2 MONITORING WATER QUALITY IN ESTUARIES AND COASTAL AREAS: AN OVERVIEW

This chapter presents an overview of marine water quality, and how threats to coastal and estuarine systems can affect human health and the environment. Section 2.1 describes the nature and dynamics of estuaries, including the natural and anthropogenic phenomena that affect these environments. Section 2.2 discusses the water quality problems encountered in Long Island Sound, including the primary pollution problem in the Sound: decreased levels of dissolved oxygen, or hypoxia. Section 2.3 presents an overview of marine water quality monitoring for the physical, chemical, and biological parameters of concern in estuaries and coastal areas. This section also lists Web sites for further information on the ecology and pollution problems of watersheds, estuaries, and coastal regions.

2.1 THE NATURE AND DYNAMICS OF ESTUARIES

To develop and implement an effective plan for a comprehensive estuarine monitoring network, it is important to understand the nature and dynamics of estuaries in general, and also to understand the details of the particular estuary, embayment, harbor, or river to be monitored. These details include the bathymetry, tidal range, circulation patterns, and pollution problems that are being encountered.

The estuarine environment is a complex blend of continuously changing habitats. Unlike fresh water rivers and lakes, estuaries can produce a wide range in the values of physical and chemical parameters that will be recorded, and frequent changes occur in these values both with tidal cycles and meteorological events. In streams, rivers, and lakes, water quality parameters are more likely to fluctuate within a well-defined range largely determined by rainfall and season, and these values are often homogenous throughout the water body. In an estuary, in contrast, these parameters can change abruptly in time and space, are dependent on the measurement location, and may or may not reflect general environmental conditions throughout the estuary.

Two key phenomena that control physical and chemical parameters in estuaries are tidal flushing and stratification (vertical or horizontal). Tidal flushing is the net transport for water (as well as sediments and contaminants) out of an estuary with tidal flow and river flow. Stratification is layering of the estuary generally associated with the inflow of denser salt water at depth and the outflow of more buoyant fresh water at the surface. Layering can also occur when seasonal heating causes a sharp differential or thermocline (interface where temperature changes rapidly with depth) so that the warm surface layer is isolated from the colder bottom layer. A good overview of estuarine dynamics as they relate to monitoring is provided in the publication *Volunteer Estuary Monitoring—A Methods Manual* (*http://www.epa.gov/owow/estuaries/monitor*) developed by EPA and the Center for Marine Conservation (now the Ocean Conservancy).

Superimposed on these naturally occurring variations are changes caused by human intervention, including modification of flow and bathymetry (for example, through construction of barriers to flow or dredging) and the input of pollutants, including excess nutrients and toxics. Often the status, trends, and episodic changes in the levels of these pollutants are the focus of a monitoring effort. Typical pollution problems in estuaries include nutrient enrichment leading to accelerated eutrophication (excessive plant growth); low dissolved oxygen (DO) levels associated with eutrophication and/or flow restrictions; toxics in the water column or sediments, particularly petroleum hydrocarbons and heavy metals from point discharges and non-point source runoff; algal blooms, which can be toxic to marine organisms and humans; and the proliferation of invasive species.

What Are Estuaries, and Why Are They Important?

Unlike many features of the landscape that are easily described, estuaries are transitional zones that encompass a wide variety of environments. Loosely categorized as the zone where fresh and salt water meet and mix, the estuarine environment is a complex blend of continuously changing habitats. To qualify as an estuary, a waterbody must fit the following description:

> ***"a semi-enclosed coastal body of water which has free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage."***

The estuary itself is a rather well-defined body of water, bounded at its mouth by the ocean and at its head by the upper limit of the tides. It drains a much larger area, however, and pollutant-producing activities near or in tributaries even hundreds of miles away may still adversely affect the estuary"s water quality.

