CASE STUDY
SAN FRANCISCO BAY PROGRAM:
MANAGING COASTAL RESOURCES OF THE U.S.

The following case study is extracted from U.S. Geological Survey Fact Sheet FS-053-95 (available online at: http://water.usgs.gov/wid/html/sfb.html)

Coastal ecosystems, such as bays and estuaries, are among our most disturbed natural environments. These ecosystems also are among our most valuable habitats—estuaries supported U.S. fisheries valued at $19 billion in 1990. Although many human activities cause change in the coastal zone, they occur against a background of natural change. Effective coastal-zone management requires that we identify and understand these separate causes of ecosystem change. With this goal in mind, the United States Geological Survey (USGS) began in 1968 a broad program of scientific study in San Francisco Bay (Figure 1). The program is based on a conviction that sustained, multifaceted investigation of one estuary will produce general lessons to guide the management of natural resources associated with all our coasts.

The USGS San Francisco Bay Program has produced more than 250 reports, including three books and a review of the human modifications of the bay. These publications are a source of guidance to resource managers as they work to understand how human activities (such as water diversion, commercial trade, and waste inputs) cause change in the coastal zone. The program has been organized around themes. One of the most important themes is the integrated study of nutrients, toxic substances, and living resources at lower levels of the food chain—the phytoplankton and bottom dwelling invertebrates. Close collaboration between chemists and ecologists has helped to explain how plant and animal species of coastal ecosystems are organized into food chains, how nutrients and toxic contaminants are incorporated into these food chains, and how the lessons learned from detailed scientific understanding can be applied to develop effective monitoring programs and rational environmental standards.

Nutrient Enrichment

Human settlement around coastal water bodies has led to increased inputs of nutrients such as nitrogen and phosphorus. Many estuaries are now among the most intensively fertilized environments on Earth. Each day, San Francisco Bay receives more than 800 million gallons of municipal wastewater containing 60 tons of nitrogen. In response to these concerns, the USGS developed a biological monitoring procedure that has been used continuously since 1977 near a waste-treatment facility. Monitoring continued as wastewater-treatment technologies improved. This is the longest continuous record of contaminant concentrations in a natural environment of the United States. The transfer of monitoring procedures developed by the USGS to local agencies and businesses serves as a model of cooperation between research and regulatory agencies.

Management Questions

Water-quality managers need to know how nutrient inputs cause changes in water quality, the natural capacity of coastal waters to assimilate added nutrients, the level of waste treatment required to protect living resources from the harmful effects of nutrient enrichment, and if programs of nutrient reduction are having beneficial effects.

USGS Contributions

Since 1968, the continuous study of San Francisco Bay by the USGS has given that agency a unique opportunity to follow ecosystem responses to improved wastewater-treatment methods as mandated by State and Federal legislation. One result of the implementation of these improved methods has been a

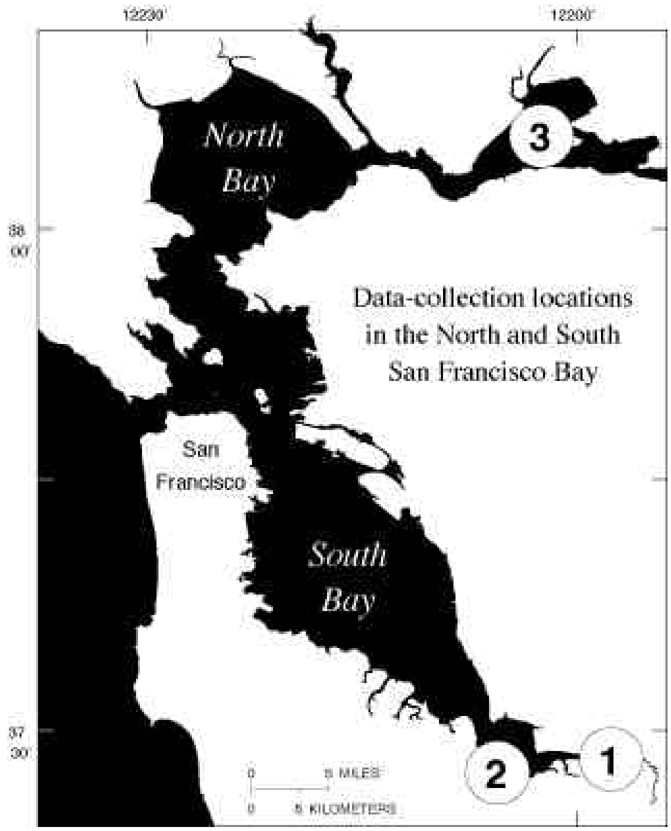

Figure 1. San Francisco Bay has been a focus of intensive investigation by the USGS since 1968.

large reduction in the input of ammonia-nitrogen from some municipal wastewater-treatment facilities (Figure 2).

USGS studies show that in spite of its nutrient enrichment, San Francisco Bay has not been affected by harmful algal blooms. This seeming paradox is explained partly by the abundant bottom-dwelling invertebrates (small clams, mussels, crustaceans) that filter the water and remove new algae as fast as they are produced. Feeding by these animals is a form of natural waste treatment that helps control the growth of algae in a nutrient-rich environment.

Concepts and measurement techniques from this USGS program are now incorporated into a locally funded and managed Regional Monitoring Program.

Lessons Learned

- The chemical quality of coastal waters can respond almost immediately to waste-treatment improvements.
- Responses of biological communities to these chemical changes can take years or even decades.
- Coastal water bodies have differing sensitivities to waste loading. The most cost-effective national strategy for regulating nutrient inputs will consider these differences among ecosystems.

For Further Information:

Visit the USGS website on San Francisco Bay at: http://sfbay.wr.usgs.gov/

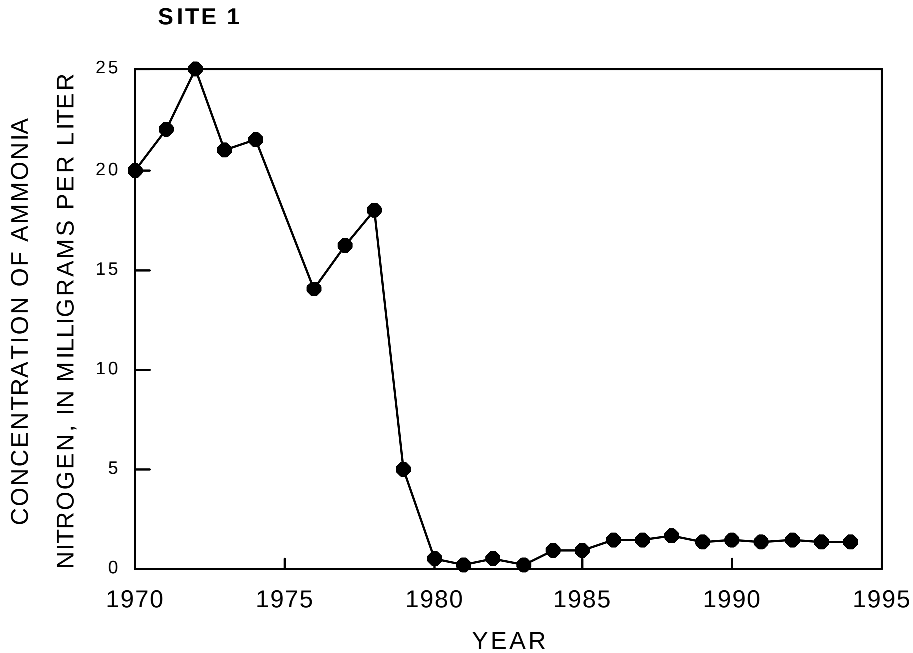

Figure 2. Implementation of advanced wastewater treatment in 1979 immediately reduced the input of ammonia- nitrogen to South San Francisco Bay. In prior decades, the South Bay had repeated episodes of oxygen depletion and animal die-offs. USGS measurements have shown a complete cessation of these episodes since 1980. Spawning salmon have recently been observed in South Bay streams for the first time since the early 1900's. See figure 1 for location of site.

CASE STUDY
LONG ISLAND SOUND - HYPOXIA
U.S. Environmental Protection Agency
http://www.epa.gov/region01/eco/lis/hypox.html

The Problem
During the summers of 1987-93, from half to two-thirds of the Sound's bottom waters experienced dissolved oxygen levels below 5 milligrams of oxygen per liter of water (mg/L). Levels of dissolved oxygen of 5 mg/L and higher are generally accepted as being protective of the Sound's estuarine life. In 1989, a particularly bad summer, more than 500 square miles (40 percent) of the Sound's bottom waters had dissolved oxygen levels less than 3 mg/L. During most of these years, dissolved oxygen in a portion of the Sound (up to 50 square miles) fell below 1 mg/L and in 1987 anoxia, the absence of any oxygen, was recorded in a portion of the Western Narrows.

These low levels of dissolved oxygen cause significant, adverse ecological effects in the bottom water habitats of the Sound. To date, research shows that the most severe effects (such as mortality) occur when dissolved oxygen levels fall below 1.5 mg/L at any time and below 3.5 mg/L in the short-term (i.e., 4 days), but that there are probably mild effects of hypoxia when dissolved oxygen levels fall below 5 mg/L. The levels regularly observed in the Sound during late summer:

- Reduce the abundance and diversity of adult finfish;
- Reduce the growth rate of newly-settled lobsters and perhaps juvenile winter flounder;
- Can kill species that cannot move or move slowly, such as lobsters caught in pots and starfish, and early life stages of species such as bay anchovy, menhaden, cunner, tautog, and sea robin;
- May reduce the resistance to disease of lobsters and other species; and
- Diminish the habitat value of Long Island Sound.

The Cause of the Problem
Excessive discharges of nitrogen, a nutrient, are the primary cause of hypoxia. Nitrogen fuels the growth of planktonic algae. The algae die, settle to the bottom of the Sound and decay, using up oxygen in the process.

Natural stratification of the Sound's waters occurs during the summer when warmer, fresher water "floats" on the top of cooler, saltier water that is more dense. This natural stratification forms a density difference between the two layers called a pycnocline. This prevents mixing of surface and bottom waters.

Oxygen from the atmosphere and photosynthesis keep the surface layer well oxygenated, but the oxygen cannot pass through the pycnocline into the bottom layer very easily. Decaying algae and other organic material in the sediment and animal respiration in the bottom layer use up oxygen faster than it is replenished. Hypoxia develops and usually persists as long as the stratification lasts (usually one to two months in late summer).

But hypoxia in Long Island Sound is too complex to fully understand using direct observations alone. Natural variations in weather and other physical factors affect the extent and severity of hypoxia. The Management Conference has constructed mathematical models in order to understand the relationship among natural variations, human-caused pollutant loadings to the Sound, and dissolved oxygen levels in the Sound. Two models, a water quality model that approximates the biological and chemical processes of the Sound and a hydrodynamic model that describes physical processes, have been developed.

An intensive field program in Long Island Sound to collect data for the computer models was undertaken from April 1988 to September 1989. These data were used to calibrate and verify the models to ensure that they reproduce the important features of the Sound. The water quality model, called LIS 2.0, provided needed insight into the causes of hypoxia and was the basis for actions to begin to reduce nitrogen discharges to the Sound. However, because it simulates the movement of the Sound's waters in only two dimensions (east-west and surface to bottom) and in a simplified manner, the LIS 2.0 model did not provide the best technical foundation for identifying the total level of reduction in nitrogen loads that should be attained or the most cost-effective means to achieve targeted reductions. The hydrodynamic model, developed by the National Oceanic and Atmospheric Administration and completed in July, 1993, uses tide and current measurements to simulate the water's circulation in three dimensions (east-west, north-south, surface to bottom). It was coupled to the water quality model, to create LIS 3.0. The LIS 3.0 model provides an advanced tool to relate sources of nitrogen from specific geographic areas to the hypoxia problem in the western Sound. Because the impact of the nitrogen load from different management zones can be deter-mined using LIS 3.0, the LISS can assign priorities for management to ensure that the most the cost-effective options are pursued.

The modeling, combined with field monitoring and laboratory studies, provided a level of detail to support some clear conclusions about hypoxia in the Sound, its causes, and its solutions. In addition, the models allowed the LISS to simulate water quality conditions as they were in the past, as they are today, and as they could be in the future under alternative nitrogen control scenarios.

- The most oxygen that can be dissolved in Long Island Sound at summer water temperatures is about 7.5 milligrams per liter (mg/L) of water. This is known as the saturation level.

- Oxygen concentrations greater than 5.0 mg/L provide healthy conditions for aquatic life. Concentrations between 5.0 mg/L and 3.5 mg/L are generally healthy, except for the most sensitive species. When concentrations fall below 3.5 mg/L, conditions become unhealthy. The most severe effects occur if concentrations fall below 2.0 mg/L, even for short periods of time.

- The growth of algal blooms in Long Island Sound is dependent upon the availability of nutrients. These blooms end when the pool of nitrogen available for continued growth is depleted.

- In pre-colonial days, natural, healthy biological activity brought oxygen levels below saturation due to the natural loadings of organic material and nitrogen, but oxygen levels probably fell below 5 mg/L only in limited areas and for short periods of time.

- Under today's higher nutrient and organic material loading conditions, minimum oxygen levels average approximately 1.5 mg/L. These levels are associated with severe hypoxia.

- By substantially reducing nitrogen loadings to the Sound, the minimum oxygen levels in the bottom waters during late summer can be increased to an average of about 3.5 mg/L, thereby significantly reducing the probability and frequency of severe hypoxia and reducing the area affected by hypoxia.

- Increases in nitrogen delivered to the Sound could significantly worsen the hypoxia problem, causing larger areas to have lower oxygen levels for longer periods of time. The probability of events like the summer of 1987, when anoxia (no oxygen) became a reality in the Sound, offshore of Hempstead Harbor, would also increase.

Understanding the components of the load of nitrogen entering the Sound is fundamental to understanding the plan:

- In 1990, defined as a baseline year by the Management Conference, the total nitrogen load was 90,800 tons per year.

- By 1992, the total nitrogen load had increased to 93,600 tons per year; this increase was anticipated and was a consequence of terminating ocean disposal of sewage sludge from New York City and the need to treat some of the sludge at facilities within the basin, reintroducing nitrogen to the wastestream.

- Of the 93,600 tons per year, approximately 39,900 tons are from natural sources and not subject to reductions by management activity.

