# Chesapeake Bay Study

## SUMMARY REPORT



September 1984

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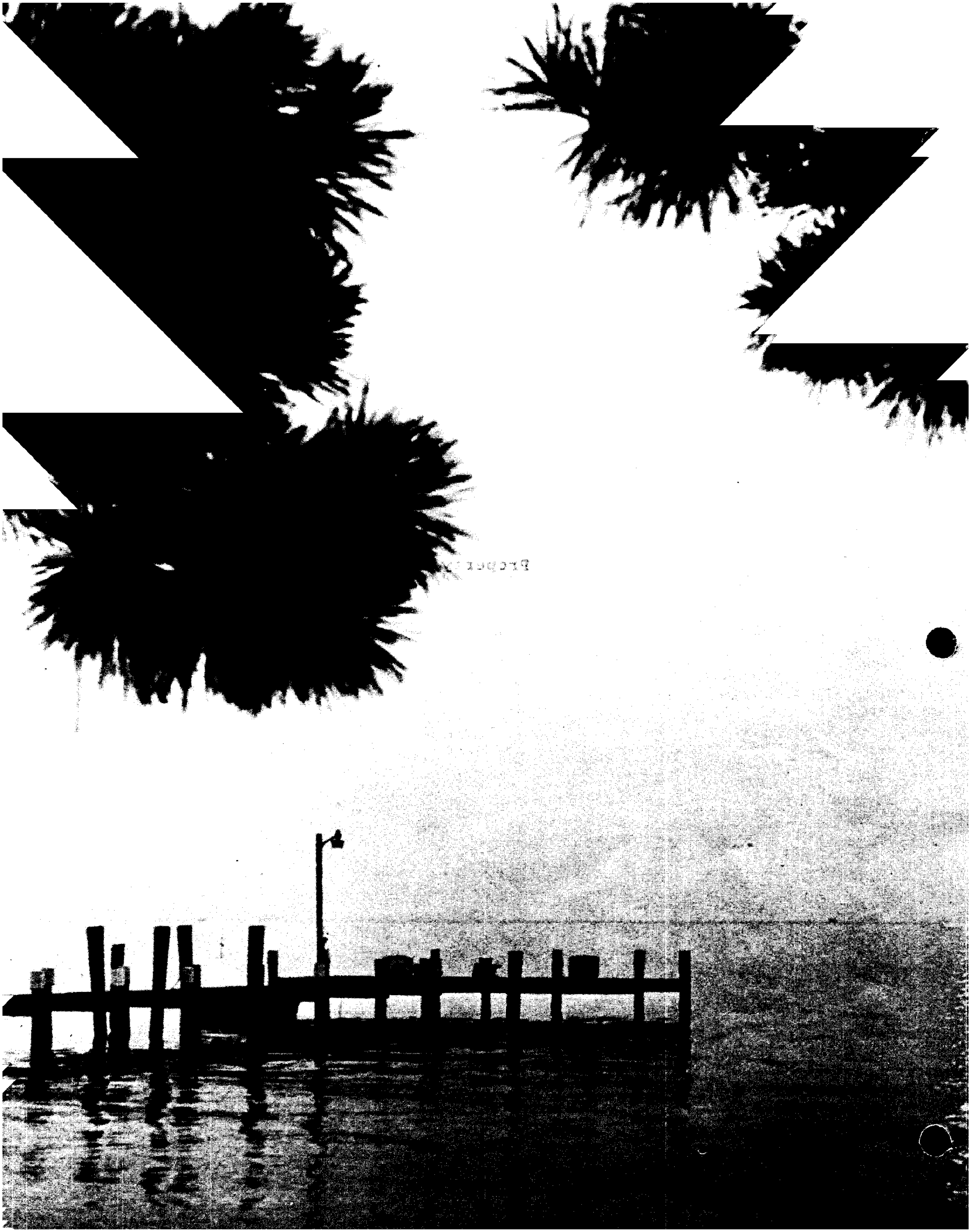
US Army Corps
of Engineers
Baltimore District

September 1984



## FOREWORD

This is one of the volumes comprising the final report on the Corps of Engineers' Chesapeake Bay Study. The report represents the culmination of many years of study of the Bay and its associated social, economic, and environmental processes and resources. The overall study was done in three distinct developmental phases. A description is provided below of each study phase, followed by a description of the organization of the report.

The initial phase of the overall program involved the inventory and assessment of the existing physical, economic, social, biological, and environmental conditions of the Bay. The results of this effort were published in a seven volume document titled *Chesapeake Bay Existing Conditions Report,* released in 1973. This was the first publication to present a comprehensive survey of the tidal Chesapeake and its resources as a single entity.

The second phase of the program focused on projection of water resource requirements in the Bay Region for the year 2020. Completed in 1977, the *Chesapeake Bay Future Conditions Report* documents the results of that work. The 12-volume report contains projections for resource categories such as navigation, recreation, water supply, water quality, and land use. Also presented are assessments of the capacities of the Bay system to meet the identified future requirements, and an identification of problems and conflicts that may occur with unrestrained growth in the future.

In the third and final study phase, two resource problems of particular concern in Chesapeake Bay were addressed in detail: low freshwater inflow and tidal flooding. In the Low Freshwater Inflow Study, results of testing on the Chesapeake Bay Hydraulic Model were used to assess the effects on the Bay of projected future depressed freshwater inflows. Physical and biological changes were quantified and used in assessments of potential social, economic, and environmental impacts. The Tidal Flooding Study included development of preliminary stage-damage relationships and identification of Bay communities in which structural and nonstructural measures could be beneficial.

