Delaware Estuary Program Regional Monitoring Plan Volume 1

DELAWARE
ESTUARY PROGRAM

DELEP Report #94-09
September 1994

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Delaware Estuary Program Regional Monitoring Plan Volume 1

September 30, 1994

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Chapter 1 Introduction

The Clean Water Act as amended by the Water Quality Act of 1987 establishes the National Estuary Program (NEP) to promote long-term planning and management of nationally significant estuaries threatened by pollution, development, or overuse. Section 320 of the Clean Water Act describes the establishment of a management conference in each estuary to develop a Comprehensive Conservation and Management Plan (CCMP). It also establishes requirements to monitor the effectiveness of actions taken pursuant to the plan.

The goal of environmental monitoring conducted as part of the CCMP implementation phase (Phase IV) is to evaluate the status and trends of monitored variables and to link the observed patterns to specific management actions. To meet this goal, it is necessary to carefully plan and coordinate the monitoring efforts of individual monitoring components and other preexisting monitoring programs (USEPA, 1992b). The development of a Regional Monitoring Plan does not necessarily mean the obsolescence of site-specific monitoring programs. In some cases, additional program coordination of existing monitoring efforts might be all that is needed. Nor is the monitoring plan "written in stone." As explained in the next section, monitoring program performance evaluation, review, and revision are important steps in the design and operation of a monitoring program. This document has been written with the knowledge that as the CCMP develops and additional work is performed, the monitoring plan will need to be revised accordingly.

The remainder of this chapter provides an overview of the Delaware Estuary Program (DELEP), an explanation of the need for and steps in the design of a regional monitoring plan, and a brief summary of the DELEP Regional Monitoring Strategy Workshop, held on October 9, 1993.

THE DELAWARE ESTUARY PROGRAM AND THE NEED FOR REGIONAL MONITORING

The DELEP was established in 1988 under the authority of the Water Quality Act of 1987 to develop a CCMP for the Delaware Estuary. The DELEP is accomplishing this work cooperatively through the States of Delaware, New Jersey, and Pennsylvania; the Delaware River Basin Commission (DRBC); and several research institutions and federal agencies. The structure of the DELEP reflects a strong commitment to consensus building among all estuary user groups, government agencies, research institutions, and the public.

The Delaware Estuary Program has established a series of 14 objectives to guide the development of management activities and the design and implementation of monitoring programs to be delineated in the CCMP (Table 1-1). Taken together, the DELEP objectives are significant because they establish a firm link to the overall objectives of the Clean Water Act to "restore and maintain the chemical, physical, and biological integrity of the nation's waters."

Table 1-1. Delaware Estuary Program Objectives

Objective 1 **Harvested finfish and invertebrate species**	To restore population levels of harvestable species of finfish and invertebrate species to levels that will support recreational and commercial fisheries (e.g., an initial target for oyster population that will support a harvest of 1,000,000 bushels annually).
Objective 2 **Bird population**	To restore or maintain populations of birds dependent on the Delaware Estuary to levels deemed attainable by comprehensive analysis (e.g., a count of 260,000 black ducks or 250,000 shorebirds).
Objective 3 **Estuary-dependent amphibians, reptiles, mammals**	To restore or maintain populations of estuarine-dependent amphibians, reptiles, and mammals to levels deemed attainable by comprehensive analysis of natural populations.
Objective 4 **Ecological balance for a diverse indigenous biota**	To maintain or restore an assemblage of organisms and their habitat throughout the Delaware Estuary and tidal wetlands that contributes to the ecological diversity, stability, productivity and aesthetic appeal of the region.
Objective 5 **Habitat**	To preserve acreage and enhance quality of shoreline and littoral habitat to sustain a balanced natural system. To restore and maintain the physical and environmental conditions necessary to achieve target levels of estuarine species. (At a minimum, maintain 1990 acreage of habitat and, if necessary, increase acreage of habitat to achieve targeted levels of species such as fish, waterfowl, shorebirds, and horseshoe crabs.)
Objective 6 **Habitat**	To restore habitat diversity (e.g., mixture, array and pattern of wetland types), values and functions of tidal and nontidal wetlands to levels commonly found in the 1920's (prior to parallel grid ditching and large-scale drainage), done in a balanced consideration of today's socioeconomic needs.
Objective 7 **Air quality**	To assess air quality impacts on estuarine resources, and support programs that reduce these impacts.
Objective 8 **Water quality**	To achieve water quality that will maintain and enhance estuarine use designations consistent with the Clean Water Act.
Objective 9 **Water supply**	To ensure an adequate supply of fresh water to the estuary to maintain habitats, distribution of salinity, and human population in 2020.
Objective 10 **Sediments**	To optimize sediment quantity and quality in a manner that maintains or enhances a balanced indigenous estuarine biota and habitat.
Objective 11 **Recreation**	To promote and enhance ample and high-quality water-based and associated terrestrially-based recreational opportunities with sustained availability for public use.
Objective 12 **Commerce**	To develop programs and actions that will be mutually beneficial to both the economy and environment of the estuary, by forging a partnership with industry, commerce and local governments in pursuit of continued economic vitality of the region, while enhancing and preserving its living and natural resources.
Objective 13 **Cultural heritage**	To preserve and enhance cultural resources and traditions in the estuary region, and promote their accessibility to the public.
Objective 14 **Pollution prevention**	To promote pollution prevention technologies and strategies that protect estuarine resources (e.g., from catastrophic spills, point sources, and nonpoint sources).

The scale and the overall magnitude of environmental problems in the Delaware Estuary have changed with time. In the past, environmental concerns were usually local and often transient. Problems could often be solved through site-specific solutions. Today, with increasing population growth and its associated demands, environmental problems are often a result of overlapping, cumulative effects that extend beyond the jurisdictional boundaries of different local, state, and federal agencies. Few environmental problems lie within the purview of a single community or a single agency.

A regional perspective to environmental management is required to address our regional problems. Regional monitoring has recently been initiated in several marine and estuarine areas because many monitoring programs were focused on the effects of particular activities at specific sites and were not providing the information that decision makers needed to address estuary-wide issues. The National Research Council's study of marine monitoring, *Managing Troubled Waters*, found that a collection of well-managed, technically correct, site-specific monitoring programs does not necessarily result in an effective regional monitoring program (NRC, 1990).

A regional monitoring perspective should increase the efficiency and usefulness of monitoring data. The collection of data using different methods at various locations and on incompatible time scales impedes data integration. Furthermore, monitoring data at a number of locations and in different formats makes it expensive to share data and conduct integrative analyses. Assessments of other, similar projects have shown that a significant portion (nearly 40 percent) of the data analysis budget is devoted to "cleaning up" and standardizing data before any analyses are conducted. (Because of the need to address data management issues head-on, the DELEP is currently addressing this issue as part of its Regional Information Management System development effort.) Regional coordination and integration of monitoring efforts should:

- Reduce overlap and duplication of monitoring efforts.
- Improve the ability to compare results between monitoring efforts.
- Increase the efficiency of collecting, managing, integrating, analyzing, and reporting data.

The DELEP already has a long history of coordinating selected monitoring efforts. It is believed that this continued coordination, along with other regional monitoring programs such as EPA's Environmental Monitoring and Assessment Program (EMAP), will be important to the effective monitoring of the estuary.

STEPS IN THE DESIGN OF THE DELEP'S REGIONAL MONITORING PLAN

The steps in the design and development of a regional monitoring program are shown in Figure 1-1. The first step is to develop monitoring objectives to define what data and information the regional monitoring program will provide. A key contribution of the Regional Monitoring Plan is the specification of monitoring objectives that will guide the design of the DELEP's regional monitoring program. Objectives should specify (1) the resource to be managed and (2) an assessable or measurable end result. Measurement endpoints provide a point of reference from which managers can assess whether conditions in the Delaware Estuary are improving, declining,

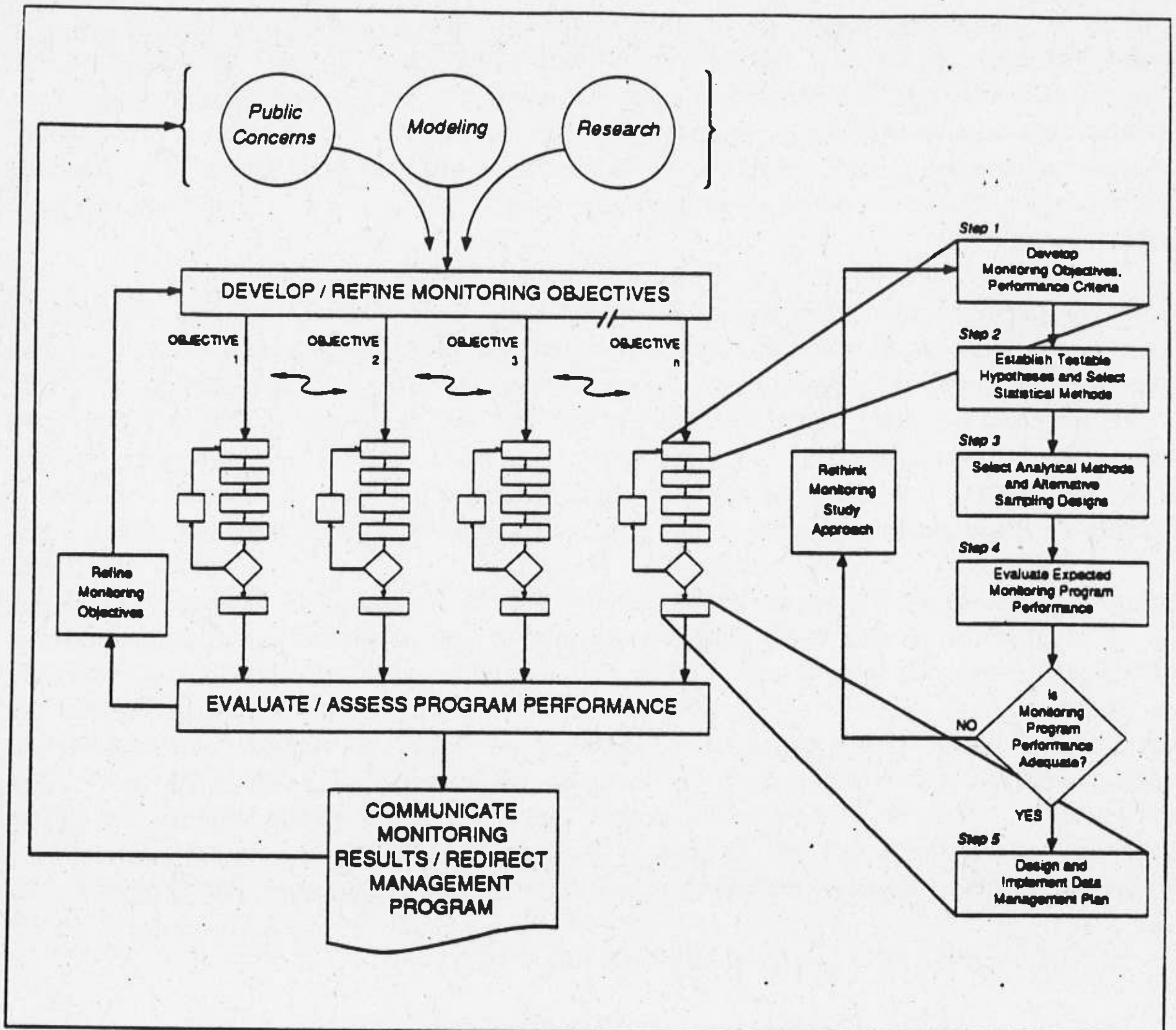


Figure 1-1. Monitoring program design (USEPA, 1992b).

or remaining the same (Figure 1-2). These endpoints will require significant refinement (potentially including research) before they are finalized in the CCMP.

The recommended procedure for ensuring that sufficient information and the correct type of information are developed in the monitoring program is to specify testable (null) hypotheses and to specify the statistical model that will be used to analyze the resulting monitoring data (Step 2). The development of testable hypotheses and the selection of statistical methods are key to evaluating the expected performance of the monitoring program.

The goal of Step 3 is to develop detailed monitoring program specifications, including field collection, laboratory analysis methods, and appropriate quality assurance/quality control protocols. Standardized sampling and analyses protocols should be followed to ensure that data collected by different groups participating in the regional monitoring program are comparable and of known quality. A series of workshops at which a small group of regional scientists and managers work together to develop standardized methods has been successful in other regions

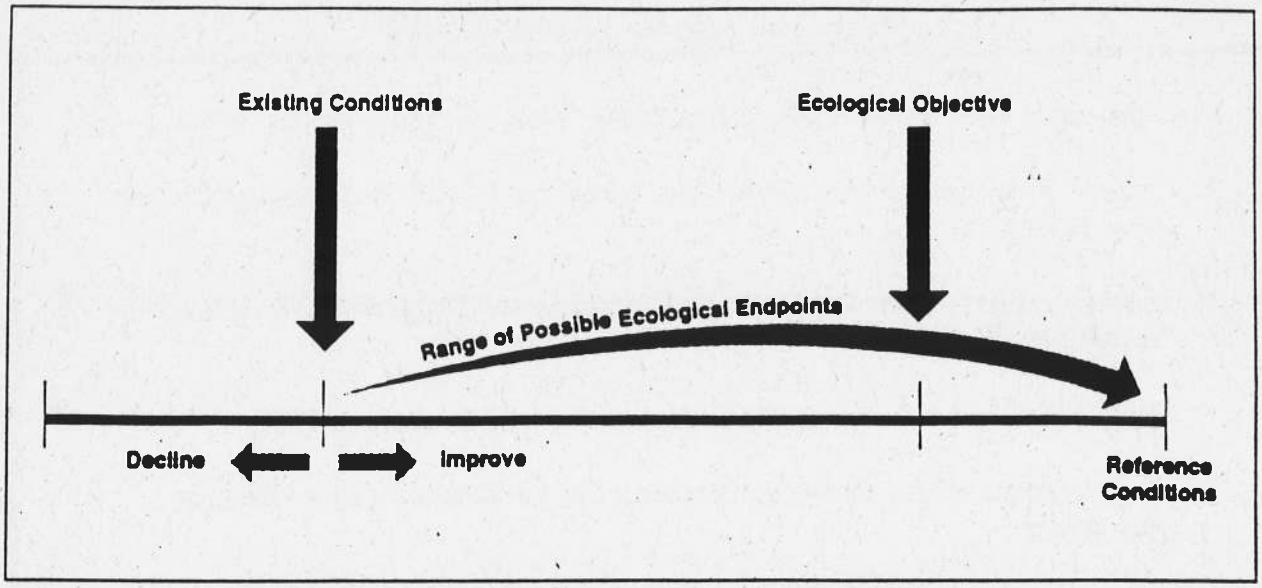


Figure 1-2. Conceptual model for establishing resource management goals (ten Brink et al., 1990).

and is highly recommended. The use of ongoing monitoring efforts or elements from these programs can significantly reduce the cost of the monitoring effort and increase the database that can be used in evaluating the effectiveness of management actions.

In Step 4 of the monitoring program design, it is determined whether the data that will be collected will meet the monitoring performance needs. Information developed in the monitoring program must be sufficiently precise and scientifically defensible. Results from this evaluation will be used as a basis for determining the efficacy of selected management strategies. Finally, periodic evaluations and reviews will identify the need to modify the monitoring program.

REGIONAL MONITORING STRATEGY WORKSHOP

The Delaware Estuary Regional Monitoring Plan is centered around five primary resource areas as defined by the DELEP and the ad hoc committee on monitoring:

- Water quality
- Toxics
- Living resources
- Habitat
- Land use

At the DELEP Regional Monitoring Strategy Workshop held on October 19, 1993, five concurrent workshop breakout sessions were held to discuss monitoring objectives for each of the five primary resource areas. The purpose of the workshop was to build on the work described in the DELEP's characterization reports (Table 1-2) and to define monitoring objectives and corresponding measurement parameters.

Table 1-2. Selected DELEP Reports

- *Status and Trends of Toxic Pollutants in the Delaware Estuary* (May 1991)
- *General Water Quality Assessment and Trend Analysis of the Delaware Estuary* (May 1991)
- *An Assessment of Fisheries Landings Records in the Delaware River Estuary* (September 1992)
- *Habitat Status and Trends in the Delaware Estuary* (September 1991)
- *An Assessment of Key Biological Resources in the Delaware River Estuary* (June 1991)

Each of the five sessions met to discuss and reach consensus on the following:

- Priority resource management goals
- Information needed to assess whether progress is being made toward achieving these goals
- Regional monitoring objectives
- Measurement parameters

Pre-workshop questionnaires were prepared and distributed to more than 100 management and technical individuals with varying backgrounds related to the Delaware Estuary. The results of the pre-workshop questionnaires are presented in Appendix A in Volume 2; a summary of the workshop and the additional comments received after the workshop are presented in Appendix B. The overall objective of the estuary monitoring program is to determine the effectiveness of the CCMP. However, this overall objective might encompass several related objectives. Table 1-3 summarizes the program objectives identified by the breakout sessions as being related to a given resource area.

In many cases, the evaluation of these program objectives involves a characterization process. In effect, the regional monitoring effort should be designed to provide both a measure of the health of the estuary and a permanent record of changes in the state of the estuary.

In many cases, the discussions from the various sessions overlapped and were highly dependent on one another, as will become more apparent in later chapters. Most breakout sessions resulted in a list of information needs required to characterize the status and trends of various measurement parameters. In many cases, however, endpoint indicators were not defined. Where possible, the information generated by the breakout sessions was used in the development of the

Table 1-3. Delaware Estuary Program Objectives

Program Objectives	Resource Area				
	Living Resources	Habitat	Water Quality	Toxics	Land Use
Objective 1 **Harvested finfish and invertebrate species**	✓			✓	
Objective 2 **Bird population**	✓			✓	
Objective 3 **Estuarine-dependent amphibians, reptiles, mammals**	✓				
Objective 4 **Ecological balance for a diverse indigenous biota**	✓	✓	x		✓
Objective 5 **Habitat**		✓			✓
Objective 6 **Habitat**		✓			✓
Objective 7 **Air Quality**				✓	
Objective 8 **Water Quality**			✓	✓	✓
Objective 9 **Water Supply**			x		✓
Objective 10 **Sediments**				✓	
Objective 11 **Recreation**					✓
Objective 12 **Commerce**					✓
Objective 13 **Cultural Heritage**					
Objective 14 **Pollution Prevention**					✓

Key: ✓ = DELEP program objective identified by breakout session.
x = DELEP program objective identified by breakout session, but considered a secondary issue.

DELEP monitoring plan. As indicated in the following chapters, however, the level of detail provided by the individual breakout sessions differed considerably and therefore the usefulness of the information provided by the breakout sessions varied with each resource area evaluated.

ORGANIZATION OF THIS DOCUMENT

The remainder of Volume 1 of this document is divided into seven chapters. Chapter 2 presents the geographic scope of the monitoring plan and explains the proposed estuary segmentation. Chapters 3, 4, 5, 7, and 8 address the five resource areas—water quality, toxic pollutants, living resources, habitat, and land use/land cover. Each chapter summarizes the monitoring objectives and measurement parameters identified by the relevant workgroup and recommended for evaluation of the CCMP. These chapters also present proposed sampling location and frequency plans for each of the resource areas of concern. The plans present the proposed number of stations and frequency of sampling in each stratum identified in Chapter 2 for each of the resource areas. Specific station locations are not presented because this could require site-specific knowledge or site visits throughout the estuary. Chapter 6 presents options for field sampling integration, as well as estimated sampling and laboratory analysis costs.

Volume 2 of this document contains appendices that support the discussion in the main portion of the document. Appendix A is a copy of the pre-workshop questionnaire results. Appendix B is a copy of the workshop summary. Appendix C provides a summary of existing monitoring programs. Appendix D is a summary of ongoing monitoring data in the Lower Delaware River Basin. Appendix E is a detailed presentation on power analysis for trend detection and allocation of samples. Appendix F identifies candidate sampling and analytical methods and associated quality assurance/quality control (QA/QC) concerns and procedures. Appendix G presents a discussion of measurement parameters (indicators) for evaluating biological integrity.

CHAPTER 2
GEOGRAPHIC SCOPE AND ESTUARY SEGMENTATION

GEOGRAPHIC SCOPE

The geographic scope of this monitoring plan includes the Delaware Bay, the tidal portion of the main stem of the Delaware River, and the tidal portions of tributaries to the bay and tidal river. For habitat and land use issues, the geographic scope includes upland as well as aquatic areas. Some vital habitat for living resources, such as birds, is found in upland areas (e.g., forests) as well as in aquatic areas. Because land use in upland areas will affect water quality and living resources, an assessment of land use throughout the watershed is required when assessing trends.

DISTRIBUTION OF SAMPLING STATIONS

The strategy for allocating monitoring stations in the Delaware Estuary affects the monitoring plans for each of the five resource areas. The first step is to select a sampling design that will adequately characterize the study area at a single point in time. Tracking resource conditions at the monitoring stations over time will provide trend data, which is a critical need for any monitoring program.

Basic Sampling Design

Three basic sampling designs were considered for this study: simple random sampling, systematic sampling, and stratified sampling. These designs are illustrated in Figure 2-1.

With simple random sampling, sample locations are selected randomly and independently. While this method is unbiased, it does not guarantee that the samples selected will be representative of the study area. For example, it is possible that all of the samples will be located at one end of the estuary and therefore the results might be misleading.

Systematic sampling involves collecting samples along a fixed grid or transect that is randomly located. The regular spacing ensures that samples will be collected from all portions of the estuary and therefore the results will be more representative of the entire estuary on average. Because systematic sampling ensures even coverage, there is less variability in the results of different sample outcomes (grid or transect placements) and therefore the confidence intervals for estimates based on the samples will be narrower.