- The remaining 53,700 tons of nitrogen per year are associated with human activities and have the potential to be reduced through management actions.

- 10,700 tons of nitrogen per year enter the Sound through its boundaries -- the East River in the west and The Race in the east; efforts to reduce this substantial western load will come under the auspices of the New York-New Jersey Harbor Estuary Program.

- 2,200 tons of nitrogen per year enter the Sound from direct atmospheric deposition; the Management Conference estimates that this load will be reduced to 1,540 tons of nitrogen per year through implementation of the 1990 Clean Air Act amendments.

- The remaining 40,800 tons of nitrogen per year are a result of human activity coming from point and nonpoint source discharges in the Sound's drainage basin and are the subject of the plan. Point source discharges, primarily sewage treatment plants, result in 32,400 tons of nitrogen each year and nonpoint source discharges, such as agricultural and stormwater runoff, result in 8,400 tons of nitrogen each year.

The Plan to Solve the Problem

The goal of the hypoxia management plan is to eliminate adverse impacts of hypoxia resulting from human activities. Achievement of this goal will require very large investments of capital, a long-term commitment, and the assistance of the New York-New Jersey Harbor Estuary Program. Therefore, the Management Conference has established interim targets for dissolved oxygen and has outlined a phased approach to achieving them, using what is known now to support early phases and committing to take additional steps as increased understanding of the environment will dictate in the future.

Interim Dissolved Oxygen Targets

Using scientific information on the relationship between oxygen levels and ecological effects, the Management Conference has established interim target levels for oxygen that, if achieved, would minimize the adverse impacts of hypoxia. In summary, the interim dissolved oxygen targets for the bottom waters of the Sound are to:

- Maintain existing dissolved oxygen levels in waters that currently meet State standards;

- Increase dissolved oxygen levels to meet standards in those areas below the State standards but above 3.5 mg/L; and,

- Increase short-term average dissolved oxygen levels to 3.5 mg/L in those areas currently below 3.5 mg/L, ensuring that dissolved oxygen never goes below 1.5 mg/L at any time.

- There are also interim targets for the surface waters of the Sound.

Phased Approach
The Management Conference is implementing a phased approach to reducing nitrogen loadings to the Sound from point and nonpoint source discharges within the Sound's drainage basin.

- Phase I, as announced in December of 1990, froze nitrogen loadings to the Sound in critical areas at 1990 levels to prevent hypoxia from worsening.

- Phase II, as detailed in the plan, includes significant, low-cost nitrogen reductions that begin the process of reducing the severity and extent of hypoxia in the Sound.

- Phase III will present nitrogen reduction targets to meet the interim targets for dissolved oxygen, which will prevent most known lethal and sublethal effects of hypoxia on the Sound's estuarine life. Phase III also will lay out the approach for meeting the nitrogen load reduction targets.

Phase I - The Nitrogen Loading Freeze
Phase I was announced in December 1990. It called for a freeze on point and nonpoint nitrogen loadings to the Sound in critical areas at 1990 levels. It committed the States and local governments to specific actions to stop a 300-year trend of ever increasing amounts of nitrogen entering the Sound.

Since 1990, activities have been underway in New York and Connecticut to manage nitrogen from sources within the New York and Connecticut portions of the drainage basin, starting with adoption of the Phase I “freeze” on loadings.

- Connecticut reacted quickly to obtain $15 million in State funds to ensure that the nitrogen freeze was implemented. Consent orders are in place to cap the nitrogen loads at the 15 affected facilities.

- In New York City, the New York State Department of Environmental Conservation (NYSDEC) and the city have reached full agreement on sewage treatment permit limits, freezing total nitrogen loadings at 1990 levels.

- In Westchester County, the NYSDEC has issued final permits to the four existing sewage treatment plants, freezing their aggregate load at the 1990 level. This was done with the full agreement of the county.

- On Long Island, the NYSDEC proposed individual permits that freeze the loads from individual discharges at 1990 levels; in response, the dischargers proposed establishment of an aggregate limit. State and local authorities agreed on aggregate load limits for targeted facilities.

Phase I agreements to control nonpoint sources centered around three categories:

- Use of existing nonpoint source and stormwater management programs to focus on nitrogen control with the objective of freezing the loads.
- Assessing tributary loads to Long Island Sound to begin planning for their control.
- Assigning priorities for management to coastal subbasins where nitrogen loads were estimated to be the highest.

Phase II - Low Cost Nitrogen Reductions

For Phase II, the LISS made a commitment in 1994 to reduce nitrogen discharges to the Sound from peak loadings by approximately 7,550 tons per year. This phase consists of incorporating a variety of low-cost nitrogen removal technologies at selected sewage treatment plants. The States have moved aggressively to implement nitrogen control activities, using innovative strategies and seeking the cooperation of local governments.

In Connecticut, the goal was to achieve a reduction of 850 tons per year in nitrogen loads. The State of Connecticut has awarded more than $15 million through its State Clean Water Fund to 11 southwestern sewage treatment plants to test and demonstrate the efficiency of upgrades for nitrogen treatment. In addition, the first plant in the State designed to denitrify has been constructed in Seymour. As of December 1997, the load of nitrogen from plants in the Phase II agreement has been reduced by almost 900 tons per year, exceeding the Phase II goal.

The State of New York revised the permits issued to sewage treatment plants, with the consent of local authorities, to establish nitrogen limits at 1990 levels. The permits include an aggregate load for facilities within Management Zones 7-11 (New York City, Westchester County, and Long Island). The New York goal was to reduce nitrogen loadings by 6,700 tons per year from peak loadings from actions to be completed by 2006. The goal of these actions was to compensate for the increased load due to sludge treatment and reduce loadings back below 1990 levels. As of 1997, one sewage treatment plant in Westchester County and four in New York City have implemented nitrogen removal technologies. New York City is required to implement additional nitrogen removal technologies at the upper East River sewage treatment plants. As of December 1997, the load of nitrogen from sewage treatment plants in New York had decreased by 3,000 tons per year from peak loadings. In addition, New York City has entered into a consent order to provide nitrogen removal at the reconstructed Newtown Creek facility, scheduled for completion in 2007.

In addition, both States have:

- Developed materials and conducted training for treatment plant personnel on nitrogen removal technologies and procedures.
- Required sewage treatment plants to identify in their plans how they will remove nitrogen, if required to do so.
- Required nutrient monitoring at sewage treatment plants to improve understanding of nitrogen sources and treatment plant capability.
- Increased the share of nonpoint source pollution control funds targeted to projects that reduce nitrogen loads to the Sound.

- Formulated Coastal Nonpoint Pollution Control Programs to address coastal nonpoint sources of nitrogen.
- Undertaken demonstration projects that address a variety of nonpoint source control issues and technologies (e.g., urban runoff treatment by artificial pond/wetland systems, parking lot runoff treatment, septic system technologies to treat and remove nitrogen, controlling runoff from agricultural land and from marinas).

As of December 31, 1997, nitrogen loadings to the Sound from point and non-point sources within the New York and Connecticut portions of the watershed have been reduced as a result of these activities by 3,900 tons per year from peak loadings.

Phase III - Nitrogen Reduction Targets to Eliminate Severe Hypoxia

While steps taken in Phases I and II will help to reduce the extent of hypoxia, additional nitrogen reduction is needed to restore the health of Long Island Sound. Phase III sets the course by setting specific nitrogen reduction targets for each of the 11 management zones around the Sound. An array of environmental and economic considerations were taken into account throughout the process.

Oxygen Benchmarks

The water quality standard for oxygen in Long Island Sound is 6 mg/L in Connecticut and 5 mg/L in New York. Modeling indicates that even if maximum nitrogen reduction technologies were implemented, the water quality standards for oxygen would not be achieved throughout the summer in all areas of the Sound. To help establish priorities for action, the LISS has identified oxygen conditions that will minimize adverse impacts on living resources of the Sound.

Two major research efforts, a laboratory study by the EPA's Office of Research and Development and a field study by the Connecticut Department of Environmental Protection (CTDEP) have provided much of the information on how low oxygen conditions affect living resources in the Sound. Both studies corroborated that severe effects occurred whenever levels of oxygen fell below 2.0 mg/L. The field surveys noted large reductions in the number and types of aquatic life present. The lab experiments recorded reductions in growth and increases in mortality. In both studies, effects became significant when oxygen levels fell below 3.5 mg/L, though some effects occurred at levels between 3.5-5.0 mg/L.

As a result, the LISS has determined that unhealthy conditions occur whenever oxygen levels fall below 2.0 mg/L at any-time or remain below 3.5 mg/L over a 24-hour period. Most adverse impacts can be prevented if oxygen levels exceed these conditions, and they have been used as benchmarks to assess the relative benefits of alternative management strategies for improving the health of Long Island Sound.

Cost-effectiveness

LISS managers looked at a range of nitrogen reduction options for the three major sources of nitrogen in the watershed, sewage treatment plants, industrial facilities, and nonpoint source runoff to determine the most cost-effective option.

- *Sewage Treatment Plants*: As nitrogen removal requirements become more stringent, the cost of controls tends to increase. To identify a cost-effective level of treatment, LISS managers arrayed the possible nitrogen reduction options for all 70 sewage treatment plants in the 11 management zones and calculated the average oxygen improvement in the Sound per dollar spent. Improvements at sewage treatment plants that had better than average cost-effectiveness at improving oxygen conditions in the Sound were identified. These actions, in total, could achieve a 62 percent reduction in loads, or 122,044 pounds/day.

- *Industrial Facilities*: A limited number of industrial facilities directly contribute nitrogen to the Sound; all are located in Connecticut and contribute an estimated 6,717 pounds per day of nitrogen to the Sound. Because information on the cost of reducing nitrogen from industrial sources was not readily available, these facilities were not included in the cost analyses used for sewage treatment plants. Instead, the cost-effective level of treatment identified for sewage treatment plants, 62 percent, was applied to the industrial sources, resulting in a 4,165 pounds per day reduction for industrial facilities. This represents an aggressive but cost-effective level of nitrogen control for these sources.

- *Nonpoint Sources*: Decisions on controls of nonpoint source runoff must be made in the broader context of watershed management, since control measures will also help reduce suspended solids, toxic contaminants, pathogens, and floatable debris. The LISS recommends that aggressive controls of nonpoint source pollution be implemented for both existing and new development, through both habitat protection and restoration activities, and structural and nonstructural best management practices. This effort could result in a 10 percent reduction in the non-point source load from sources within the New York and Connecticut portions of the watershed, or 2,604 pounds per day.

Adding the potential nitrogen reductions from cost-effective controls on sewage treatment plants, industrial sources, and nonpoint runoff sources results in a total reduction of 128,813 pounds per day (23,500 tons per year). The next step is to allocate responsibility for achieving these reductions among the 11 management zones fairly.

Allocating Responsibility

The cost curve analysis provided an option for allocating nitrogen reductions among the sewage treatment plants. Sewage treatment plant upgrades with greater than average cost-effectiveness would be implemented while upgrades with below average cost-effectiveness would not be implemented. However, the LISS decided that relying on the cost curve analysis alone would not be a fair or even feasible approach and would not provide the best solution to allocating nitrogen reduction.

There are several reasons for this conclusion. Most importantly, the cost estimates were general and not uniform in their development. More accurate cost estimates must await detailed facilities planning based upon a clear definition of the nitrogen discharge limits that will have to be met. In addition, local concerns and considerations such as the need to purchase land for expansion and to distinguish between costs for nitrogen removal versus ongoing maintenance, expansions for growth, and secondary upgrade needs (which were not included in the cost estimates) were not addressed evenly in the cost analysis.

Cost considerations aside, it is necessary for all sewage treatment plants to share the burden of nitrogen removal. All sewage treatment plants contribute nitrogen to Long Island Sound, albeit with different effect. All jurisdictions will benefit from improved water quality. Therefore, it is reasonable to expect all contributors to the problem to con-tribute to the solution.

For those reasons, LISS has assigned each management zone equal responsibility to reduce its share of the nitrogen load. To achieve a similar level of oxygen improvement from reductions allocated to each zone by the same percentage, the load reduction target was adjusted slightly to 23,800 tons per year from the original 23,500 tons per year. The total human-derived load coming from sewage treatment plants, industrial point sources, and nonpoint sources, including atmospheric depositions within the water-shed, is 40,650 tons per year. Therefore, the Soundwide nitrogen target is a 58.5 percent reduction in the human-derived load from point and nonpoint sources in the watershed.

Phase III Actions

Phase III actions will minimize adverse impacts of hypoxia caused by human activities in a cost-effective manner, while ensuring that new information is gathered to refine and improve management over the long term. Using the framework described above, the LISS set a 58.5 percent reduction target for the enriched load of nitrogen from sources within the New York and Connecticut portions of the watershed.

Strategies

Attaining the nitrogen reduction targets will require aggressive control of point sources, such as sewage treatment plants and industrial sources, and nonpoint sources, such as on-site sewage systems and runoff from roads, parking lots, and construction sites. To achieve the reduction targets, the States, working with local governments, will select the mix of point and nonpoint source controls to be implemented in each management zone. Recognizing that each watershed is different, the plan provides the States and municipalities considerable flexibility in determining how nitrogen reduction actions are carried out within each zone.

By August 2000, the States will take the following actions:

- Develop watershed plans for each management zone that will set the course for achieving the targets as scheduled.

- Consistent with those plans, incorporate limits on the amount of nitrogen that can be discharged from sewage treatment plants and industrial sources into discharge permits.

- Conduct comprehensive nonpoint source management and habitat restoration activities.

Because the total nitrogen load entering the Sound from human sources is dominated by point source discharges, the plan emphasizes technologies that can be applied to sewage treatment facilities and industrial discharges.

In order to achieve significant reductions in the nonpoint source nitrogen load, home owners, farmers, businesses, municipalities, and the States will need to reduce current inputs of nitrogen to the watershed and restore and preserve the nitrogen removal capabilities of existing natural systems. These reductions can be achieved using a number of approaches—resource-based land use decisions at the local level, watershed-wide use of appropriate structural and nonstructural best management practices (e.g., stormwater detention ponds, artificial wetlands, streetsweeping, cleaning catch basins), habitat protection and restoration, and pollution prevention management practices. All approaches will require a concerted education and outreach effort.