The final report of the Chesapeake Bay Study is composed of three major elements: (1) Summary, (2) Low Freshwater Inflow Study, and (3) Tidal Flooding Study. The *Chesapeake Bay Study Summary Report* includes a description of the results, findings, and recommendations of all the above described phases of the Chesapeake Bay Study. It is incorporated in four parts:

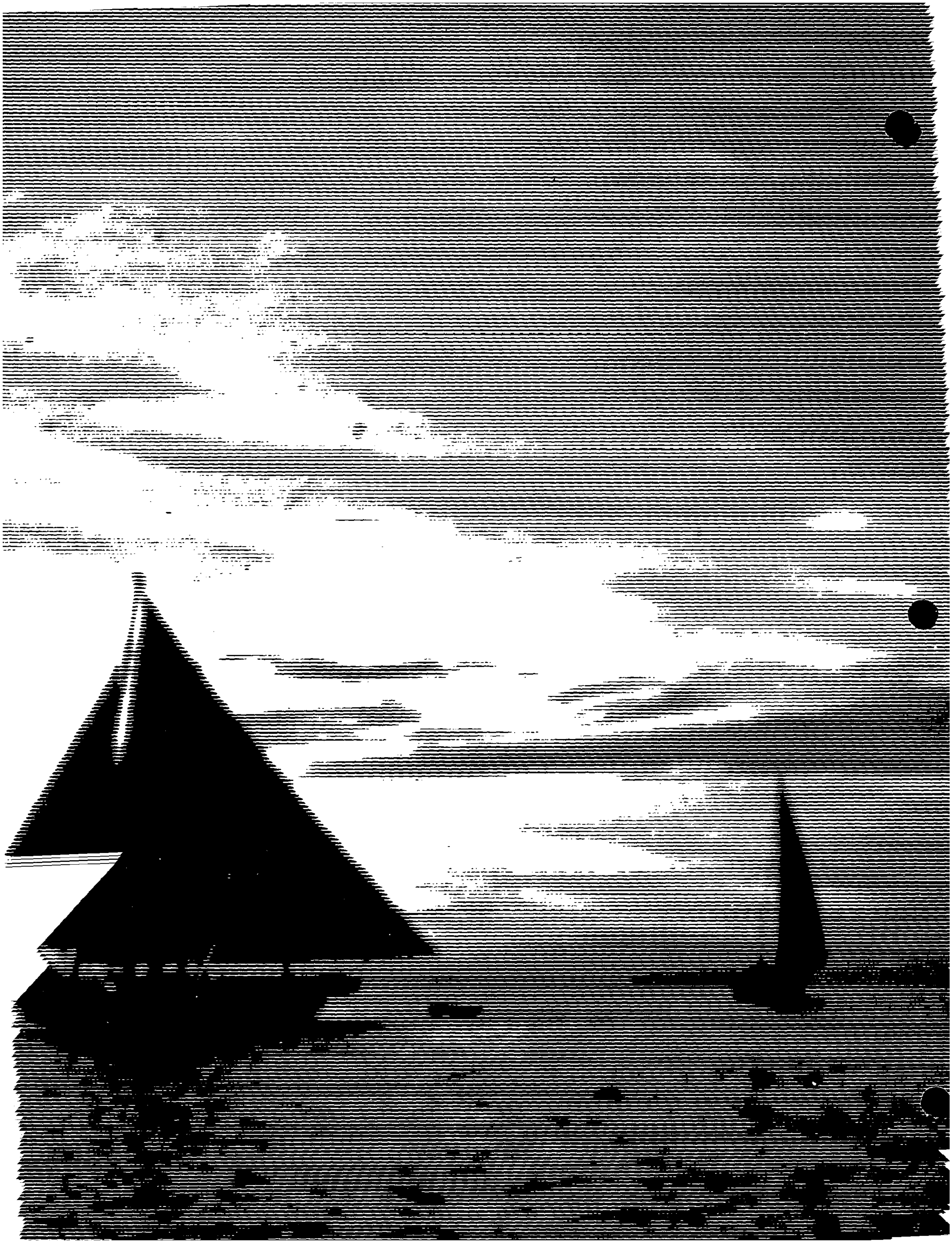
- Summary Report
- Supplement A—Problem Identification
- Supplement B—Public Involvement
- Supplement C—Hydraulic Model

The *Low Freshwater Inflow Study* consists of a Main Report and six supporting appendices. The report includes:

- Main Report
- Appendix A—Problem Identification
- Appendix B—Plan Formulation
- Appendix C—Hydrology
- Appendix D—Hydraulic Model Test
- Appendix E—Biota
- Appendix F—Map Folio

The *Tidal Flooding Study* consists similarly of a Main Report and six appendices. The report includes:

- Main Report
- Appendix A—Problem Identification
- Appendix B—Plan Formulation, Assessment, and Evaluation
- Appendix C—Recreation and Natural Resources
- Appendix D—Social and Cultural Resources
- Appendix E—Engineering, Design, and Cost Estimates
- Appendix F—Economics