Simple Random: Samples are independently located at random

Systematic: Samples are located at regular intervals

Stratified: The study area is divided into nonoverlapping strata and samples are obtained from each

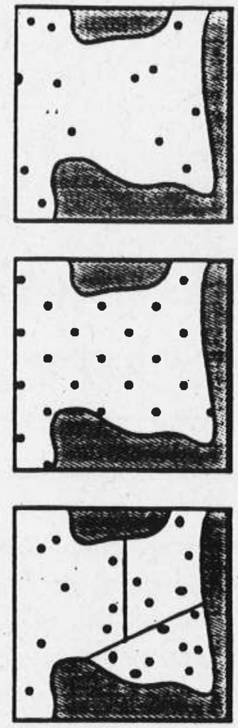


Figure 2-1. Descriptions of basic sampling designs (USEPA, 1992b).

Stratified sampling is conducted by dividing the study area into contiguous, nonoverlapping segments and then sampling each segment separately. This approach has several advantages from both a managerial and a statistical standpoint. Because separate estimates are obtained for each segment, management decisions can be made on a segment-by-segment basis. In addition, stratification helps to ensure that all portions of the study area will be represented. Stratified sampling also allows the sampling effort to be allocated to each segment in proportion to the amount of variability within the segment, which results in the need for fewer samples overall.

Estuary-Wide Distribution of Sampling Stations

For purposes of allocating samples across the estuary, a stratified design is recommended over a simple random or systematic design for the estuary-wide distribution of sampling stations for the following reasons:

- Different environments and biological communities will frequently require management goals that are specific for distinct segments of the estuary.

- Although an estuary-wide management action might be implemented, questions are commonly asked regarding whether the action is having the desired effect for particular segments of the estuary.

- Samples can be allocated to the different segments in proportion to the size of the segment and variability within the segment, and in inverse proportion to the cost of sampling those segments. This approach ensures that the minimum variance will be obtained for a given cost.

- A geographically stratified sampling scheme does not preclude assessments of estuary-wide status and trends.

The key issues considered when developing the proposed stratification were simplicity, physical boundaries, water depth, types and distribution of biological resources, and anthropogenic influences. Figure 2-2 depicts the Delaware Estuary's salinity zones and 10-meter isobathymetric line (Versar, 1991). Figure 2-3 depicts the location of oyster seed beds and planted grounds (Dynamac, 1991). In addition, there is a weakfish spawning area near Cape Henlopen (Dynamac, 1991).

The proposed segmentation is presented in Figure 2-4. The segmentation corresponds to the DRBC zones for the tidal portion of the river. The bay portion of the estuary was divided into three segments based on the 10-meter isobathymetric line. Two alternative segmentation schemes were also considered but not used:

- Further subdivide Zone 6C at the transition from the bay to the Delaware Tidal River.

- End Segment 6 at the transition from the Delaware Tidal River to the bay, and divide the bay into two parts, Zones 7L and 7R.

Samples can be allocated to each of the seven segments in a number of ways. For the purpose of this monitoring plan, samples were allocated to each segment based on the length of the segment. Using a rough estimate of length, the following weights were assigned to each segment:

Segment	Weight
2	18
3	18
4	18
5	18
6C	55
6L	32
6R	32

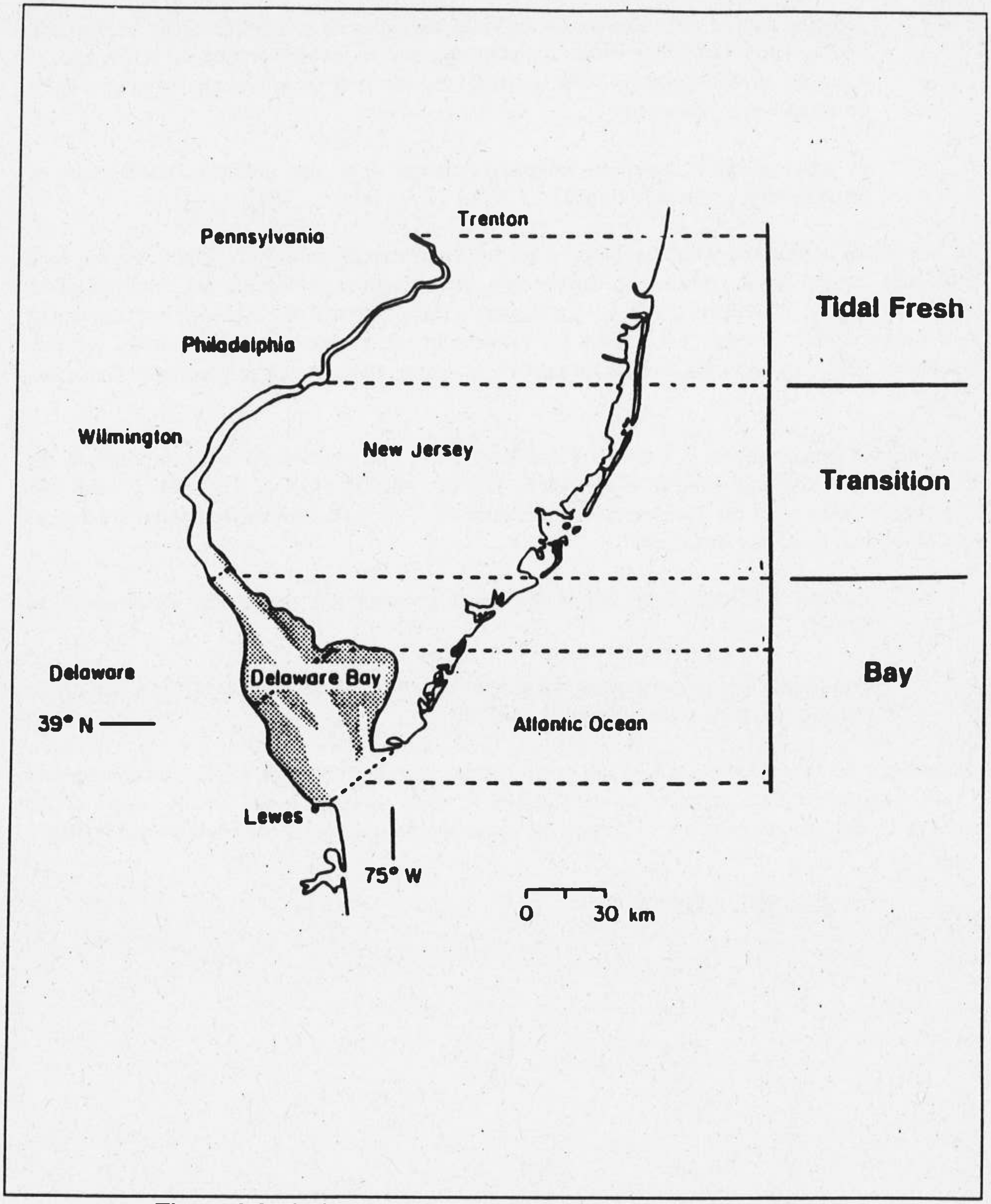


Figure 2-2. Delaware Estuary salinity regions (Versar, 1991).

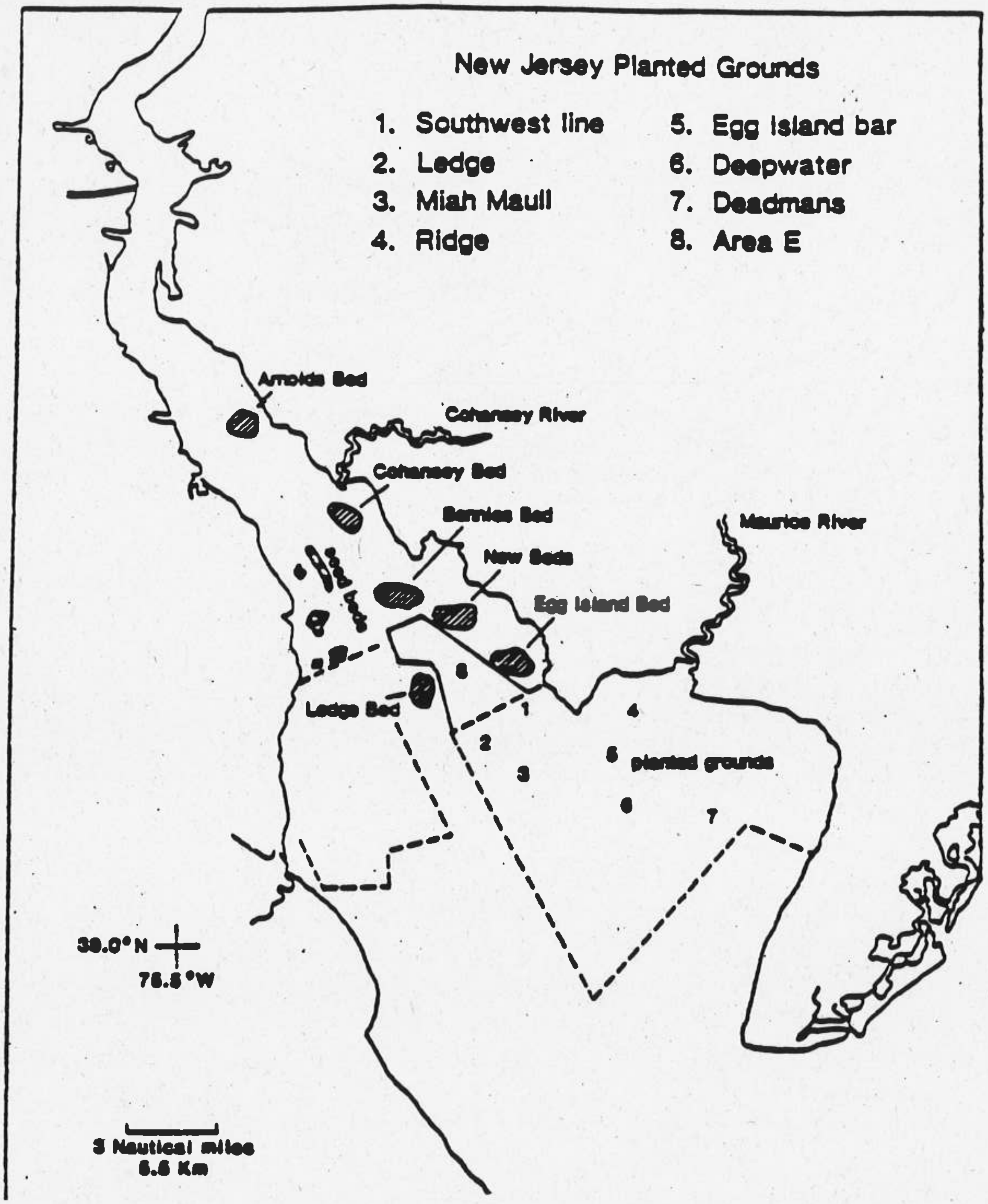


Figure 2-3. Oyster beds and planted grounds, Delaware Bay (Dynamac, 1991).

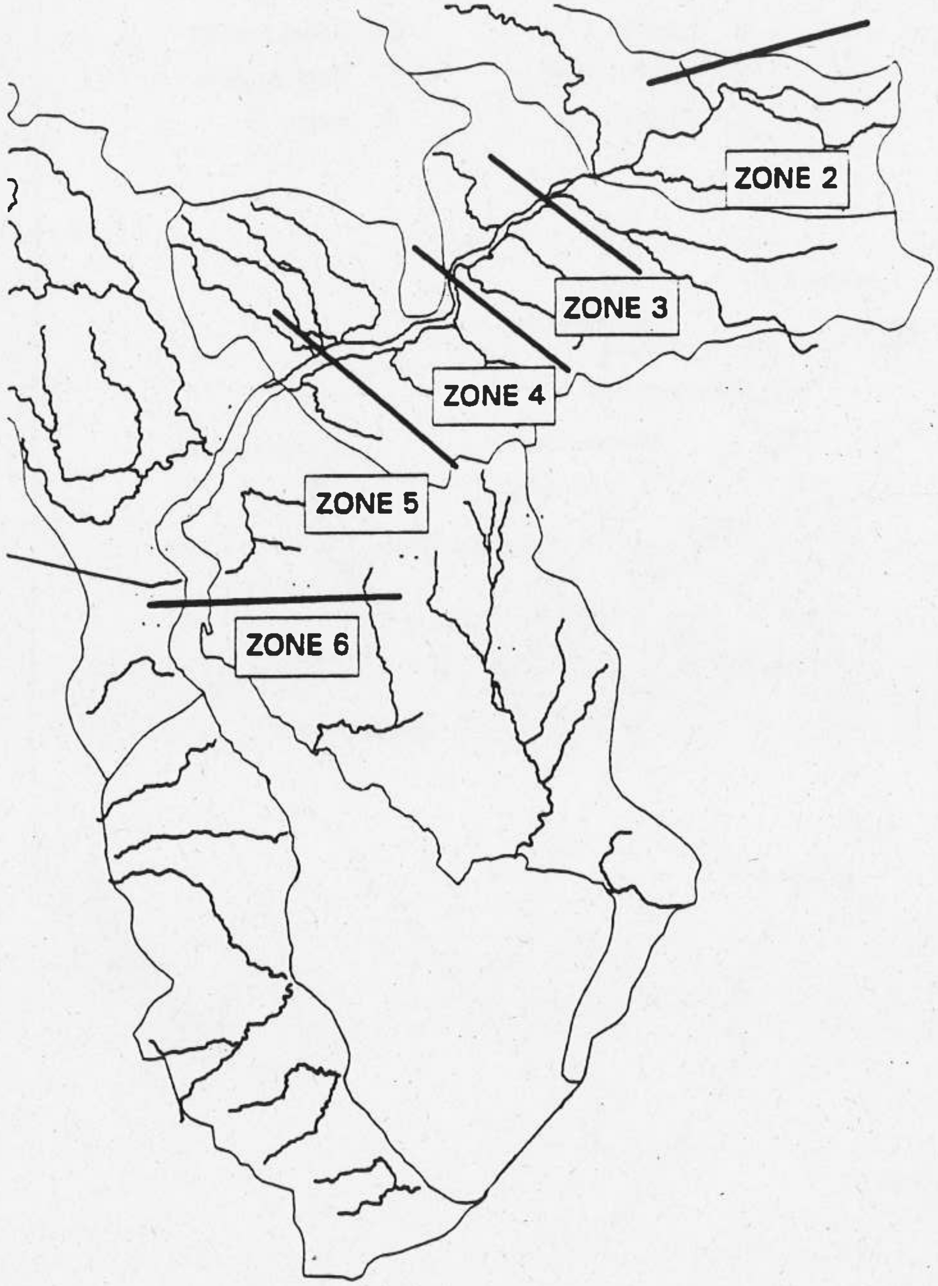


Figure 2-4. Proposed segmentation of the Delaware Tidal River and Estuary.

In addition to developing a stratification for the Delaware Tidal River and Estuary, it is also necessary to segment the tidal tributaries. It is anticipated that the objectives (and performance criteria) for the tributaries might be different, and as a result a separate analysis would be appropriate. For this report, segmentation is based on tributary flow. The largest seven tributaries (other than the nontidal Delaware River) were selected for monitoring. Together, these seven tributaries represent more than 70 percent of the tributary flow (excluding nontidal Delaware River). The selected tributaries and weights are presented below.

Tributary	Weight Based on Tributary Flow[a]
Maurice River	549.4
Cohansey River	392.2
Christina River	863.7
Chester Creek	343.0
Schuylkill River	1000.0[b]
Rancocas Creek	655.0
Neshaminy Creek	517.0

[a] Weights were then normalized to be of comparable magnitude with the tidal river weights.
[b] Weight capped at 1000.

Distribution of Sampling Stations Within a Segment

Sampling stations should be distributed within each segment to optimize the likelihood of obtaining representative samples for the segment. A systematic distribution of sampling stations within segments is recommended because it ensures even coverage over the entire segment. In addition, the following guidelines should be considered:

- When possible, stations should not be located adjacent to known anthropogenic sources of contamination. Site-specific monitoring of contaminant sources and suspected contaminated receiving environments will be covered by compliance monitoring programs.

- Because water quality, sediment quality, and biological samples along with some site-specific habitat measures might be collected simultaneously at program sampling locations, final sampling station locations will be influenced by and should incorporate sampling designs for water quality, species abundance, and other components of the regional monitoring program.

- Where appropriate, stations from existing programs should be incorporated if they meet the minimum data quality objectives and QA/QC requirements.

CHAPTER 3
LIVING RESOURCES

Resident biological communities are an evolutionary product of both long-term environmental conditions and short-term fluctuations. Thus, living resources are integrators of the effects of large- and small-scale changes in the physical and chemical environment (Karr, 1991; Dauer, 1993; Weisberg et al., 1993; Barbour et al., In press). The concept of biological integrity, developed by Karr and Dudley (1981), has recently become an operational framework for assessing water resource integrity (Karr, 1991 and references therein). Biological integrity can be an effective indicator for discerning effects from five primary classes of variables: water quality, habitat quality, hydrodynamics, energy sources, and biotic interactions. Thus, biological (i.e., living resources) integrity has been identified as a critical indicator of the health of the Delaware Estuary and as a key component of the Delaware Estuary Program Regional Monitoring Plan.

During the October 1993 DELEP Monitoring Strategy Workshop, the Living Resources Workgroup specified the time period, sensitivity, power, and confidence level for living resource monitoring objectives. Understandably, these are preliminary estimates that might change for certain monitoring objectives as more is learned about the likely issues associated with various management action plans. In general, all living resource monitoring objectives can be characterized by the following:

- Taxon, assemblage, or group of interest

- Life stage

- Minimum time period in which a trend must be detectable

- Minimum magnitude of a trend that must be detectable (sensitivity)

- Power, or the probability of detecting a trend that is real

- Confidence level, or the probability that an observed trend is real

The remainder of this chapter presents the recommended monitoring objectives for living resources in the Delaware Estuary, the measurement parameters related to living resources, performance criteria on which the monitoring plan is based and should later be evaluated, and a sampling location and frequency plan for biological monitoring in the estuary. It should be noted that in the future more specific monitoring objectives might need to be adopted to focus on narrower problems such as impingement and entrainment, bioassays to detect pollution effects, or the status of oyster seed beds.

MONITORING OBJECTIVES, MEASUREMENT PARAMETERS, AND PERFORMANCE CRITERIA

The Living Resources Workgroup identified multiple candidate monitoring objectives for the Delaware Estuary Program Regional Monitoring Plan (outlined in Table 3-1). Some of the objectives are related to monitoring population status and trends for individual species, whereas others are focused on community-level information. Although single-species monitoring approaches will provide data on the status of those species, such approaches will not provide an assessment of ecosystem condition. Although community/assemblage-level sampling and analysis also do not provide a complete assessment of ecosystem condition, they will provide a more realistic and cost-effective assessment. Multiple monitoring objectives can often be addressed using a community/assemblage-level sampling and analysis approach. Because various taxa have different tolerances and responses to environmental stressors, monitoring programs based on multiple assemblages are likely to be more sensitive to the presence of those stressors. It is thus recommended that DELEP establish a monitoring program that samples (or coordinates analysis and interpretation of) at least two organism groups or assemblages: benthic macroinvertebrates and demersal fish. The assemblages composing the benthic macroinvertebrates and demersal fish are recommended for the following reasons:

- Particular life stages are relatively sedentary, and their reaction to exposure to deteriorating water-sediment quality conditions provides a reliable assessment of conditions (benthos).

- They have relatively long life spans, allowing them to indicate and integrate water/sediment quality conditions (benthos and demersal fish).

- They consist of different species that exhibit different tolerances to stress and can be classified into functional groups (benthos and demersal fish).

- They are commercially important or are important food sources for economically or recreationally important species (benthos and demersal fish).

- They have an important role in cycling nutrients and other chemicals between the sediments and the water column (benthos) (Dauer, 1993, and references therein).

- They are important for public perception of estuary quality (benthos and demersal fish) (EMAP [Weisberg et al., 1993]).

Therefore, the objectives recommended for living resource monitoring in the Delaware Estuary are the following:

- Determine the status and trends in benthic macroinvertebrate community populations and composition that are occurring as a result of management actions taken as part of the CCMP.

Table 3-1. Monitoring objectives recommended by Living Resources Workgroup

Issue/Resource of Concern	Monitoring Objective
Harvestable Fish and Invertebrates	Estimate current populations and changes in populations over time for each of several selected species and life stages Estimate current commercial and recreational harvest
Bird Populations	Estimate current populations and changes in populations of selected shore and other bird species Estimate current nesting populations and changes in populations of black ducks
Estuary-Dependent Amphibians, Reptiles, and Mammals	Estimate current populations and changes in populations of selected vernal pool amphibians Estimate current populations and changes in populations of selected marsh and estuarine species (e.g., diamond back terrapins, muskrats)
Ecological Balance for a Diverse Indigenous Fauna	In each of three salinity zones, measure change in phytoplankton production Take a census of each of several key wetland vegetation species In each of three salinity zones, estimate percent area with impaired benthos In each of three salinity zones, estimate changes in populations of other ecologically important species and groups

- Determine the status and trends in demersal fish community populations and composition that are occurring as a result of management actions taken as part of the CCMP.

The monitoring results are to be compared to the goals set forth in the DELEP CCMP and the changes that are expected to occur as a result of the additional management actions recommended in the CCMP. The basic purposes of the monitoring are to determine whether living resource management in the estuary is working and whether changes are needed and, secondarily, to better understand the condition and natural variability in biological communities. Changes in living resources must also be compared to changes in other interdependent variables such as water quality in order to assess the effectiveness of the CCMP and/or the need to make changes in management actions.

It should be noted that plankton production and community composition will be monitored as a component of the water quality program, as discussed in Chapter 4 of this document.

Although it would be useful to assess the status and trends of pelagic fish communities in the Delaware Estuary, there is currently no agreed-upon and meaningful method for assessing the results of such a monitoring effort that can be used to link conditions in the estuary with trends in the pelagic fish community. Therefore, no pelagic fish monitoring program for the Delaware Estuary is recommended at this time. Such a program could be included in a monitoring plan once meaningful analysis methods have been developed.

Two ongoing living resources monitoring programs in the Delaware Estuary have provided the basis for the recommendations presented in this chapter. They are the U.S. Environmental Protection Agency's (EPA's) Environmental Monitoring and Assessment Program (EMAP) and the Delaware Department of Natural Resources and Environmental Control's (DNREC's) demersal fish sampling program.