While some of the water in an estuary flows from the tributaries that feed it, the remainder moves in from the sea. When fresh and salt water meet, the two do not readily mix. Fresh water flowing in from tributaries is relatively light and overrides the wedge of more dense salt water moving in from the ocean. This density differential often causes layering or stratification of the water, which significantly affects both circulation and the chemical profile of an estuary.

Estuaries are critical for the survival of many species. Tens of thousands of birds, mammals, fish, and other wildlife depend on estuarine habitats as places to live, feed, and reproduce. They provide ideal spots for migratory birds to rest and refuel during their journeys. Many species of fish and shellfish rely on the sheltered waters of estuaries as protected places to spawn, giving estuaries the nickname "nurseries of the sea." Hundreds of marine organisms, including most commercially valuable fish species, depend on estuaries at some point during their development.

Besides serving as an important habitat for wildlife, the wetlands that fringe many estuaries perform other valuable services. Water draining from upland areas carries sediments, nutrients, and other pollutants. But as the water flows through wetlands, much of the sediments and pollutants are filtered out. This filtration process creates cleaner and clearer water, which benefits both people and marine life. Wetland plants and soils also act as natural buffers between the land and ocean, absorbing flood-waters and dissipating storm surges. This protects upland organisms as well as valuable real estate from storm and flood damage. Salt marsh grasses, mangrove trees, and other estuarine plants also prevent erosion and stabilize the shoreline.

Among the cultural benefits of estuaries are recreation, scientific knowledge, education, and aesthetic value. Boating, fishing, swimming, surfing, and bird watching are just a few of the numerous recreational activities people enjoy in estuaries. They are often the cultural centers of coastal communities—focal points for commerce, recreation, history, customs, and traditions. As transition zones between land and ocean, estuaries are invaluable laboratories for scientists and students, providing countless lessons in biology, geology, chemistry, physics, history, and social issues. Estuaries also provide a great deal of aesthetic enjoyment for the people who live, work, or recreate in and around them.

Finally, the tangible and direct economic benefits of estuaries should not be overlooked. Tourism, fisheries, and other commercial activities thrive on the wealth of natural resources that estuaries supply. Protected estuarine waters also support important public infrastructure, serving as harbors and ports vital for shipping, transportation, and industry.

From *Volunteer Estuary Monitoring—A Methods Manual*
http://www.epa.gov/owow/estuaries/monitor

2.2 ENVIRONMENTAL ISSUES AND WATER QUALITY IN LONG ISLAND SOUND

Long Island Sound is the largest and most heavily utilized estuary in the Northeast. The waters of Long Island Sound support a large and diverse ecosystem which includes tidal marshes, benthic communities, commercially valuable fish and shellfish, marine bird populations, and marine mammals. Its waters also support a wide variety of human activities, including marine transportation, commercial fishing, aquaculture, and recreation. More than 8 million people live in the Long Island Sound watershed and millions more flock yearly to the Sound for recreation. More than $5 billion is generated annually in the regional economy from boating, commercial and sport fishing, swimming, and beachgoing.

Unfortunately, until fairly recently, many decisions regarding the uses of Long Island Sound and the surrounding watershed were made without considering the impacts on the Sound's water quality and biological diversity. In general, increased residential, commercial, and recreational developments—and their pollution-related effects—are the main threats to Long Island Sound. By altering land surfaces, increasing runoff of rainwater, and reducing the natural filtration of undeveloped landscapes, this development has greatly intensified the rate at which pollutants (including toxic chemicals, nutrients, and pathogens) reach the Sound from the land. Air pollutants such as those from car emissions reach Long Island Sound as well.

Obsolescent sewer systems and poorly maintained septic systems are also major sources of pollutants (nutrients, toxic substances, and pathogens) entering Long Island Sound. Many older sewer systems were designed with combined sewer overflows (CSOs) to let rainwater runoff flow through the same pipes as sewage. During mild precipitation, the rainwater and sewage remain separated due to a dividing wall inside the pipes. To accommodate a surge of rainwater during heavy precipitation, engineers included a gap at the top of the dividing wall allowing overflowing rainwater to come in contact with untreated human sewage. This contaminated rainwater bypasses treatment and is dumped directly into Long Island Sound. These combined sewer overflow systems are currently in use in eight cities around the Sound: New York City, Norwalk, Jewett City, Derby, Norwich, Shelton, Bridgeport, and New Haven.