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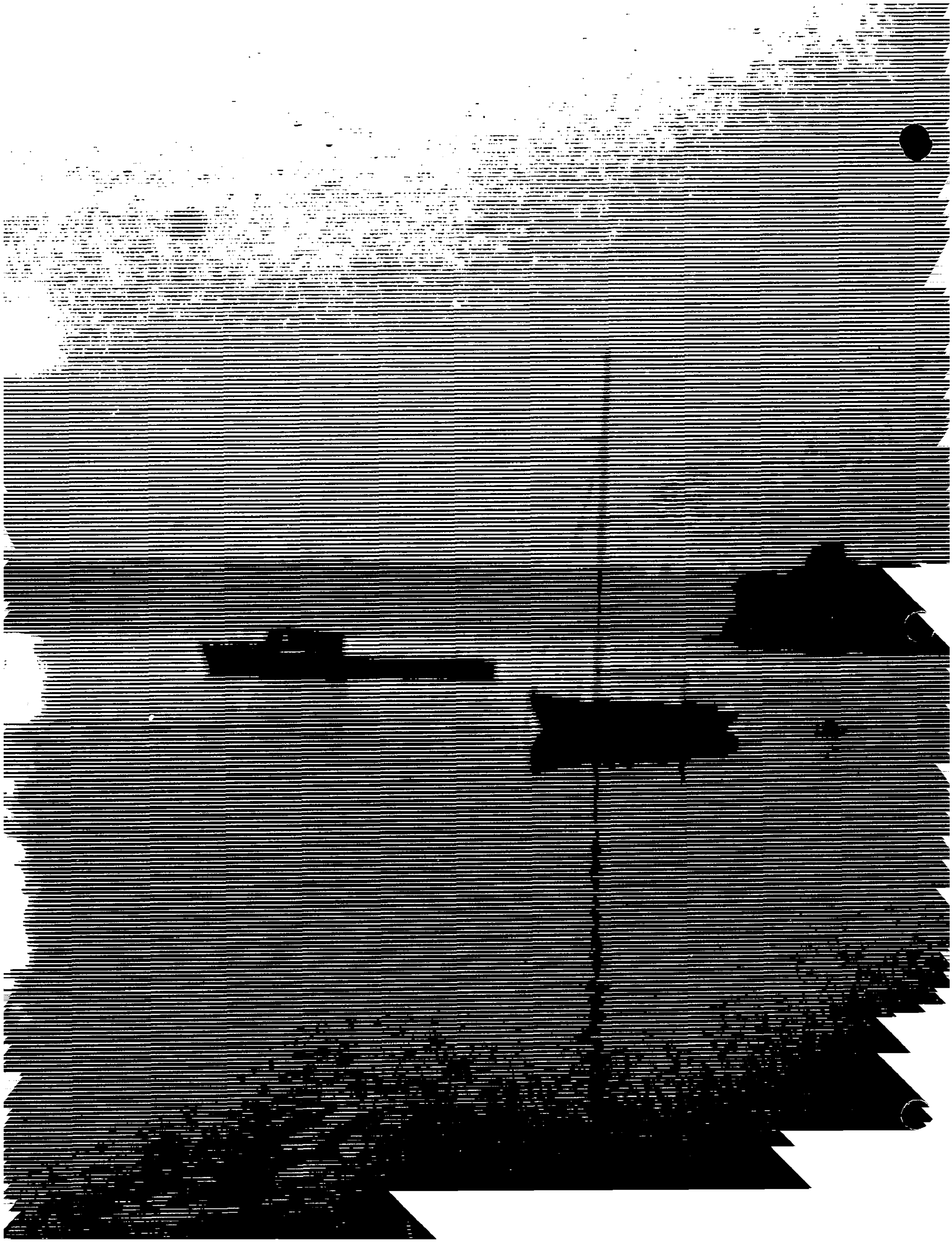


# Chapter I

## Introduction

Chesapeake Bay is a vast natural, economic, recreation, and social resource. The Bay and its numerous tributaries serve many purposes. It provides a transportation network on which much of the region's economic development has been based, wide variety of water-oriented recreation opportunities, a home for numerous fish and wildlife species, a source of water supply for both municipalities and industries, and a disposal site for many waste products. Human activities interact with the natural resources and processes of the Bay to create a diverse system. Unfortunately, problems sometimes arise when people's uses of the resources conflict with each other or with the natural environment. Thus, the impetus for the Chesapeake Bay Study came from a need to plan for the most efficient use of the Bay's natural resources.

The Chesapeake Bay Study Area was defined as the shaded portion of Figure 1. It encompassed all the counties and Standard Metropolitan Statistical Areas (SMSA) adjacent to or directly influencing Chesapeake Bay and its sub-estuaries. In all, almost 25,000 square miles in parts of three states and the District of Columbia were included. The shaded portion of Figure 1 contains about 20,600 square miles of land area and 4,400 square miles of water surface, and is hereafter referred to as the "Study Area" or the "Bay Region." The area under examination was expanded during the water demand projection phase of the Low Freshwater Inflow Study to include the entire Chesapeake Bay drainage area (over 64,000 square miles). The boundary of the Chesapeake Bay drainage area is shown on Figure 1 along with the primary Study Area.

## Authority

The authority for the Chesapeake Bay Study and the construction of the related hydraulic model was provided in Section 312 of the River and Harbor Act of 1965, adopted on October 27, 1965. This section reads as follows:

(a) The Secretary of the Army, acting through the Chief of Engineers, is authorized and directed to make a complete investigation and study of water utilization and control of the Chesapeake Bay Basin, including the waters of the Baltimore Harbor and including, but not limited to the following: navigation, fisheries, flood control, control of noxious weeds, water pollution, water quality control, beach erosion, and recreation. In order to carry out the purposes of this section, the Secretary, acting through the Chief of Engineers, shall construct, operate, and maintain in the State of Maryland a hydraulic model of the Chesapeake Bay Basin and associated technical center. Such model and center may be utilized, subject to such terms and conditions as the Secretary deems necessary, by any department, agency, or instrumentality of the Federal Government or of the States of Maryland, Virginia, and Pennsylvania, in connection with any research, investigation, or study being carried on by them of any aspect of the Chesapeake Bay Basin. The study authorized by this section shall be given priority.

(b) There is authorized to be appropriated not to exceed $6,000,000 to carry out this section.

An additional appropriation for the Chesapeake Bay Study was provided in Section 3 of the River Basin Monetary Authorization Act of 1970, adopted on June 19, 1970. This section reads as follows:

> In addition to the previous authorization, the completion of the Chesapeake Bay Basin Comprehensive Study, Maryland, Virginia, and Pennsylvania, authorized by