Although only underway for 3 years in the Delaware Estuary, EMAP is considered an important program for determining the biological status of the estuary because of its program design. The DNREC's program is considered important because of its 16-year database on demersal fish populations. However, DNREC sampling stations are restricted to waters belonging to the State of Delaware and thus might not be representative of the entire estuary.

During the 1993 DELEP Region Monitoring Strategy Workshop, the Living Resources Workgroup recommended the following performance criteria for living resources:

- Sensitivity: twofold to threefold change in populations
- Time period: 10 years
- Power: 80 percent probability of detection
- Confidence: 90 percent confidence level

These are also the criteria being recommended for the evaluation of this monitoring plan.

SAMPLING LOCATION AND FREQUENCY PLAN

Benthic Macroinvertebrates

It is recommended that DELEP coordinate with EMAP-Near Coastal for the benthic macroinvertebrate sampling design. In addition to a randomized sampling design that meets all statistical requirements for characterizing the Delaware Estuary, coordination with EMAP allows DELEP to use EMAP-collected data, reducing the financial burdens on DELEP.

EMAP's future sampling design in the Delaware Estuary is to sample six grid cells in the lower bay and four transects in the tidal Delaware River. DELEP should supplement those by sampling one to three additional sites (randomly selected) for each EMAP site, as well as sites on the tidal tributaries, so that the sampling fits the EMAP plan for increased sample densities in selected estuaries. Such an approach would result in 12 to 24 sampling stations in the lower bay, 8 to 16 stations in the tidal Delaware River (4 zones x 2 to 4 sampling locations), and 14 to 28 stations in the tributaries (7 tributaries x 2 to 4 sampling locations).

Investigation of EMAP results (Weisberg et al., 1993) indicates that 24 samples per year in the lower bay are probably sufficient to characterize the benthic invertebrate communities within the precision required (i.e., 80 percent probability of detecting trends representing twofold to threefold changes over a period of 10 years with 90 percent confidence). Similarly, 16 samples across the Delaware River associated with the 4 zones and 4 samples in each of the tributaries (28 total) are probably sufficient to meet the performance criteria. Nevertheless, as additional data are gathered, periodic power analyses are recommended to determine whether sample density should be increased or decreased. An important advantage of the grid-cell EMAP design is that it can accommodate both higher and lower sample densities, as long as samples can be randomly allocated to grid cells.

The randomized sampling design can also be made to accommodate historical, fixed-station data for trend analysis. Each station is examined for selection bias, and unbiased stations are included and biased stations are excluded as follows: fixed stations are assigned to their respective grid cells if the stations had originally been selected on the basis of providing regular spatial coverage of the estuary; fixed stations selected for proximity to outfalls, known contaminated sites, known pristine sites, or the end of a pier near a laboratory are excluded from baywide estimation and trend analysis.

Biased fixed stations (e.g., those purposefully placed at outfalls or contaminated areas) are not used to assess estuary-wide conditions and trends, but they are useful for site-specific investigations (recovery, compliance monitoring) and for calibration of metric response to stressors. Site-specific stations will always be used for these purposes, but they must not be confused with randomly selected stations for estimation of estuary condition and trends.

The sampling location and frequency plan presented in this chapter is based on the randomized grid design discussed above. The number of stations proposed is designed to provide estuary-wide coverage (i.e., lower bay, tidal river, and seven tributaries). Based on suggestions made by the Delaware Estuary Monitoring Program Steering Committee, two sampling periods are proposed—winter and summer. The proposed sampling and frequency plan for benthic macroinvertebrates in the Delaware Estuary is presented in Table 3-2 and Figure 3-1. Two monitoring plan options are presented. The difference between the two options is a doubling in the number of randomly allocated stations under option 2. The DELEP would benefit financially under both options from a coordination of sampling with EMAP. The current sampling location and frequency plan under EMAP is also shown in Table 3-2. It should be noted that EMAP is not the only program collecting benthic macroinvertebrate samples in the Delaware Estuary. The states and other organizations are also taking benthic macroinvertebrate samples. Therefore, the current EMAP sampling effort presented in Table 3-2 represents only a portion of the total benthic macroinvertebrate monitoring effort in the Delaware Estuary. A summary of existing monitoring programs in the Delaware Estuary is presented in Appendix C in Volume 2 of this document.

Table 3-2. Benthic Macroinvertebrate Sampling Locations and Frequency

	Option 1			Option 2			Current EMAP		
Segment	Proposed # Samples per Year	Proposed # Stations	Proposed Sampling Frequency	Proposed # Samples per Year	Proposed # Stations	Proposed Sampling Frequency	# Samples per Year	# Stations	Sampling Frequency
Main Stem	16	8 (2/segment for 4 segments)	Semiannually (winter and summer)	32	16 (4/segment for 4 segments)	Semiannually (winter and summer)	4	4	Annually
Bay	24	12	Semiannually (winter and summer)	48	24	Semiannually (winter and summer)	6	6	Annually
Tidal Rivers	28	14 (2/tributary for 7 tributaries)	Semiannually (winter and summer)	56	28 (4/tributary for 7 tributaries)	Semiannually (winter and summer)	0	0	N/A

NOTE: Location of sampling sites would be randomly selected within each zone. Zone 6 would not be separated into three subzones (L, C, R) for the randomized selection.

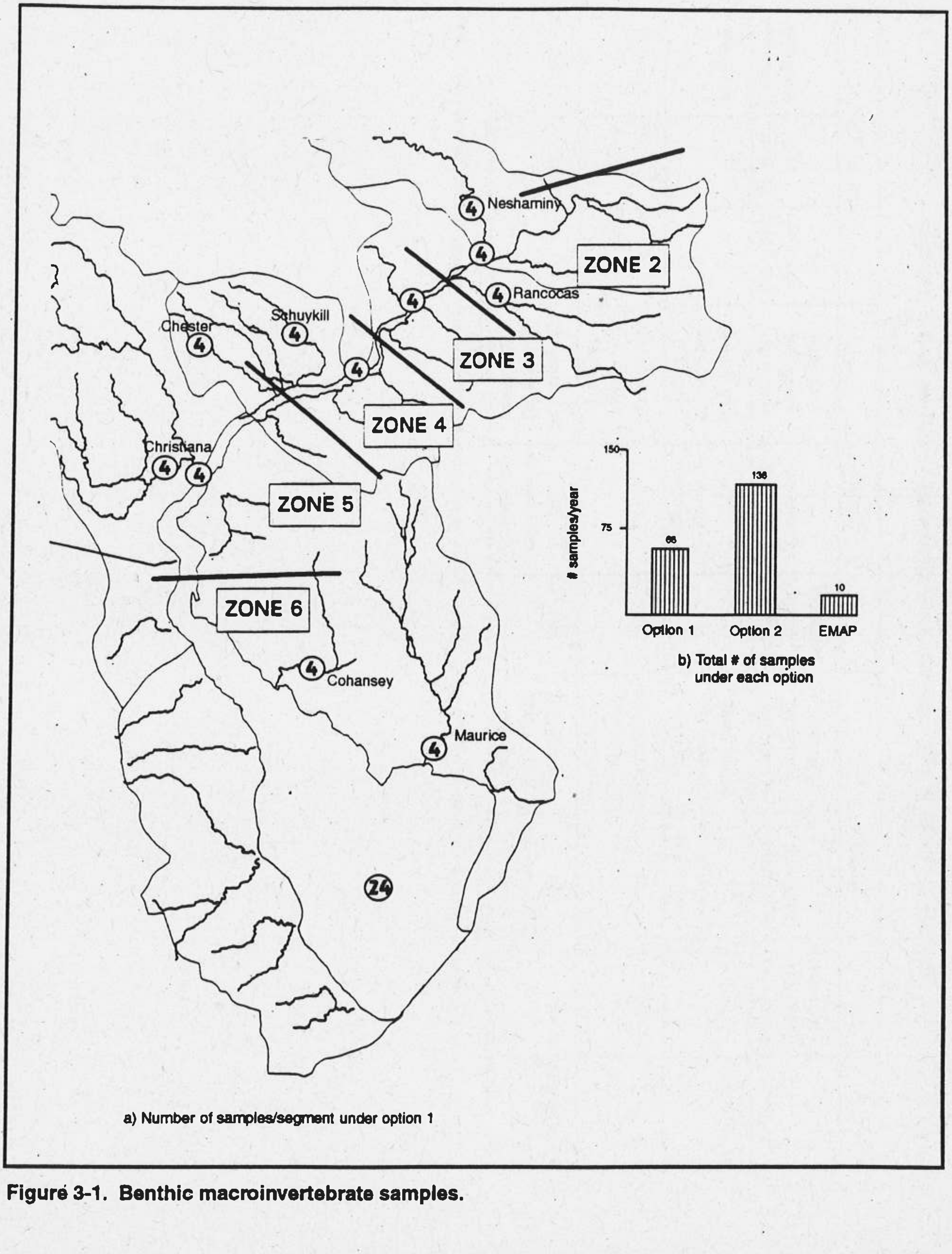


Figure 3-1. Benthic macroinvertebrate samples.

The sampling location plan presented in Table 3-2 is unbiased with regard to the number of sampling locations allocated to each segment of the Delaware River and each of the seven major tributaries. Each segment of the Delaware River has two (Option 1) or four (Option 2) proposed sampling stations and each of the tidal tributaries also has two (Option 1) or four (Option 2) proposed sampling stations. The purpose of this unbiased approached to allocating sampling stations to segments of the Delaware River and tidal tributaries is to ensure that all portions of the study area are well represented and to optimize the likelihood of obtaining representative samples for each segment. However, the Delaware Estuary Program might choose to locate more of the sampling stations in segments that are known or suspected to be experiencing stress (e.g., segment 4) and fewer sampling locations in other segments (e.g., segments upstream of Philadelphia).

Dermersal Fish

The sampling location plan for demersal fish presented in this chapter is based on the EMAP design and the current DNREC monitoring program. The type of sampling design used by DNREC has been expanded to include estuary-wide coverage, rather than only Delaware waters. Because program objectives for DNREC require acquisition of monthly data, it might be necessary for DNREC to retain its current sampling station density and sampling frequency. However, for estimating estuary-wide conditions, it is more critical to have some number of sampling stations distributed throughout the estuary. The proposed sampling location and frequency plan for demersal fish in the Delaware Estuary is presented in Table 3-3 and Figure 3-2. Two monitoring plan options that expand the DNREC-type program to include the entire estuary, not just Delaware waters, are presented. The difference between the two options is an increase in the frequency of sampling under option 2. The increase does not result in a doubling of stations throughout the estuary, as was the case with option 2 for benthic macroinvertebrate sampling, because of the current density of the existing DNREC program in Delaware waters. The locations and sampling frequency under the current DNREC program are also illustrated in Table 3-3.

The sampling location and frequency plan presented in Table 3-3 is a combination of the sampling approach currently used by DNREC and the network design used by EMAP. Two DNREC demersal fish sampling programs are in operation on the Delaware side of the bay and in the Delaware River: juvenile collections and adult collections. For the juvenile collections, a 16-foot bottom trawl is used at a total of 34 stations in the bay for monthly collections from April through October. For the adult collections, a 30-foot trawl is used at a total of nine stations in the bay for monthly collections from March through December. In the main stem of the Delaware River, monthly samples for juveniles only are taken from April through October from six stations. Under the current DNREC program, no samples are taken from the major tributaries.

Under Option 1 of the sampling plan proposed in Table 3-3, the 6 current DNREC stations along the main stem of the Delaware River plus 6 additional (new) stations would be sampled semiannually for juveniles and 12 new stations would be sampled for adults. In the bay, 7 of the existing 34 juvenile stations in Delaware waters are included in the sampling plan under Option 1. Seven new stations on the New Jersey side of the bay (below Dividing Creek) are then

Table 3-3. Demersal Fish Sampling Locations and Frequency

	Option 1			Option 2			Current DNREC		
Segment[1]	Proposed # Samples per Year[2]	Proposed # Stations	Proposed Sampling Frequency	Proposed # Samples per Year	Proposed # Stations	Proposed Sampling Frequency	# Samples per Year	# Stations	Sampling Frequency
Main Stem	a. 24 b. 24	a. 12 (3/segment for 4 segments) b. 12	Semiannually May-June Sept.-Oct.	a. 72 b. 72	a. 12 (3/segment for 4 segments) b. 12	Once/month Mar.-May Aug.-Oct.	a. 42	a. 6	Once/month, Apr.-Oct.
Bay	a. 28 b. 28	a. 14 b. 14	Semiannually May-June Sept.-Oct.	a. 84 b. 84	a. 14 b. 14	Once/month Mar.-May Aug.-Oct.	a. 238 b. 90	a. 34 b. 9	a. Once/month, Apr.-Oct. b. Once/month, Mar.-Dec.
Tidal Tributaries	a. 28	a. 14 (2 for each of 7 tributaries)	Semiannually May-June Sept.-Oct.	a. 84	a. 14 (2 for each of 7 tributaries)	Once/month Mar.-May Aug.-Oct.	0	0	N/A

[1]Location of sampling sites would be randomly selected within each zone (Zones 2-5). Zone 6 would not be further subdivided.
[2]Two fish sampling programs:
- a. juvenile collections
- b. adult collections

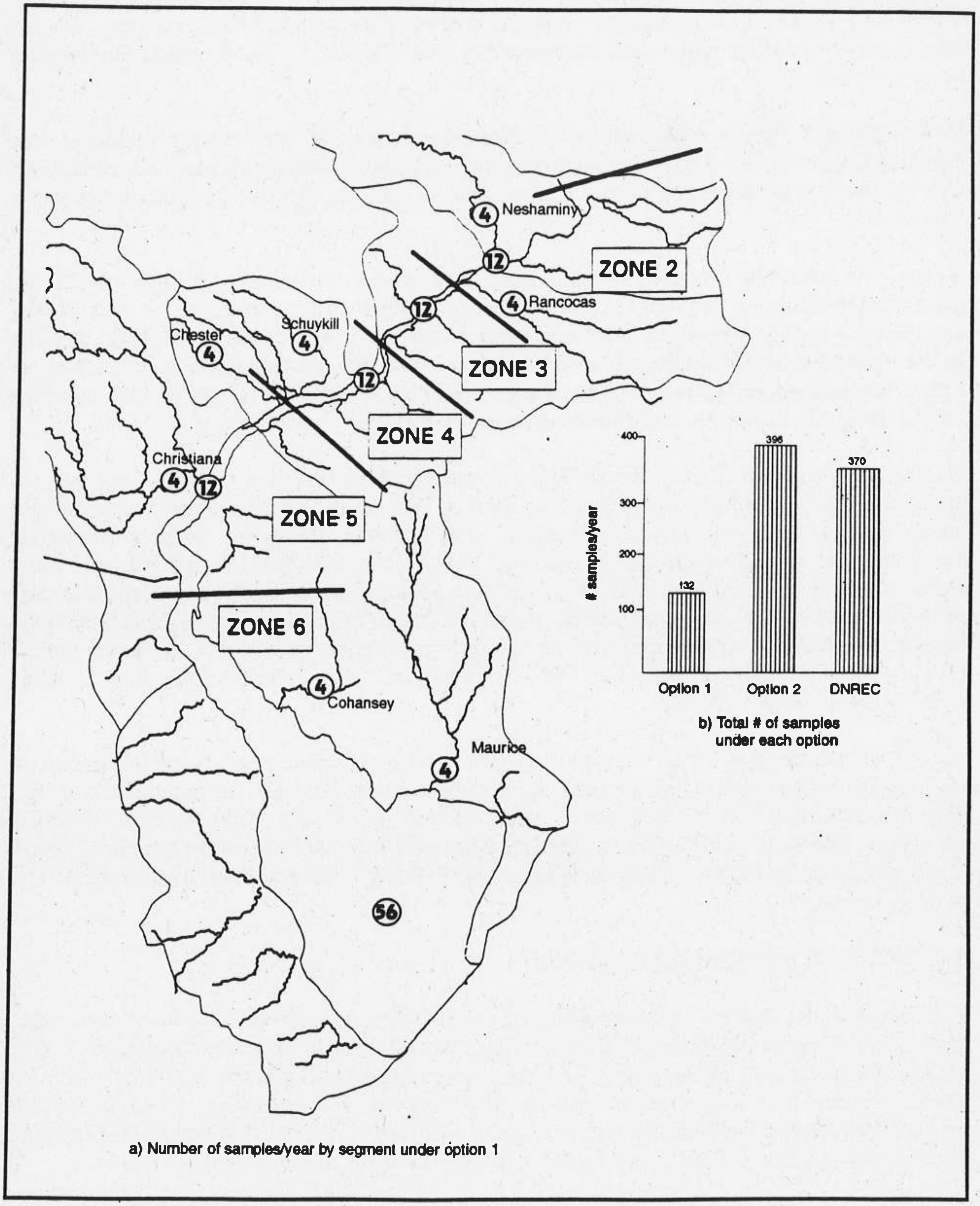


Figure 3-2. Demersal fish samples.

Option 1. Seven new stations on the New Jersey side of the bay (below Dividing Creek) are then included in the sampling plan. Seven of the nine current adult stations on the Delaware side of the bay are also included in the sampling plan. Seven new stations on the New Jersey side are added, for a total of 14 adult stations. Stations in the bay are sampled twice per year. For the tidal rivers, 14 juvenile stations are recommended under Option 1. These stations are sampled twice per year.

Under Option 2 for the main stem of the Delaware River, the bay, and the tributaries, the sampling frequency would be increased to monthly from March through May and August through October for both juveniles and adults. The number of sampling stations does not change under Option 2.

It should be noted that it is not feasible to use a 30-foot trawl for sampling for adult fish in the main stem or tributaries, primarily because of safety concerns. Fast currents, bottom obstructions, and shipping traffic combine to make this method impractical and unsafe. For adult sampling in the main stem and tributaries, it is recommended that gill nets, seines, or electrofishing be used. For example, multipanel experimental gill nets could be used to sample for both juveniles and adults in the main stem and tributaries, supplemented by electrofishing.

It should be noted that DNREC demersal fish juvenile and adult trawl programs are not the only programs collecting samples in the Delaware Estuary. The states and other organizations are also taking demersal fish samples in the estuary. For example, Delaware conducts a sampling program for spawning striped bass in the tidal river, using electrofishing and gill nets, and a sturgeon monitoring program. New Jersey conducts a Blue Crab survey, an adult American shad survey, a juvenile American shad survey, a juvenile striped bass survey in the tidal river, and a tagging program for adult striped bass in the bay (see Appendix C). Therefore, the current DNREC sampling effort presented in Table 3-3 represents only a portion of the total sampling effort in the Delaware Estuary.

As was the case for the benthic macroinvertebrate sampling location plan, the sampling location plan for demersal fish presented in Table 3-3 is unbiased with regard to the number of sampling locations allocated to each segment of the Delaware River and each of the seven major tributaries. The Delaware Estuary Program might choose to locate more of the sampling stations in segments that are known or suspected to be experiencing stress and fewer sampling locations in other segments.

ADDITIONAL RECOMMENDATIONS

It is recommended that the Delaware Estuary Program adopt a multimetric approach to assessing biological data as part of its Regional Monitoring Plan. Multimetric approaches combine a series of assemblage-based metrics (terms or enumerations representing some aspect of biological characteristics) into a single measure of biological integrity. The multimetric approach has been adopted for estuaries in Florida and in the Virginian Coastal Province. The multimetric approach is described in greater detail in Appendix G in Volume 2 of this document.

CHAPTER 4
WATER QUALITY

Water quality in the Delaware Estuary has significantly improved over the last three decades. During this time period, many local wastewater treatment plants—or publicly owned treatment works (POTWs)—have been upgraded so that most are now discharging at least secondary treated effluents. These upgrades translate into decreased loadings of suspended solids, nutrients, and oxygen-demanding substances into the estuary. Documentation of these improvements can be seen in the results of the different monitoring programs throughout the Delaware Estuary. Future water quality monitoring programs should be designed to account for improvements in the overall water quality of the estuary, the ability to detect changes in water quality resulting from ongoing and future management actions, and cost.

For the purposes of this document, *water quality monitoring* will refer to the monitoring of those water quality parameters other than toxics. More specifically, conventional pollutants will be the focus of this chapter. *Conventional pollutants* will be defined as those pollutants which are well understood by scientists and include organic wastes (or oxygen-demanding substances), sediment (or other suspended solids), acid (or substances that change pH), pathogens (bacteria and viruses), nutrients (primarily nitrogen and phosphorus, but also carbon and silica), and heat. Other parameters included with the conventionals are dissolved oxygen, salinity, alkalinity, hardness, and plankton.

Many point and nonpoint sources of pollutants are present in the Delaware Estuary. Point sources are principally located in the tidal river portion of the Delaware Estuary and are made up of a mixture of POTWs, industrial sources (e.g., steel, chemical, refined oil products, and textiles), combined sewer overflows, and storm sewer outfalls. Although point sources are generally controlled by permit programs, permit limits and compliance need to be evaluated periodically to ensure that water quality goals in the estuary are being met.

Nonpoint sources can be found throughout the contributing watershed and are associated with activities including farming, construction, and urbanization. Since point sources are no longer considered to be the major source of pollutants—at least in terms of conventional pollutants-efforts are now shifting to nonpoint sources of pollutants and management activities are being developed to specifically address nonpoint source problems.

The overall quality of water in the Delaware Estuary has improved significantly, as indicated by water quality parameters such as increased estuary-wide dissolved oxygen and lower levels of nutrients. The improvements in water quality throughout the estuary can be illustrated with dissolved oxygen. At some monitoring locations in the estuary, dissolved oxygen was measured at 0.1 mg/L during the 1970s. When the same locations were evaluated during 1990, the minimum dissolved oxygen levels approached 4.0 mg/L. Najarian Associates (1991) reported that other conventional pollutants exhibited similar trends toward improved water quality; for example, total ammonia concentrations and fecal coliform levels have decreased throughout most of the estuary during the past 30 years.