Nearly half of the homes and businesses in the Long Island Sound watershed have septic tank waste disposal systems. When these systems are properly sited and maintained on a regular basis, they provide an excellent waste management alternative. When they are situated in areas that do not allow for proper operation, however, or are not pumped out regularly, they often contaminate surface water and groundwater. Other sewage-related pollution sources include inadequately treated sewage discharges from boats, illegal connections to storm drain systems, and waterfowl and animal wastes.

These pollution problems can result in hypoxia, or decreased levels of dissolved oxygen. Excess nutrients from pollutants entering the Sound cause rapid growth of marine plants. As the organic matter produced sinks to the bottom, bacteria use DO in the water to decompose it. Because of the unusually large numbers of decomposing plants, the oxygen levels in the Sound's deeper waters can become dangerously low, threatening the health of bottom-dwelling species.

While the surface water layer of Long Island Sound stays oxygenated through contact with the atmosphere and photosynthesis, oxygen cannot penetrate down into deeper water layers due to a barrier called a pycnocline. (A pycnocline is a separation between two layers of different densities.) The differences in density between the top and lower layers of water prevent the mixing of surface and bottom waters. Oxygen from top layers of water, therefore, doesn't reach the bottom layers of water.

In Long Island Sound, hypoxia has been directly linked to a number of ecosystem impacts, including:

- Reduction in the number and variety of adult finfish.
- Reduction in the growth rate of juvenile lobsters and winter flounder.
- Dying off of species such as lobster, starfish, bay anchovy, menhaden, cunner, tautog, and sea robin.

The presence of pathogens (disease-causing organisms) carried in sewage and runoff may also adversely affect the health of many species—including humans. People exposed to pathogens through the ingestion of improperly cooked contaminated shellfish, or by swimming in contaminated waters, can contract diseases such as salmonellosis and hepatitis A. Beaches and shellfishing areas are often closed due to pathogen contamination.

Another concern is elevated levels of heavy metals and toxic chemicals created through human activity (industry, marinas, precipitation runoff, sewage treatment plants, car exhaust, pesticides, and household chemicals) that are collecting in the sediments of Long Island Sound. While the health risks of these chemicals on local animal and plant life are still in question, Connecticut and New York have issued "consumption advisories" for species known to carry concentrated amounts of polychlorinated biphenyls (PCBs). These include striped bass, bluefish, eels, lobsters, and crabs.

More detailed information on status and trends in the health of Long Island Sound can be found on the EPA Long Island Sound Office Web site at *http://www.epa.gov/region01/eco/lis*.

2.3 THE ROLE OF WATER QUALITY MONITORING

Keeping track of water quality status and trends requires close monitoring of a number of physical, chemical, and biological parameters. A systematic and well-planned monitoring program can identify water quality problems and help answer questions critical to their solutions. These questions include:

- Is there a problem?
- If so, how serious?
- Does the problem affect only a portion of the estuary, or the entire body of water?
- Does the problem occur sporadically, seasonally, or year round?
- Is the problem a naturally occurring phenomenon or caused by human intervention, or a combination of the two?

If monitoring activities have not been undertaken in the past, the monitoring project can be used to establish a baseline even if a pollution problem has not been identified. If reliable historical data exist for comparison, the current monitoring project can document changes in the estuary from past to present. These data may serve as a warning, alerting environmental managers to the development of an environmental problem, or on the positive side, confirm the effectiveness of restoration initiatives.