Timing

The planning, financing, and construction of upgrades to sewage treatment plants necessary to achieve the 58.5 percent reduction target will require sustained effort and commitment over a long period of time. Therefore, the LISS recommends phasing-in the necessary reductions over 15 years:

- 40 percent in 5 years,

- 75 percent in 10 years, and

- 100 percent in 15 years.

Cost

The *Comprehensive Conservation and Management Plan* identified that the cost of achieving maximum nitrogen removal from all point sources would range from $6 to $8 billion ($5.1 to $6.4 billion in New York State and from $900 million to $1.7 billion in Connecticut). Because of the successful demonstration of full scale nitrogen removal technologies at sewage treatment plants undertaken as part of Phase II, the estimated costs of capital improvements at sewage treatment plants have decreased. The estimated cost of achieving maximum nitrogen removal levels at the 70 treatment plants in New York and Connecticut is now about $2.5 billion

Because of the cost-effective approach described above, the LISS nitrogen reduction strategy would not require all treatment plants to meet limit-of-technology reductions. As a result, the incremental capital cost of achieving the Phase III point source controls was estimated to be $300 million for New York State and $350 million for Connecticut. These cost estimates have been questioned and will be revised as more detailed facility planning and design is performed. However, they show clearly that the potential cost of achieving our goals can be much less than originally estimated.

Nonpoint source controls will be implemented as part of broader watershed and habitat protection efforts. The cost of controlling nonpoint sources is more difficult to estimate than the cost of point source controls. Rather than one type of technology applied to a similar source, a variety of strategies can be applied to control a variety of nonpoint sources of nitrogen. As a result, the costs of achieving nonpoint nitrogen reductions will be addressed in the zone-by-zone plans developed by the States.

Financing

As recommended in the *Comprehensive Conservation and Management Pla*n, the main source of funding for these wastewater treatment facility improvements will be the State Revolving Fund programs. The EPA, through the federal Clean Water Act, provides financing to support State Revolving Fund loan programs.

Connecticut uses the capitalization grant from EPA to leverage with State bond funds to provide grants and low interest loans, at 2 percent interest over 20 years, to finance improvements at municipal facilities. Connecticut provides about $50 million per year in State bonding to supplement the $15 million per year provided under the Clean Water Act. At this capitalization rate, Connecticut should be able to meet municipal financing needs to implement Phase III nitrogen reductions. During fiscal year 1997, CTDEP awarded $250 million from their Clean Water Fund to finance projects of benefit to Long Island Sound, including major sewage treatment plant upgrades in Norwalk and Waterbury.

New York State established its State Revolving Fund in the custody of the Environmental Facilities Corporation. This public corporation benefits local governments in New York State by offering below-market interest rate loans to municipalities to finance wastewater improvements. Currently, the interest rate is set at up to one-half of the market rate to be repaid in 20 years. Lower rates of interest, including zero interest loans, are available for communities that can demonstrate an inability to pay the standard subsidized rate. Another major source of funding in New York State is the $1.75 billion Clean Water/Clean Air Bond Act approved by voters in November 1996. The Bond Act targeted $200 million for Long Island Sound that will be available for sewage treatment upgrades, habitat restoration, nonpoint source control, and pollution prevention.

The possible funding sources for non-point source controls reflect the diversity of both the sources and the control options. Grant funding through federal and State water quality management, natural resources management, and coastal zone management programs is available for nonpoint source activities. The State Revolving Fund loan program is also available to fund stormwater management and habitat restoration projects but has not been used to a great extent for these types of activities due to the magnitude of existing point source funding needs in Connecticut and New York.

Effluent Trading

To provide further flexibility and incentives for maximizing the timeliness and cost-effectiveness of nitrogen reduction actions, the LISS is investigating the feasibility of allowing effluent trading. Trading, if employed as part of the nitrogen reduction effort, may be an innovative way to use market forces to more efficiently meet water quality goals. The LISS is developing a trading proposal and will convene a public forum for federal, State, and local water quality officials, together with public and private interests, to evaluate its potential.

Enforcement

The provisions of the federal Clean Water Act provide a vehicle for ensuring that nitrogen reduction targets are legally enforceable. Section 303(d) of the Act requires the identification of a Total Maximum Daily Load for pollutants that will result in the attainment of water quality standards. Once a Total Maximum Daily Load has been established, the act calls for reductions to be allocated to sources so that the load target is met. New York and Connecticut and EPA will use their authorities to provide an enforceable foundation for achieving the nitrogen reduction targets. By August, 1998 the States will propose a Total Maximum Daily Load designed to meet State oxygen standards. The current Long Island Sound standards were developed with limited data on how low oxygen levels affect aquatic life in Long Island Sound. EPA is currently developing regional marine oxygen criteria that will provide a more scientifically valid basis for the development of oxygen standards. Based on this information, the States may, in the future, modify their oxygen standards. While LISS managers predict significant improvement in water quality as the nitrogen reduction targets are implemented, the attainment of current water quality standards at all times and in all areas is not expected. For this reason, the LISS will continue to assess what other kinds of actions will be needed to bring the Sound into full compliance with water quality standards.

These actions may include control of nitrogen and carbon sources outside of the Long Island Sound basin (e.g., tributary import from point and non-point sources north of Connecticut, atmospheric deposition, boundary import from point and nonpoint sources affecting New York Harbor and The Race). Alternatives to nitrogen reduction, such as aeration, will need to be considered as a possible means to achieve water quality standards in remaining areas.

Evaluating Progress

The LISS will track, monitor, and report on progress in meeting the nitrogen reduction targets annually. In addition, a formal review of the goals and objectives of the program will be performed every 5 years, coinciding with the progress checkpoints for nitrogen reduction. The review will consider:

- Progress and cost of implementation, including a reevaluation of the knee-of-the-curve analysis used to establish the Phase III nitrogen reduction targets,
- Improvements in technology, including the results of quality controlled pilot projects,
- The regional dissolved oxygen criteria to be published for comment,
- Water quality standards,
- Refined information on the ecosystem response to nitrogen reductions,

- The results of peer reviewed modeling, and
- Research on the impacts of hypoxia to living resources and their habitats.

Each of these factors will be considered in a balanced manner in the reevaluation process. As a result of the review, the LISS may recommend improvements that could result in changes in how the overall program will be implemented.

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CASE STUDY
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808-956-8693
http://data.ecology.su.se/MNODE/North%20America/NRB.HTM

Narragansett Bay, Rhode Island (41˚ 35’ N, 71˚ 20’W), is a relatively well mixed, near-oceanic salinity estuary on the northeast (Atlantic) coast of the U. S. It occupies an area of 264 km^2 (Table 1) and has a mean depth of 9.7 m. Note that both the area and volume differ from the comments in Nixon et al. (1995), but seem consistent with Kremer and Nixons (1978) explicit tabulation. Freshwater flow into the system averages about 8.2 x 10^6 m^3/d, from a watershed of 3500 km^2. Primary production in the system is dominated by phytoplankton (29 mol C m^{-2} yr^{-1}) with a C:N:P ratio of about 112:13:1. The budget described below is based on data collected primarily in the late 1970’s and through much of the 1980’s. Details of this kind of analysis can be found at the LOICZ - Biogeochemical Modelling web site at: http://data.ecology.su.se/MNODE/index.htm.

Sector area and volume data are from Kremer and Nixon (1978). Sector nutrient concentrations are annual averages (based on surface and deep water data) also from Kremer and Nixon. Sector nutrient masses are calculated as volume x concentration. The sectors at the bay mouth (#5, 8) are used for "oceanic values."

Nutrient exchange fluxes (Table 2) are calculated using an average 26-day exchange time, as calculated by Pilson (1985) with a water and salt budget (analogous to procedure in Gordon et al., 1996). The bay

Table 1. Sector areas, volumes, and nutrient concentrations. Data are used to calculate volume-averaged concentrations for the outer portion of the bay ("ocean") and the bay proper

SECT. #	VOL.10^6 m^3	AREA 10^6 m^2	DIP µM	NH4 µM	NO3 µM	Sum DIN µM	DIP 10^6 mol	NH_4 10^6 mol	NO_3 10^6 mol	S DIN 10^6 mol
1	130	20.1	1.8	12	11	23	0.23	1.56	1.43	2.99
2	300	44.6	1.5	7	6	13	0.45	2.10	1.80	3.90
3	115	28.5	1.6	3	6	9	0.18	0.35	0.70	1.05
4	463	61.9	1.4	4	4	8	0.65	1.85	1.85	3.70
5	204	20.0	1.0	1	3	4	0.20	0.27	0.60	0.87
6	222	26.0	1.2	2	5	7	0.27	0.44	1.11	1.55
7	573	38.5	1.0	2	4	6	0.57	1.15	2.29	3.44
8	554	24.2	0.7	1	2	3	0.39	0.39	1.11	1.50
SUM	2561	264								
		bay	1.3	4	5	9				
		ocean (secs. # 5,8)	0.8	1	2	3				

Table 2. Hydrographic exchange fluxes of nutrients

SOURCE OF FLUX	DIP 10^6mol/yr	NH_4 10^6mol/yr	NO_3 10^6mol/yr	DIN 10^6mol/yr
residual flow	-3	-7	-11	-18
net exchange flow	-18	-108	-108	-216
total hydrography	-21	-115	-119	-234

volume divided by the residence time gives a mixing exchange volume of 98.5 x 10^6 m^3/d, while the residual outflow equals the freshwater inflow (i.e., 8.2 x 10^6 m^3/d). It would, in principle, be possible to time-step through the data (at monthly increments, for example). However, to do that would require having the flow data to go with the nutrient data. Further, inspection of the graph by Nixon et al. (1995) of flow data and comparison of Pilson's (1985) flow—residence time regression equation suggests that the residence time over this range of flow is well approximated by a constant value for the exchange time. Various authors describe the bay as well mixed, and this is supported by the water composition data in Kremer and Nixon (1978). We therefore use a 1-box model to perform these calculations, rather than a vertically stratified model to describe hydrographic fluxes.

In Table 3, all boundary fluxes except hydrography were taken directly from by Nixon et al. (1985). Hydrographic flux was calculated as above. Δ Y's (the nonconservative fluxes) are calculated by difference (as described in Gordon et al., 1996). No data are available for DOP, DON, or for either inorganic or organic C, so the budget is based on inorganic N and P only. As discussed by Gordon et al. and consistent with comments in Nixon et al., it seems safe to assume that DOP and DON nonconservative fluxes do not contribute strongly to the overall nonconservative fluxes in this system.

Rates for the D Y's per unit area are calculated using the bay area of 264 km^2 (Table 4). Note that this area estimate is about 25% lower than the value used by Kremer and Nixon (1978). We have used the smaller area and volume on the basis that these are the data used to calculate the volume-averaged concentrations. Net (nfix-denit) is calculated on the assumption that the N:P ratio of D DIP is 13:1, then D DIN is balanced. Net (p-r) is calculated from the DIP flux, using a C:P ratio of 112:1.

Table 3. Total boundary fluxes of nutrients and inferred internal reactions—the system budget

Process	DIP 10^6mol/yr	NH_4 10^6mol/yr	NO_3 10^6mol/yr	DIN 10^6mol/yr
atmosphere	0	6	19	25
rivers	13	113	177	290
urban runoff	2	13	4	17
sewage	9	136	6	142
hydrography	-21	-115	-119	-234
D Y	-3	-153	-87	-240
(nfix-denit)				-201

Table 4. Nonconservative fluxes of materials and stoichiometrically inferred biogeochemical pathways

	DIP mmol m^{-2} yr^{-1}	NH_4 mmol m^{-2} yr^{-1}	NO_3 mmol m^{-2} yr^{-1}	DIN mmol m^{-2} yr^{-1}	C mol m^{-2} yr^{-1}
D Y	-11	-580	-329	-909	
D DIN_{exp}				-143	
(nfix-denit)				-766	
(p-r)					1.2

Nixon et al. (1995) have data with which the present budgetary estimates may be compared: They estimate DIP and DIN fluxes from the ocean to the bay by a hydrographic budget analogous to values used here for both influx and efflux, but they do not use this same hydrography to estimate nutrient fluxes to the ocean. Their inward DIP and DIN fluxes, obtained by time-stepping through the oceanic nutrient concentration data (bottom water only), are 27 and 115 x 10^6 mol/yr. The calculations here (using annual average data) are 29 and 108 x 10^6 mol/yr. The agreement is within 10%. It should be close, because both Nixon et al. and the calculations here are performing essentially the same calculation. Three points for minor disagreement would be that the values here just used a constant exchange rate (instead of time-varying); values used here were picked data off a graph; and surface and bottom values were averaged (on the graph, these are effectively identical in the outermost bay sectors).

Instead of using hydrography to estimate outward DIP and DIN flux, those authors estimate DIP and DIN fluxes from the bay to ocean by difference with other terms in their budget, to close the budget. They get 41-51 x 10^6 and 240-470 x 10^6 mol/yr. Again pulling the hydrographic terms apart, the calculations here yield 50 x 10^6 and 342 x 10^6 mol/yr (in both cases, within their range). It is worth noting that if the water exchange volume is incorrect, it would affect both influx and efflux of nutrients, hence have a relatively small effect on the difference between influx and efflux. The point here, of course, is that the difference between influx and efflux is probably more reliable than either of the individual fluxes.
Nixon et al. use a variety of considerations for two different sets of incubation data to assign baywide denitrification a range of 85-170 x 10^6 mol/yr (compared to 201 x 10^6 from the hydrographic budget; using their high values, agreement is within 20%).

Those authors estimate respiration to consume 8100 to 9200 x 10^6 mol/yr of organic C. Using their estimate for primary production (p) of 29 mol C m^{-2} yr^{-1} and the DIP-derived estimate for production - respiration (*p-r*) of 1.2, *r* is estimated to be 27.8 mol C m^{-2} yr^{-1}. Scaling by the bay area, this gives respiration to be 7340 x 10^6 mol/yr (within 20% of their lower estimate). If we were to use the are value given in Nixon et al. (328 km^2, instead of the value of 264 km^2 from Kremer and Nixon (1978), the respiration would be 9118 x 10^6 mol/yr (within their range).

