (such as with the USGS SPARROW regression model) will help to improve estimates of nutrient sources and loadings. Flyovers are planned to measure chlorophyll *a*, which will help to identify the timing and location of algal growth. Other planned sampling, monitoring, and modeling will help identify sediment transport and dynamics in the bay from the head of tide to the ocean. Together, information from the discrete samples, continuous monitors, and remotely operated vehicles will help identify locations of elevated ammonia, depleted oxygen, and where turbidity may limit algal growth. Anticipated findings will be useful for managing nutrients in Delaware Bay, as well as in other estuarine and coastal waters across the Nation. In addition, the information will help to forecast future effects of climatic change, such as movement of the salt front towards drinking-water intakes, impacts from sea-level rise on wetlands, and possible increasing temperatures causing decreasing dissolved oxygen and degradation of biological resources in the estuary.

Web Access:

Delaware River Basin Commission: http://www.state.nj.us/drbc/

U.S. Geological Survey, New Jersey Water Science Center: http://nj.usgs.gov/projects/2454BSB/natmonitornet/

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Robert Tudor, robert.tudor@drbc.state.nj.us (608) 883-9500, ext. 208

Major partners:

- Delaware River Basin Commission
- Partnership for the Delaware Estuary
- Delaware Department of Natural Resources and Environmental Control
- New Jersey Department of Environmental Protection
- New Jersey Water Monitoring Coordination Council
- University of Delaware, College of Marine and Earth Studies
- Rutgers Institute of Marine and Coastal Sciences
- Mid-Atlantic Coastal Ocean Observing Regional Association (MACOORA)
- U.S. Environmental Protection Agency (EPA)
- National Oceanography and Atmospheric Administration (NOAA)
- U.S. Geological Survey (USGS)

Background on the National Water Quality Monitoring Network for U.S. Coastal Waters and their Tributaries ("Network")

The Network began in response to a recommendation in *An Ocean Blueprint for the 21st Century* by the U.S. Commission on Ocean Policy in 2004. The Council spearheaded the design, along with more than 80 participants from government and non-governmental organizations. The design was approved by the Advisory Council for Water Information (ACWI) in 2006 (http://acwi.gov/monitoring/network/).

The Network integrates biological, chemical, and physical features and includes nine resource compartments, thereby linking uplands to the coastal ocean (see box). The Network leverages diverse sources of data and information and assessment tools; augments existing monitoring programs; and links observational capabilities. The intended outcome is enhanced information about the health of our oceans and coastal ecosystems and inland influences on coastal waters for improved resource management.

The Network is a continuum of observations in:

- Estuaries
- Nearshore
- Offshore and Exclusive Economic Zone
- Great Lakes
- Coastal Beaches

With flow and flux from:

- Rivers (Hydrologic Unit Code 6)
- Coastal Streams
- Atmosphere
- Groundwater
- Wetlands

A key feature of the design is its clear linkages with management issues—such as related to nutrient enrichment, oxygen depletion, toxic contaminants, and beaches—that are important to a broad community of users, including federal agencies, coastal states, tribes, researchers, and non-governmental organizations. Other selected features of the design include involvement of IOOS and regional associations for monitoring offshore compartments and coastal management; a linked data network; inclusion of monitoring to meet diverse objectives (including fixed and probabilistic designs); and provisions for data comparability, management, and access.

Refinements to the network were recommended in 2008 relating to nutrient parameters and detection limits; additional contaminants; inclusion of coastal wetlands and atmospheric contributions; ancillary data needed for biological assessments (http://acwi.gov/monitoring/network/Network_refinement_summary.pdf).

Since 2007, Network concepts have been piloted and implemented in San Francisco Bay, Lake Michigan, and Delaware Estuary. During the first year, monitoring gaps were examined in relation to the proposed Network design. Individual reports and a national synthesis of findings are available, highlighting common management issues relating to nutrient enrichment, sediment, and toxic contaminants; inadequate monitoring sites and frequency; and the need for enhanced data management and integration across organizations.

Beginning in 2008, additional monitoring was initiated in the three pilot areas to fill gaps needed to address water-quality issues. In the Delaware Estuary pilot, monitoring and assessment of nutrients and carbon were added to current USGS tidal stations and estuary boat run sites, and real-time monitoring (such as for temperature, specific conductance, pH, dissolved oxygen, and turbidity) were added to selected river and estuary sites. In the Lake Michigan pilot, three new monitoring sites were added; nutrient monitoring was enhanced at 17 existing USGS sites; Semi-Permeable Membrane Devices (SPMDs) were deployed at 20 sites to assess potential toxicity from hydrophobic organic contaminants; and automated underwater vehicles (AUVs) were implemented in tributary mouths in the Milwaukee harbor environments and the bay of Green Bay. In the San Francisco Bay pilot, real-time monitoring for suspended-sediment was expanded, and nutrient and phycotoxin monitoring was enhanced at selected sites.

For more information on the Network:

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