A strict cause-and-effect relationship cannot be demonstrated for the trends seen in water quality throughout the Delaware Estuary over the past 30 years. It is clear, however, that improvements in point source discharges (i.e., POTW upgrades to secondary treatment) can be linked to the improvements in water quality. Although much of the Delaware Estuary exhibits improved water quality, the estuary has yet to achieve an equilibrium in terms of water quality and there are still areas that require improvement. Future water quality management activities will require judicious monitoring efforts to determine additional improvements and to provide input to planning future water quality management strategies (Najarian Associates, 1991).

Toxic materials are believed to present the next major challenge in meeting designated uses of the estuary, and they are specifically addressed in Chapter 5 of this plan. However, there are still water quality problems related to conventional pollutants (e.g., dissolved oxygen, nutrients, pathogens). As a result, the Delaware Estuary Program has identified water quality as a continuing concern for the estuary that is to be addressed in the Delaware Estuary Program Monitoring Plan. This chapter will focus on water quality parameters other than toxic pollutants and will present a monitoring plan that builds on the monitoring efforts of the past and presents several options for future monitoring efforts.

MONITORING OBJECTIVES, MEASUREMENT PARAMETERS, AND PERFORMANCE CRITERIA

An important part of developing a monitoring program is the development of succinct monitoring objectives and performance criteria. During the October 1993 DELEP Regional Monitoring Strategy Workshop, the Water Quality Workgroup identified several important issues related to water quality monitoring. Although dissolved oxygen levels appear to be meeting or exceeding those necessary to achieve designated uses, issues related to dissolved oxygen depletion remain important. Nutrient and organic substance enrichment (i.e., increases in nitrogen, phosphorus, and biochemical oxygen demand (BOD)) were raised as significant monitoring issues. Other conventional pollutants, such as pathogens, thermal discharges, and pH, remain important variables to monitor. Related monitoring issues, such as time scales (e.g., wet-weather events or low-flow conditions) were mentioned as somewhat important. The workgroup did not, however, identify any specific time frames or performance criteria for evaluating trends in water quality.

A historical review of water quality trends is also necessary to develop a comprehensive and useful water quality monitoring program. As previously stated, water quality in the Delaware Estuary has significantly improved over the past 30 years. Dissolved oxygen levels are high enough to support most aquatic species throughout the estuary year-round. Maintaining high dissolved oxygen levels in the future is as important as developing management strategies to reduce pollutants such as nutrients. Resource managers must also continually evaluate water quality monitoring data to assess the impacts of management activities targeted at different pollutants (i.e., toxic pollutants) on water quality problems typically associated with conventional pollutants (e.g., algal blooms).

Monitoring Objectives

The Water Quality Workgroup suggested two general objectives for a water quality monitoring program for the Delaware Estuary:

- Determine the status and trends in ambient levels of water quality parameters.

- Determine changes in estuary loadings based on water quality parameters.

These general objectives (as a starting point) and best professional judgment were used to establish the following proposed water quality monitoring objectives for the Delaware Estuary:

- Determine the status and trends in ambient levels of conventional water quality parameters throughout the entire Delaware Estuary to indicate changes in present water quality.

- Determine whether water quality standards are met for conventional pollutants in each of the identified segments of the Delaware Estuary.

The first objective will show how management actions are affecting water quality in the estuary. If existing conditions are considered to be a newly-defined baseline for conventional pollutants, then future water quality conditions can be compared to existing conditions to determine whether additional improvements are being made. Depending on how performance criteria are set, changes in water quality can also be linked to management actions. A broad-based monitoring program (i.e., one that measures a variety of parameters at many locations around the estuary) should give an indication of how management actions targeted at a specific pollutant are performing. An example is nonpoint source best management practices for reducing erosion or controlling sediment. Monitoring turbidity and suspended solids should indicate the effectiveness of the management activities. Reductions in BOD, increases in dissolved oxygen, or reductions in nutrients might also result from controlling sediment and reducing erosion.

Some management actions targeted at specific pollutants could possibly result in undesirable changes in water quality as a result of impacts from other pollutants. For example, some scientists have suggested that levels of toxic pollutants might be responsible for keeping phytoplankton blooms in check. A management activity that targets industrial and nonpoint sources of copper could result in reduced copper concentrations in the estuary. Depending on the ambient levels of nutrients such as nitrate and orthophosphate, phytoplankton abundance could increase dramatically as a result of reduced copper concentrations. This, in turn, could lead to increased turbidity and BOD and decreased dissolved oxygen. Additional management activities targeting nutrients would then need to be implemented. This example is not presented to suggest that toxic pollutants should not be controlled. Rather, it illustrates that as management actions are implemented to control a particular pollutant or group of pollutants, other water quality concerns need to be evaluated as well.

The second water quality monitoring objective will show how improvements in water quality are reflected in the overall health of the estuary. Water quality standards can be used as a benchmark with which to compare existing conditions within the estuary. The intensity of the monitoring efforts should reflect the accuracy needed to predict the difference between the ambient concentrations of a particular parameter and the standard.

Measurement Parameters

The Water Quality Workgroup identified a variety of parameters that would be indicative of water quality within the Delaware Estuary (Table 4-1). Some parameters are also important for determining the toxicity or form of certain other parameters. For example, pH will influence the chemical form of metals and therefore must be measured in conjunction with metals to provide useful information related to toxicity. Other parameters in this category include salinity, temperature, alkalinity, and hardness. The parameters listed in Table 4-1 are those recommended for measurement in the Delaware Estuary Program Regional Monitoring Plan.

The Delaware Estuary Monitoring Program Steering Committee also recommended that an assessment be made of plankton communities (both phytoplankton and zooplankton). Although phytoplankton blooms are currently not a major problem in the Delaware Estuary, some local managers and scientists fear that reducing toxic contaminant levels in the estuary may result in rapid phytoplankton growth and reduced dissolved oxygen in the estuary. Changes in phytoplankton biomass and phytoplankton and zooplankton community structure might provide an early indication of potential water quality problems.

Performance Criteria

Performance criteria enable managers to make the following decisions based on the monitoring data:

- What level of detail will be necessary to make decisions?
- What level of difference will be detected with the data?

Selection of performance criteria will determine the number of samples needed in a monitoring program and thus the cost. It is also important to note that selecting performance criteria requires knowledge of the system being studied (i.e., a historical perspective of the variability of the measurements) and the time frame in which trends are required to be detected. The ability to detect future changes in water quality will be directly related to the variation of the measurements and indirectly related to the precision desired. For a water quality parameter with high variability and for which the detection of a small level of change is desired, many more measurements will be necessary than for a parameter with less variation and for which the detection of a greater degree of change is desired.

Two levels of performance are proposed for the Delaware Estuary. For detecting broad-based changes in conventional pollutants, a 50 percent change over a 10-year period from the existing mean concentrations is recommended. This level of performance will give managers a reasonable and cost-effective way to detect long-term changes in the water quality parameters of concern. New management actions can be examined for effectiveness with this level of effort. Detecting

Table 4-1. Conventional Water Quality Parameters to Be Measured in the Delaware Estuary

Physical Properties	Temperature Salinity Suspended Solids Turbidity (clarity) Dissolved Oxygen

Chemical Properties	pH
	Alkalinity
	Hardness (for waters with salinities <2 ppt)
	Biochemical Oxygen Demand
	Nutrients
	  Nitrogen
	    total inorganic
	    ammonia
	    nitrate
	    organic
	  Phosphorus
	    total
	    inorganic (orthophosphate)
	  Carbon
	  Silica

Biological Properties	Bacteria
	  Coliform
	    total
	    fecal
	  Enterococcus
	Plankton
	  Phytoplankton
	    chlorophyll *a*
	    community assessments
	  Zooplankton
	    community assessments

a 20 percent change over a 10-year period is the second level of performance proposed. When these two levels of performance are compared with existing monitoring efforts, a tiered monitoring plan can be established for the Delaware Estuary.

SAMPLING LOCATION AND FREQUENCY PLAN

To determine the locations and frequency of sampling for monitoring water quality parameters in the Delaware Estuary, three separate statistical analyses of historical data were conducted:

- Evaluation of the effect of the number of stations on performance.

- Evaluation of the effect of sampling frequency on performance.

- Estimation of the number of samples per segment necessary to meet monitoring program performance criteria.

An evaluation of data for each of the parameters of concern being recommended as part of this monitoring plan was not conducted as part of this analysis because of the level of effort that would be required. Rather, selected individual parameters were used as indicators of the performance of historical data for all parameters of potential concern, as discussed below. Appendix E in Volume 2 presents the detailed results of those evaluations.

Determining the number of samples necessary for each of the performance levels depends on several factors. Historical data are analyzed to determine the variation inherent in the measurements. For the conventional water quality parameters, nitrate, orthophosphate, ammonia, and dissolved oxygen were used as surrogates for a determination of historical variation. These parameters were chosen because historical measurements were readily available and scientists feel relatively comfortable with the variability associated with these measurements. Sampling allocations were then chosen based on estimates of variability for each of the four surrogate parameters using power analysis (power = 0.8, 90 percent confidence). Numbers of samples were derived for the main stem of the estuary, the bay, and the major tributaries.

In this analysis, the impact of estimating the monthly mean in May, a month with typically more wet-weather events, and August, a low-flow month, has been evaluated. Table 4-2 summarizes the sample allocation scheme using segment-specific estimates of central tendency and variability expected in May and August for a variety of water quality measurements. The number of samples has been determined for estimating the mean concentration with a 90 percent confidence interval equal to 20 and 50 percent of the mean for each waterbody grouping (i.e., tidal river, Delaware Bay, and tidal tributaries).

Although it is not possible to sample for every water quality parameter (measurement variability among parameters differs and cost would be prohibitive), Table 4-2 provides a guide for selecting a sampling scheme. As shown in Table 4-2, the total number of monthly samples ranges from 35 to 195 samples month to achieve an estimate of the mean within 20 percent. Nitrate falls in the middle of this range with 86 to 109 samples. The estimated numbers of samples required to detect 20 and 50 percent changes in nitrate (as presented in Table 4-2) were used to design the water quality location and frequency plan illustrated in Table 4-3 and Figure 4-1. Table 4-3 provides monthly and yearly sampling frequencies for the current Delaware River Basin Commission (DRBC) water quality monitoring program, a low-level sampling option (Option 1), and a high-level sampling option (Option 2). The low-level effort would allow the detection of an approximately ±25 percent change in the parameter mean. Similarly, the high-level effort would be sensitive enough to detect a ±10 percent change in the mean. Again, it is important to note that this sampling plan is a good start and that all of the parameters might not yield sensitivities in the desired range because a mid-range value was used to determine the sampling frequency. Depending on the specific water quality parameter, detection of a 20 or 50 percent change about the mean might or might not be a useful indication of water quality trends in the estuary. This will be especially true when measured concentrations are close to detectable levels. In such circumstances, a ±10 percent change may be significant or it might represent variation (noise) in the measurements. For some parameters, a more intensive sampling regime might be necessary if managers want to detect small changes in water quality.

Table 4-2. Allocation of Samples for Water Quality

	Alternative Sampling Plan Comparison			
	20% Variation about Mean		**50% Variation about Mean**	
Water Quality Indicator	**Spring**	**Summer**	**Spring**	**Summer**
Dissolved Oxygen				
Tidal River	10	15	1	3
Delaware Bay	14	29	3	7
Tidal Tributaries	11	17	0	3
Total	35	61	4	13
Ammonia Nitrogen				
Tidal River	50	56	20	25
Delaware Bay	77	86	26	34
Tidal Tributaries	57	53	29	22
Total	184	195	75	81
Nitrate Nitrogen				
Tidal River	30	18	7	5
Delaware Bay	48	37	11	8
Tidal Tributaries	31	31	8	8
Total	109	86	26	21
Inorganic Phosphorus				
Tidal River	37	34	9	9
Delaware Bay	45	42	11	10
Tidal Tributaries	33	31	8	8
Total	115	107	28	27

Table 4-3. Water Quality Sampling Location and Frequency

	Option 1[1]			Option 2[2]			Current DRBC		
Segment	Proposed # Samples per Year	Proposed # Stations	Proposed Sampling Frequency	Proposed # Samples per Year	Proposed # Stations	Proposed Sampling Frequency	# Samples per Year	# Stations	Sampling Frequency
Main Stem	72	8 (2/segment for 4 segments)	Once/month from March thru November	288	16 (4/segment for 4 segments)	Twice/month from March thru November	234	13	Twice/month March thru November
Bay	99	11	Once/month from March thru November	396	22	Twice/month from March thru November	90	5	Twice/month March thru November
(6C)	(45)	(5)		(180)	(10)		(90)	(5)	
(6L)	(27)	(3)		(108)	(6)		(0)	(0)	
(6R)	(27)	(3)		(108)	(6)		(0)	(0)	
Tidal Rivers	63	7 (1 tributary for 7 tributaries)	Once/month from March thru November	252	14 (2/tributary for 7 tributaries)	Twice/month from March thru November	0	0	N/A

[1]Option 1 = estimate mean within approximately 50%.
[2]Option 2 = estimate mean within approximately 20%.

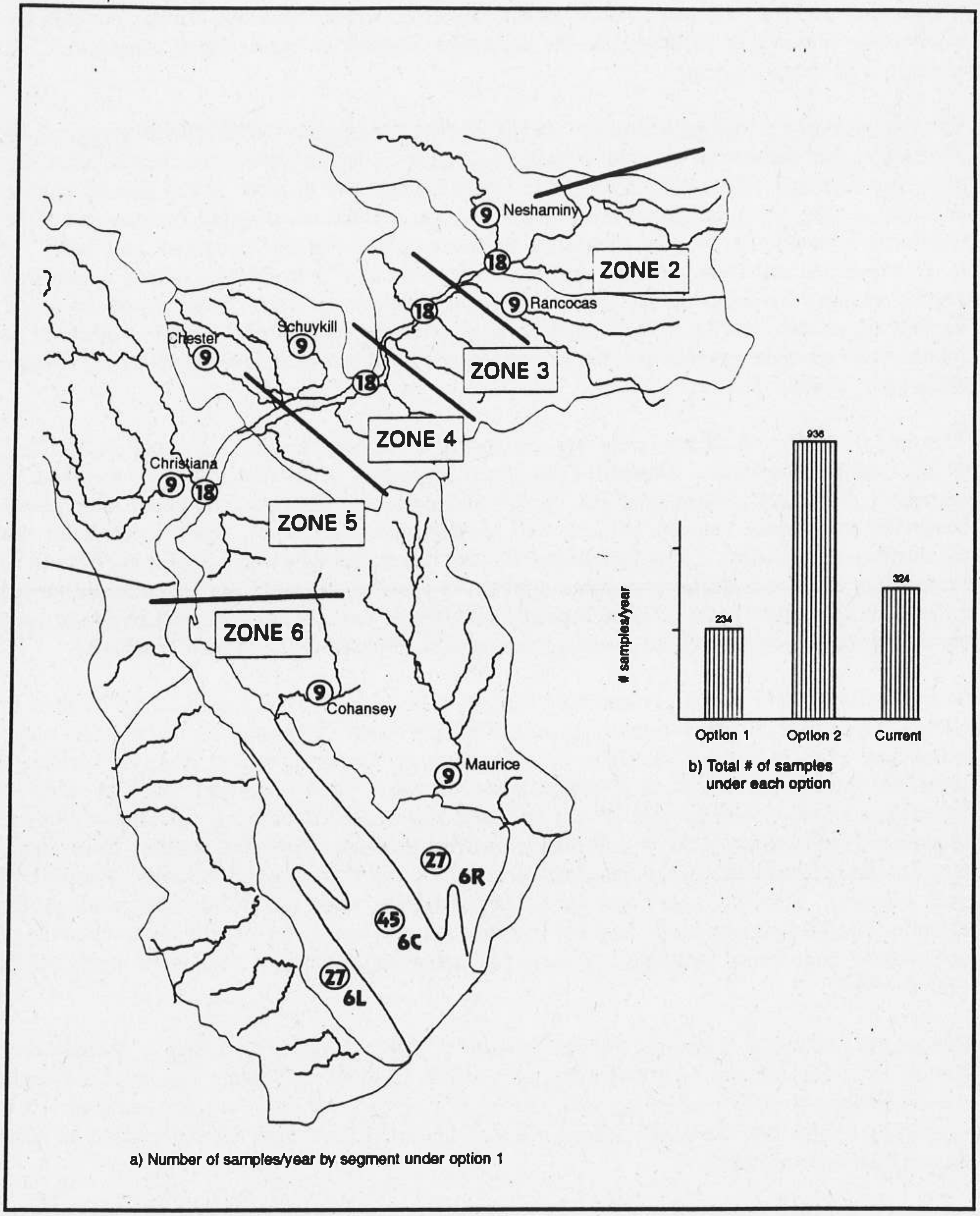


Figure 4-1. Water Quality Samples.

It should also be noted that the DRBC sampling program is not the only program collecting water quality samples in the Delaware Estuary. The states and other organizations are also taking water quality samples. Therefore, the current DRBC sampling effort presented in Table 4-3 represents only a portion of the total water quality monitoring effort in the Delaware Estuary. A summary of existing monitoring programs in the Delaware Estuary is presented in Appendix C in Volume 2 of this document.

The two proposed sampling frequency options bracket the existing DRBC sampling regime for the total annual number of samples. Comparing the locations of the existing DRBC sampling plan with Option 1 (the low-level sampling option) shows that to detect a ±25 percent change in water quality fewer samples can be taken, but the number of sampling stations should be increased, especially in the tidal tributaries, to better detect changes throughout the estuary. It is recommended that these sampling frequencies be used as a basis for determining a sampling regime to meet the needs of managers around the Delaware Estuary. Selection of the actual number of samples and locations should be done with the specific management objectives in mind. Then an initial number of samples and locations can be determined, based on the options outlined in Table 4-3.

This initial number of samples need not necessarily be exactly the numbers specified in either of the suggested options. Depending on the management objectives, the number could be anywhere within the ranges specified by the two options. This number would then give a sensitivity somewhere between ±10 and ±25 percent, depending on the specific parameter and measurement variability. These options should also be considered a starting point and should be reevaluated as the monitoring program matures. As actual monitoring data are collected for the various water quality parameters of concern, analyses of the measurement sensitivity for each parameter can be computed and sampling frequencies adjusted to the desired sensitivity.

The sampling location plan presented in Table 4-3 is unbiased with regard to the number of sampling locations allocated to each segment of the Delaware River and each of the seven major tributaries. Each segment of the Delaware River has two (Option 1) or four (Option 2) proposed sampling stations and each of the tidal tributaries has one (Option 1) or two (Option 2) proposed sampling stations. The purpose of this unbiased approached to locating sampling stations to segments of the Delaware River and tidal tributaries is to ensure that all portions of the study area are well represented and to optimize the likelihood of obtaining representative samples for each segment. However, the Delaware Estuary Program might choose to locate more of the sampling stations in segments that are known or suspected to be experiencing stress (e.g., segment 4) and fewer sampling locations in other segments (e.g., segments upstream of Philadelphia).

The yearly sampling frequency for the low-level sampling option (Option 1) is shown in Figure 4-1. The number of samples for each major segment is shown. The bar chart insert compares current DRBC sampling with the high-level and low-level sampling options. It is interesting to note that the current efforts are more intensive than those needed for Option 1, but the locations are different.

It is important to remember that this monitoring plan was developed to meet the broadly defined monitoring objectives previously discussed in this chapter. The objectives are to determine whether water quality changes are occurring in the estuary as a whole and whether water quality standards are being met throughout the estuary. This monitoring plan can be augmented with increased efforts at specific locations around the estuary to determine the effects of local management actions to reduce impacts from various source, including nonpoint sources.

These increased monitoring efforts can also target areas around the estuary that are identified by local experts as potential problem areas needing additional monitoring (e.g., the upper reaches of the main stem of the bay, or in areas such as the Philadelphia-Camden section during low flow). Although they will be important to local decisions, these additional monitoring locations might be useful only for supplementing the data collection design presented herein. Expertly chosen locations will tend to add bias to the monitoring plan, and this will limit the broad-scale usefulness of these data.

All of the conventional pollutants should be sampled at the frequency depicted in Table 4-3, once per month from March through November. Some of the Delaware Estuary Monitoring Program Steering Committee members desired winter data, and these could be acquired at the same frequency (once per month). To measure phytoplankton abundance, it is recommended that chlorophyll *a* be measured whenever samples are taken for the conventional pollutants at each station. The Delaware Estuary Monitoring Program Steering Committee also recommended that plankton diversity be assessed. General sampling for both phytoplankton and zooplankton could be accomplished with a seasonal frequency—spring, summer, and fall; winter sampling could be omitted. As an option, plankton sampling could be refined to take place only during certain times of the year; for example, when the water is at a certain temperature or when plankton communities might be especially important to the growth of larval or juvenile fish species.

Chapter 5
Toxic Pollutants

The presence of toxic chemicals in the water and sediments of the Delaware Estuary can have adverse ecological and human health effects. The potential consequences of the bioaccumulation of toxic chemicals in estuarine organisms include mortality in susceptible organisms, lethal or sublethal chronic responses in susceptible organisms, and transfer of increasingly greater concentrations of toxic pollutants to organisms at higher trophic levels, including humans. In addition, endangered marine mammals (specifically dolphins) and turtles feed in the estuary, and their health can be affected by the consumption of chemically contaminated food.

Human health impacts related to exposure to toxic chemicals in the aquatic environment (either directly or indirectly through the consumption of contaminated fish and shellfish tissues) include carcinogenic and noncarcinogenic effects. In addition, advisories for the consumption of contaminated seafood result in denied access to estuarine resources and recreational opportunities and can have a serious economic effort on the seafood business and estuary-dependent recreational businesses, as well as an effect on human attitudes concerning the estuary.

Elevated concentrations of toxic pollutants in the water, sediment, and fish of the Delaware Estuary have been measured in recent monitoring programs (Church et al., 1988; Jacobsen et al., 1991; DRBC, 1988, 1992). In addition, fish advisories have been issued for channel catfish, white perch, and American eel in portions of the estuary because of potentially hazardous concentrations of polychlorinated biphenyls (PCBs) and chlordane in the edible portion of these fish species. For these reasons, the Monitoring Subcommittee of the Delaware Estuary Program has identified toxic pollutants as a major concern for the estuary that is to be addressed in the Delaware Estuary Monitoring Plan.