Efforts to control the release of nutrients into Narragansett Bay have recently addressed nitrogen contributions from Publically Owned Treatment Works (POTWs) throughout the watershed. One nutrient reduction option currently being pursued is to maximize nitrogen removal from the final effluent by modifying operating conditions with existing equipment at the facility. Retrofitting existing facilities will also be considered where appropriate. A second venue involves drafting water quality based permit limits over the next few years to limit nitrogen in the final effluent of POTWs. Finally, a total maximum daily load (TMDL) for nitrogen is currently under development for the Providence River upstream of Narragansett Bay through the NPDES permitting process. A model is being developed that once calibrated, will set nitrogen load limits for POTWs that discharge to the river.

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CASE STUDY
NUTRIENT MANAGEMENT AND SEAGRASS RESTORATION IN TAMPA BAY, FLORIDA

Holly Greening, Tampa Bay Estuary Program

Abstract: Participants in the Tampa Bay Estuary Program have agreed to adopt nitrogen loading targets for Tampa Bay based on the water quality and related light requirements of the seagrass species *Thalassia testudinum*. Based on modeling results, it appears that light levels can be maintained at necessary levels by "holding the line" at existing nitrogen loadings. However, this goal may be difficult to achieve given the 20% increase in the watershed's human population and associated 7% increase in nitrogen loading that are projected to occur over the next 10-20 years.

To address the long-term management of nitrogen sources, a Nitrogen Management Consortium of local electric utilities, industries and agricultural interests, as well as local governments and regulatory agency representatives, has developed a Consortium Action Plan to address the target load reduction needed to "hold the line" at 1992-1994 levels. To date, implemented and planned projects collated in the Consortium Action Plan meet and exceed the agreed-upon nitrogen loading reduction goal.

The Tampa Bay estuary is located on the eastern shore of the Gulf of Mexico in Florida, USA. At more than 1000 km^2, it is Florida's largest open water estuary. More than 2 million people live in the 5700 km^2 watershed, with a 20% increase in population projected by 2010. Land use in the watershed is mixed, with about 40% of the watershed undeveloped, 35% agricultural, 16% residential, and the remaining commercial and mining.

Major habitats in the Tampa Bay estuary include mangroves, salt marshes and submerged aquatic vegetation. Each of these habitats has experienced significant areal reductions since the 1950s, due to physical disturbance (dredge and fill operations) and water quality degradation, particularly impacting the seagrasses due to loss of light availability. Five species of seagrass are commonly found in Tampa Bay, with *Thalassia testudinum* (turtlegrass) and *Syringodium filiforme* (manatee grass) dominating in the higher salinity areas and *Halodule wrightii* (shoalgrass) and *Ruppia maritima* (widgeon grass) most commonly found in lower salinities.

The importance of seagrass as a critical habitat and nursery area for fish and invertebrates, and as a food resource for manatees, sea turtles and other estuarine organisms has been recognized by the Tampa Bay resource management community for several decades. In 1990, Tampa Bay was accepted into the U.S. Environmental Protection Agency's (EPA) National Estuary Program. The Tampa Bay National Estuary Program (TBNEP), a partnership that includes three regulatory agencies and six local governments, has built on the resource-based approach initiated by earlier bay management efforts. Further, it has developed water quality models to quantify linkages between nitrogen loadings and bay water quality, and models that link water quality to seagrass goals.

Recent recommendations from the National Academy of Science National Research Council (NRC) include those which regional watershed programs might consider in developing nutrient management strategies. The NRC recommendations are based on the process designed by the Tampa Bay Estuary Program partners to develop and implement a seagrass protection and restoration management program for Tampa Bay. Critical elements of the Tampa Bay process are to:

1. Set specific, quantitative seagrass coverage goals for each bay segment.
2. Determine seagrass water quality requirements and appropriate nitrogen loading targets.
3. Define and implement nitrogen management strategies needed to achieve load management targets.

STEP 1. SET QUANTITATIVE RESOURCE MANAGEMENT GOALS

Establishment of clearly defined and measurable goals is crucial for a successful resource management effort. In 1992, TBNEP adopted an initial goal to increase current Tampa Bay seagrass cover to 95% of that present in 1950.

Based on digitized aerial photographic images, it was estimated that approximately 16,500 ha of seagrass existed in Tampa Bay in 1950. At that time, seagrasses grew to depths of 1.5 m to 2 m in most areas of the bay. By 1992, approximately 10,400 ha of seagrass remained in Tampa Bay, a loss of more than 35% since the 1950 benchmark period. Some (about 160 ha) of the observed loss occurred as the result of direct habitat destruction associated with the construction of navigation channels and other dredging and filling projects within existing seagrass meadows, and is assumed to be nonrestorable through water quality management actions.

In 1996, the TBNEP adopted a bay-wide minimum seagrass goal of 15,400 ha. This goal represented 95% of the estimated 1950 seagrass cover (minus the nonrestorable areas), and includes the protection of the existing 10,400 ha plus the restoration of an additional 5,000 ha.

STEP 2. DETERMINE SEAGRASS WATER QUALITY REQUIREMENTS AND APPROPRIATE NITROGEN LOADING RATES

Once seagrass restoration and protection goals were established by the participants, the next steps established the environmental requirements necessary to meet agreed-upon goals and subsequent management actions necessary to meet those requirements.

A. Determine environmental requirements needed to meet the seagrass restoration goal
Recent research indicates that the deep edges of *Thalassia testudinum* meadows, the primary seagrass species for which nitrogen loading targets are being set, correspond to the depth at which 20.5% of subsurface irradiance (the light that penetrates the water surface) reaches the bay bottom on an annual average basis. The long-term seagrass coverage goal can thus be restated as a water clarity and light penetration target. Therefore, in order to restore seagrass to near 1950 levels in a given bay segment, water clarity in that segment should be restored to the point that allows 20.5% of subsurface irradiance to reach the same depths that were reached in 1950.

B. Determine water clarity necessary to allow adequate light to penetrate to the 1950 seagrass deep edges
Water clarity and light penetration in Tampa Bay are affected by a number of factors, such as phytoplankton biomass, non-phytoplankton turbidity, and water color. Water color may be an important cause of light attenuation in some bay segments; however, including color in the regression model did not produce a significant improvement in the predictive ability of the regression model. Results of the modeling effort indicate that, on a baywide basis, variation in chlorophyll *a* concentration is the major factor affecting variation in average annual water clarity.

C. Determine chlorophyll a concentration targets necessary to maintain water clarity needed to meet the seagrass light requirement
An empirical regression model was used to estimate chlorophyll a concentrations necessary to maintain water clarity needed for seagrass growth for each major bay segment. The adopted segment-specific

annual average chlorophyll a targets (ranging from 4.6 µg/l to 13.2 µg/l) are easily measured and tracked through time, and are used as intermediate measures for assessing success in maintaining water quality requirements necessary to meet the long-term seagrass goal.

D. Determine nutrient loadings necessary to achieve and maintain the chlorophyll a targets

Water quality conditions in 1992-1994 appear to allow an annual average of more than 20.5% of subsurface irradiance to reach target depths (i.e., the depths to which seagrasses grew in 1950) in three of the four largest bay segments. Thus, a management strategy based on "holding the line" at 1992-1994 nitrogen loading rates should be adequate to achieve the seagrass restoration goals in these segments. This "hold the line" approach, combined with careful monitoring of water quality and seagrass extent, was adopted by the TBNEP partnership in 1996 as its initial nitrogen load management strategy.

As an additional complicating factor, a successful adherence to the "hold the line" nitrogen loading strategy may be hindered by the projected population growth in the watershed. A 20% increase in population, and a 7% increase in annual nitrogen load, are anticipated by the year 2010. Therefore, if the projected loading increase (a total of 17 U.S. tons per year) is not prevented or precluded by watershed management actions, the "hold the line" load management strategy will not be achieved.

STEP 3. DEFINE AND IMPLEMENT NITROGEN MANAGEMENT STRATEGIES NEEDED TO ACHIEVE LOAD MANAGEMENT GOALS

Local government and agency partners in the TBNEP signed an Intergovernmental Agreement (IA) in 1998 pledging to carry out specific actions needed to "hold the line" on nitrogen loadings. The IA includes the responsibility of each partner for meeting the nitrogen management goals, and a timetable for achieving them. How those goals are reached will be left up to the individual communities as defined by them in their Action Plans. The Tampa Bay National Estuary Program was also renamed the Tampa Bay Estuary Program as part of the progression from the planning phase to implementation of the adopted Comprehensive Conservation and Management Plan.

To maintain nitrogen loadings at 1992-1994 levels, local government Action Plans address that portion of the nitrogen target which relates to non-agricultural stormwater runoff and municipal point sources within their jurisdictions, a total of 6 U.S. tons of nitrogen per year through the year 2010 (Table 1).

To address the remaining 11 U.S. tons of nitrogen of the 17 total per year each year through the year 2010 needed to "hold the line" (attributed to atmospheric deposition, industrial and agricultural sources and springs), a Nitrogen Management Consortium of local electric utilities, industries and agricultural interests, as well as the local governments and regulatory agency representatives in the TBEP, was established (Table 2). The Nitrogen Management Action Plan developed by public and private partners in the Consortium combines for each bay segment all local government, agency and industry projects that will contribute to meeting the five year nitrogen management goal. To ensure that each partner was using similar nitrogen load reduction assumptions for similar projects, guidelines for calculating nitrogen load reduction credits were developed with the partners, and were used by each of the partners in the development of their action plans.

The types of nutrient reduction projects included in the Consortium's Nitrogen Management Action Plan range from traditional nutrient reduction projects such as stormwater upgrades, industrial retrofits and agricultural best management practices to actions not primarily associated with nutrient reduction, such as land acquisition and habitat restoration projects. A total of 105 projects submitted by local governments, agencies and industries are included in the Plan; 95% of these projects address nonpoint

Table 1. Tampa Bay Nitrogen Management Goals

SOURCE CATEGORY	CUMULATIVE 1995-1999 GOALS FOR NITROGEN REDUCTION/MANAGEMENT							TOTAL (reduction in annual load) (tons)
	Pinellas County	City of Clearwater	City of St. Petersburg	Hillsborough County	City of Tampa	Manatee County	TB Consortium*	
Old Tampa Bay	0.30	0.20	0.05	0.40	0.10	<0.01	1.05	2.10
Hillsborough Bay	<0.01	<0.01	<0.01	4.75	8.45	<0.01	28.25	41.50
Middle Tampa Bay	<0.01	<0.01	0.90	2.50	<0.01	0.50	7.15	11.05
Lower Tampa Bay	<0.01	<0.01	<0.01	<0.01	<0.01	8.35	17.00	25.35
Boca Ciega Bay	0.85	<0.01	1.05	<0.01	<0.01	<0.01	2.00	3.90
TOTAL	1.15	0.20	2.00	7.65	8.55	8.85	55.45	83.85
%	1.4	0.2	2.4	9.1	10.2	10.6	66.1	100.0

* Tampa Bay Nitrogen Management Consortium

Table 2. Public and Private Partners of the Tampa Bay Nitrogen Management Consortium, July 2001

Public Partners:	Private Partners:
City of Tampa	Florida Phosphate Council
City of Clearwater	Florida Power & Light
City of St. Petersburg	Tampa Electric Company
Manatee County	Florida Strawberry Growers Association
Hillsborough County	IMC-Phosphate
Pinellas County	Cargill Fertilizer, Inc.
Manatee County Agricultural Extension Service	CF Industries, Inc.
Environmental Protection Commission of Hillsborough County	Pakhoad Dry Bulk Terminals
Tampa Bay Regional Planning Council	Eastern Associated Terminals Company
Florida Department of Environmental Protection	CSX Transportation
Florida Fish and Wildlife Commission/Florida Marine Research Institute	
Southwest Florida Water Management District	
U.S. Army Corps of Engineers	
U.S. Environmental Protection Agency	
Tampa Port Authority	
Tampa Bay Estuary Program	
Florida Department of Agriculture and Consumer Services	

sources and account for 71% of the expected total nitrogen reduction. Half (50%) of the total load reduction will be achieved through public sector projects, and 50% by industry.

Table 3 summarizes expected reductions from those projects which were completed by the end of 1999. A total of 134 tons per year reduction in nitrogen loading to Tampa Bay is expected from the completed projects, which exceeds the 1995-1999 reduction goal of 84 tons per year by 60%. An updated estimate of nitrogen loadings to the bay from all sources was initiated by TBEP in summer 2001, after which the effectiveness of the proposed projects in maintaining loads to the bay will be evaluated.

Examples of specific projects and expected nitrogen loading reductions include the following:

Stormwater facilities and upgrades: Stormwater improvements or new facilities include both public and private examples. Stormwater retrofits using alum injection to urban lakes reduced total nitrogen (TN) loading by an estimated 6.4 tons per year. Stormwater improvements eliminated an estimated 2 tons of TN loading per year. Industrial stormwater improvements at phosphate

Table 3. Tampa Bay Nitrogen Management Consortium Summary of Goals and Expected Reductions (cumulative tons TN reduced or precluded/year by the year 2000

Bay Segment	1995-1999 Nitrogen Reduction Goal	Expected Reduction: Completed or Ongoing Projects[1]	Expected Reduction: Atmospheric Deposition[2]
Old Tampa Bay	2.10	5.1	3.6 - 6.2
Hillsborough Bay	41.5	65.9	13.9 - 24.0
Middle Tampa Bay	11.1	21.1	4.6 - 7.9
Lower Tampa Bay	25.4	36.2	5.7 - 10.0
Boca Ciega Bay	3.9	5.6	1.2 - 2.1
Total	84.0	133.9	29.0- 50.2

[1] Projects have been completed or are under construction. These summaries do not include reductions expected from atmospheric deposition reductions.

[2] Range of atmospheric deposition reductions expected, based on two methods.

fertilizer factories and transport terminals reduced almost 20 tons TN loading per year by the year 2000.

Land acquisition and protection: Land acquisition and maintenance of natural or low intensity land uses precludes higher density uses and higher rates of TN loading. Land acquisition precluded more than 15 tons TN loading per year by the end of 1999.

Approved overlay districts requiring additional nutrient control in management areas precluded an estimated 10 tons per year TN loading.

Wastewater reuse: Wastewater reuse programs resulted in a 6.4 ton per year reduction on TN loading. Conversion of septic systems to sewer reduced TN loading by 1.7 tons per year.