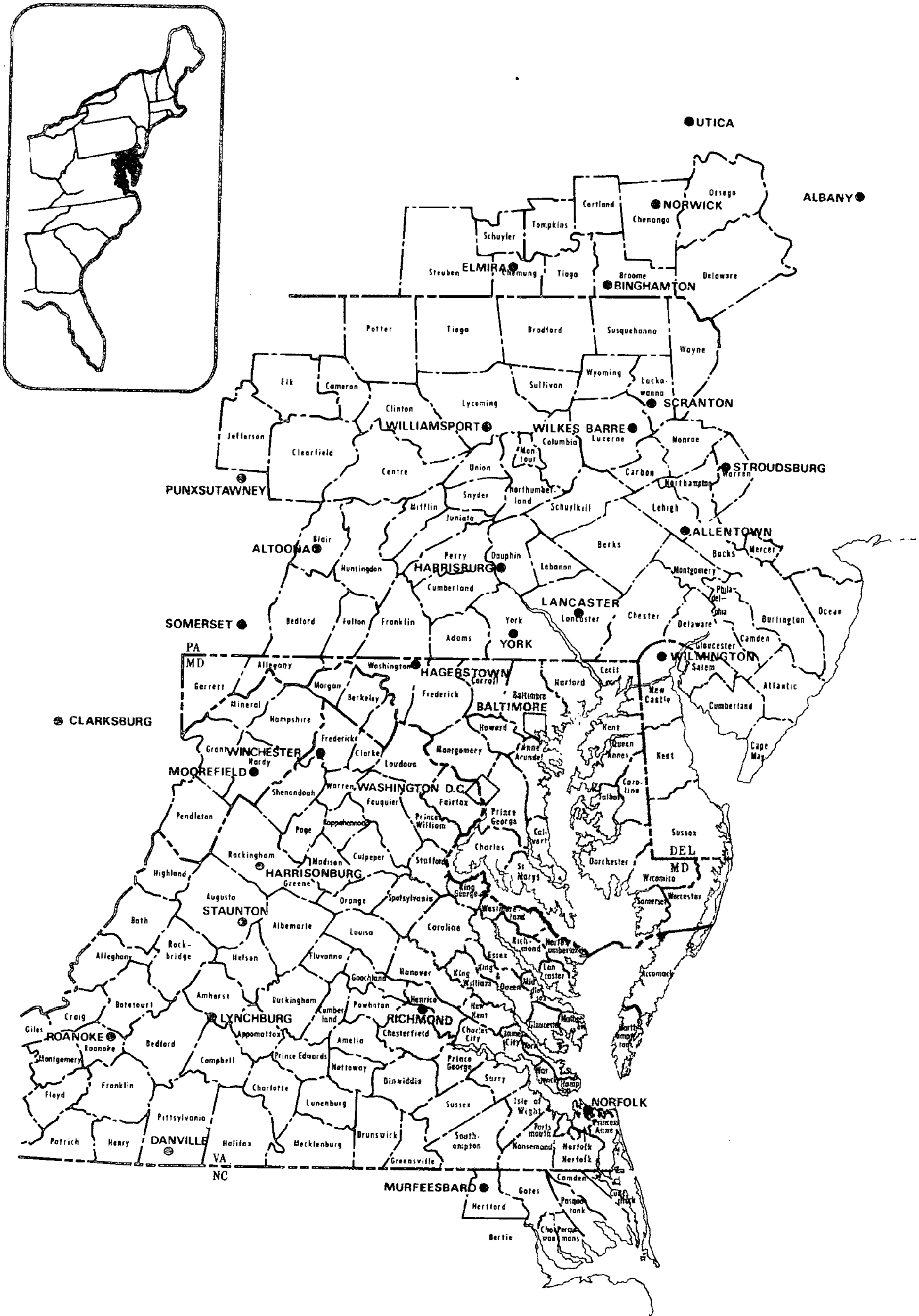



*Figure 1 Chesapeake Bay Study Area*

the River and Harbor Act of 1965 is hereby authorized at an estimated cost of $9,000,000.

In June 1972, Tropical Storm Agnes moved through the mid-Atlantic states causing extensive damage to the resources of Chesapeake Bay. Public Law 92-607, the Supplemental Appropriation Act of 1973, was signed on October 31, 1972 and included $275,000 for additional studies of the storm's effect on Chesapeake Bay.

## Study Purpose and Scope

Historically, measures taken to control and utilize the water and related land resources of the Bay Region were oriented toward solving individual problems. No thorough examination had been undertaken which considered the interrelationships among the Bay's resources, problems, and solutions.

The Chesapeake Bay Study was initiated in 1967 to fill this gap. The study's overall purpose was to conduct a comprehensive investigation of the entire Bay Region so that the most beneficial uses could be made of its resources. Within this broad study purpose, three major study objectives were established. These are:

- To assess the existing physical, chemical, biological, economic, and environmental conditions of Chesapeake Bay.
- To project the future water resource needs of the Bay Region to the year 2020.
- To formulate and recommend solutions to priority problems using the Chesapeake Bay Hydraulic Model.

As directed in the authorization, the study included the construction and operation of a hydraulic model. The purpose in using a physical model was to examine complicated hydraulic processes not readily amenable to analysis by other analytical methods. The Chesapeake Bay Hydraulic Model was constructed between 1973 and 1976 at Matapeake, Maryland. Following model adjustment and verification, tests were performed between 1978 and 1982. The hydraulic model provided a means of reproducing, to a manageable scale, many of the natural events and human changes affecting the Bay.

The level of detail in this report is generally of a framework scope. The report identifies existing and future conditions, present and potential problems, and possible solutions. It has not been prepared as a detailed authorization document which recommends specific projects for implementation. Rather, systematic comparisons are made of various alternatives in terms of technical feasibility; economic, environmental, social, and cultural impacts; implementation arrangements; and public acceptability. Due to the range of alternatives considered, the diverse geographic nature of the Study Area, and the complexity of the Bay itself, only the significant effects of the alternatives are evaluated.

## Study Process and the Report

The study was conducted in three phases; each responsive to one of the objectives. The first phase was completed in 1973. It consisted of an inventory of existing conditions. The findings were published in a document titled *Chesapeake Bay Existing Conditions Report*. Included in the seven-volume report was a description of the existing physical, economic, recreation, social, biological, and environmental conditions of Chesapeake Bay. This report was the first published document that furnished a comprehensive survey of the entire Bay Region and treated Chesapeake Bay as a single entity. More importantly, the *Existing Conditions Report* assembled much of the data required to project future water resource needs in the Study Area and to assess the ability of the Bay to satisfy these needs.

A projection of future conditions was completed in 1978. The results were published in the 12-volume *Chesapeake Bay Future Conditions Report*. The primary focus of this second phase was on the projection of water resource needs to the year 2020. In addition, problems and conflicts were identified which could result from uncontrolled growth and use of the Bay's resources. Taken together, the *Existing Conditions Report* and the *Future Conditions Report* provided the basic information necessary to address the third study objective.