During the October 1993 DELEP Regional Monitoring Strategy Workshop, the Toxic Pollutant Workgroup identified the following major issues of concern associated with toxic pollutant contamination in the Delaware Estuary:

- Toxic impacts on other trophic levels.
- Ecological effects of toxic pollutants (i.e., food chain interactions, fish health—adverse effects on the pathology of the animal).
- The level of monitoring sufficient to make informed decisions.

- Protection of human health and the ecosystem from the adverse effects of toxic pollutants.

The Toxic Pollutant Workgroup also identified the parameters of greatest concern in the Delaware Estuary that should be the focus of any toxic pollutant monitoring effort, the objectives for toxic pollutant monitoring, and a sampling frequency plan (in both space and time) for each of the contaminants of concern in each of four media (water, sediment, tissue, and air). The Toxic Pollutant Workgroup did not establish the desired time frame for the detection of changes, confidence levels, or minimum detectable changes for evaluating trends.

The remainder of this chapter presents the objectives for monitoring toxic pollutants in the Delaware Estuary, the measurement parameters of concern related to toxic pollutants, performance criteria on which the monitoring plan is based and should later be evaluated, and a sampling location and frequency plan for monitoring toxic pollutants in the estuary.

MONITORING OBJECTIVES, MEASUREMENT PARAMETERS, AND PERFORMANCE CRITERIA

The Toxic Pollutant Workgroup recommended that toxic pollutant monitoring be used to support two general monitoring objectives:

- Determine the concentration levels of "toxic chemicals of concern" in water, sediment, air, and biota.

- Determine trends in levels of "toxic chemicals of concern" in water, sediment, air, and biota.

These objectives are designed to show how management actions are affecting concentrations of toxic materials in the resources of the Delaware Estuary.

The Toxic Pollutant Workgroup also identified the toxic parameters of greatest concern in Delaware Estuary water, sediment, air, and biota (Table 5-1). The toxic chemicals of concern identified in Table 5-1 are those which should be measured as part of the Delaware Estuary Regional Monitoring Plan and thus will be those measured to meet the monitoring objectives identified above. It should be noted that the chemical form of some toxic pollutants in the environment is more important for monitoring than the total quantity of a metal or class of organics (for example, organic versus inorganic mercury). The chemical form of toxic pollutants, therefore, should be a consideration during analysis of samples. Also, the bioavailability of some forms of toxic pollutants, especially metals, can vary with salinity, pH, or other environmental factors. Those factors should be considered when evaluating the results of sample analyses, especially when results are used to estimate exposure risks and trends.

Performance criteria are typically determined by the use of historical data and the application of statistical methods to evaluate the data. In the case of water column toxic chemical contamination in the Delaware Estuary, there are insufficient historical data to evaluate program performance. Existing measurements of organics and metals from the Delaware Estuary are below the detection limit and therefore could not be used in an evaluation of performance.

Table 5-1. Toxic Parameters of Concern in Delaware Estuary Water, Sediment, Air, and Biota

Parameter	Water	Sediment	Air	Biota
Metals				
mercury	✓	✓	✓	✓
arsenic	✓	✓	✓	✓
lead	✓	✓	✓	✓
copper	✓	✓	✓	✓
chromium	✓	✓	✓	✓
silver	✓	✓	✓	✓
zinc	✓	✓	✓	✓
cadmium	✓	✓	✓	✓
Chlorinated pesticides		✓		✓
PCBs		✓	✓	✓
Volatile organics	✓		✓	
PAHs		✓	✓	✓
General toxicity	✓	✓		
Pathology				✓

Consequently, a detailed statistical analysis of existing toxic pollutant water column data was not conducted. As explained in the following section of this chapter, it is recommended that the stations used for water quality sampling (identified in Chapter 4) also be used for water column toxic pollutant sampling. The sampling for toxic pollutants, however, should be less frequent than that for other water quality parameters, especially in the bay portion of the estuary. As additional water column toxic pollutant data are gathered, the evaluation of such data might indicate the need to increase or decrease the data-gathering effort in the future. Sufficient data are available to evaluate the performance (i.e., sensitivity) of existing toxic pollutant data for Delaware Estuary sediment and tissue. For the purpose of evaluating alternative sampling designs, the minimum detectable changes used in this analysis are 20 and 50 percent changes in mean concentrations over a 10-year period ($\alpha = 0.1$, power = 0.8), the same values used in the analysis of water quality data in the previous chapter. Sampling allocations were based on a 90 percent confidence interval about the annual mean concentration equal to 20 and 50 percent of mean concentration.

Depending on the toxic pollutant of concern, a 20 or 50 percent change over mean concentration might or might not be a useful indicator of trend. For very low concentrations of a contaminant, a 20 percent increase could be a significant change or it could represent statistical noise. As the Delaware Estuary Program Regional Monitoring Plan is implemented and results are evaluated, managers might decide that a change in sampling frequency for a particular contaminant is necessary to better evaluate trends. However, it is beyond the scope of this effort to develop contaminant-specific sampling location and frequency plans. It is also doubtful that the Estuary Program could afford to implement such a plan. Therefore, the toxic pollutant sampling plan presented in this chapter will result in oversampling for some parameters and undersampling for others. As the plan is implemented and trends in detected levels of toxic contaminants are determined, managers will need to adjust their sampling plans to address those contaminants of greatest concern, which might not be adequately covered under the existing monitoring plan.

It should be noted that the Toxic Pollutant Workgroup of the DELEP Regional Monitoring Strategy Workshop suggested that, with the exception of the Philadelphia area, existing atmospheric deposition monitoring is sufficient in the tidal portion of the Delaware Estuary (the focus of this monitoring plan). Therefore, the remainder of this chapter focuses on monitoring of toxic pollutants in water, sediment, and tissue.

SAMPLING LOCATION AND FREQUENCY PLAN

Water Column

As mentioned previously, it is recommended that the sampling location plan used for water quality monitoring also be used for monitoring toxic pollutants in the water column. Only the sampling frequency would change. The sampling frequency plan presented here is based on the recommendations of the Toxic Pollutant Workgroup of the DELEP Regional Monitoring Strategy Workshop. The workgroup recommended monthly water column toxic pollutant sampling for heavy metals and volatile organics between August and October and during short-term, wet-weather events in the tidal rivers and quarterly sampling for toxicity in the tidal rivers. The optional sampling plans presented here suggest monthly sampling for heavy metals and volatile organics in the tidal rivers between March and November to coincide with water quality parameter sampling. The Toxic Pollutant Workgroup recommended semiannual sampling for only heavy metals in the water column from the bay. The proposed sampling location and frequency plan options for measuring toxic pollutants in the water column are illustrated in Table 5-2 and Figure 5-1. As additional water column toxic pollutant data are gathered, the performance of these sampling plans should be evaluated and adjusted as necessary to meet the desired performance criteria.

Sediment and Tissue

Sufficient toxic pollutant data for sediment and biota were available to evaluate data performance (i.e., sensitivity) and to design a sampling location and frequency plan for measuring toxic pollutants in these media. As was the case in developing the water quality monitoring plan (Chapter 4), three separate statistical evaluations of historical data were conducted:

- Evaluation of the effect of the number of stations on performance.
- Evaluation of the effect of sampling frequency on performance.
- Estimation of the number of samples per segment necessary to meet monitoring program performance criteria.

Table 5-2. Water Column Toxic Pollutant Sampling Locations and Frequency

Segment	Parameter	Option 1			Option 2		
		Proposed # Samples per Year	Proposed # Stations	Proposed Sampling Frequency	Proposed # Samples per Year	Proposed # Stations	Proposed Sampling Frequency
Main Stem	Heavy metals and volatile organics	72	8 (2/segment for 4 segments)	Once per month from March thru November	144	16 (4/segment for 4 segments)	Once per month from March thru November
	Toxicity	32	8 (2/segment for 4 segments)	Quarterly	64	16 (4/segment for 4 segments)	Quarterly
Bay 6(C) 6(L) 6(R)	Heavy metals	22 (10) (6) (6)	11 (5) (3) (3)	Semiannually	44 (20) (12) (12)	22 (10) (6) (6)	Semiannually
Tidal Tributaries	Heavy metals and volatile organics	63	7 (1/tributary for 7 tributaries)	Once per month from March thru November	126	14 (2/tributary for 7 tributaries)	Once per month from March thru November

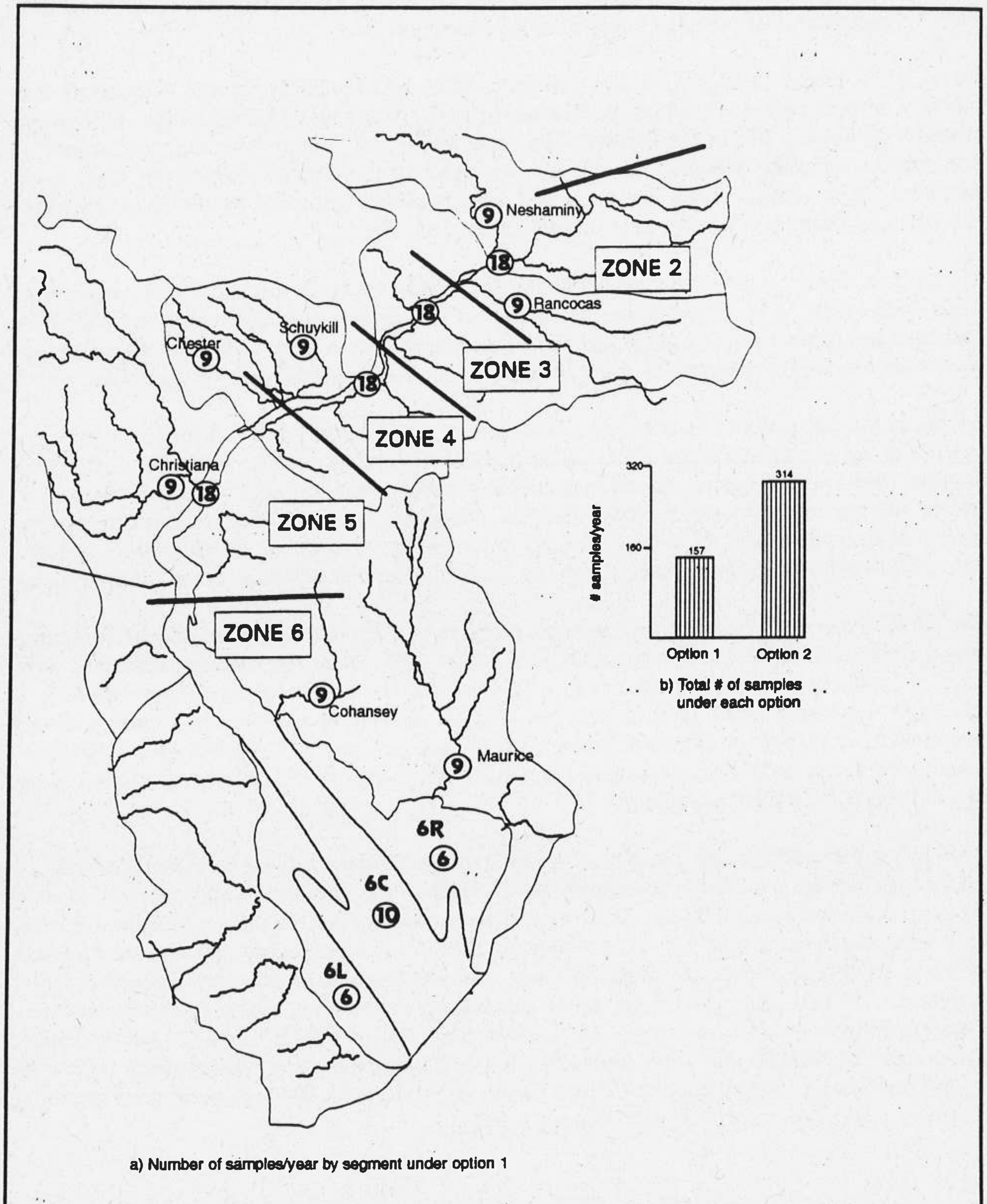


Figure 5-1. Water column samples for toxic pollutants.

An evaluation of data for each of the toxic pollutants of concern being recommended as part of this monitoring plan was not conducted as part of this effort. Rather, specific pollutants known to be affecting the Delaware Estuary were used as indicators of the performance of historical data for all contaminants of potential concern, as discussed below.

Based on a recent Delaware Estuary sediment study (ADL, 1993), it was determined that mercury, lead, copper, and total polynuclear aromatic hydrocarbons (PAH) are among the leading stressors of aquatic life in the Delaware Bay and tidal river. As a result, for the purpose of designing a sampling scheme, the analysis presented in this chapter focuses on these toxic variables. It is recommended, however, that all parameters identified by the Toxic Pollutant Workgroup (Table 5-1) be measured during actual sampling.

Typically, sediment contaminant concentrations for the bay are much lower and less variable than those for the tidal river. Nonetheless, the coefficient of variation ranged from 0.8 to 1.2 for both sediment and tissue residue concentrations. Lead concentrations were typical of this range and were used to evaluate the sensitivity of alternative monitoring plans for toxic pollutants.

To determine the number of stations needed to detect trends in toxic pollutant levels in sediment and tissue, an evaluation of the effect of the number of stations sampled during each event on program performance was conducted by simulating annual sampling with one sample from 3, 5, and 10 stations over 10 years for lead. For lead, increasing the number of stations per segment from 5 to 10 resulted in a 17 percent increase in sensitivity—from 0.64 ppb per year (30 percent of overall mean concentration) to 0.54 ppb per year (25.6 percent of overall mean concentration).

The effect of sampling frequency on expected program performance was evaluated by simulating annual, semi-annual, and quarterly sampling for lead. The other monitoring parameters were fixed at three stations per segment over a 10-year period. Quarterly sampling resulted in a minimum detectable trend of 0.19 ppb per year (9 percent of overall mean concentration) compared to a minimum detectable trend of 0.36 ppb per year (17 percent of overall mean concentration) for semi-annual sampling and 0.68 ppb per year (32 percent of overall mean concentration) for annual sampling.

To estimate the annual mean concentration within a specified 90 percent confidence interval, it is a straightforward calculation to estimate the number of samples and to allocate them to each segment in the Delaware Estuary. This calculation is based on the variability of historical data, the desired confidence interval, and the percent change in mean concentration to be detected. In this analysis, the impact of estimating the annual mean sediment and tissue concentration is evaluated. Table 5-3 summarizes the sample allocation scheme using segment-specific estimates of central tendency and variability found in data from NOAA's NS&T, EMAP, and STORET. The number of samples has been determined for estimating the mean concentration with a 90 percent confidence interval equal to 20 and 50 percent of the mean for each water body grouping (i.e., tidal river, Delaware Bay, and tidal tributaries).

Table 5-3. Allocation of Samples for Toxic Pollutants

Toxic Measurements	Alternative Sampling Plan Comparison			
	20% Variation in Mean		50% Variation in Mean	
	Sediment	Tissue	Sediment	Tissue
Mercury-Sediment/Tissue				
Tidal River	50	64	20	44
Delaware Bay	64	104	19	60
Tidal Tributaries	51	65	21	47
Total	165	233	60	151
Lead-Sediment/Tissue				
Tidal River	60	44	32	12
Delaware Bay	74	56	26	15
Tidal Tributaries	58	41	29	14
Total	192	141	87	41
Copper-Sediment/Tissue				
Tidal River	40	60	13	32
Delaware Bay	75	90	26	40
Tidal Tributaries	41	60	14	33
Total	156	210	53	105
Total PAH-Sediment				
Tidal River	44		14	
Delaware Bay	37		8	
Tidal Tributaries	45		14	
Total	126		36	

In the development of the sampling location and frequency plan for toxic pollutants in sediment and tissues, an attempt was made to consider the recommendations made at the DELEP Regional Monitoring Strategy Workshop by the Toxic Pollutant Workgroup and to coordinate any sampling design with the sampling plan recommended for other parameters (i.e., living resources) in the estuary in order to reduce the level of effort and cost associated with monitoring.

For toxic pollutants in sediment, the Toxic Pollutant Workgroup recommended semiannual (spring and fall) sampling of heavy metals, chlorinated pesticides, PCBs, PAHs, and toxicity in the tidal rivers and annual sampling of heavy metals, chlorinated pesticides, PCBs, and PAHs in the bay. The Toxic Pollutant Workgroup also recommended at least annual sampling of tissues for heavy metals, chlorinated pesticides, PCBs, PAHs (methylated), and pathology in both the tidal rivers and the bay, depending on the species. The recommended fish/shellfish species for tissues samples were:

- Tidal Rivers
  - mussel (tissue pathology)
  - white perch (fillet)
  - striped bass (fillet)
  - channel catfish (fillet)
  - others (as necessary)

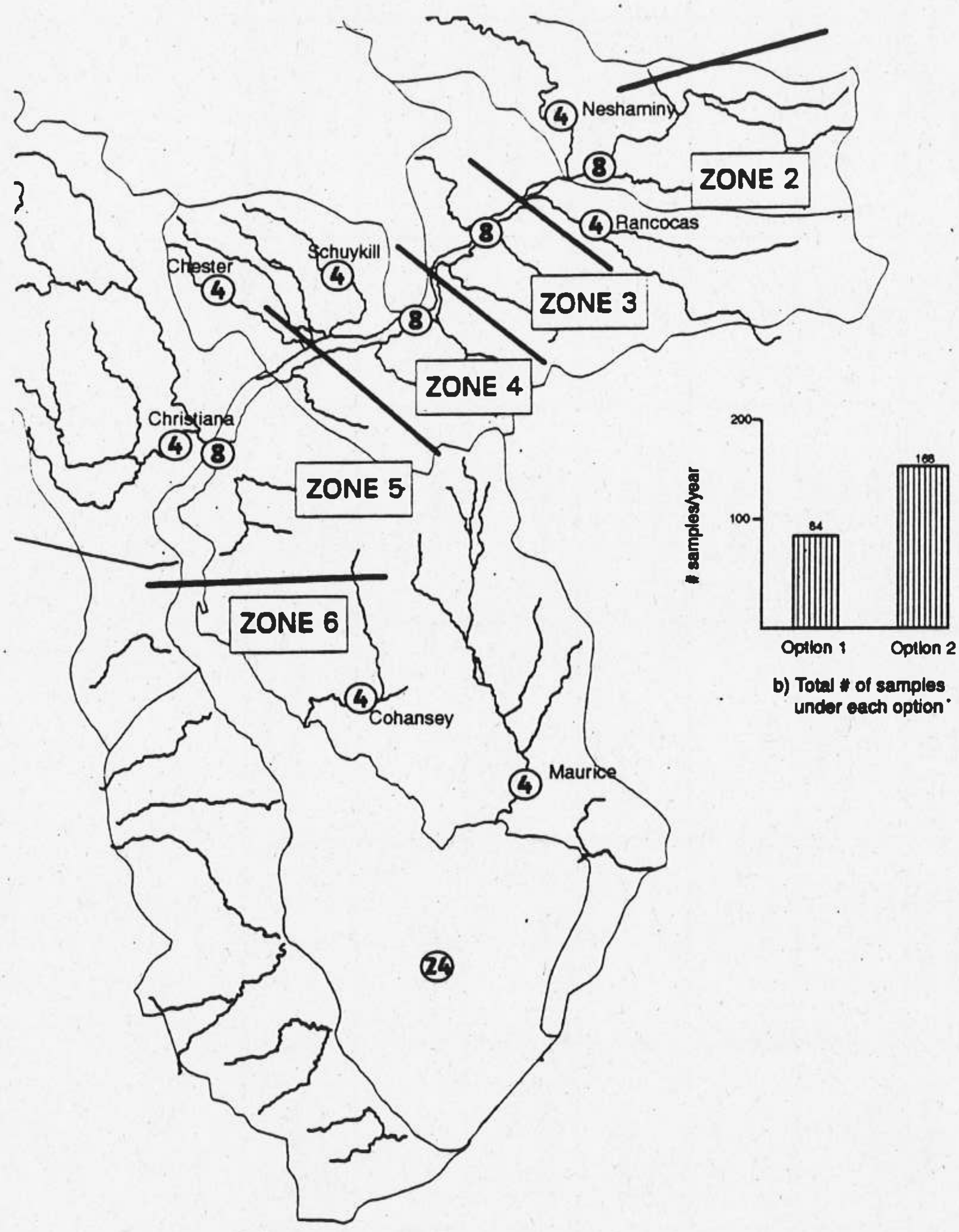
- Bay
  - oysters (whole body)
  - summer flounders (fillet)
  - weakfish (fillet)
  - anchovy (whole body—ecological)
  - menhaden (whole body—ecological)

In addition to sampling of the species recommended by the Toxic Pollutant Workgroup, the Delaware Estuary Program should also consider tissue sampling of other species that are nonmigratory. The monitoring of smaller, less motile species (e.g., arthropods and trophically important aquatic or semi-aquatic plants) can provide additional useful information to managers.

As shown in Table 5-3, the number of samples of lead required to detect 20 and 50 percent changes in mean concentrations of toxic pollutants in sediment and tissue fell within the mid range of the toxic pollutants analyzed. Using lead as a model, the sampling location and frequency plans for benthic macroinvertebrates and dermersal fish would also be adequate for sampling for toxic pollutants in sediment and tissue. The proposed sampling locations and frequency plans for toxic pollutants in Delaware Estuary sediment and tissues are illustrated in Table 5-4 and Figures 5-2 and 5-3. The monitoring plan for toxic pollutant in sediment is modeled after the sampling location and frequency plan developed for benthic macroinvertebrates presented in the living resources chapter (Chapter 3). The monitoring plan for fish tissue residue is modeled after the plan developed for dermersal fish populations (also presented in Chapter 3). The differences between the sampling location and frequency plans presented in the living resources chapter and those presented here are the number of stations for measuring toxic pollutants in the sediment along the main stem of the Delaware River (twice as many as for benthic macroinvertebrate sampling) and the frequency of sampling for fish tissue analysis in all segments of the estuary under Option 1 (half as often as for fish population studies). Also, under Option 2 there are fewer sampling stations for fish tissue analysis and they are sampled less frequently than are locations for fish population assessments (with the exception of samples taken in the tidal tributaries). There is currently no coordinated, estuary-wide monitoring program for sampling toxic pollutants in sediment or tissue in the Delaware Estuary; therefore, the current level of effort for measuring these parameters has not been estimated.