Many different parameters contribute to overall water quality, including the amount of oxygen in the water, the concentration of nutrients available to marine life, and turbidity (the number of particles in the water blocking sunlight). Water temperature, salinity, and current speed and direction are parameters that affect the distribution and impact of pollutants and the resulting health of a body of water. How all these parameters vary down through the water column is also important. The current state of technology allows scientists to measure these parameters continuously at different depths. Continuous monitoring lets us see whether or not the management initiatives used by many towns in the state are working to improve water quality.

Monitoring can be conducted at regular sites on a continuous basis ("fixed station" monitoring); at selected sites on an as-needed basis or to answer specific questions (intensive surveys); on a temporary or seasonal basis (for example, during the summer at bathing beaches); or on an emergency basis (such as after a spill). Increasingly, monitoring efforts are aimed at determining the condition of entire watersheds—the area drained by rivers, lakes, and estuaries. This is because scientists have come to realize the impact of land-based activities on the waters that drain the land, and the interconnectedness of all types of waterbodies, including those beneath the ground.

There are many ways to monitor water conditions. Monitoring specialists perform chemical measurements to monitor the constituents in water, sediments, and fish tissue, such as levels of dissolved oxygen (DO), nutrients, metals, oils, and pesticides. Physical measurements of general conditions such as temperature, flow, water color, and the condition of stream banks and lake shores are also important. Biological measurements of the abundance and variety of aquatic plant and animal life and the ability of test organisms to survive in sample water are also widely used to monitor water conditions.

Generally, water quality monitoring focuses on the physical and chemical parameters, and a few key biological parameters such as indicator bacteria associated with sewage contamination. These key parameters are summarized below. These parameters and their importance in monitoring the health of an estuary are described in detail in *Volunteer Estuary Monitoring—A Methods Manual* at *http://www.epa.gov/owow/estuaries/monitor*. (Note that the MYSound program currently is using only certain parameters that are affordable and technically straightforward to monitor: temperature, salinity, and dissolved oxygen)

2.3.1 PHYSICAL PARAMETERS

Temperature—Temperature is a commonly measured water quality parameter, and is a critical factor influencing chemical and biological processes in an estuary. For instance, increased temperature decreases the level of oxygen that can be dissolved in the water column. Water temperature influences the rate of plant photosynthesis, the metabolic rates of aquatic organisms, and the sensitivity of organisms to toxic wastes, parasites, diseases, and other stresses. Temperature is recorded in degrees Celsius (Centigrade) or Farenheit.

Salinity—Salinity is the amount of salts dissolved in water expressed in parts per thousand (ppt) or 0/00. It controls the type of species that can live in an estuary but also influences physical and chemical processes such as flocculation and the amount of DO in the water column.

Suspended Material Concentration and Turbidity—Suspended material concentration is the amount of material that is suspended in the water column and is measured as the amount of material retained in a filter. Smaller particles are considered dissolved solids. The sum of suspended and dissolved solids is referred to as total solids. All three measures are recorded in terms of mg/l. Turbidity is a measure of water clarity, that is, the ability of water to transmit light, and is influenced by the level of suspended material in the water column. Turbidity is often measured visually using a Secchi disk. Elevated levels of suspended material and turbidity occur naturally through erosion, storm runoff, and the input of plant material on a seasonal basis. However, these parameters can also indicate degraded water quality if the elevated levels are caused by excessive erosion due to upland development, organic material due to nutrient enrichment, or uncontrolled discharges from sewage treatment plants and industrial facilities.

Current Speed and Direction—Understanding the current velocity in an estuary, and how it changes spatially and with depth, can provide valuable insight in interpreting changes in other physical and chemical parameters. For instance, high current velocities near the bottom can entrain sediment and increase turbidity. Flow into an estuary from the sea on an incoming tide can raise salinity and lower temperature. Current velocity is specified by direction (0 to 360 degrees) and speed (m/sec).