In this third phase, the most pressing problems were identified and preliminary solutions were formulated. The two problems receiving the most attention in the third phase were tidal flooding along Chesapeake Bay shorelines and low freshwater inflow to Chesapeake Bay. The tidal flooding problem and alternative solutions are discussed in Chapter V.

## Study Participants and Coordination

The problems of the Chesapeake Bay are of such complexity and magnitude and involve so many varied disciplines that no single entity could be expected to have the requisite personnel, equipment, and technical know how to accomplish the many special studies needed to complete this comprehensive investigation. Such expertise does exist, however, among the many agencies which have historically been responsible for certain features of water resource development.

The study was conceived as a coordinated partnership among federal, state, and local agencies and interested scientific institutions. Each involved agency was asked to provide leadership in those disciplines in which it had special competence. To furnish the necessary avenues for public participation, an Advisory Group, a Steering Committee, and five Task Groups were established (see Figure 2). The initial planning of the study was coordinated with the former National Council of Marine Resources and Engineering Development through its Committee on Multiple Use of the Coastal Zone.

The overall management of the Chesapeake Bay Study was the responsibility of the District Engineer of the Baltimore District, Corps of Engineers. His staff included professionals from the fields of engineering, economics, and the social, physical, and biological sciences. Hydraulic modelling expertise was provided by personnel from the Corps of Engineers' Waterways Experiment Station (WES) in Vicksburg, Mississippi.

The involvement of the general public was also an important facet of study coordination. The purpose in establishing such coordination was to provide two-way communication between the Corps and the public-at-large. A number of public involvement techniques were employed. An informal liaison was established with the Citizen's Program for Chesapeake Bay, Inc. (CPCB), an organization representing a wide range of groups in the Bay Region. It participated actively in the first two study phases. Two sets of public meetings were held. One was held at the study's outset to inform the public of study initiation and to solicit views as to the direction the study should take. The second was held near the completion of the future projections phase to inform the public of progress on the overall program and to solicit views regarding the study findings to date.

In addition to the study's planning reports, a number of other printed materials and techniques were used to inform the public about the study. These included a leaflet on the hydraulic model, reprints of articles, transcripts from public meetings, periodic newsletters, tours of the hydraulic model, and a film titled *Planning for a Better Bay.*

More information about study coordination and public participation can be found in Chapter VI of the *Summary Report* and in *Supplement B, Public Involvement.*

## Prior Corps Reports and Supporting Studies

The need for a complete and comprehensive investigation of Chesapeake Bay has long been recognized. One

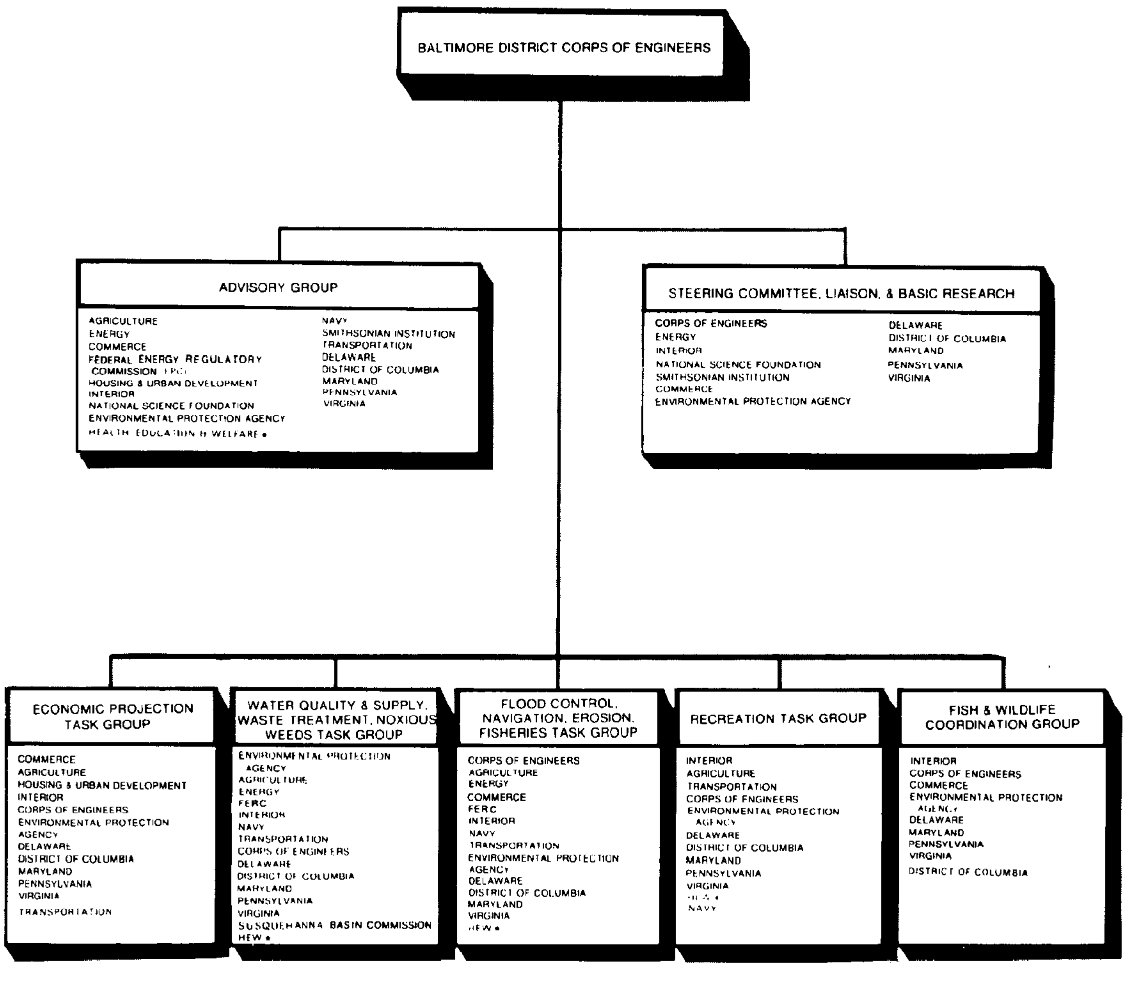



*Figure 2 Chesapeake Bay Study Organization*

of the first steps toward what might be considered a systems analysis was a 1959 report titled *Chesapeake Bay Fishing Harbor Economics Study, Maryland and Virginia.* The study provided, for the first time, a broad overview of the commercial fishing industry and a consistent basis for the comparison of fishing benefits in the Bay Region.