Emissions reduction: Estimated emissions reduction from coal-fired electric generating plants between 1995-1997 resulted in reductions of NO_x emissions of 11,700 - 20,000 tons. To estimate the reduction of nitrogen deposition which reaches the bay (either by direct deposition to the bay's surface, or by deposition and transport through the watershed), a 400:1 ratio (NO_x emissions units to nitrogen units entering the bay) is assumed. Expected reductions from atmospheric deposition thus ranged from 29 to50 tons per year by 1999. To date, emissions reductions have not been included in the estimated total TN reduction to the bay, pending agreement on estimation methods.

Habitat restoration: Although typically conducted for reasons other than nutrient reduction, habitat restoration to natural land uses reduces the amount of TN loading per acre in runoff. Habitat restoration projects have been completed or are underway in all segments of Tampa Bay's watershed. Estimated TN load reduction from completed habitat restoration projects totaled an estimated 7 tons per year.

Agricultural BMPs: Water use restrictions have promoted the use of microjet or drip irrigation on row crops (including winter vegetables and strawberries) and in citrus groves. Micro-irrigation has resulted in potential water savings of approximately 40% or more over conventional systems and an estimated 25% decrease in fertilizer applied. Nitrogen reduction estimates from these actions total 6.4 TN tons per year.

Education/public involvement: For those projects for which nitrogen load reductions have not been calculated or measured, but some reductions are expected, the Consortium Action Plan assumes a 10% reduction estimate until more definitive information is available. These programs have reduced TN loading by an estimated 2 tons per year.

Industrial upgrades: A phosphate fertilizer mining and manufacturing plant has terminated the use of ammonia in flot-plants (an element of the fertilizer manufacturing process), resulting in a reduction of 21 tons per year of nitrogen loading. Other fertilizer manufacturing companies have upgraded their product conveyor systems, resulting in a TN reduction of more than an estimated 10 tons per year due to control of fertilizer product loss. The termination of discharge by an orange juice manufacturing plant into a tributary of Tampa Bay has resulted in a reduction of more than 11 tons per year TN loading.

The approach advocated by the TBEP stresses cooperative solutions and flexible strategies to meet nitrogen management goals. This approach does not prescribe the specific types of projects that must be included in the Action Plan; Consortium partners have been encouraged to pursue the most cost-effective options to achieve the agreed-upon goals for nitrogen management. The TBEP will review and revise nitrogen management goals every five years, or more often if significant new information becomes available.

SUMMARY

The Tampa Bay management community has agreed that protection and restoration of Tampa Bay living resources is of primary importance. Through the TBEP process (initiated in 1991), partners have adopted nitrogen loading targets for Tampa Bay based on the water quality requirements of *Thalassia testudinum* and other native seagrass species. A long-term goal has been adopted to achieve 15,400 ha of seagrass in Tampa Bay, or 95% of that observed in 1950. To reach the long-term seagrass restoration goal, a 7% increase in nitrogen loading associated with a projected 20% increase in the watershed's human population over the next 20 years must be offset. Government and agency partners in the Tampa Bay Estuary Program and private industries and interests participating in the Nitrogen Management Consortium have identified and implemented specific nitrogen load reduction projects to ensure that water quality conditions necessary to meet long-term living resource restoration goals for Tampa Bay are achieved.

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CASE STUDY
RESTORING CHESAPEAKE BAY WATER QUALITY

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Original Nutrient Reduction Goal

In 1987, the Chesapeake Bay Program partners set a 40 percent reduction goal for nitrogen and phosphorus to improve low oxygen conditions in the deep trench of the mainstem bay. The goal was later defined to apply only to "controllable" sources, and only from the States—Maryland, Virginia, Pennsylvania—and the District of Columbia are also listed as impaired tidal waters.

All listed impaired waters are scheduled to have a Total Maximum Daily Load or TMDL developed. A TMDL defines the pollutant load that a waterbody can assimilate without causing violations of water quality standards and allocates the loading to contributing point sources and nonpoint source categories. Once a TMDL is established by a State and approved by EPA through regulatory action, it is implemented through regulatory and nonregulatory programs. A regulatory TMDL covering the entire 64,000 square mile bay watershed will be put in place by 2011 if bay water quality is not restored.

Keeping A Cooperative Approach to Bay Restoration

To avoid potential negative impacts that a regulatory TMDL process might have on the successful, cooperative efforts being used by the States' tributary strategy programs, the Chesapeake 2000 Agreement lays out a series of commitments directed toward seeking a cooperative solution to restoring bay water quality by 2010.

The bay watershed partners will define the water quality conditions necessary to support bay living resources—fish, crabs, oyster, and bay grasses by 2001. These required conditions will be defined through a series of Chesapeake Bay water quality criteria for dissolved oxygen, water clarity, and chlorophyll *a* currently under development.

Important distinct bay and tributary tidal water habitats are being identified and characterized as designated uses, where the above bay criteria will be applied to fully protect the aquatic living resources.

The States with bay tidal waters—Maryland, Virginia, Delaware, and the District of Columbia—have all committed to adopting these bay criteria and tidal water designated uses into their individual State water quality standards by 2003.

Critical to supporting the States' adoption of the bay criteria and refined tidal waters designated uses will be a baywide Use Attainability Analysis (UAA).

Loading caps on nutrients and sediments needed to meet the bay water quality criteria will be allocated to major tributary basins and individual States within those basins by December 2001.

Tributary strategies, detailed implementation plans to reach the allocated loading caps will be developed in cooperation with local watershed stakeholders.

A reevaluation planned for 2005 will provide an opportunity for any necessary mid-course corrections on the road to restoring bay water quality by 2010.

Bay Criteria: Defining Restored Bay Water Quality

The Chesapeake 2000 Agreement committed the signatories to the following: "by 2001, define the water quality conditions necessary to protect aquatic living resources." These water quality conditions are being defined through the development of Chesapeake Bay specific water quality criteria for dissolved oxygen, water clarity, and chlorophyll *a*. Collectively, these three water quality parameters provide the best and most direct measures of the impacts of too much nutrient and sediment pollution on the bay's aquatic living resources—fish, crabs, oysters, and underwater bay grasses.

Bay Criteria

Dissolved Oxygen

Fish and other aquatic life require levels of dissolved oxygen to survive. Seasonal algae blooms deplete dissolved oxygen, potentially rendering deep waters of the bay uninhabitable to certain species, such as the endangered Atlantic Sturgeon during certain times of the year. Bay dissolved oxygen levels should be those required by the aquatic communities inhabiting different parts of the bay during different times of the year, fully reflective of natural conditions.

Chlorophyll a

Measurements of chlorophyll indicate levels of phytoplankton or algal biomass in the water column. Bay chlorophyll levels should be moderate: not so high as to cause harmful algal blooms that lead to poor quality food, shading of light in shallow water habitats, and low dissolved oxygen conditions when the algae die off and sink to the bottom.

Water Clarity

Underwater grasses collectively are an essential component of the bay's living resources habitat. Decreased water clarity inhibits the growth of underwater bay grasses. Water clarity is adversely affected by increased sediment loads and algal biomass spurred by excess nutrient inputs to the bay. Bay water quality conditions should generally provide high water clarity—sunlight penetration—to support restoration of underwater grasses throughout the bay's extensive shallow water habitats.

Chesapeake Bay Dissolved Oxygen Criteria

Chesapeake Bay Dissolved Oxygen Dynamics

The Chesapeake Bay has a built-in, natural tendency toward reduced dissolved oxygen conditions, particularly within its deeper waters because of the physical morphology and estuarine circulation. Its highly productive, shallow waters, coupled with its tendency to retain, recycle, and regenerate the nutrients delivered from the atmosphere and surrounding watershed set the stage for a nutrient-rich environment. The mainstem Chesapeake Bay and its major tidal rivers with deep channels coming off shallower, broad shoal waters, and the significant influx of freshwater flows result in stratification of the water column, essentially locking off deeper bottom waters from mixing with higher oxygenated surface waters. Combined together, the retention/efficient recycling of nutrients and water column stratification lead to severe reductions in dissolved oxygen concentrations during the warmer months of the year, generally May to September.

Nearshore, shallow waters in the Chesapeake Bay also periodically experience episodes of low to no dissolved oxygen conditions, in part, resulting from intrusions of bottom water forced onto the shallow flanks by sustained winds (Carter et al.1978, Tyler 1984, Seilger et al.1985, Malone et al.1986). Diel cycles of low dissolved oxygen conditions often occur in nonstratified shallow waters where nighttime water column respiration temporarily depletes dissolved oxygen levels (D'Avanzo and Kremer 1994).

The timing and spatial and volumetric extent of hypoxic and anoxic waters vary from year to year, largely driven by local weather patterns, timing and magnitude of freshwater river flow and concurrent delivery of nutrients and sediments into tidal waters, and the corresponding springtime phytoplankton bloom (Officer et al.1984, Seliger et al.1985). In Chesapeake Bay mainstem, the onset of low to no dissolved oxygen conditions can be as early as April and persist through September, until fall turnover of the water column. The deeper waters of major tidal tributaries can exhibit hypoxic and anoxic conditions, with the nature, extent, and magnitude of low dissolved oxygen and the causative factors varying from river to river.

The scientific underpinnings of these Chesapeake Bay specific criteria have been in the works for decades. Seasonal low dissolved oxygen conditions in the Chesapeake Bay were first documented in the 1930s (Newcombe and Horne 1938). Basic understanding of dissolved oxygen dynamics, critical to derivation of criteria reflective of ecosystem process, began with the research cruises of the Chesapeake Bay Institute from the 1950s through the late 1970s. A 5-year multidisciplinary research program starting in the late 1980s, funded by the Maryland and Virginia Sea Grant Program, yielded significant advances in understanding of all facets of oxygen dynamics, effects, and ecosystem implications (Smith et al. 1991). These investigations laid the groundwork for more management-focused applications of the science.

Chesapeake Bay Dissolved Oxygen Restoration Goal

Published in 1992, the Chesapeake Bay dissolved oxygen restoration goal was developed in response to the Chesapeake Executive Council's commitment "to develop and adopt guidelines for the protection of water quality and habitat conditions necessary to support the living resources found in the Chesapeake Bay system and to use these guidelines." The dissolved oxygen restoration goal consisted of a narrative statement supported by specific target dissolved oxygen concentrations applied over specified averaging periods and locations. Dissolved oxygen effects information was compiled for 14 identified target species[1] of fish, molluscs, and crustaceans as well as for other supporting benthic and planktonic species within the bay food web. The target concentrations and their specified temporal averaging and spatial application were determined from analysis of dissolved oxygen levels that would provide the levels of protection described within the narrative restoration goal. Best professional judgment was used in areas where there were gaps in the information base on dissolved oxygen effects available a decade ago.

The original dissolved oxygen restoration goal and its supporting framework made three breakthroughs at that time of significance to supporting derivation and management application of the Chesapeake Bay specific dissolved oxygen criteria within this document. The dissolved oxygen target concentrations varied with vertical depth through the water column as well as horizontally across the expanse of the bay and its tidal tributaries, directly reflecting variations in required levels of protection for different living resource habitats. The averaging periods for each target concentration were tailored to specific habitats, recognizing that short-term exposures to concentrations below the target concentrations were allowable and still protective of living resources. The dissolved oxygen goal document contained a methodology through which water quality monitoring data and model-simulated outputs collected over varying frequencies could be directly assessed in terms of the percentage of time that areas of bottom habitat or volumes of water column habitat were predicted to meet or exceed the applicable target dissolved oxygen concentrations.

Regionalizing the EPA Virginian Province Saltwater Dissolved Oxygen Criteria

With the publication of the EPA *Ambient Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras* came a decade's worth of systematically developed dissolved oxygen effect data along with synthesis and close evaluation of several decades of effects data published in the scientific

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[1] These target species were from a larger list of commercially, recreationally , and ecologically important species reported in *Habitat Requirements for Chesapeake Bay Living Resources-Second Edition* (Funderburk *et al.* 1991).

peer reviewed literature (Thursby et al.2000). The approach to derive these dissolved oxygen criteria combined features of the traditional water quality criteria with a new biological framework. A mathematical model was used to integrate time (replacing the concept of an averaging period) and establish protection limits for different life stages (i.e., larvae verus juveniles and adults). Where practical, data were selected and analyzed in manners consistent with the *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (hereafter referred to as the EPA Guidelines) (Stephan et al.1985).

The EPA Virginian Province dissolved oxygen saltwater criteria document addressed three areas of protection: (1) juvenile and adult survival, (2) growth effects, and (3) larval recruitment effects. In doing so, the criteria document segregated effects on juveniles and adults from those on larvae. The survival data on the sensitivity of the juveniles and adults are handled in a traditional EPA guidelines manner. To address cumulative effects of low dissolved oxygen on larval recruitment to the juvenile life stage (i.e., larval survival as a function of time) a new biological approach was taken. These criteria were derived using a mathematical model that evaluates the effect of dissolved oxygen conditions on larvae by tracking the intensity and duration of low dissolved oxygen effects across the larval recruitment season. Protection of larvae of all species is provided by using low dissolved oxygen effects data on larval stages of nine sensitive estuarine/coastal organisms.

The Virginian Province saltwater dissolved oxygen criteria document and its underlying effects database and methodologies were structured to support regional specific derivation of dissolved oxygen criteria tailored to the species, habitats, and nature of dissolved oxygen exposure regimes of different estuarine, coastal, and marine waters. The segregation by life stages allows the criteria to be factored into the refined tidal water designated uses, which themselves, in part, reflect use of different habitats by different life stages. This segregation by life stage is a significant difference from traditional aquatic life criteria.

However, the Virginian Province saltwater criteria were not explicitly set up to address natural vertical variations in dissolved oxygen concentration. If Chesapeake Bay specific criteria were derived through a strict application of the EPA saltwater criteria methodology, there would not be the flexibility needed to tailor each set of criteria to the refined tidal water designated uses. The resultant bay criteria would be driven solely by larval effects data irrespective of depth and season.

The Chesapeake Bay specific criteria were derived through the regional application of the Virginian Province effects database and application of traditional toxicological and new biological-based criteria derivation methodologies. Chesapeake Bay specific science was factored directly into each step of the criteria derivation process. The extensive Virginian Province dissolved oxygen effects database was first focused down on only Chesapeake Bay species and then supplemented with additional Chesapeake Bay species effects data from the scientific literature. The Virginian Province larval recruitment model was modified to better reflect Chesapeake Bay conditions, with its application broadened to include additional Chesapeake Bay species. Finally, specific steps were taken to factor the requirement to provide protection of species listed as threatened/endangered in Chesapeake Bay into the bay-specific criteria.