Meteorological Parameters (Weather)—The meteorological parameters typically measured are wind speed and direction, air temperature, and rainfall. Information on meteorological conditions can be very valuable in interpreting water quality data and explaining changes in water quality parameters. For instance, elevated temperatures and light winds can cause thermal stratification in an estuary, which may lead to decreased mixing and DO, particularly at depth. High winds associated with passage of a storm or cold front can promote vertical mixing, which will increase DO and possibly suspended material concentration, particularly in shallow water. Increased rainfall will decrease salinity in surface layers and perhaps lead to density stratification.

2.3.2 CHEMICAL PARAMETERS

Oxygen is a key parameter of interest in water quality monitoring, because nearly all aquatic life needs oxygen to survive. The two oxygen parameters monitored are DO and biological oxygen demand (BOD). DO is the level of oxygen in the water column in molecular form that is available to support life and is reported in milligrams per liter (mg/l). The DO level is controlled by mixing at the air/water interface, temperature and salinity, the level of photosynthesis (which produces oxygen), and decomposition of organic material (which depletes oxygen). Generally, DO levels of greater than 4 mg/l indicate an adequate supply of DO to support marine species growth and activity, while levels from 1-3 mg/l indicate hypoxic conditions, which are detrimental to marine life. DO below 1 mg/l indicates anoxia, a condition in which no life that requires oxygen can be supported. BOD measures the amount of oxygen that organisms would require in decomposing the organic material in the water column and in chemical oxidation of inorganic matter, and is indicative of pollution levels. For instance, unpolluted water has a BOD of less than 5 mg/l, while raw sewage has a BOD of 150 to 300 mg/l. Wastewater effluent might have a BOD from 8 to 150 mg/l.

Nutrients—especially nitrogen and phosphorus—are key water quality parameters in estuaries, because they have significant direct or indirect impacts on plant growth, oxygen concentrations, water clarity, and sedimentation rates. They influence both the overall biological productivity of the estuary and the decline of the estuary through eutrophication. Nitrogen is essential in protein and DNA synthesis in organisms and photosynthesis in plants. Phosphorus is critical to metabolic process. Primary nitrogen species of interest in the estuarine environment include nitrate (NO_3), nitrite (NO_2), and ammonia and ammonium (NH_3 and NH_4). Nutrient concentrations are reported in mg/l. Unlike DO, there are no set criteria for nutrient levels because nutrients themselves are not a threat to marine life, although they can contribute to problems such as excessive plant growth, low DO, and accelerated eutrophication. Excessive nutrients can also trigger toxic algae blooms. However, these adverse effects are dependent on other factors besides nutrient levels.

pH and Alkalinity are two additional parameters that provide insight into changing water quality conditions in an estuary. Both can be determined by simple tests. Although these parameters are generally not as critical as DO and nutrients, they are important to ecosystem health because most aquatic plants and animals are adapted to a specific range of pH and alkalinity. Sharp variations outside of this range can be detrimental. In addition, pH and alkalinity influence the estuarine carbon cycle, which involves the movement of carbon from the atmosphere into plant and animal tissue and into water bodies. The pH of water is the measure of how acidic or basic it is. A pH level of 1 to 7 indicates degrees of an acidic solution, while a level of 7 to 14 indicates degrees of a basic solution. Alkalinity is a measure of water's capacity to neutralize acids and is influenced by the presence of alkaline compounds in the water such as bicarbonates, carbonates, and hydroxides. Alkalinity is reported as mg/l of calcium carbonate ($CaCO_3$).

Chlorophyll a—Chlorophyll *a* is a green pigment found in phytoplankton, which represents the first trophic level in the primary production cycle. The amount of chlorophyll *a* in the water column is indicative of the biomass of phytoplankton, which in turn can indicate nutrient levels in the water column (or excess nutrients if the chlorophyll *a* values are elevated). Excessive nutrients and plant growth can in turn decrease DO levels and increase turbidity.