Table 5-4. Toxic Pollutants in Sediment and Tissue Sampling Locations and Frequency

Sediment/ Tissue	Segment	Option 1			Option 2		
		Proposed # Samples per Year	Proposed # Stations	Proposed Sampling Frequency	Proposed # Samples per Year	Proposed # Stations	Proposed Sampling Frequency
Sediment	Main Stem	32	16 (4/segment for 4 segments)	Semiannually May-June Sept.-Oct.	64	32 *(8/segment for 4 segments)	Semiannually May-June Sept.-Oct.
	Bay	24	12	Semiannually May-June Sept.-Oct.	48	24	Semiannually May-June Sept.-Oct.
	Tidal Tributaries	28	14 (2 for each of 7 tributaries)	Semiannually May-June Sept.-Oct.	56	28 (4 for each of 7 tributaries)	Semiannually May-June Sept.-Oct.
Tissue	Main Stem	12	12 (3/segment for 4 segments)	Annually Sept.-Oct.	32	16 (4/segment for 4 segments)	Semiannually May-June Sept.-Oct.
	Bay	14	14	Annually Sept.-Oct.	36	18	Semiannually May-June Sept.-Oct.
	Tidal Tributaries	14	14 (2 for each of 7 tributaries)	Annually Sept.-Oct.	42	21 (3 for each of 7 tributaries)	Semiannually May-June Sept.-Oct.



a) Number of samples/year by segment under option 1

b) Total # of samples under each option

Figure 5-2. Sediment samples for toxic pollutants.

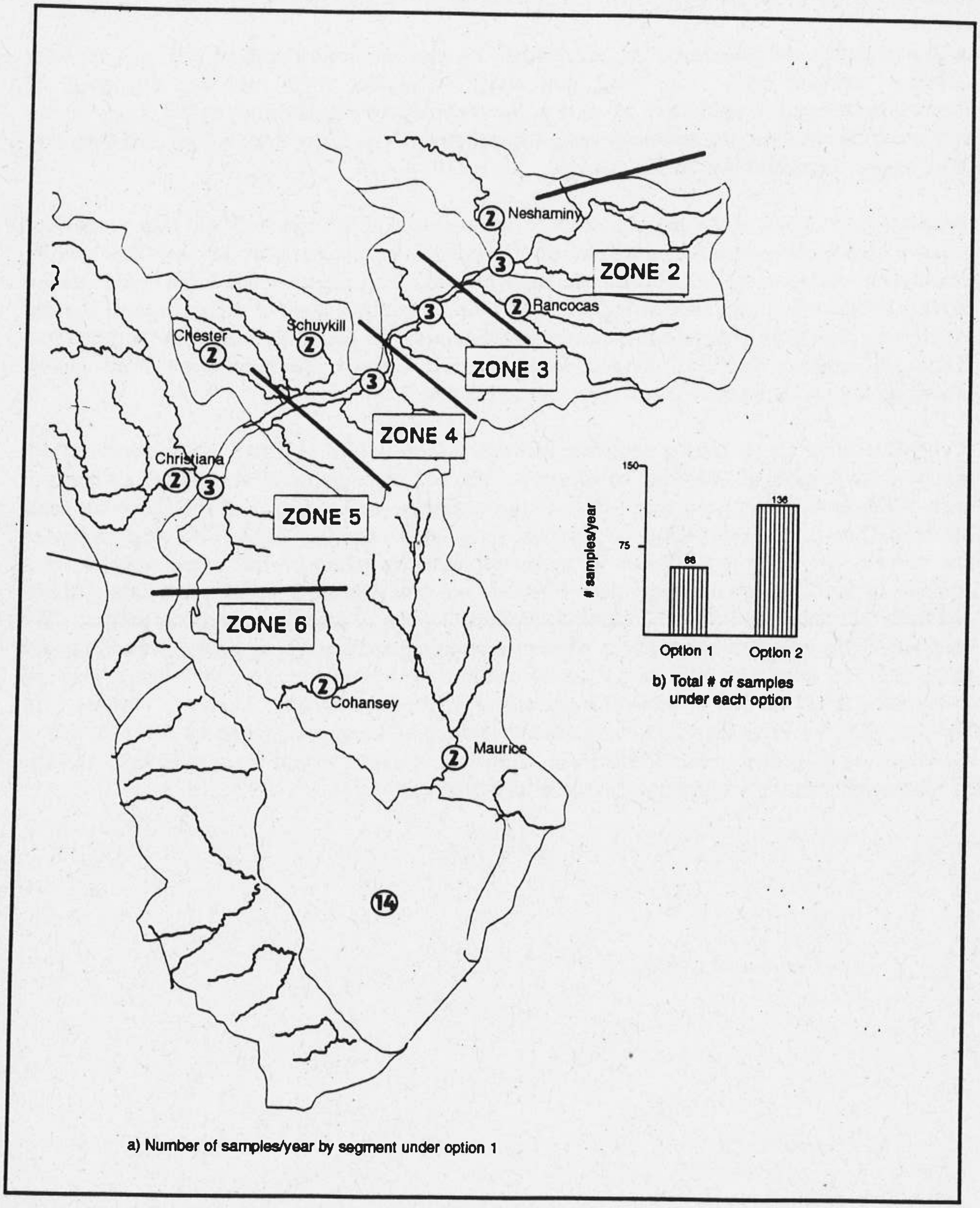


Figure 5-3. Tissue samples for toxic pollutants.

Under Option 1, full sampling (September-October) is recommended in an attempt to account for toxic accumulation that has taken place within the estuary, primarily for those species which exhibit seasonal migration outside the estuary during winter months.

In implementing sediment sampling, care should be taken to locate sampling sites in areas with different sediment types (e.g., sand, silt, clay). Sediment types influence the levels of contaminants found in sediments, as well as the contaminant's availability to living organisms. It is recommended that the sediment sampling regime provide a good cross-sectional sampling of all major sediment types in the estuary.

Samples taken as part of the analysis of toxic contaminants in fish tissue should also be used for gross pathological evaluation, such as liver condition or presence of tumors, that can be associated with toxic material bioaccumulation results. It is recommended that the Delaware Estuary Program begin its monitoring program with the minimal level of effort required to meet monitoring objectives and performance criteria (Option 1). As priorities change and as additional funding becomes available to conduct more intensive surveys, the monitoring effort can be increased to provide more detailed information (Option 2).

It should also be noted that the sampling location plan presented in Table 5-4 is unbiased with regard to the number of sampling locations allocated to each segment of the Delaware River and each of the seven major tributaries. For sediment samples, each segment of the Delaware River has four (Option 1) or eight (Option) proposed sampling stations and each of the tidal tributaries has one (Option 1) or two (Option 2) proposed sampling stations. For tissue samples, each segment of the Delaware River has three (Option 1) or four (Option 2) proposed sampling station and each tidal tributary has two (Option 1) or three (Option 2) proposed sampling stations. The purpose of this unbiased approach to allocating sampling stations to segments of the Delaware River and tidal tributaries is to ensure that all portions of the study area are well represented and to optimize the likelihood of obtaining representative samples for each segment. However, the Delaware Estuary Program might choose to locate more of the sampling stations in segments that are known or suspected to be experiencing stress (e.g., segment 4) and fewer sampling locations in other segments (e.g., segments upstream of Philadelphia).

CHAPTER 6
FIELD SAMPLING INTEGRATION AND ESTIMATED SAMPLING AND LABORATORY ANALYSIS COSTS

FIELD SAMPLING INTEGRATION

In an effort to reduce the costs of monitoring in the Delaware Estuary, an attempt has been made in this monitoring plan to integrate field sampling of parameters related to living resources, water quality, and toxic pollutants and to integrate sampling with existing field monitoring programs. Two alternatives for field collection activities are suggested in this chapter based on the sampling location and frequency plans presented in Chapters 3, 4, and 5. Under the first alternative, three field collection activities that integrate water quality sampling with water column toxic pollutant sampling, benthic macroinvertebrate sampling with sediment toxic pollutant sampling, and fish population sampling with fish tissue residue sampling are suggested. Under the second alternative, all parameter samples would be taken during water quality sampling when required under the sampling location and frequency plan. The second alternative would be less costly but would require considerably more planning and coordination. The two sampling alternatives are discussed below.

Sampling Alternative 1: Three Separate Field Activities

The first field activity integrates the collection of water quality samples and water column toxic pollutant samples. The proposed number of stations for sampling each of these parameters is the same; only the sampling frequency is different (Table 6-1). Water quality samples would always be taken at least as often as samples of toxic pollutants in the water column. Therefore, when necessary, water column toxic pollutant samples could be taken during water quality sampling cruises.

The second field activity integrates the collection of benthic macroinvertebrate samples and sediment toxic pollutant samples. Based on the sampling location and frequency plans presented in Chapters 3 and 5, with the exception of sediment sampling in the main stem of the Delaware River, both sampling activities would take place at the same locations and with the same frequency (Table 6-2). Sampling for toxic pollutants in the sediment of the main stem of the

Table 6-1. Water Quality and Water Column Toxic Pollutant Sampling

	Option 1						Option 2					
	Proposed # Samples per Year		Proposed # Stations		Proposed Sampling Frequency		Proposed # Samples per Year		Proposed # Stations		Proposed Sampling Frequency	
Segment	WQ	Tox	WQ	Tox	WQ	Tox	WQ	Tox	WQ	Tox	WQ	Tox
Main Stem	72	72	8	8	1/month (Mar.-Nov.)	1/month (Mar.-Nov.)	288	144	16	16	2/month (Mar.-Nov.)	1/month (Mar.-Nov.)
Bay	99	22	11	11	1/month (Mar.-Nov.)	2/year	396	44	22	22	2/month (Mar.-Nov.)	2/year
Tidal Tributaries	63	63	7	7	1/month (Mar.-Nov.)	1/month (Mar.-Nov.)	252	126	14	14	2/month (Mar.-Nov.)	1/month (Mar.-Nov.)

Table 6-2. Benthic Macroinvertebrate and Sediment Toxic Pollutant Sampling

	Option 1						Option 2					
	Proposed # Samples per Year		Proposed # Stations		Proposed Sampling Frequency		Proposed # Samples per Year		Proposed # Stations		Proposed Sampling Frequency	
Segment	Benth	Tox	Benth	Tox	Benth	Tox	Benth	Tox	Benth	Tox	Benth	Tox
Main Stem	16	32	8	16	2/year	2/year	32	64	16	32	2/year	2/year
Bay	24	24	12	12	2/year	2/year	48	48	24	24	2/year	2/year
Tidal Tributaries	28	28	14	14	2/year	2/year	56	56	28	28	2/year	2/year

Delaware River would take place at twice as many stations as benthic macroinvertebrate sampling. Therefore, sampling for benthic macroinvertebrates and toxic pollutants in sediment in the bay and tidal tributaries would occur simultaneously at the same locations and with the same frequency. Benthic macroinvertebrate samples in the main stem of the Delaware River would be taken when necessary (at half the locations) during sampling for toxic pollutants in the sediment.

The third field activity integrates the collection of demersal fish samples for population assessments and for tissue residue studies. There are more sampling locations in the main stem of the Delaware River and the bay for fish population samples than there are for fish tissue residue samples (Table 6-3). (Half of the fish population sampling locations are for adults and half are for juveniles.) The numbers of stations for fish population samples and fish tissue residue samples in the tidal tributaries are similar. In addition, under Options 1 and 2, the sampling frequency for fish population sampling in all segments of the estuary is more frequent than for fish tissue residue sampling. Therefore, fish tissue residue samples would be taken when necessary during fish population assessment sampling.

Sampling Alternative 2: All Samples Taken During Water Quality Sampling

The second alternative assumes that most samples for each of the parameters, including living resources and toxic pollutants, can be taken during the water quality sampling cruises. More water quality samples are taken each year than any other type of sample. Therefore, if benthic macroinvertebrate, sediment, fish tissue, and fish population samples could be taken during the same cruise as water quality samples, some savings in cost would be realized. Although there are fewer proposed sampling locations for water quality than for some of the other parameters, water quality samples are taken more frequently (i.e., monthly) and therefore research crews and vessels would be active on more than enough days during the year to sample all locations for the other sample parameters. Although such a sampling regime is possible, its accomplishment would require significant coordination.

ESTIMATED COSTS

The cost estimates presented in this section are rough estimates based on the number of sampling locations that would be visited every year and the number of samples for various parameters that would be analyzed every year. These estimates are based on costs associated with field sampling and laboratory analysis only; costs associated with analysis of data, reporting, and administration have not been included in the estimates. Two cost estimates are presented for each of the monitoring options developed in this plan. The first assumes that three separate sampling activities would take place, as discussed in the previous section. The second assumes that samples for each of the parameters (living resources, water quality, and toxic pollutants) would be taken (when necessary) during water quality sampling.

Several assumptions have been made in developing these cost estimates. For fish population studies it has been assumed that the identification, measurement, and pathological inspection of samples would take place during the cruise. Subsamples of fish would be frozen for toxic pollutant analysis. Composite samples (five fish) of one species of fish would be used for chemical analyses of tissue. Two to three sediment grabs would be taken at each location for benthic macroinvertebrate and sediment analyses. Benthic macroinvertebrate samples would be

Table 6-3. Fish Population and Fish Tissue Residue Sampling

	Option 1						Option 2					
	Proposed # Samples per Year		Proposed # Stations		Proposed Sampling Frequency		Proposed # Samples per Year		Proposed # Stations		Proposed Sampling Frequency	
Segment	Fish[1]	Tissue	Fish[1]	Tissue	Fish	Tissue	Fish[1]	Tissue	Fish[1]	Tissue	Fish	Tissue
Main Stem	a. 24 b. 24	12	a. 12 b. 12	12	2/year	1/year	a. 72 b. 72	32	a. 12 b. 12	16	6/year	2/year
Bay	a. 28 b. 28	14	a. 14 b. 14	14	2/year	1/year	a. 84 b. 84	36	a. 14 b. 14	18	6/year	2/year
Tidal Tributaries	28	14	14	14	2/year	1/year	84	42	14	21	6/year	2/year

[1]a = juvenile collections; b = adult collections.

sieved and organisms picked on board the vessel during the cruise. During water quality sampling cruises, salinity, pH, dissolved oxygen, and temperature would be measured on board the vessel. All other analyses would be conducted in the laboratory. It has also been assumed that all field and laboratory equipment is available and that no costs would be required for its use other than labor costs.

The estimated costs for conducting laboratory analyses are presented in Tables 6-4 and 6-5. The estimated costs for field sampling vary depending on which of the two sampling alternatives is selected, as discussed in the previous section. If water quality and water column toxic pollutant samples are taken separately from all other types of samples, it is estimated that it will cost approximately $125 to sample each location. This is based on the assumption that only two crew members (80 hours/week) are required at $50/hour and that 8 locations can be visited each day (32 locations in a week, assuming 1 day per week for preparation, maintenance, etc.). If benthic macroinvertebrate and sediment samples are taken separately from all other types of samples, it is estimated that it will cost approximately $250 to sample each location. This estimate is based on the assumption that three crew members (120 hours/week) are required at $50/hour and that a maximum of six locations can be visited each day (24 locations in a week). If fish population and fish tissue residue samples are taken separately from all other samples types, it is estimated that it will cost approximately $300 to sample each location. This estiamte is based on the assumption that three crew members (120 hours/week) are required at $50/hour and that a maximum of 5 locations can be visited each day (20 locations in a week).

If all parameter samples are taken at a location at the same time, it is estimated that it will cost approximately $500 to sample each location. This estimate is based on the assumption that three crew members (120 hours/week) are required at $50/hour and that only 3 locations can be visited each day (12 locations in a week). If fish sampling and water quality/water column toxic pollutant sampling are conducted at the same time, it is estimated that it will cost approximately $300 to sample each location. This is based on the assumption that three crew members (120 hours/week) are required at $50/hour and that 5 locations can be visited each day (20 locations in a week). Fish sampling locations are sampled more frequently than are benthic macroinvertebrate/sediment locations. Therefore, if sampling efforts are combined for the various parameters, it is assumed that all benthic macroinvertebrate/sediment locations can be sampled when locations are sampled for other parameters.

Based on these cost assumptions, the costs for field sampling under each of the sampling alternatives and for both monitoring plan options are represented in Tables 6-6 and 6-7. Estimated total costs (sampling and analysis) range from $449,770 per year to $1,138,850 per year, depending on the sampling alternative and option selected (Table 6-8).

INTEGRATION WITH EXISTING SAMPLING PROGRAMS

The costs presented in the previous section reflect a rough estimate of the total cost associated with monitoring for the three resource areas discussed in Chapters 3, 4, and 5. These costs do not, however, take into consideration those monitoring programs already in place to measure many of the same parameters being suggested in this monitoring plan. Therefore, the costs presented in the previous section do not necessarily reflect "new" costs for monitoring for the 1

Table 6-4. Laboratory Costs: Toxic Pollutant Parameters

	Cost/Sample ($)			# Samples						Total Costs ($)					
	Water	Sediment	Tissue	Water		Sediment		Tissue		Water		Sediment		Tissue	
Parameter				Op 1	Op 2	Op 1	Op 2	Op 1	Op 2	Op 1	Op 2	Op 1	Op 2	Op 1	Op 2
Metals	250	275	275	157	314	84	168	40	110	39,250	78,500	23,100	46,200	11,000	30,250
Pesticides	--	225	225	--	--	84	168	40	110	--	--	18,900	37,800	9,000	24,750
Volatiles	150	--	--	135	270	--	--	--	--	20,250	40,500	--	--	--	--
PAHs	--	175	175	--	--	84	168	40	110	--	--	14,700	29,400	7,000	19,250
Toxicity[a]															
acute	200	400	--	32	64	84	168	--	--	12,800	25,600	67,200	134,400	--	--
chronic	400	--	--	32	64	--	--	--	--	25,600	51,200	--	--	--	--
Total Costs										97,900	195,800	123,900	247,800	27,000	74,250

[a] Assumes two species are tested for acute and chronic toxicity.

Table 6-5. Laboratory Costs: Water Quality and Population Parameters

Parameter	Cost/Sample ($)	# Samples		Total Cost ($)	
		Option 1	Option 2	Option 1	Option 2
Water Quality					
alkalinity	20	36[1]	72[1]	720	1440
hardness	20	36[1]	72[1]	720	1440
nutrients	80	234	936	18,720	74,880
chlorophyll *a*	70	234	936	16,380	65,520
fecal	50	234	936	11,700	46,800
BOD	70	234	936	16,380	65,520
Population					
phytoplankton	300	78[2]	78[2]	23,400	23,400
zooplankton	300	78[2]	78[2]	23,400	23,400
benthic macro.	300	68	136	20,400	40,800
Total	---	---	---	131,820	343,200

[1]Sampled only from upper two segments of Delaware River (i.e., fresh water).
[2]Sampled only three times a year rather than monthly or twice monthly.

Table 6-6. Estimated Field Sampling Costs Assuming Three Separate Sampling Activities

Sample Parameters	Cost/Sampling Location ($)	# Sampling Locations		Total Cost ($)	
		Option 1	Option 2	Option 1	Option 2
Water Quality/Water Column Toxic Pollutants	125	234	936	29,250	117,000
Benthic Macroinvertebrates/ Sediment	250	84	168	21,000	42,000
Fish Population/ Tissue Residue	300	132	396	39,600	118,800
Total	---	450	1,500	89,850	277,800

Table 6-7. Estimated Field Sampling Costs Assuming All Parameters Are Collected During Water Quality Sampling

Sample Parameters	Cost/Sampling Location ($)	# Sampling Locations		Total Cost ($)	
		Option 1	Option 2	Option 1	Option 2
Water Quality/Water Column Toxic Pollutants; Benthic Macroinvertebrates/ Sediment; and Fish Population/Tissue Residue	500	84	168	42,000	84,000
Water Quality/Water Column Toxic Pollutants and Fish Population/Tissue Residue	300	48	228	14,400	68,400
Water Quality/Water Column Toxic Pollutants	125	102	540	12,750	67,500
Total	---	234	936	69,150	219,900

Table 6-8. Estimated Total Costs

Sampling Alternative	Option 1			Option 2		
	Field Cost ($)	Lab Cost ($)	Total Cost ($)	Field Cost ($)	Lab Cost ($)	Total Cost ($)
All samples taken during water quality sampling	69,150	380,620	449,770	219,900	861,050	1,080,950
Three separate sampling activities	89,850	380,620	470,470	277,800	861,050	1,138,850

Delaware Estuary. Ongoing monitoring programs such as those of EMAP, DNREC, DRBC, the states, and other organizations might be realigned and integrated to accomplish most of the sampling activities proposed in this plan without a significant increase in costs.

CHAPTER 7
HABITAT

The Delaware Estuary is composed of a variety of habitat types, ranging from open water areas to wetlands. This variety of habitat supports numerous plant, fish, and wildlife species. The continued health and biological diversity of the estuarine system is dependent on the maintenance of varied and abundant high-quality habitat, particularly wetlands, because most bay species depend on wetland habitats during some portion of their life cycle. Thus, the Delaware Estuary Program has identified habitat quantity and quality as an issue of concern to be addressed in the Delaware Estuary Program Regional Monitoring Plan.

Habitat protection is best carried out from a broad ecosystem perspective to ensure that an optimal variety and distribution of habitats are protected and that needed physical and hydrologic connections between adjacent habitats are maintained. During the October 1993 DELEP Monitoring Strategy Workshop, the Habitat Workgroup identified four overreaching habitat-related issues:

- **Habitat Diversity.** The determination of the diversity of habitat types throughout the Delaware Estuary or portions of the estuary is important to the understanding of the critical processes of the estuary.