In 1961, the District Engineer, Baltimore District, prepared a pamphlet concerning Chesapeake Bay called *An Appraisal of Water Resource Needs Projected to the Year 2060.* This pamphlet recommended that a cooperative study be made by federal and state agencies responsible for various Bay resources. In the same year, a basin plan for Chesapeake Bay was prepared by the Baltimore District in cooperation with the Norfolk District. The *Basin Plan, Chesapeake Bay* was based on readily available information and consisted of a brief description of the status of water development and planning in the Bay Region. It also presented a program for bringing the basin plan up to date. This basin plan was the first attempt to assemble comprehensive information about the Bay's resources, but it understandably provided only a very superficial analysis.

These reports and similar studies conducted by other agencies highlighted the need for a comprehensive study that produced a Bay-wide management plan. Advances in hydraulic modelling also stimulated interest in using such techniques to evaluate certain hydrodynamic phenomena in Chesapeake Bay. Thus, the authorizing legislation provided by Section 312 of the *River and Harbor Act of 1965* directed that a comprehensive study be conducted, and that a hydraulic model be used in support of such a study.

The resulting Chesapeake Bay Study was conducted between 1967 and 1983. During this time, several interim documents were published by the Baltimore District. Two of the most important of these, the *Existing Conditions Report* and the *Future Conditions Report,* have already been discussed in a previous section. A third interim report titled *Impact of Tropical Storm Agnes on Chesapeake Bay* was published in October 1975.

Studies and reports were also prepared by others in direct support of the Corps' comprehensive study. The economic and demographic projections, for example, were prepared by the Bureau of Economic Analysis (BEA), U.S. Department of Commerce. Projections of industrial water supply were prepared specifically for this study by the Bureau of Domestic Commerce, U.S. Department of Commerce. All agricultural water demand projections, including rural domestic, livestock, and irrigation uses, were done by the Economic Research Service (ERS), U.S. Department of Agriculture. All projections and inventories relative to recreational uses were made by the then Bureau of Outdoor Recreations (BOR), U.S. Department of the Interior. The fish and wildlife analyses were conducted jointly by the Fish and Wildlife Service (USFWS), U.S. Department of the Interior, and the National Marine Fisheries Service (NMFS), U.S. Department of Commerce. The Chesapeake Research Consortium, Inc. prepared a report concerning the biota of Chesapeake Bay, and the projections of electric power needs were prepared by the Federal Power Commission. Western Eco-Systems Technology Inc. and the U.S. Fish and Wildlife Service prepared reports which assisted in the assessment of the effects of decreasing freshwater inflow on the biota of the Bay. These supporting studies, and others too numerous to mention in this *Summary Report,* served as information sources for the Chesapeake Bay Study.

## Related Water Resource Activities

Since the Chesapeake Bay Study was initiated in 1967, a wide variety of related water resource activities have been underway. Some of these have had a direct bearing on the outcome of the study. Other activities have benefited from the information generated during the Chesapeake Bay Study. Still others have benefited from tests conducted on the Chesapeake Bay Hydraulic Model. The following paragraphs discuss the more important of these activities.

A number of large reservoirs were completed within the Bay's drainage area during the study. These projects included: Aylesworth Creek, Foster Joseph Sayers, Raystown, Cowanesque, and Tioga-Hammond Lakes in the Susquehanna River Basin; Bloomington and Little Seneca Lakes in the Potomac River Basin; and Gathright Lake in the James River Basin. While most of these projects are primarily for flood control and recreation, some do offer substantial capability for low flow augmentation. Likewise, dozens of small navigation and shoreline erosion projects have been completed along the Bay and its tributaries.

Several major studies dealing with critical problems in specific geographic areas have also been finished. The *Metropolitan Washington Area Water Supply Study,* for instance, was conducted by the Corps of Engineers. The Corps examined the water supply problem facing Washington, DC, and seven surrounding counties in Maryland and Virginia. The Potomac River is the area's major water supply source, and solutions were proposed which stressed better management of that resource. A complementary study was performed by the State of Maryland to determine the proper amount of flowby (water remaining in the river after all withdrawals have been made) during low flow conditions in the Potomac River. The minimum flowby level was defined to be the amount of water necessary to maintain acceptable aquatic habitat in the lower fluvial and upper estuarine portions of the Potomac River. Additionally, the United States Geological Survey (USGS) conducted a study of the Potomac River estuary to better understand the interactions of hydrodynamic, chemical, and biological processes in the tidal river-estuarine system.

Two major channel deepening studies were also completed by the Corps of Engineers during the course of the Chesapeake Bay Study. The *Norfolk Harbor and Channels Study* proposed deepening the channels and improving the anchorage areas serving the port of Hampton Roads. The *Baltimore Harbor and Channels Study* also proposed similar improvements for the facilities serving the port of Baltimore. It should be noted that tests were conducted on the Chesapeake Bay Hydraulic Model for both of these studies.

One other important study, known as the Chesapeake Bay Program, was conducted by the U.S. Environmental Protection Agency (EPA) between 1976 and 1983. The EPA was directed to coordinate research concerning Chesapeake Bay, and especially to assess the principal factors adversely affecting the Bay's water quality. The EPA was also charged with determining which government agencies had resource management responsibilities and with devising ways to improve coordination among them. The three main areas of focus concerning water quality were: the presence of toxic substances, nutrient enrichment, and the reduction of valuable submerged aquatic vegetation (SAV).