Toxic Contaminants—With the industrialization of many estuaries, the amount of toxic contaminants entering estuaries has greatly increased. These contaminants include heavy metals (such as mercury, lead, cadmium, zinc, chromium, and copper), petroleum hydrocarbons, and synthetic organic compounds such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides (e.g., dichlorodiphenyl-trichloroethane). Many of these toxic contaminants are persistent, can be incorporated into sediments, and can be concentrated in the food chain, so that they pose a magnified threat to animals at higher trophic levels and to humans. They are generally measured through laboratory analysis (which can often be complex and time-consuming), although field test kits are available for some heavy metals and other contaminants. The contaminant concentrations are usually reported in mg/l.

2.3.3 BIOLOGICAL PARAMETERS

Pathogens (Indicator Bacteria)—A key parameter of interest, particularly for estuaries in urban areas, is the presence of pathogens. Pathogens are viruses, bacteria, and protozoans that can cause disease. They are a critical concern in areas where waters are used for swimming, boating, fishing, shellfishing, or other pursuits that lead to human contact or food consumption. Direct testing for pathogens is very expensive and impractical. Instead, the potential levels of pathogens in estuaries are tracked by monitoring "indicator bacteria"—so called because their presence indicates that fecal contamination has occurred. The four indicators commonly monitored include total coliform, fecal coliform, E. coli, and enterococci, all of which are bacteria normally prevalent in the intestines and feces of warm blooded animals, including wildlife, farm animals, pets, and humans. The indicator bacteria themselves are not pathogenic. Values are recorded as the number of bacteria per ml of water. Environmental managers establish numerical standards for limits to these values for swimming, shellfishing, and other activities.

Selected Web Sites on the Ecology and Pollution Problems of Watersheds, Estuaries, and Coastal Regions

EPA Office of Wetlands, Oceans, and Watersheds—*http://www.epa.gov/owow*
- **Coastal areas—*http://www.epa.gov/owow/oceans***
- **Estuaries—*http://www.epa.gov/owow/estuaries***
- **Watersheds—*http://www.epa.gov/owow/watershed***
- **Water quality monitoring—*http://www.epa.gov/owow/monitoring***

This site provides a wealth of background information on monitoring, protecting, and restoring estuaries, watersheds, and coastal wetlands.

Estuary-Net Project *http://inlet.geol.sc.edu/estnet.html*
Estuary-Net was developed by the National Estuarine Research Reserve System in response to water quality issues arising in coastal areas. This project strives to develop collaborations among high schools, community volunteer water quality monitoring groups, local officials, state Coastal Zone Management (CZM) programs and National Estuarine Research Reserves (NERRS) to solve non-point source pollution problems in estuaries and their watersheds.

Estuary-Live Project *http://www.estuarylive.org/*
The Estuary-Live Project is an educational Web site focusing on estuarine ecology and environmental protection.

Restore America's Estuaries *http://www.estuaries.org*
This Web site is maintained by Restore America's Estuaries, an NGO alliance of regional and community-based environmental organizations. It provides information on legislation to protect America's estuaries and information on estuary restoration programs.

Chesapeake Bay *http://www.aqua.org/education/teachers/chesapeake.html*
This site is maintained by the National Aquarium in Baltimore and supported by the Chesapeake Bay Foundation. It provides a comprehensive source of information on the protection of Chesapeake Bay and large estuarine ecosystems in general.

NOAA Coastal Services Center *http://www.csc.noaa.gov*
The NOAA Coastal Services Center provides valuable information to coastal resource managers on smart coast growth, coastal hazards, habitat protection, and coastal monitoring (including water quality monitoring, remote sensing, and GIS development).

A comprehensive inventory of coastal and estuary monitoring programs is provided on the **Coastal Ocean Observing System page *http://www.csc.noaa.gov/coos***

Coastal America *http://www.coastalamerica.gov*
Coastal America is a unique partnership of federal agencies, state and local governments, and private organizations. This Web site is an excellent source of information and links on protecting, preserving, and restoring the nation's coasts.