- **Status and Trends.** Assessing the current status or condition of the habitat and trends or changes in that condition over time is an issue that is linked closely with living resources.

- **Connectivity to Other Habitats.** Utilization of various habitat for the different life stages of organisms and various functions requires that connectivity among habitats be maintained.

- **Biotic Population Dynamics.** The health or condition of the species composing and utilizing the habitat type needs to be assessed by monitoring the living resources.

This chapter presents information directed at those monitoring objectives identified as priority by the Habitat Workgroup, which include the spatial extent, the physical quality and integrity, and the biological associations of the estuarine habitat. It provides general suggestions on appropriate data-gathering procedures, habitat classification terminology, and recommendations on the frequency of collection.

MONITORING OBJECTIVES

The Habitat Workgroup identified the following monitoring objectives necessary to characterize the structure and function of the habitat of the Delaware Estuary. The associated information needs relate to the specific elements of the objectives that would be monitored.

- Determine the areal extent of habitat structure.
  Information needs: quantity (acres, square miles, etc.) and specific criteria for habitat typing.

- Document the extent of fragmentation of critical habitat due to human activities.
  Information needs: size of habitat type, shape of habitat type, distribution in and around the Delaware Estuary.

- Evaluate the viability of connectivity within habitat types.
  Information needs: dispersal and reproductive mechanisms for maintenance of targeted species.

- Document the species composition (fauna and flora) of the habitat structure.
  Information needs: percent composition, assemblage relationships.

- Determine the substrate characteristics as they pertain to habitat structure.
  Information needs: particle size, chemistry, percent composition.

- Characterize the hydrological elements that influence particular habitat types.
  Information needs: frequency of inundation/saturation, period of inundation/saturation, depth of inundation/saturation.

- Document various physicochemical determinants of habitat structure such as salinity, dissolved oxygen, temperature, pH, and nutrients.
  Information needs: salinity regime, water quality measurements, toxic pollutants/ nutrients measurements.

To address the monitoring objectives effectively, the relationship between land use patterns and the quality of the habitat structure needs to be determined, particularly for parameters related to fragmentation and connectivity. For connectivity issues, there should be support for compilation of ecological literature documenting or providing information on habitat requirements of living resources.

Losses of aquatic vegetation acreage in an area of particular concern might be the compelling reason for the evaluation of habitat within the estuary. The primary sources of this information are maps, aerial photography, and remote sensing. Aerial photography or remote sensing can measure changes in acreage, cover types, drainage, configuration, and other spatial parameters related to overall habitat condition and health. If resources are limited, the monitoring program might involve only an assessment of the aerial extent of wetlands. If more resources are available and it is decided that a functional assessment will be undertaken, the researcher must decide which functions are of greatest interest in the area of study or which will provide the most information concerning habitat attributes perceived to be of greatest value to the area.

The most important characteristics of habitat as identified by the Habitat Workgroup include areal extent, fragmentation, connectivity, species composition, substrate characteristics, hydrology, water quality, toxics, and salinity. The relationship between each of these monitoring objectives and various habitat types is presented in Table 7-1. Only a subset of the objectives will pertain to any one habitat type. Therefore, the monitoring of the structure and function of habitat will require a different mix of methods for individual habitat types.

MEASUREMENT PARAMETERS

Specific measurement parameters are identified for each of the monitoring objectives. These parameters are the basis for monitoring habitat characteristics in the Delaware Estuary (Table 7-2). Of the objectives identified by the Habitat Workgroup, only connectivity would be difficult to monitor on a regular basis because the measurement parameters for this objective are not well-defined. The measurement of connectivity requires an ecological assessment of the dispersal and reproductive mechanisms for maintenance of targeted habitat species and assemblages. This type of assessment might best be considered as part of the living resource assessment, where certain features of the habitat are considered as biological indicators. Although physicochemical parameters such as salinity, dissolved oxygen, temperature, pH, and nutrients, as well as toxic pollutants, are important determinants of habitat structure, these parameters would be measured as part of the general water quality and toxic pollutant assessment.

Areal Extent of Habitat Structure

Biological resources, as well as physical and hydrological processes, are influenced by the amount of coverage of different habitat types in the estuary. How the different habitat types are to be classified can be related back to the breakdown developed by the Delaware Estuary Habitat Task Force (in Table 7-1). However, for the broad-scale monitoring at which this objective is targeted, resolution might be more appropriate if the categories of habitat are more coarse. Day et al. (1989) present the physical and biological characteristics of an eight-category classification (*their* Table 1.1) that encompasses all of the Task Force habitat types with the exception of "coastal plain intermittent pond" and "terrestrial" (Table 7-3).

Some data related to habitat characterization can be collected via remote sensing, whereas others are best gathered onsite by measurement or observation simultaneously with other sampling efforts. Areal extent of habitat structure, expressed in terms of square miles, hectares, or acres, is best measured by quantity determinations from aerial photography or satellite remote sensing. The habitat nomenclature or classification most likely to be useful for describing these types of data is related to broad-scale terminology such as that presented as tier 1 in Table 7-3. Some of the habitat types in tier 2 can be considered a mixture of intermediate and broad-scale terminology. Remote sensing provides reliable documentation of the extent of open water and of wetlands, though it might not be able to give a depth profile of the channel or the species composition of wetlands vegetation.

Table 7-1. Relationship Between Monitoring Objectives and Habitat Types

Habitat Types		Area	Fragmen.	Connect.	Species Compos.		Substrate Charac.	Hydrology	WQ & Toxics	Salinity
					Fauna	Flora				
Estuarine	Open Water			✓	✓			✓	✓	✓
	Sublittoral	✓	✓			✓	✓	✓	✓	✓
	Sandy Beaches	✓			✓		✓			✓
	Mud Bar & Mud Flat	✓			✓		✓		✓	✓
	Benthic Substrate	✓			✓		✓		✓	✓
	Salt/Brackish Marsh	✓	✓	✓		✓	✓	✓	✓	✓
	FW/Tidal Marsh	✓	✓	✓		✓	✓	✓	✓	
Palustrine	Palustrine Submerged Aquatic	✓	✓			✓	✓	✓	✓	
	FW Nontidal Marsh	✓	✓	✓		✓	✓	✓	✓	
	Scrub-shrub Wetlands	✓	✓	✓		✓	✓	✓	✓	
	Coastal Plain Intermittent Pond	✓	✓	✓		✓	✓	✓	✓	
	FW Swamp	✓	✓	✓		✓	✓	✓	✓	
	Riverine Substrate	✓					✓		✓	
Terrestrial	Oak/Pine	✓	✓	✓		✓	✓			
	New field/grassland	✓	✓	✓		✓	✓			
	Mesic Mixed Forest	✓	✓	✓		✓	✓			
	Scrub/shrub	✓	✓	✓		✓	✓			
	Evergreen Forest	✓	✓	✓		✓	✓			
	Old Field	✓	✓	✓		✓	✓			

Table 7-2. Measurement Parameters of the Habitat Monitoring Methods

Elements (From Objectives)	Information Needs	Measurement Parameters
Area	quantity (acres)	areal extent
	specific criteria for typing	composition
Fragmentation	size of habitat type	areal extent
	shape of habitat type	configuration
	distribution	mapping
Connectivity	dispersal mechanisms	dispersal mechanisms
	reproductive mechanisms	reproductive mechanisms
Species Composition	percent composition	faunal composition and abundance
	assemblage relationships	floral composition and abundance
Substrate Characteristics	particle size	particle size
	chemistry	pH organic composition toxics dissolved oxygen salinity
	percent composition	grain size composition
Hydrology	frequency of inundation/saturation	frequency
	period of inundation/saturation	period
	depth of inundation/saturation	depth
Water Quality and Toxics	salinity regime	salinity
	water quality	dissolved oxygen temperature pH
	toxics/nutrients	toxics nutrients

Table 7-3. Two Tiers of Habitat Classification that Can Be Considered of Relatively Broad-Level Specificity (Tier 1) and Intermediate-Level Specify (Tier 2).

Habitat Classification (Day et al., 1989) (Tier 1)	Habitat Types (Habitat Task Force) (Tier 2)
High Physical Energy Areas	Sandy Beaches Mud Bar and Mud Flats Benthic Substrate
Mid-Estuarine Systems: Middle Salinity Plankton -Nekton System	Open Water
Mid-Estuarine Systems: Deep Benthos	Benthic Substrate Riverine Substrate
Shallow Littoral Areas: Submerged Grassbeds	Sublittoral Benthic Substrate Palustrine Submerged Aquatic
Shallow Littoral Areas: Algal Mats	Open Water Sublittoral Mud Bar and Mud Flats Benthic Substrate
Wetlands	Salt/Brackish Marsh Freshwater Tidal Marsh Freshwater Nontidal Marsh Scrub-Shrub Wetlands Freshwater Swamp
Reefs, Worm, and Clam Flats	Sublittoral Benthic Substrate Mud Bar and Mud Flats
Oligohaline	Open Water Riverine Substrate
no related categories	Coastal Plain Intermittent Pond
no related categories	Terrestrial (All Types)

Note: Additional Physical Descriptors are Necessary for More Specific Habitat Characterization.

Extent of Critical Habitat Fragmentation

Fragmentation is defined as "the breakup of an extensive ecosystem into a number of smaller patches" (Leibowitz et al., 1992). These patches can be presented as a classification of ecosystem patches (Forman and Godron, 1981; 1986, as cited in Leibowitz et al., 1992) defined as follows:

A. **Environmental resource patches**—normal components of a heterogenous environment.

B. **Ephemeral patches**—transient patches that occur from normal, short-term fluctuations.

C. **Spot disturbance patches**—result from small-scale disturbances within the landscape matrix.

D. **Introduced patches**—result from anthropogenic disturbances either intentionally or accidentally.

E. **Remnant patches**—the opposite of spot disturbances; occur when a large disturbance happens, reducing the natural landscape (background matrix) to patches.

Sullivan et al. (1991) suggested that there had been relatively little degradation of the Delaware Estuary tidal wetlands due to fill activities conducted to benefit residential or industrial development. However, most records they located showed fragmentation in the form of substantial alteration of wetlands integrity by channelization and impoundment. These were done to provide mosquito control capacity and habitat for migratory waterfowl and other wildlife.

Data on habitat fragmentation should be considered as complementary to those discussed in the previous section on areal extent and could probably be evaluated using the same methods and printed images. Evaluation of habitat fragmentation will necessarily have a primary focus on a more restricted set of habitat types, specifically, wetlands, riparian vegetation (width and length of vegetated buffer zones), and extent of intact (or undeveloped) shoreline. To increase the accuracy of habitat fragmentation estimates, the critical separation distance between two habitat segments should be decided; for example, if the distance considered an indicator of fragmentation is narrower than a pencil lead (depending on the scale of the image), these critical features might not necessarily be detected. Likewise, separation of habitat segments might be natural and would need to be determined through examination of the imagery. The same terminology as discussed under "areal extent" should be used to document fragmented habitat, but fragmented habitat should also be characterized by the above patch descriptors.

Viability of Connectivity Within and Among Habitat Types

Offsite populations of organisms represent the pool of biological resources that can potentially recolonize areas where a species might have become locally extinct (MacArthur and Wilson, 1967; Leibowitz et al., 1992). The ability of plants and animals to act as "recolonizers" is dependent on a number of factors, including:

- Dispersal ability
- Reproductive capacity
- Adaptability to variable habitat conditions
- Distance between habitat patches

All organisms have a home range that can restrict the ability of individuals of a species to "locate" new, suitable habitat in the event that their present habitat becomes physically or chemically degraded. The smaller the present range of a species, the more critical the patch size, shape, and distance from other patches become to that species (Peters, 1988; Pulliam et al., 1992). Individuals of that species might not be able to disperse the distance required to find suitable habitat if the patches are small and have wide distances between them. The ability of a species to colonize new habitats is also dependent on the number of individuals that emigrate from the parent population; the more that emigrate, the higher the probability that colonization will occur.

To determine the minimum critical size of a habitat patch for maintaining the existence of a species, it is necessary to know habitat suitability requirements for individual species (Hansen et al., 1993). Thus, it is necessary that, for this monitoring objective, critical habitat characteristics and configuration are associated with targeted species identified as economically or ecologically important to the Delaware Estuary. Once these associations have been made by assembly of literature related to the ecology of the species, judgments on the viability of habitat connectivity can be made from the remote sensing habitat characterizations of other objectives described above.

Species Composition (Fauna and Flora) of the Habitat Structure

For each of the sampling stations randomly selected as described in Chapter 3, both biological characteristics and specific parameters of plant community structure should be collected. Faunal characteristics should be documented as described in Chapter 3; vegetative composition should also be collected based on *type of vegetation* (herbaceous, nonvascular; submerged, floating, or emergent aquatic vegetation; algae) and *species composition*. The latter would require a sampling crew member with experience in the taxonomy of wetland and aquatic plants.

No site-specific sampling of wetland or terrestrial fauna or flora is recommended as part of this regional monitoring plan. Such sampling should be conducted as part of research, compliance, remediation/mitigation, or other site-specific purposes.

Substrate Particle Characteristics Related to Habitat Structure

Substrate particle data can be easily collected by analysis of substrate that is retrieved by the van Veen grab sampler during benthic macroinvertebrate sampling. The invertebrate subsamples are to be taken back to the laboratory for sorting and analysis. It is recommended that another portion of the composited grab sample be retained for sediment particle size analysis in the laboratory. The Wentworth grade classification scheme (USGS, 1977-1984) should be used for classification of randomly selected particles. From these data, it would be possible to calculate percent composition of sample by, for example, coarse sand (0.5-1.0 mm diameter). Cumulative distribution frequency is used for describing dominant particle sizes in streams (Rosgen, 1993 [in review]) with designations such as "D75 = coarse sand," meaning that 75 percent of the particles are equal to or smaller than 0.5 mm in diameter.

The Habitat Workgroup also suggested that analyses be performed to provide data on sediment chemistry. These data can also be obtained from sediment samples taken during benthic macroinvertebrate sampling.

Characterization of Hydrological Elements that Influence Particular Habitat Types

Factors identified by the workgroup as important were hydrological influences on different habitats. Specific information needs were the frequency, duration, and depth of inundation or saturation. For tidal habitats, much of this information will be available from the U.S. Geological Survey (USGS) and The National Oceanic and Atmospheric Administration (NOAA). These hydrological data should be associated with both broad and more specific habitat types, using the same terminology as that discussed earlier (Table 7-1).

Physicochemical Determinants of Habitat Structure

The Habitat Workgroup identified several measures of water physicochemical measurements that should be addressed because of their potential for affecting the suitability of habitat for biological colonization. These parameters are salinity, dissolved oxygen, temperature, pH, nutrients, and toxic pollutants, and most will be measured as part of the water quality and toxic pollutants portions of this monitoring plan (Chapters 4 and 5, respectively).

SAMPLING LOCATION AND FREQUENCY

The delineation and characterization of habitat would extend over the entire Delaware Estuary. Habitat mapping, of which much is available in historical data sets, would be done as a single, intensive effort. Subsequent monitoring would be targeted to specific habitat types or would monitor changes over time with changes in land use patterns or perturbation sources. Techniques that include aerial photography, satellite imagery, and mapping would be used to cover broad geographical areas, whereas ground-truthing techniques (i.e., the use of transects and quadrants) would focus on specific habitat locations. A suggested frequency of habitat sampling is presented in Table 7-4.

COSTS

As mentioned previously, data necessary to address six of the seven habitat monitoring objectives identified by the Habitat Workgroup at the 1993 DELEP Monitoring Strategy Workshop can be acquired during sampling for the other resource areas (i.e., living resources, water quality, and toxic pollutants) or through the acquisition of existing data (i.e., USGS and NOAA tide data), and thus the additional costs associated with acquiring these data should not be significant. However, relatively significant costs could be incurred in obtaining data to address the seventh objective: determining the areal extent of habitat structure.

Satellite imagery and aerial photography represent two primary sources of data used for surface and distributed mapping. The processes for obtaining land use data from these sources are very different. Compiled in a digital format, satellite imagery is processed and classified into a digital product representing the target land feature categories. Under current technologies that are commercially available, satellite imagery probably does not provide the resolution required for conducting habitat areal assessments. However, as improved technologies become commercially available and demands increase, habitat data derived from satellites should become more attainable. As a result, it might be necessary to revise the alternatives presented in this report to reflect commercially available technologies.

Table 7-4. Frequency of Habitat Sampling

Habitat Elements	Frequency of Sampling
Areal extent	once every 5 years
Fragmentation	once every 2 years
Connectivity	once every 2 years
Species composition	annually (index period) commensurate with biological collections
Substrate characterization	annually (index period) commensurate with biological collections
Hydrology	annually (index period) based on USGS and NOAA data
Water quality and toxic pollutants	annually (index period) commensurate with water quality and toxic pollutant collections

Obtaining digital land use data from aerial photographs involves data acquisition, analysis, data transfer, and digitization. Aerial photographs can be acquired from existing sources or generated by contracting overflights. Analysis involves the delineation of land use based on a classification system and the application of minimum mapping rules. Data transfer and digitization include the process of moving land use delineation data from the aerial photographic base to a digital format. This process can be achieved using a variety of methods and technologies.

Land use delineations at a habitat scale require larger-scale photography and specialized analysis. Habitat-level analysis should be conducted using at least 1:24,000 scale or larger (ex. 1:12,000) color infrared photography (CIR). Aerial photography at 1:24,000 scale or larger can be obtained through the USGS's ESIC or contracted overflights. There are cost advantages to obtaining pre-existing aerial photography (Table 7-5); however, at larger scale ranges, the coverage may be incomplete and selection limited. Although contracting overflights to obtain aerial photography is expensive when compared to using pre-existing sources, contracting overflights has some advantages: complete coverage, user-specified scale, and controlling the time of year.

Coverage cost calculations are based on an estimated 180-mile flight line distance. Stereographic coverage at 1:24,000 scale (9x9 inch frame size) with 60 percent forward overlap is approximately 2 miles per frame. Coverage of a 180-mile flight line would require approximately 90 frames. Stereographic coverage at 1:12,000 scale (9x9 inch frame size) with 60 percent forward overlap is approximately 1 mile per frame. Coverage of a 180-mile flight line would require approximately 180 frames.

Table 7-5. Approximate Cost of Aerial Photography Acquisition for Habitat Scale Mapping Effort.

Source	Film Type	Format	Scale	Cost/ Frame	Cost/Target Area
USGS/ESIC	CIR[1]	9x9 in	1:24,000	$24	$2,160
USGS/ESIC	CIR[2]	9x9 in	1:24,000	$16	$1,440
Contract Overflight	CIR[1]	9x9 in	1:24,000	$75	$6,750
USGS/ESIC	CIR[1]	9x9 in	1:12,000	$24	$4,320
USGS/ESIC	CIR[2]	9x9 in	1:12,000	$16	$2,880
Contract Overflight	CIR[1]	9x9 in	1:24,000	$75	$13,500

[1]Film positive product (recommended over paper print product).
[2]Paper print product.

Chapter 8
Land Use/Land Cover

A knowledge of land use and land cover is important for meeting many planning and management activities within the Delaware Estuary basin. As for other types of monitoring programs, land use/land cover monitoring provides quantitative information necessary for evaluating the current status and the spatial and temporal trends and changes in land use/land cover patterns. Specifically, monitoring changes in land use/land cover pattern (e.g., urban, agriculture, etc.) provides data necessary for assessing potential impacts on the estuary resources including water quality, habitat, and living resources. In addition, land use/land cover monitoring at a watershed or regional scale allows the assessment of various socioeconomic demands.

With the new technological advances in representing and processing spatially distributed data, the geographic information system (GIS) is becoming the main framework for organizing land use/land cover monitoring information. The GIS provides users with the ability to overlay multiple types of data layers, such as land use, soils, and topography. The use of overlays can greatly enhance the planning and management recommendations that can be anticipated from land use/land cover monitoring. In fact, during the 1993 DELEP Monitoring Strategy Workshop, the Land Use Workgroup strongly recommended the use of GIS for land use monitoring to support the Delaware Estuary Program. Furthermore, Delaware, Pennsylvania and New Jersey are in the process of developing statewide GIS layers that include land use/land cover distributions. These layers cover the entire river basin draining to the Delaware Estuary.

Major technical considerations faced by GIS users, especially when dealing with mapping data layers, include (1) the areal extent of the coverage; (2) the mapping resolution, accuracy, and scale; and (3) the classification of the features to be mapped and represented on GIS layers. These considerations need to be resolved based on the intended uses of the coverage and the time and resources that can be allocated to the development of the coverage.

The land use monitoring program for the Delaware Estuary should document the current status, enable detection of both the temporal and spatial changes in land use/land cover patterns, and support DELEP managers in addressing land use/land cover concerns identified by the Land Use Workgroup at the 1993 Workshop. These concerns are presented below in order of priority:

- Protection of critical and sensitive areas

- Growth and development

- Pollutant loadings and NPS pollution
- Population and economic trends and indicators
- Protection of water supplies

This chapter summarizes the results and recommendations of the Land Use Workgroup and presents several monitoring options available to the Delaware Estuary Program.

MONITORING OBJECTIVES

To address the land use/land cover concerns identified by the Land Use Workgroup and to measure progress in achieving many of the DELEP objectives, data from monitoring land use/land cover in the estuary basin are needed. Therefore, the land use/land cover monitoring program should allow for assessing the spatial and temporal distribution of specific land uses/land cover by allowing (1) delineation and quantification of relevant indicators (land use features) and (2) assessment of changes of these features over time.

The Land Use Workgroup identified the following specific monitoring objectives and associated information needs:

- Document changes in critical and sensitive habitat.
  Information needs: location and boundary delineation of wetlands (saltwater and freshwater), forest areas, riparian lands, streams, rivers, lakes, beaches, dunes, and floodplains.

- Document changes in growth, development and land use patterns.
  Information needs: existing land use patterns (high- and low-density residential, commercial, industrial, agricultural) particularly for waterfront areas, public access routes, abandoned urban areas, or other areas that might be targeted for redevelopment including farmland.