Current State water quality standards generally require 5 mg/L of dissolved oxygen throughout all of the bay's waters—from the deep trench near the bay's mouth to the shallows at the head of the bay. Even though the 5 mg/L standard is baywide, bay region scientists believe *natural* conditions dictate that in some sections of the bay, such as the deep channel, bay waters *cannot* achieve the current 5 mg/L standard during the warmer months of the year. Additionally, scientists believe other areas, such as prime migratory fish spawning areas, require *higher* levels of dissolved oxygen to sustain life during the late winter to early summer timeframe. The amount of oxygen needed in the bay tidal waters depends on specific needs of the aquatic living resources and where they live and during which time of the year they live there.

The Chesapeake Bay dissolved oxygen criteria vary significantly across the five proposed tidal water designated uses to fully reflect the wide array of species living in these different bay habitats (Figure 1). These working draft dissolved oxygen criteria were developed by the Chesapeake Bay Dissolved Oxygen Criteria Team, a bay region team composed of scientists, State and federal managers, and technical stakeholders (Table 1). A draft document describing the Chesapeake Bay Dissolved Oxygen Criteria in greater detail is available for review and comment at www.chesapeakebay.net. There is a year-long process and schedule, including three public reviews, leading to publication of these Chesapeake Bay specific water quality criteria by EPA by June 2002.

Chesapeake Bay Chlorophyll *a* Criteria
Chlorophyll *a* is used to measure the abundance and variety of microscopic plants or algae that form the base of the food chain in the bay. Excessive nutrients can stimulate nuisance algae blooms, resulting in reduced water clarity, reduced amount of good quality food and depleted oxygen levels in deeper water. By its very nature, chlorophyll *a* is both an integrated biological measure of production of the primary food source of the entire bay food web as well as a critical indicator of water quality through its direct role in reducing light penetration and fueling bacterial processes leading to low dissolved oxygen levels. As stated upfront by Harding and Perry (1997), "chlorophyll *a* is a useful expression of phytoplankton biomass and is arguably the single most responsive indicator of N [nitrogen] and P [phosphorus] enrichment in this system [Chesapeake Bay]." Determining the levels of chlorophyll *a* which are fully protective of the refined designated uses of the vast tidal waters that compose the Chesapeake Bay and tributaries must factor in all the different roles chlorophyll *a* plays in defining a restored, more balanced Chesapeake Bay ecosystem.

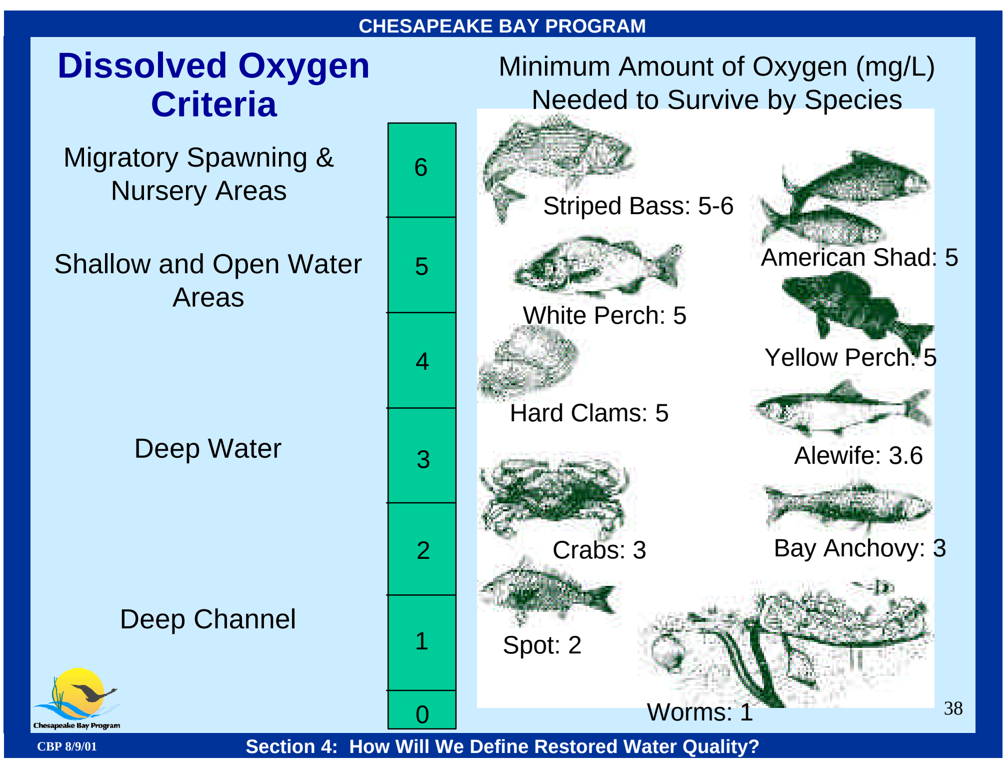

Figure 1. Dissolved Oxygen Criteria, Chesapeake Bay.

Table 1. Working Draft Chesapeake Bay Dissolved Oxygen Criteria (July 3, 2001)

Designated Use	Criteria Concentration/Duration	Temporal Application
Migratory spawning and nursery	7 day mean of 6 mg/L[a]	February 15th - June 10th
	Instantaneous minimum of 5 mg/L	
	30 day mean of 5 mg/L	June 11th - February 14th
	7 day mean of 4 mg/L	
	Instantaneous minimum of 3.5 mg/L	
Shallow/open water	30 day mean of 5 mg/L	All year round
	7 day mean of 4 mg/L	
	Instantaneous minimum of 3.5 mg/L	
Deeper water	30 day mean of 3 mg/L	April through September
	Instantaneous minimum of 1.7 mg/L	
	30 day mean of 5 mg/L	October through March
	7 day mean of 4 mg/L	
	Instantaneous minimum of 3.5 mg/L	
Deep channel	Instantaneous minimum of 1 mg/L	April through September
	30 day mean of 5 mg/L	October through March
	7 day mean of 4 mg/L	
	Instantaneous minimum of 3.5 mg/L	

[a] Applied to tidal fresh waters with long term averaged salinities less than 0.5 parts per thousand.

The derivation of the Chesapeake Bay chlorophyll *a* criteria were based on the convergence of several independent lines of evidence—historical observed concentrations, literature values related to trophic status, direct contributions to light attenuation, and contribution to dissolved oxygen conditions—collaborating chlorophyll *a* concentrations derived as a result of characterizing set of phytoplankton reference communities.

Phytoplankton Reference Community/Food Quality Connection

Estimates of phytoplankton taxon biomasses were derived from the Maryland and Virginia Chesapeake Bay Monitoring Program phytoplankton count data (1984-1999) and along with other phytoplankton indicators—chlorophyll *a*, pheophytin, and primary productivity—were used to investigate differences in biomass, taxonomic composition, and food value for the range of water quality conditions currently experienced in the Chesapeake Bay. The biological data were sorted into categories based on season- and salinity-specific concentrations/levels of three parameters in the associated water quality data: dissolved inorganic nitrogen, ortho-phosphate and Secchi depth. Relatively small secchi depths and excess dissolved inorganic nitrogen and excess ortho-phosphate characterized the Poor water quality categories. Relatively high light levels and algal growth-limiting concentrations of dissolved inorganic nitrogen and ortho-phosphate characterized the good water quality categories. Mixed water quality conditions (i.e., one or two water quality parameters qualified as Better but the other(s) did not) and extreme subsets of the Poor and Better categories (i.e. Worst and Best) were also investigated. Qualitative and quantitative measures of the phytoplankton community composition and biomass distributions were then evaluated relative to these water quality classifications and implications for food quality and quantity for filter feeding fish and shellfish.

Historically Observed Concentrations
Several recent in-depth reviews and evaluations of historically observed (1950s to early 1980s) and current (1984-1998) chlorophyll *a* concentrations provide a strong basis for collaborating the Chesapeake Bay specific chlorophyll *a* criteria (Harding 1994, Harding and Perry 1997, Olson and Lacouture, in review). Using information from five decades of water quality data provides insights into both chlorophyll *a* concentrations that are attainable under a range of otherwise natural conditions (meteorological, river flow, tidal flushing) as well as concentrations reflective of a healthier bay ecosystem.

Literature Values Related to Trophic Status
Throughout the scientific literature, there are several defining papers which through synthesis of a wide array of data from many different aquatic systems center down on ranges of conditions reflective of different trophic states of water bodies (e.g., Wetzel 1985, Ryding and Rast 1989, Smith et al.1992). Chlorophyll *a* is a principal parameter quantified within these literature reviews. The strength of this collaborative line of evidence is that information is drawn from diversity of systems across the spectrum of healthy to clearly eutrophied water bodies. This approach provides insights into common characteristics associated with trophic status that can not be drawn through the study of a single, although large, water body like Chesapeake Bay.

Direct Contributions to Light Attenuation
Over the past four decades, the Chesapeake Bay ecosystem has had an extensive, widely distributed underwater grass community undergo severe declines followed by a decade and a half slow but steady recovery. The bay management and scientific communities have invested significant resources in the investigation of this grand natural experiment, learning much about the causes of the decline and potential solutions for continued, yet accelerated restoration. Two comprehensive technical synthesizes of this wealth of scientific knowledge and insights have been published which provide direct quantitative insights into the role of chlorophyll *a* in the recovery of underwater bay grasses (Batiuk et al.1992, 2000). This collaborative line of evidence draws on the chlorophyll *a* connection to reductions in light penetration through the water column.

Contribution to Dissolved Oxygen Conditions
It is well known and documented that algae uneaten by higher trophic levels—zooplankton, oysters and fish of all kinds—becomes the fuel, through its breakdown by bacteria, for reducing dissolved oxygen levels. Through an analysis of Chesapeake Bay water quality model simulated outputs from scenarios which simulated dissolved oxygen conditions which met the dissolved oxygen criteria, the model simulated chlorophyll *a* concentrations of desired dissolved oxygen conditions were quantified.

Appropriate chlorophyll *a* levels vary, depending on the salinity of the water. The proposed criteria for chlorophyll *a* are split out from tidal freshwater all the way to very salty—polyhaline—waters. Season of the year is also important, with spring and summer being the most important times of year that high chlorophyll *a* levels can impact living resources in the bay.

These working draft chlorophyll *a* criteria were developed by the Chesapeake Bay Chlorophyll and Nutrient Criteria Team, a bay region team composed of scientists, State and federal managers, and technical stakeholders (Table 2). A draft document describing the Chesapeake Bay Chlorophyll *a* Criteria in greater detail is available for review and comment at www.chesapeakebay.net. There is a

Table 2. Working Draft Chesapeake Bay Chlorophyll *a* Criteria (July 3, 2001)

Salinity Regime	Chesapeake Bay Chlorophyll Criteria (ug/L)			
	Spring (March-May)		Summer (July-September)	
	Median	Maximum	Median	Maximum
Tidal Fresh	8	12	9	16
Oligohaline	10	23	6	23
Mesohaline	6	27	7	16
Polyhaline	3	7	4	9

year-long process and schedule, including three public reviews, leading to publication of these Chesapeake Bay specific water quality criteria by EPA by June 2002.

Connection to Underwater Bay Grasses

The loss of submerged aquatic vegetation, or SAV, from shallow waters of Chesapeake Bay, which was first noted in the early 1960s, is a widespread, well-documented problem. Although other factors, such as climatic events and herbicide toxicity, may have contributed to the decline of SAV in the bay, the primary causes are eutrophication and associated reductions in light availability. The loss of SAV beds are of particular concern because these plants create rich animal habitats that support the growth of diverse fish and invertebrate populations. Similar declines in SAV have been occurring worldwide with increasing frequency during the last several decades. Many of these declines have been attributed to excessive nutrient enrichment and decreases in light availability.

Chesapeake Bay Water Clarity Criteria

One of the major features contributing to the high productivity of Chesapeake Bay has been the historical abundance of SAV. There are over 20 freshwater and marine species of rooted, submerged flowering plants in bay tidal waters. These underwater grasses provide food for waterfowl and are critical habitat for shellfish and finfish. SAV also affect nutrient cycling, sediment stability, and water turbidity.

The health and survival of these plant communities in Chesapeake Bay and its tidal tributaries depend on suitable environmental conditions that define the quality of SAV habitat. Key to the restoration of these critical habitats and food sources is the return of levels of light penetration in shallow waters necessary to support the survival, growth, and repropagation of diverse, healthy underwater bay grass communities.

Bay Water Clarity Derivation Approach

Through the combined efforts of the bay's scientific and resource management communities, two internationally recognized technical syntheses of information supporting quantitative habitat requirements for Chesapeake Bay SAV have been published in the past decade (Batiuk et al.1992, Batiuk et al. 2000). Key findings, the underlying light requirements, and management-oriented diagnostic tools and restoration targets have been reported in the peer reviewed scientific literature (Dennison et al. 1993, Kemp et al. in review; Gallegos 2001, Koch 2001, Bergstrom in preparation, Carter and Rybicki in preparation, Karrh in preparation, Kemp et al. in preparation). These two technical syntheses of worldwide literature, bay-specific research and field studies, and recent model simulation and data evaluation provide the scientific foundation for the Chesapeake Bay water clarity criteria described here. Readers are encouraged to consult these two syntheses and the resultant scientific literature papers for more in-depth technical details and documentation.

The Chesapeake Bay specific water clarity criteria derivation follows four successive stages: first, determination of water-column-based light requirements for SAV survival and growth, then quantification of the factors contributing to water column light attenuation. The contributions from epiphytes to light attenuation at the leaf surface are then factored into methods for estimating total light attenuation. Finally, a set of minimal light requirements are determined as the actual criteria values.

The draft bay criteria propose that water clarity criteria should apply to areas of the bay that are up to 2 meters deep (approximately 6 feet). Areas where SAV never occurred historically, or where natural factors prevent its growth (e.g., strong currents, rocky bottoms) would be excluded. The water clarity criteria reflect the different light requirements for underwater plant communities that inhabit low salinity versus higher salinity shallow water habitats throughout the bay (Figure 2).