In the EPA's report titled *Chesapeake Bay Program: Findings and Recommendations,* the Chesapeake Bay Program's research documented the serious impact of the nutrients and toxic chemicals released from point and nonpoint sources on the Bay's water and sediment quality and on the vitality and abundance of its living resources. Moreover, forecasts indicate that the sources of these pollutants will continue to grow in number and change in nature, resulting in corresponding increases in the levels of the pollutants entering the Bay.

The EPA Chesapeake Bay Program findings clearly indicate that the Bay is an ecosystem with increasing pollution burdens and declines in desired resources. It is also evident that actions throughout the Bay's watershed affect the water quality of the rivers flowing into the Bay. Degradation of the Bay's water and sediment quality can, in turn, affect the living resources. Thus, effective management of the Chesapeake Bay must be based on an understanding of, and an ability to control both point and nonpoint sources of pollution throughout the Chesapeake Bay basin. To achieve this objective, it is essential that the states and federal government work closely together to develop specific management plans to reduce the flow of pollutants into the Bay, and to restore and maintain the Bay's ecological integrity.

As presented in the aforementioned report, EPA made specific recommendations for monitoring and research, control of nutrients, reduction in toxic compounds, and management of the environmental quality of the Bay System. The reader is referred to the above document for a complete listing of the recommendations.

Other related water resources studies and activities too numerous to mention here are described in *Supplement A—Problem Identification.*

# Chapter II

## Study Area Description

The following chapter provides an overview of the Chesapeake Bay Study Area. A general description of the Bay is given along with a summary of the existing and probable future conditions. Existing conditions were defined as those physical, ecological, demographic, and economic characteristics of the region at the time of study. They formed the basis for projecting the probable future conditions that would be expected in the absence of any water resource development or management plan. So important were these tasks that two major interim reports were prepared. These two reports, the *Existing Conditions Report* (1973) and the *Future Conditions Report* (1978), were among the first to provide a comprehensive assembly of information about the Bay Region. Much of the information which follows in this chapter is extracted from these earlier reports. It should be recognized that the data from these earlier reports were developed nearly 10 years ago and that some of the information may be outdated. These earlier data were updated only where the information was readily available.

## The Chesapeake Bay

Chesapeake Bay is quite young. It is generally believed that it was formed about 10,000 years ago at the end of the last Ice Age. When the great glaciers melted, uncountable billions of gallons of water poured back into the world's oceans. The ocean level rose several hundred feet and inundated large stretches of the coastal rivers. The ancient Susquehanna River, which had drained directly into the Atlantic Ocean near what is now the mouth of the Bay, was one of these "drowned" waterways. This newly formed body of water was later to be named "Chesapeake Bay."

Chesapeake Bay varies from 4 to 30 miles in width and is about 200 miles long. Although the Chesapeake is the largest estuary in the United States, with a surface area of approximately 4,400 square miles, the average depth of the Bay proper is only about 28 feet. About two-thirds of the Bay is 18 feet deep or less.

The ebb and flood of the tides and the incessant action of the waves are the most readily perceptible water movements in the Bay. Average maximum tidal currents range from 0.5 knots to over 2 knots (1 knot equals 1 nautical mile or 6,067 feet per hour). The mean tidal fluctuation is small, generally between one and two feet. Except during periods of unusually high winds, waves in the Bay are relatively small, generally less than 3 feet in height.

Within the Bay proper and its major tributaries, there is superimposed on the tidal currents a less obvious, nontidal, two-layered circulation pattern. This pattern is characterized by a net seaward flow of lighter, lower salinity water in the upper layer and a flow up the estuary of heavier, higher salinity waters in the deeper layer. This phenomenon is illustrated on Figure 3. Tidal currents provide some of the energy necessary for the mixing of the two layers.

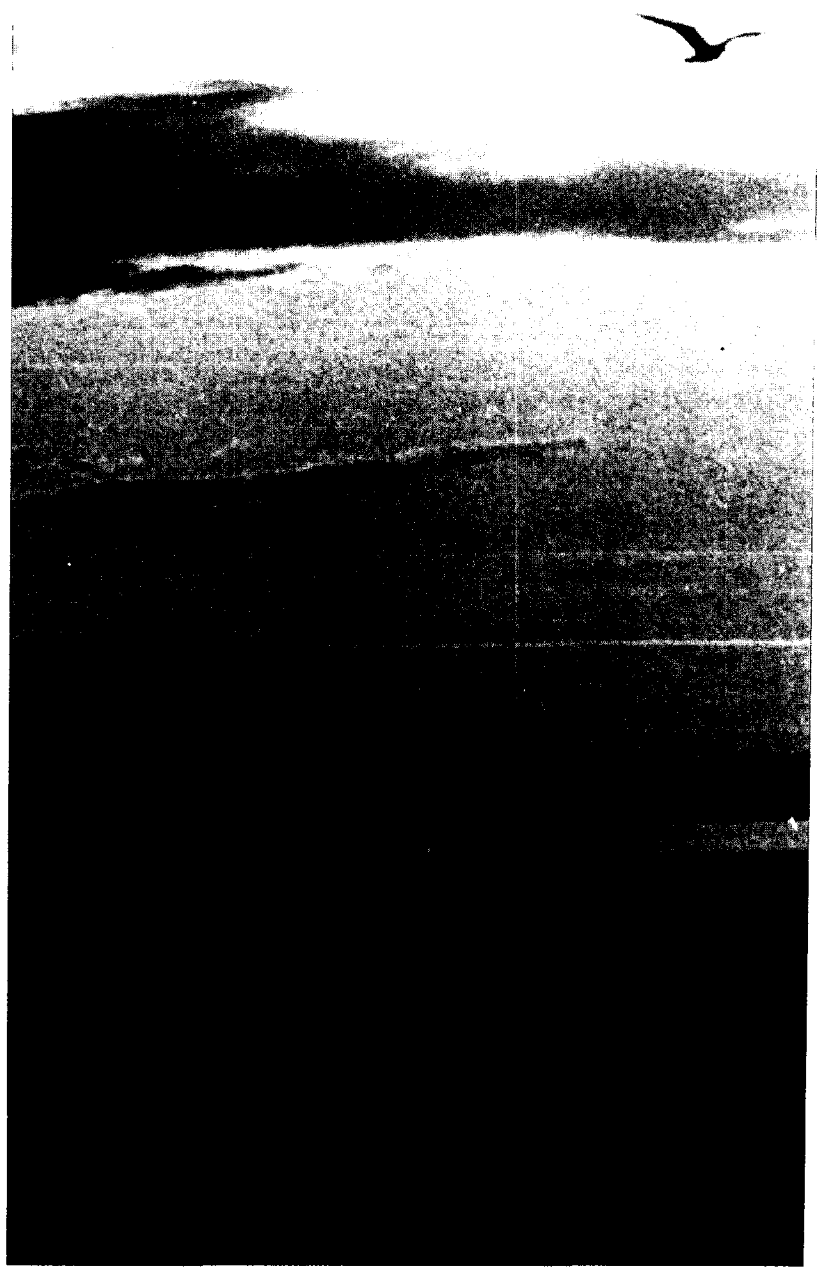
The mixing of sea water and freshwater in the estuary creates salinity variations within the system. In Chesapeake Bay, salinities range from about 33 parts per thousand (ppt) at the mouth of the Bay near the Atlantic Ocean to near zero at the north end of the Bay and at the heads of its tributary embayments. Higher salinities are generally found on the Eastern Shore than on comparable areas of the Western Shore. Salinity patterns also vary seasonally according to the amount of freshwater flowing into the Bay system.