- Assess pollutant loadings and nonpoint source pollution.
  Information needs: location of land privately and publicly owned, areas of tax base increase, impervious surfaces and other parameters necessary for water quality studies, sources of pollution (i.e., targeted "hot spots"), and sources of pollutants of concern such as heavy metals, nutrients, and toxics from pesticide uses and other land use activities.

- Document population and economic trends and indicators.
  Information needs: population numbers and spatial information, quantity and location of housing starts, job market and employment area changes, unemployment rates, land use/land cover changes over a specific interval of time, economic growth indices, and sectorial analysis.

- Document changes in water supply and demand. This issue was not discussed by the Land Use Workgroup due to time limitations.

MONITORING APPROACHES

Each of the states in the Delaware Estuary basin has land use/land cover information; however, there are temporal and spatial differences from state to state. Delaware has 1984 land use/land cover data digitized at a 1:63,360 scale. The maps are being updated by the Delaware Department of Agriculture based on 1994 information. New Jersey has maps that have not been digitized based on information from 1975 to 1978. They are at a scale of 1:63,360, and there are no plans for updating. The cost is $3.00 to $5.00 for the base maps and $3.00 per overlay. Pennsylvania information (digitized) is available from the USGS. The maps are based on information from 1972 to 1978 and are at a scale of 1:250,000. The cost is $2.50 to $4.00 per map. USGS has 1:250,000 scale land use/land cover maps available for $2.50 to $4.00 each. Dates range from 1972 to 1978, and there are no plans for updating the information. USGS land use/land cover and digital elevation maps can be downloaded through INTERNET for free.

The best way to monitor changes in land use/land cover is to obtain or generate digitized land use/land cover information. With digitized land use/land cover information, changes from one data set to the next can be compared and changes indicated. For example, if the land use/land cover information for the watershed is digitized in 1990 and again in 1995 (using the same land use/land cover classification code), changes in land use/land cover densities can be noted.

Satellite imagery and aerial photography are two primary sources of digitized data used for land use/land cover mapping. The processes for obtaining land use/land cover data from these sources are very different. Compiled in a digital format, satellite imagery is processed and classified into a digital product representing the target land use/land cover categories. Considering current technologies and conditions, obtaining, processing, and classifying satellite imagery is becoming a viable option for monitoring the status and trends of land use/land cover patterns.

Obtaining digital land use/land cover data from aerial photographs involves data acquisition, analysis, data transfer, and digitization. Aerial photographs can be acquired from existing sources or generated by contracting overflights. Analysis involves the delineation of land use/land cover based on a land cover classification system and the application of mapping rules. Data transfer and digitization include the process of moving land use/land cover delineation data from the aerial photographic base to a digital format. The approach recommended by the Land Use Workgroup for managing land use/land cover data and for producing overlay maps is through the use of a geographic information system (GIS).

As an option, a relatively low-cost way to monitor habitat, land cover, and land use changes basin-wide is to monitor a small, statistically representative portion of the study area. The selected area coverage can be from randomly selected sample areas (one or more from geographically stratified segments of the study area). These data can be obtained from sources such as subdivision and site plan documents filed with county and local government agencies. Typically, these are relatively large-scale plans showing lines of demarcation between totally disturbed, partially disturbed, and undisturbed areas. Most plans are in a digitized format. Changes in land use can then be extrapolated throughout the watershed.

Document Changes in Critical and Sensitive Habitat

Documenting changes in critical and sensitive habitats involves assessing the spatial and temporal distribution of specific habitats by (1) delineation and quantification of these habitats (e.g., wetlands, forests, riparian areas, beaches, floodplains, etc.) and (2) assessment of changes in these features over time. The types of changes that should be looked for include changes in areal extent, fragmentation, connectivity, species composition, and substrate characteristics. (See Chapter 7 for further discussion on habitat monitoring considerations.) Data acquisition methods include aerial photographs, satellite imagery, and field crews. Habitat level analysis should be conducted using at least 1:24,000 scale or larger (1:12,000) color infrared photography (CIR). Aerial photography at 1:24,000 scale or larger can be obtained through the USGS's Earth Science Information Center (ESIC) or contracted overflights. Although there are cost advantages to obtaining pre-existing aerial photography, at larger scale ranges the coverages can be incomplete and selection limited. Contracting overflights to obtain aerial photography is expensive when compared to using pre-existing sources; however, complete coverage, user-specified scale, and controlling the time of season are some of the advantages of contracting overflights. Approximate costs for aerial photography acquisition for habitat scale monitoring are summarized in Table 7-5.

Document Changes in Growth, Development, and Land Use Patterns

Documenting changes in growth, development, and land use patterns involves delineation and evaluation of temporal changes in land use patterns. For purposes of documenting the land use pattern changes in the Delaware Estuary, it is recommended that the analysis be performed using at least a 1:40,000 scale or larger. The approximate costs for the aerial photography are summarized in Table 8-1.

Costs are based on a study area coverage estimate of 110 7.5-minute quadrangle maps. The number of frames needed to provide stereographic coverage for a 7.5-minute quadrangle (10 frames) was obtained from National Aerial Photography Program (NAPP) literature. Coverage is based on 60 percent front overlap and 30 percent side overlap between frames. At this time, New Jersey and Delaware are creating land use maps from 1:24,000 base maps. New Jersey is using a 2.5-acre minimum map unit.

In addition to creating a land use/land cover layer for incorporation into a GIS, additional layers should be integrated into the GIS. These layers are summarized in Tables 8-2 and 8-3. In addition to the attributes listed in Tables 8-2 and 8-3, existing land uses and future uses should be located and digitized using local zoning maps and comprehensive plan maps. Presented below are four general options for obtaining land use/land cover data for the Delaware Estuary. The costs associated with developing and maintaining a GIS will vary depending on the number of layers included in the system and the level of detail desired.

<u>Option 1.</u> Use available land use/land cover data supplied by Delaware, Pennsylvania, and New Jersey. Due to differences in the state programs, temporal continuity and uniformity of classification between data sets cannot be ensured. Therefore, meaningful land use/land cover change comparisons might be restricted to each state. Reducing cost is the main advantage of using available data.

Table 8-1. Approximate Cost of Aerial Photographic Acquisition

Source	Film Type	Format	Scale	Cost/ Frame	Cost/7.5 Quad	Cost/ Study Area
NAPP/ESIC	CIR[1]	9x9 in	1:40,000	$24	$240	$26,400
NAPP/ESIC	CIR[2]	9x9 in	1:40:000	$16	$160	$17,600
Contract Overflight	CIR[1]	9x9 in	1:40,000	$75	$750	$82,500

[1]CIR: color infrared photography. Film positive product (recommended over paper print product).
[2]Paper print product

Option 2. Use aerial photography from NAPP. NAPP objectives include providing a complete coverage of the conterminous United States and updating this database on a 5-year cycle. NAPP photographic products can be obtained through the USGS's ESIC. This option would establish a single classification system for the study area and allow for updating land use/land cover at 5-year intervals. Current available NAPP coverage includes Delaware (1988, 1989), Pennsylvania (1987, 1988), and New Jersey (1991, 1992). The disadvantages of this option would include acquisition, analysis, data transfer, and digitization costs and difficult temporal comparisons between states.

Option 3. Use satellite information (e.g., Landsat data) to digitize land use/land cover distribution in the Delaware Estuary. The advantages of this option include (1) homogeneous land use/land cover data layer (same classification, resolution, and scale); (2) homogeneous land use/land cover coverage data; and (3) as technology advances, possible significant reduction of costs associated with this option.

EPA's Office of Research and Development (ORD) is planning to make 1991 Landsat Thematic Mapper scenes available to EPA Regions 2 and 3. The resolution of the data set is only 30 meters, but Regional staff can use it as a base for further classification. The data set will provide an aerially consistent coverage for the entire estuary region within a few years.

Option 4. Contract overflights to obtain aerial photography. Contracting overflights is expensive when compared to obtaining pre-existing aerial photography. However, contracting overflights to obtain aerial photography provides complete coverage, user-specific scale, and control over the season in which data are acquired.

Assess Pollutant Loadings and Nonpoint Source Pollution

Pollutant loadings and nonpoint source pollution can be assessed by incorporating water quality and watershed modeling into a GIS. Information needs include land use, land use density,

Table 8-2. Series 2 database model (after Tetra Tech, 1993).

Data Layers	Major Map Features	Feature Types	Major Tabular Attributes
Core Base Map			
Survey Control	Control points	Point	Coordinate Values
	State plane coordinates	Point	SPC values
	Lat/Long coordinate lines	Line	Lat/Long coordinate values
Transportation	Interstate highways	Network	Highway #, Mile #
	Primary road network	Network	Road number, Mile #
	Railroads	Network	Railroad Name, Mile #
Political / Administrative Boundaries	Municipal and county boundaries	Polygon	City/County Name
	Legislative and Congressional districts	Polygon	District number
	State and Federal lands boundaries	Polygon	Name, area, usage
Hydrography	Primary rivers	Network	Name, Mile #
	Major reservoirs/lakes	Polygon	Name, Area
	Major aquifers	Polygon	Name, Area
Topography	DEM	3D	Elevation
	Spot elevation	Point	
Custodial Thermatic Databases			
Transportation	Secondary road network	Network	Mile #, Road #
Hydrography	Secondary rivers and streams	Network	Name
	Minor aquifers	Polygon	Name, area
Political / Administrative Boundaries	GLO boundaries	Polygon	Tract #, document #
	OTLS	Polygon	Tract #, document #
Energy Transmission Features	Hazardous liquid pipelines	Network	Operator, product, dimension
	Natural gas pipelines	Network	Operator, product, dimension
Land Cover / Land Use	Agricultural areas	Polygon	Agriculture type, code, acreage
	Commercial areas	Polygon	
	Residential areas	Polygon	Area name, area #
	USFWS Wetlands	Polygon	Name, classification
	Floodplains		
	Floodprone areas	Polygon	Soil types, names
Well Locations	Oil wells	Point	Well Name, owner, capacity
	Gas wells		
	Water wells		

Table 8-2. (continued).

Data Layers	Major Map Features	Feature Types	Major Tabular Attributes
Land Cover / Land Use	Agricultural areas	Polygon	Agriculture type, owner, acreage
	Commercial areas	Polygon	
	Residential areas	Polygon	Area name, area #
	Waste disposal sites	Point, Polygon	Site name, waste type, volume
	USFWS Wetlands	Polygon	Name, classification
Surficial Geology / Soils	Soil boundaries	Polygon	Soil types, code
Floodplains	Flood prone areas	Polygon	Area
Well Locations	Oil wells	Point	Well Name, owner, capacity
	Gas wells		
	Water wells		
Environmental Features	Forestry areas	Polygon	Type, name
	Protected wetlands	Polygon	Wetland name, depth, volume
Incidents / Point Features	WQ Sampling points	Point	Code or name, type
	Hazardous waste storage/ processing sites	Point	
	Contamination sites	Point	
	Industrial solid waste site	Point	
	Municipal landfills	Point	
	Wastewater outfalls	Point	
	Water rights diversion	Point	
	Petroleum storage tanks	Point	
Historical / Archaeological Features	Histrorical sites	Point, Polygon	Site name, area, age
	Archaeological sites	Point, Polygon	
Recreational Facilities	Recreational areas	Polygon	Area, park, or course name
	Parks	Polygon	
	Golf courses	Polygon	
Biological Distribution	Wildlife areas	Polygon	Wildlife category, species code
Demography	TIGER centerlines	Network	Address ranges
	Census blocks and tracts	Polygon	Census data, block #, tract #
	ZIP code units	Polygon	ZIP codes

Table 8-3. Series 3 database model (after Tetra Tech, 1993)

Data Layers	Major Map Features	Feature Types	Major Tabular Attributes
Core Base Map			
Survey Control	Control points	Point	Coordinate Values
	State Plane grid	Point/Line	SPC Coordinates
	Lat/Long grid	Line	Lat/Long coordinate values
Transportation	Interstate highways	Network	Highway #, Mile #
	Primary road network	Network	Road number, Mile #
	Railroads	Network	Railroad Name, Mile #
Political / Administrative Boundaries	Municipal and county boundaries	Polygon	City/County Name
	Legislative and Congressional districts	Polygon	District number
Hydrography	Primary rivers	Network	Name, Mile #
	Major reservoirs/lakes	Polygon	Name, Area
	Major aquifers	Polygon	Name, Area
Topography	Index contour	Line	Elevation
	Intermediate contour		
	Index depression contour		
	Spot elevation		
Custodial Thermatic Databases			
Transportation	Secondary road network	Network	Mile #, Road #
	Tertiary road network	Network	Mile #, Road #
Hydrography	Secondary rivers and streams	Network	Name, mile #
	Tertiary rivers amd streams	Network	Name, mile #
	Minor aquifers	Polygon	Name, area
Political / Administrative Boundaries	GLO boundaries	Polygon	Tract #, document #
	OTLS	Polygon	Tract #, document #
Energy Transmission Features	Hazardous liquid pipelines	Network	Operator, product, dimension
	Natural gas pipelines	Network	Operator, product, dimension
	Electric transmission lines	Line	Owner name, ID #
Utility Distribution / Collection	Natural gas lines, major	Line	Main ID number
	Natural gas service area	Polygon	Service name, capacity
	Sewer service area	Polygon	
	Sewer trunk lines	Line	
	Water lines, major	Line	
	Water service area	Polygon	
	Electric service area	Polygon	Company name, customers

Table 8-3. (continued).

Data Layers	Major Map Features	Feature Types	Major Tabular Attributes
Environmental Features	Forestry areas	Polygon	Type, name
	Protected wetlands	Polygon	Wetland name, depth, volume
Incidents / Point Features	WQ Sampling points	Point	Code or name, type
	Hazardous waste storage/ processing sites	Point	
	Contamination sites	Point	
	Industrial solid waste site	Point	
	Municipal landfills	Point	
	Wastewater outfalls	Point	
	Water rights diversion	Point	
	Petroleum storage tanks	Point	
Historical / Archaeological Features	Historical sites	Point, Polygon	Site name, area, age
	Archaeological sites	Point, Polygon	Site name, area
Recreational Facilities	Parks	Polygon	Name, area #
	Golf courses	Polygon	Course name
Biological Distribution	Wildlife areas	Polygon	Wildlife category, species code
Demography	TIGER centerlines	Network	Address ranges
	Census blocks and tracts	Polygon	Census data, block #
	ZIP code units	Polygon	ZIP codes
Meteorology	Precipitation Isolines	Line	Precipitation amount

Geographic Information Systems Business Plan (1992) and land cover; location of land privately and publicly owned; areas of tax base increase; impervious surfaces; sources of nonpoint source pollution (i.e., targeted "hot spots"); areas of land disturbance; sources of pollutants of concern such as heavy metals, nutrients, and toxics; ground water recharge areas; surface waters; wetlands; and other parameters necessary for water quality studies. These data can be obtained from a variety of sources including aerial photographs, various tax base studies, emergency response plans that list locations of toxic materials, permit databases that give locations and descriptions of industrial and commercial activities, comprehensive plans and zoning maps that provide locations of existing and planned land development activities, coastal zone management plans that identify major activities in water front and offshore areas, and regional plans that identify locations of point source dischargers.

Several models and calculation methodologies that incorporate land use information to assess nonpoint source pollution loadings are available and in use in estuaries throughout the United States. Specific details on these and other models and methodologies can be found in *Compendium of Watershed-scale Models for TMDL Development* (USEPA, 1992a). The following are commonly used models that would be appropriate for use in the Delaware Estuary.

- **Generalized Watershed Loading Functions (GWLF).** This computer model calculates point and nonpoint pollutant loads from urban and agricultural watershed through continuous simulation using a daily time step. The model will evaluate the pollutant loading effects of land use changes. Model components include rainfall/runoff assessment and surface water/ground water quality analysis. The model is based on simple runoff, sediment, and ground water relationships combined with empirical chemical parameters. It can be applied to relatively large watersheds with multiple land uses and point sources and can be used to calculate loadings for total and dissolved nutrients (nitrogen and phosphorus) and sediment. The model provides simulation output for annual and seasonal runoff, streamflow, watershed erosion, and sediment yield; annual and seasonal total and dissolved nitrogen and phosphorous loads in streamflow and ground water discharge to streamflow; annual erosion and total/dissolved nitrogen and phosphorous loads from each land use; and annual and seasonal pollutant loadings by land use type and pollution source.

- **Nonpoint Pollution Source Model for Analysis and Planning (NPSMAP).** This computer model calculates wasteload and load allocations for multiple land use watersheds through a continuous simulation using a hourly time step. The model is a spreadsheet-based program that operates within Lotus 1-2-3 using three primary computation modules. The model incorporates point and nonpoint sources in evaluating water quality for nitrogen and phosphorus. Model components include runoff and pollutant loading assessment, simulation of wet detention or wetland system controls for each subbasin or stream segment, snowfall/snowmelt, and irrigation/drainage. NPSMAP can be applied to nonpoint source runoff and nutrient loadings (including surface water storage in reservoirs and wetlands), point source discharges, streamflow, ground water levels, irrigation uses, and water quality. This model lacks sediment evaluation, and the simulation period is limited to 1 year. The model provides simulation output for daily runoff, streamflow, ground water, water quality (loads and concentrations), treatment plant discharges, stream segment load capacities, point source wasteload allocations, and nonpoint source load allocations, bar graphs, statistical summary, probability distributions of runoff and loadings, and nonpoint source runoff and loads.

- **Agricultural Nonpoint Source Pollution Model (AGNPS).** This computer model simulates pollutant loads from agricultural watersheds, performs storm-event and point source simulations, and evaluates BMPs. Model components include rainfall/runoff assessment; water quality analysis (the examination of four pollutants: nitrogen, phosphorus, chemical oxygen demand, and sediment); unsaturated/saturated zone routines; and economic analysis, and linkage to GIS is possible. Water flow is predicted using the unit hydrograph approach, while the SCS curve number is applied to estimate runoff volume. Model applications include surface water flow routing, erosion, and sediment and chemical transport. This model does not handle pesticides; nutrient transformation and instream processes are also neglected. Currently the model examines only a single event and rainfall intensity is not considered. The model provides simulation output for sediment (yield, concentration, and particle size), chemical pollutant concentrations and loads, and hydrology output for storm runoff volume and peak rate.

- **Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS).** This computer model performs simulations on agricultural watersheds with an emphasis on erosion and sediment yield. Model components include rainfall/runoff assessment, overland and channel flow, nutrient and pesticide loading, erosion, and sediment transport and deposition.. The model is based on water movement relationships, event-based particle transport, and a pollutant correlation relating concentration, sediment yield, and runoff volume. ANSWERS can be applied for hydrologic and erosion response of agricultural land or construction sites, identification of critical areas for erosion, and siting and evaluation of BMPs. Pollutants examined are phosphorus, nitrogen, and sediment (some versions include pesticides). This model is limited by the fact that a mainframe computer is needed for large watershed simulations; also, chemical transformations of phosphorus and nitrogen are neglected. Simulation output includes alternative erosion control management practices on the basis of an element or an entire watershed and limited graphic representations.

- **Storm Water Management Model (SWMM).** This model performs continuous and storm event simulation with variable or user-specified time steps for urban stormwater processes. Single, continuous, intermittent, multiple, and diffuse sources/releases can be used. Model components include rainfall runoff assessment, water quality analysis (for ten pollutants including sediment), soil/ground water contamination, and as an option point source inputs. Several modules or blocks are included to model a wide range of watershed quality and quantity processes. This model can be applied for surface water routing, urban watershed analysis, and urban stormwater and combined systems. The model lacks graphics routines, and simulations for water quality and solids transport are weak. The model produces output for time series of flow, stage, and constituent concentration at any point in the watershed; seasonal and annual summaries are also provided.

- **Hydrological Simulation Program (HSPF)**. This model, written in FORTRAN, provides modeling for pollutant loads and water quality in complex watersheds. It also provides simulations for continuous and storm events with single, continuous, intermittent, multiple, and diffuse source/release, in addition to BMP evaluation and design criteria. Model components include watershed hydrology assessment; surface water quality analysis (for seven pollutants: three sediment components, one user-specified pesticide, BOD, ammonia or nitrate, and orthophosphate); pollutant decay and transformation; and soil/ground water contaminant runoff processes. Water quality is simulated by a lumped parameter model. This model can be applied for surface and subsurface pollutant transport to receiving water with subsequent simulation of instream transport and transformations. It is limited to use for well-mixed rivers and reservoirs where extensive water quality sampling has been performed for calibration. The model provides simulation output for time series of the runoff flow rate, water quality, and water quantity and quality at any point in a watershed. It also provides output analysis for frequency and duration of modeling events.

One effective way of controlling nonpoint source pollution is to implement stormwater management planning. This offers a proactive solution to controlling nonpoint sources of pollution. Once sources or potential sources of NPS pollution and estimated loadings are determined, local governments can develop stormwater management regulations and guidelines to ensure the control of nonpoint sources of pollution associated with stormwater runoff. Stormwater management planning can also be implemented in already developed areas through the development of retrofit plans to correct problems with existing stormwater management systems. Good stormwater management plans include such features as open space requirements, minimum stormwater control requirements (e.g., control the runoff from a 2-year/24-hour storm event), and pollution prevention requirements (e.g., minimize fertilizer and pesticide application).

Document Population and Economic Trends and Indicators

Population and economic trends and information can be obtained from a variety of sources, including the U.S. Census Bureau, and from data compiled by local, state, and regional economic development authorities. The types of information that should be available from these sources include population changes over time, areas of growth or depletion, quantity and location of housing starts, temporal and spacial job market changes, unemployment rates, land use changes over specific intervals of time, economic growth indices, and sectorial analysis.

Document Changes in Water Supply and Demand

Changes in water supply demand are affected by temporal and spatial changes in population, number of water-dependent activities and industries, the availability of fresh water, and the level of treatment necessary. Local, state, and regional government authorities involved in supplying municipal water, such as public works department heads and water treatment facility planners, are a good source of trend information regarding fresh-water supplies and demands.

CHAPTER 9
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