These working draft water clarity criteria were developed by the Chesapeake Bay Water Clarity Criteria Team, a bay region team composed of scientists, State and federal managers, and technical stakeholders (Table 3). A draft document describing the Chesapeake Bay Water Clarity Criteria in greater detail is available for review and comment at [www.chesapeakebay.net.](www.chesapeakebay.net) There is a year-long process and schedule, including three public reviews, leading to publication of these Chesapeake Bay specific water quality criteria by EPA by June 2002.

These Chesapeake Bay criteria will be applied to a series of designated uses which, in turn, reflect key habitats throughout the bay and its tidal tributaries.

Excessive Nutrient and Sediment Loads
The causes of these water quality impairments—excessive loadings of nitrogen, phosphorus, and sediment—will be addressed through commitments to determine reductions in loadings needed to achieve the bay criteria. These required loading reductions will be established as caps on loadings

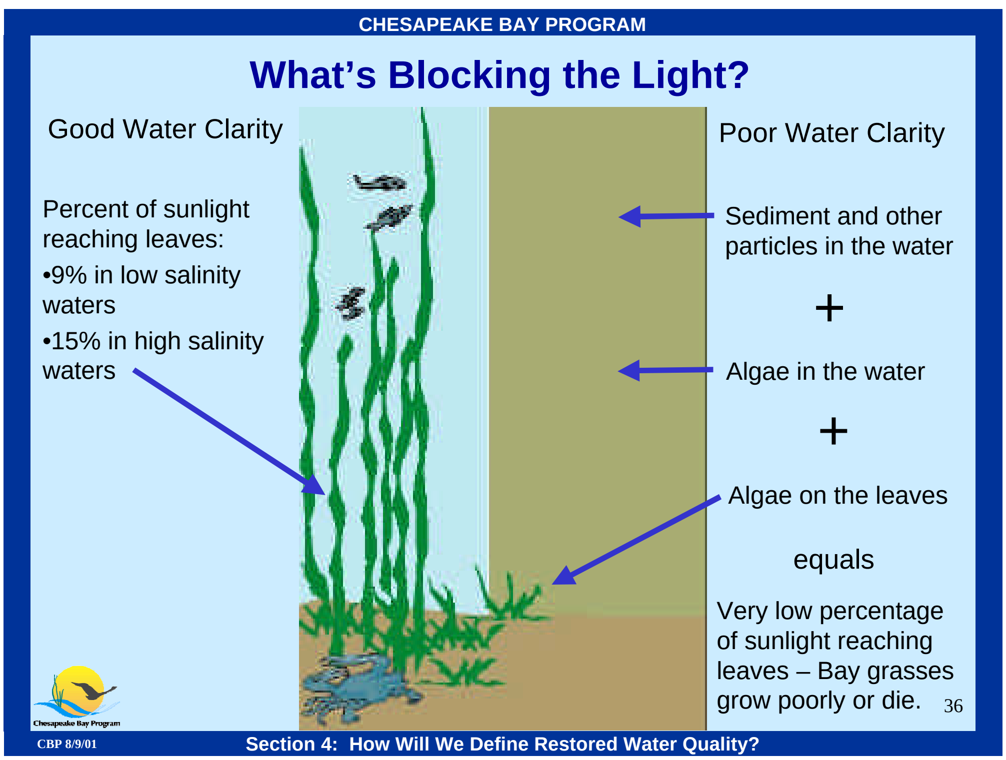

Figure 2. Bay Water Clarity.

Table 3. Working Draft Chesapeake Bay Water Clarity Criteria (July 3, 2001)

Habitat Category	Criteria Concentration (percent ambient light)	Temporal Application
Tidal fresh shallow water	9 %	April - October
Oligohaline shallow water	9 %	April - October
Mesohaline shallow water	15 %	April - October
Polyhaline shallow water	15%	March-May, Sept-Nov.

allocated to each tributary basin within the Chesapeake Bay watershed. This approach is consistent with EPA's regional establishment of ambient concentration-based nutrient criteria, but places more emphasis on the water quality parameters with a direct impact on aquatic living resources. Through this approach nutrients and sediments are addressed directly through caps on loading determined through application of the linked bay airshed-watershed-tidal water quality models and analysis of Chesapeake Bay Monitoring Program data in place of the development of ambient nutrient and sediment criteria.

Relationship with National Efforts to Develop Nutrient Criteria

At the same time, a parallel effort is currently underway by EPA to develop ecoregion specific numerical nutrient criteria across the country to meet the objectives of the Clean Water Action Plan. A nutrient criteria team has been established by EPA-Region III to implement the National Nutrient Strategy issued by EPA last year for the mid-Atlantic region. The EPA Region III team is focusing its nutrient criteria development efforts on the free flowing stream, rivers, lakes, and wetlands within the mid-Atlantic States, not the Chesapeake Bay tidal waters. Whereas the bay criteria are focused on dissolved oxygen, water clarity and chlorophyll *a*, the EPA Region III team is developing ambient concentration criteria for total nitrogen, total phosphorus, chlorophyll, and turbidity.

The advanced scientific understanding of water quality impacts on aquatic bay living resources combined with the state of the art linked bay airshed-watershed -water quality models enabled the bay watershed partners to develop criteria for water quality measures directly influencing aquatic resources. The cause of reduced water quality conditions—too much nitrogen, phosphorus, and sediment—will be addressed through the establishment of loading caps. The bay models enable the partners to effectively translate the desired dissolved oxygen, water clarity, and chlorophyll *a* conditions back into reduced loadings of nutrients and sediments from the surrounding watershed and airshed. Bay science has shown that it is the delivered loads of nutrients and sediment, not just the ambient concentrations, that have had an impact on oxygen, light, and algae levels in the bay tidal waters.

Bay Tidal Water Designated Uses

Because conditions throughout the Chesapeake Bay tidal water habitats differ based on depth, salinity and season, a uniform baywide water quality standard does not take into account the varying needs of different plants and animals. As a result, current State water quality standards, which differ between the four jurisdictions with tidal waters, need to be revised and expanded to account for the natural variability in conditions found throughout the bay. Each of the three bay criteria will differ from one region of the bay and its tidal tributaries to another, as determined by the plants and animals residing in that area. Once the bay criteria and the tidal water designated uses are adopted as State water quality standards, these tailored set of standards will apply to similar habitats across all jurisdictions.

An area's designated use refers to a waterbody's function—such as fishable or swimable—and takes into account the use of the water body for public water supply, the protection of fish, shellfish, and wildlife, as well as its recreational, agricultural, industrial and navigational purposes. The existing Maryland, Virginia, Delaware, and District of Columbia designated uses for the bay's tidal waters do not fully reflect the wide variety of different habitats found throughout the bay and its tidal tributaries. Where two jurisdictions boundaries join, each State has different designated uses for the same waterbodies.

Five refined Chesapeake Bay tidal water designated uses have been established to more fully reflect the different aquatic living resource communities inhabiting a variety habitats and, therefore, the different intended aquatic life uses of those tidal habitats (Figure 3).

The *Migratory Spawning & Nursery* designated use is the propagation and growth of balanced indigenous populations of ecologically, recreationally, and commercially important anadromous, semi-anadromous, and tidal fresh resident fish species inhabiting spawning and nursery grounds.

The *Shallow Water* designated use is the propagation and growth of balanced, indigenous populations of ecologically, recreationally, and commercially important fish, shellfish and underwater grasses inhabiting shallow waters habitats.

The *Open Water* designated use is the propagation and growth of balanced, indigenous populations of ecologically, recreationally, and commercially important fish, and shellfish species that inhabit open water habitats.

The *Deep Water* designated use is the propagation and growth of balanced, indigenous populations of ecologically, recreationally, and commercially important fish and shellfish species inhabiting deep water habitats.

The *Deep Channel* designated use is to provide a refuge for balanced, indigenous populations of ecologically, recreationally, and commercially important fish species that depend on deep channel

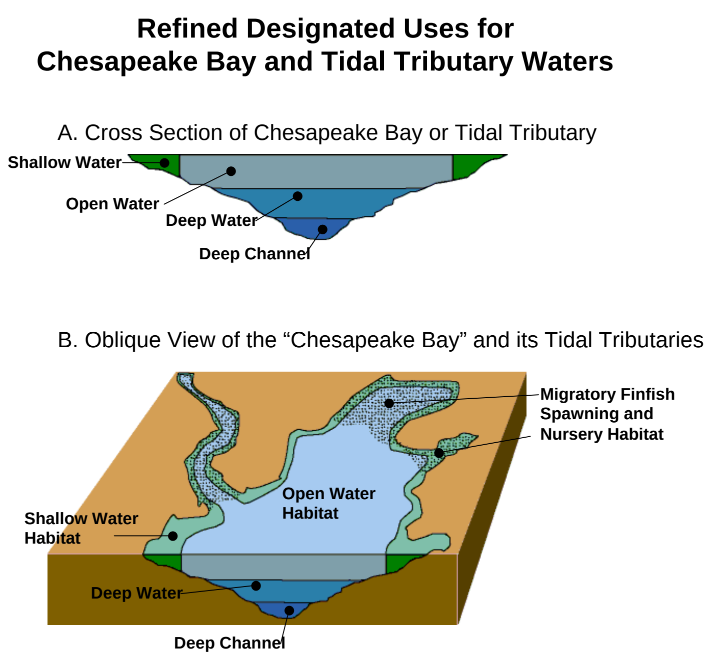

Figure 3. Refined Designated Uses for Chesapeake Bay Tidal Tributary Waters.

habitats for overwintering during colder months of the year and the propagation and growth of benthic infaunal and epifaunal worms and clams that provide food for bottom feeding fish and crabs.

These tidal water designated uses were developed by the Chesapeake Bay Water Quality Standards Coordinators Team, a bay region team composed of water quality standards coordinators from all six States, the District of Columbia, EPA Region 2, 3, and headquarters offices. Table 4 shows how refined tidal water designated uses relate to the bay criteria.

The watershed partners are evaluating the refined tidal water designated uses and the applicable bay criteria through a baywide use attainability analysis. The final tidal water designated uses will be adopted by Maryland, Virginia, Delaware, and the District of Columbia, along with the applicable bay water quality criteria into their State water quality standards by 2003. These refined designated uses will add more specifics to the existing State designated uses and apply consistently across jurisdictions for similar habitats.

Baywide Use Attainability Analysis

The Chesapeake 2000 Agreement commits the States with bay tidal waters—Maryland, Virginia, and Delaware—and the District of Columbia to adopt into their State water quality standards as consistent set of bay criteria and designated uses across bay tidal habitats. Whenever there is a proposed change in water quality standards, such as that being undertaken for Chesapeake Bay waters, it is necessary to assess attainment of the designated uses and underlying criteria. Such an assessment is called a Use Attainability Analysis or UAA.

A UAA is used by States to justify changes to their water quality standards by assessing the physical, chemical, biological, economic, or other factors affecting attainment of the designated use. The UAA describes the scientific attributes of the waterbody, both natural conditions and conditions brought about by human contribution. If the attributes of the waterbody make attaining the use impossible, or if there are economic reasons why the use cannot be attained, the UAA is used to clearly document these reasons. Finally, the UAA describes how the proposed standards will protect existing uses. All six bay watershed States—New York, Pennsylvania, Maryland, Virginia, West Virginia and Delaware—along with the District of Columbia and EPA are working together with bay watershed partners to carry out such an

Table 4. Chesapeake Bay Criteria Needed for Protection of the Proposed Tidal Waters Designated Uses

	Dissolved Oxygen	**Chlorophyll *a***	**Water Clarity**
Migratory Spawning and Nursery	✔	✔	
Shallow Water	✔	✔	✔
Open Water	✔	✔	
Deep Water	✔		
Deep Channel	✔		

assessment. A use attainment assessment on a scale as large as the 64,000 square mile Chesapeake Bay watershed has never been carried out.

Adopting Bay Criteria as State Water Quality Standards

Water quality standards combine water quality criteria and designated uses to produce a target numeric value assigned to a waterbody that, if achieved, will maintain healthy water quality. Through the Chesapeake 2000 Agreement, Maryland, Virginia, and the District of Columbia are committed to adopting the new bay criteria–dissolved oxygen, water clarity, and chlorophyll *a*—along with the refined tidal water designated uses as State water quality standards. Delaware, which shares bay tidal waters with Maryland in its portion of the Nanticoke River watershed, has made the same commitment through the six-State memorandum of agreement. Together, the States and the District must achieve these new bay-specific water quality standards needed to support restored estuarine ecosystem if the Chesapeake Bay is to be removed from the list of impaired waters.

Why New State Standards

Existing State water quality standards are applied broadly across each State's tidal waters, without recognition of the variety of habitats. Each State has different water quality standards applied to the same tidal waters, whereas the aquatic living resources in bay habitats, which do not recognize these jurisdictional boundaries, may have the same water quality needs. Currently, dissolved oxygen is the only numerical water quality standard adopted by all three States and the District of Columbia that addresses nutrient- and sediment-related water quality pollution problems.

So compliance with existing State water quality standards will not fully protect the living resources in the bay waters. In some critical habitats of the bay, specifically migratory fish spawning and nursery areas, existing State water quality standards will not fully protect more sensitive life stages. In other cases, reaching existing standards is not possible owing to natural conditions found in deeper bay waters during the warmer months of the year. Existing State water quality standards do not include measures to protect underwater bay grasses or fully support good quality fish food.

Setting and Allocating New Cap Loads

The Chesapeake 2000 Agreement commits the signatories to determining the nutrient and sediment load reductions necessary to achieve the water quality conditions that protect aquatic living resources. Those load reductions will then be assigned or allocated to each major tributary basin in the form of cap loads. Cap loads are the maximum amounts of pollutants allowed to flow into a waterbody and still ensure achievement of State water quality standards. In this case, the water quality standards will be the new bay criteria and refined tidal water designated uses (currently in draft) to be adopted by the States of Maryland, Virginia, and Delaware, and the District of Columbia into their standards by 2003.

Available Tools and Information

The Chesapeake Bay watershed partners will use the Chesapeake Bay Airshed, Watershed and Estuary Models, the USGS SPARROW model, along with Chesapeake Bay Monitoring Program data, to help determine these cap loads for nitrogen, phosphorus, and sediment. These models are mathematical representations that simulate the real world, interpreting various levels of actions (management scenarios) to reduce different amounts of pollutant loads. These scenarios are run through the models to determine how to achieve baywide attainment of the bay water quality criteria for dissolved oxygen, water clarity, and chlorophyll *a* as applied to the tidal water designated uses.

Cap Setting and Allocation

These models and other available information will be used to allocate loading caps to the nine major tributary basins–Susquehanna, Upper Western Shore, Patuxent, Potomac, Rappahannock, York, James, Upper Eastern Shore, and Virginia Eastern Shore (Figure 4). Each State and the District will bear a proportional burden for achieving and maintaining the cap based on their existing pollutant loadings, progress to date, effectiveness and cost efficiency considerations, and their pollutant loading effects on different tributaries.

For multijurisdictional waters like the Susquehanna, Potomac, and Eastern Shore basins, the linked watershed and bay water quality models will be used to further allocate cap load responsibilities to each State.

Working with their local stakeholders, individual States to further subdivide their major tributary basin load cap allocations into the 37 State-defined tributary strategy sub-basins.

A comprehensive 2-year schedule has been set up to coordinate the efforts of the six watershed States, the District of Columbia, and the many other involved bay watershed partners. The schedule also will ensure direct and continued involvement of local stakeholders and the general public during the entire cap load setting and allocation process. The Chesapeake Bay Water Quality Steering Committee, composed of senior managers from the seven watershed jurisdictions, EPA regional and headquarters offices, Chesapeake Bay Commission, river basin commissions, and involved stakeholders, has the overall responsibility overseeing and reaching agreement on the cap load allocations. Many of the subcommittees and workgroups within the Chesapeake Bay Program committee structure will be carrying out the technical, modeling, data interpretation, economic analysis, policy evaluation, and communication work in support of setting and allocating the nutrient and sediment cap loads.

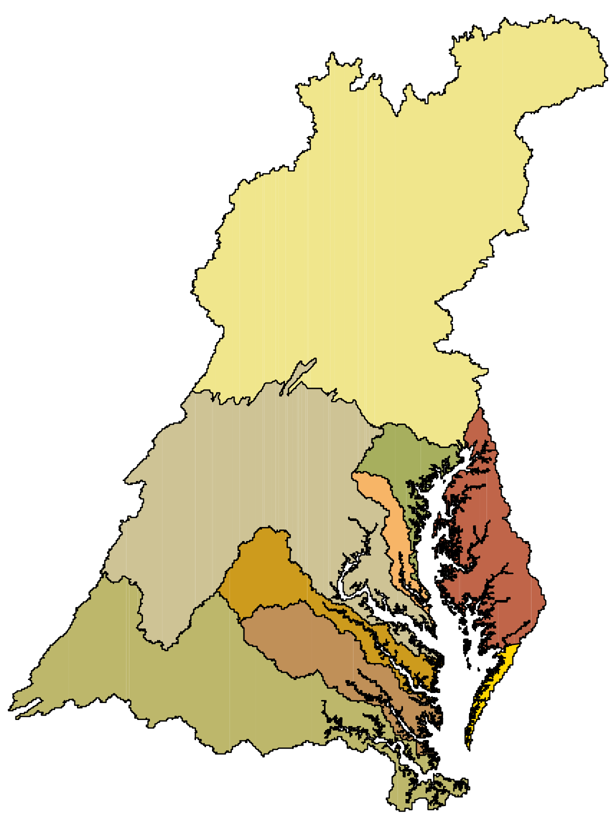

Figure 4. The Nine Major Basins.

Tributary Strategies: Local Watershed Implementation

The Chesapeake 2000 Agreement commits the bay watershed partners to "complete a public process to develop and begin implementation of revised Tributary Strategies to achieve and maintain the assigned loading goals." Tributary strategies are detailed descriptions of planned local actions—riparian forest buffer replanting, wastewater treatment upgrades, nutrient management on farms, stormwater treatment, stream restoration, and many others—and a schedule for undertaking those actions necessary to reduce nutrients and sediment loads from each tributary watershed to reach the assigned loading cap by 2010.

Development of tributary strategies has been a very driven public process with the direct involvement by local governments, watershed associations, regional organizations, and a wide variety of other interested local stakeholders. In creating the strategies, the States, and the District of Columbia work closely with those groups and individuals within each respective watershed who will be directly involved in implementation strategy. Together, they explore and evaluate a wide variety of point and nonpoint source pollution control measures. They then draft a strategy using the most effective reduction options to achieve the cap load allocated to their tributary strategy basin.

The existing Tributary Strategies were designed to achieve the 1987 Bay Agreement goal of a 40 percent reduction in nutrient loads from controllable sources from 1985 levels. Copies of these existing tributary strategies are available on-line through the respective Maryland, Virginia, Pennsylvania, and the District of Columbia tributary strategy web pages.

To restore the tidal water conditions necessary to sustain the bay's fish, crabs, oysters and underwater grasses will likely require greater reductions in nutrients in many areas then called for by the existing tributary strategies. In addition, the water clarity conditions needed to restore underwater bay grasses can not be achieved without significant reductions in sediments loads to the tidal waters. With New York, Delaware and West Virginia joining as bay watershed partners through a six-State memorandum of understanding, new tributary strategies will be developed for these States' portions of the bay watershed not previously addressed under the existing tributary strategies.

The new and revised tributary strategies will now cover all sources of nutrient and sediment pollution, including air sources, across the entire 64,000 Chesapeake Bay watershed. Tributary strategies will address nutrient and sediment loading caps allocated to 37 sub-basins across the bay watershed by the bay watershed partners. Loading reductions required through local stream and river segment regulatory TMDLs will be directly integrated into each respective Tributary Strategy as part of the overall effort to effectively "blend" the regulatory TMDL program and cooperative Chesapeake Bay Program.

Information on Local Watersheds

A wide array of information is available on local watersheds within the Chesapeake Bay basin, including information directly relevant to the overall process for setting and allocating new cap loads through the Chesapeake Watershed Profiles. Through this point and click information system linking the bay watershed partners, one can access information on pollution sources, recent modeling results, status of bay criteria attainment, long-term trends in water quality and living resources, draft cap allocations, and more from the entire bay basin scale to local watersheds.

CASE STUDY
A PERSPECTIVE FROM WASHINGTON STATE

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The issue of nutrient control for marine receiving waters in Washington State has its origin in a landmark case concerning freshwater eutrophication and lake restoration. In the early 1950's, Lake Washington, a large lake (85 km2) situated near Seattle, Washington, was showing warning signs of ecological deterioration. Following unregulated dumping of sewage from a growing urban population into the lake, classic signs of eutrophication were observed, including blooms of Oscillatoria rubescens, reduced water transparency, and very low nitrogen to phosphorus concentration ratios. The situation was studied extensively by Dr. W. T. Edmondson, a professor at the University of Washington, who explained that the changes in the lake were directly attributable to nutrient loading from sewage and wastewater (Edmondson, 1991). Edmondson made these facts known not only to the scientific community but also to the public and local government. The case resulted in the diversion of sewage away from the lake and is a classic example of how scientific observations and understanding were used to shape public policy. The sewage diversion and subsequent lake recovery were a success, with current day water quality of the Lake far exceeding that observed during the 1950's-60's.

The solution to this classic case was to divert wastewater from Lk. Washington to nearby Puget Sound, a large inland sea linked to the Pacific Ocean via the Strait of Juan de Fuca. Studies by Dr. G. C. Anderson, an oceanographer at the University of Washington, showed that phytoplankton in the Sound in the vicinity of the outfall proposed to handle the diverted wastewater were limited by light and mixing, not by nutrients. Thus, diversion of effluent from the Lake to the Sound was not "shifting the problem" but rather was an ecologically sound solution. This understanding of both limnology and oceanography laid the conceptual foundation for the formation of a large publicly funded agency (Municipality of Metropolitan Seattle, or "Metro"). It was proposed that Metro would build a new outfall at West Point, on the Main Basin of Puget Sound, divert the sewage from Lk. Washington to West Point, and thus eliminate the nutrient enrichment problem. However, the mandate to create Metro to carry forward these actions had to be approved in a public election first. Much controversy was associated with the process chronicled well in Edmondson's book "The Uses of Ecology" (Edmondson, 1991). Among numerous lines of objection, some public opinion maintained that Puget Sound's ecological health would be destroyed, despite Anderson's observations. The proposed action required two election attempts before it was approved in 1958. It is notable that the election passed before deterioration of Lk. Washington water quality was serious; certainly the local conditions were not as serious as the symptoms seen in lakes in Europe or the Midwest North America. However, deterioration of Lk. Washington conditions did continue during the five years before the Metro diversion construction commenced. The persistent, dense, and obnoxious populations of Oscillatoria galvanized public opinion that the Metro diversion was necessary. Shortly after construction of the diversion, Lk. Washington water quality improved.

The notoriety of this event and the success of the outfall constructed at West Point to not exhibit observable biological changes in Puget Sound resulted in widespread lore that "Puget Sound" cannot be eutrophied because the marine waters are not sensitive to nutrient addition. As Anderson's observations implied, the reason for the success of West Point outfall owes to the deep, well-mixed waters at the site which are flushed with a residence time on the order of days. Density-driven stratification is minimal, the phytoplankton are well mixed, and any depth gradients of oxygen and nutrients do not persist. The outfall, at 71 m depth, diffuses effluent into water that has naturally high concentrations of nitrate and this additional nitrogen burden is thought to not significantly contribute to phytoplankton nutrition.

Ammonium concentrations in excess of normal Puget Sound background levels are observed sporadically (King County 2001) near the site and may be associated with the effluent.

This example remains well-known, but it is important to note that not all of the reaches, bays, and inlets of Puget Sound have the same characteristics of West Point and the Main Basin. Greater Puget Sound is actually composed of several basins: South Puget Sound, Hood Canal, Whidbey Basin, the Main Basin, and Admiralty Inlet with its adjoining waters with the Strait of Juan de Fuca. The first three of these basins have considerable freshwater-induced stratification and are much less well-flushed than the Main Basin. Residence times of these basins range weeks to months. A study funded by EPA to provide a general review of the state of knowledge regarding nutrient-phytoplankton relations and quantify the relative nutrient sensitivity of various areas in the Sound highlighted several areas where nutrients became deplete and N:P ratios suggested nitrogen limitation (Rensel, 1991). Evidence from C-14 uptake experiments have shown that enhancements of primary production over ambient rates due to added nitrogen nutrient can be as high as 300% in South Hood Canal (Newton et al. 1995) and 83% in Budd Inlet, located in South Puget Sound near Olympia (Newton et al. 1998). Based on environmental attributes and human growth indicators, only a few places within Puget Sound were judged to be currently exhibiting signs of eutrophication; however, numerous places, particularly in South Puget, Hood Canal, and Whidbey basins, were assessed to be highly susceptible to future deterioration from eutrophication (Bricker et al. 1999).

Perhaps the first place within Puget Sound to gain wide attention for nutrient enrichment effects was southern Puget Sound, including Budd Inlet, Oakland Bay, Eld Inlet, Henderson Inlet, Case Inlet, and Carr Inlet. The Washington State Department of Ecology sponsored two studies in the 1980s to evaluate the acceptability of secondary-treated wastewater discharges to marine waters in southern Puget Sound (URS, 1985, URS, 1986a). This work identified areas where new or expanded discharges were unacceptable, based on the potential for eutrophication. A simple screening model based on effluent dilution and flushing was developed to identify the most sensitive areas.

Wastewater discharge into Budd Inlet was implicated in causing nuisance blooms of phytoplankton and adding to low dissolved oxygen concentrations noted in the bottom waters at the head of the inlet (URS, 1986b). Studies sponsored by the Washington State Department of Ecology developed the first numerical models to relate the loading of nitrogen to phytoplankton blooms and dissolved oxygen in Budd Inlet. This work was the impetus for construction of advanced wastewater treatment systems to remove dissolved inorganic nitrogen from municipal wastewater from the regional facility that discharges to Budd Inlet. In 1994, the wastewater entering Budd Inlet was treated for nitrogen removal. This has resulted in substantially lower ambient nitrogen concentrations (Eisner and Newton 1997). However, regional growth continues and more capacity to process effluent is needed. Currently, the Lacey-Olympia-Tumwater-Thurston County Wastewater Management Partnership (LOTT) is considering numerous alternatives to meet this need, including one proposal to discharge more effluent in winter when phytoplankton growth is minimal. LOTT undertook a large modeling and observational study: the Budd Inlet Science Study, which will be used to make the final permitting decisions.

Nutrient-induced increases to phytoplankton production with subsequent drawdown of bottom-water oxygen has a unique character in Puget Sound relative to other North American systems because of the influence of upwelled Pacific Ocean water. Upwelling favorable conditions off the Washington coast lead to upwelling of deep ocean waters. These relatively low-oxygenated waters are transported in, landwards, at depth through the Strait of Juan de Fuca, as the estuarine flow of Puget Sound waters flow out, seawards, at the surface. The oceanic waters entering the Puget Sound system through Admiralty Inlet can have oxygen concentrations as low as 5 mg/L, which then spread into the Main Basin and form the bottom-water of the other basins as well. Seasonally low deepwater oxygen concentrations can be found throughout Puget Sound (Newton et al., 1998; King County, 2001). Upwelling is mostly favorable in late summer, when productivity-related oxygen deficits are also maximal. The additive nature of human-caused eutrophication oxygen drawdown to this natural low oxygen quality, results in a smaller margin of error before deleterious effects would be noted.

The success of discharging nutrients into marine waters via regional Puget Sound wastewater plants, including the West Point facility, may be at a scale that has reached capacity. The Seattle metropolitan area continues to grow and new Puget Sound regional wastewater facilities are needed. The King County Council recently approved that a new facility will be required to meet growth demands and is projected for completion in 2010. The new facility will also discharge into the Main Basin, to the north of the West Point facility. King County is currently leading an extensive study to investigate impacts from nutrient loading on the area. These studies include extensive water quality sampling, experiments on the susceptibility of the waters to nutrient additions and modeling experiments to predict future impacts.

The story of nutrient control in Puget Sound continues to evolve. Ecologically sound decisions regarding nutrient management are dependent on two variables: (1) the population producing the effluent, its size, growth rate, and scale relative to the receiving waters; and (2) the sensitivity of the particular region of the Sound where the effluent is to be discharged to nutrients. Unfortunately, both of these attributes are highly variable within the Puget Sound regional area, making nutrient management decisions a challenge and arguing for the utility of careful scientific studies in companion with planning efforts.