The natural variations in salinity that occur in the Bay are part of the dynamic nature of the estuary. The resident species of plants and animals ordinarily are able to adjust to moderate changes. Sudden changes in salinity, however, or changes of long duration or magnitude, may upset the equilibrium between organisms and their environment. Abnormal periods of freshwater inflow (i.e., floods and droughts) may alter salinities sufficiently to cause widespread damage to the ecosystem.

Dissolved oxygen is another important physical parameter. Dissolved oxygen levels vary considerably, both seasonally and according to depth. During the winter, the Bay is high in dissolved oxygen. With spring and higher water temperatures, the dissolved oxygen content decreases. Surface waters stay near saturation while in deeper waters the dissolved oxygen content becomes significantly less because of increasing oxygen demands by benthic (bottom-dwelling) organisms and decaying organic material. By early fall, as the surface waters cool and sink, vertical mixing takes place. The oxygen content at all depths begins to steadily increase until there is an almost uniform distribution.

While species vary in the amount of dissolved oxygen they need to sustain respiration, many estuarine species can function in waters with dissolved oxygen levels as low as 1.0 to 2.0 milligrams per liter (mg/l). However, dissolved oxygen levels of about 5.0 mg/l are normally considered necessary to maintain a healthy environment over the long term.

The temperatures of the estuarine system are also extremely important to the biota of the Bay. Since the waters of Chesapeake Bay are relatively shallow compared to the ocean, they are more affected by atmospheric temperature conditions. Generally speaking, the annual temperature range in Chesapeake Bay is between 32 and 85 degrees Farenheit (°F). Because the mouth of the estuary is close to the sea, its temperature is more stable than that of the upper estuary. Temperature also causes variations in water density which plays a role in stratification and non-tidal circulation.



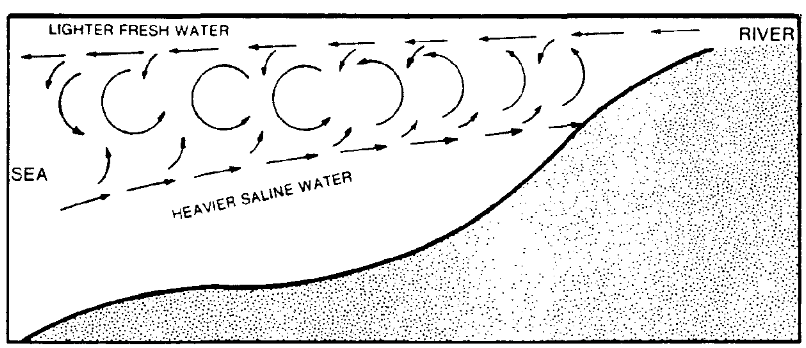



*Figure 3 Circulation in a Partially Mixed Estuary*

Light is necessary for the survival of plants because of its role in photosynthesis. Turbidity, more than any other physical factor, determines the depth to which light will penetrate waters in the estuary. While the absence of light may be beneficial to some benthic organisms, it limits the distribution of plant life because of the restriction of photosynthetic activity. This restriction of plant life (especially plankton in the open estuary) reduces the benthic and zooplankton population which in turn reduces fish productivity.

Nutrients are essential to the normal functioning of an organism. In Chesapeake Bay, important nutrients include nitrogen, phosphorus, carbon, iron, manganese, and potassium. It is generally believed that most of the nutrients required by estuarine organisms are present in sufficient quantity in Chesapeake Bay. Excesses of some nutrients are often a more important problem than deficiencies. Excesses of nitrogen and phosphorus, for example, cause increases in the rate of eutrophication. This can cause a reduction in the number of desirable species, encourage the growth of obnoxious algae, and cause low dissolved oxygen conditions from the decay of dead organisms.

It is necessary to keep in mind the interactions of these physical and chemical variables, along with many others not mentioned, when studying Chesapeake Bay. These parameters should not and, in fact, cannot be addressed separately. The Bay ecosystem is characterized by the dynamic interplay between many complex factors.

## Natural Resources and Environmental Setting

### Physiography

The Chesapeake Bay Region is divided into two physiographic provinces—the Coastal Plain and the Piedmont Plateau. These provinces run roughly parallel to the Atlantic Ocean in similar fashion to the Bay itself. They join at the fall line (see Figure 4). This natural line of demarcation generally marks both the limit of tide as well as the head of navigation.

The Coastal Plain Province includes the Eastern Shore of Maryland and Virginia, most of Delaware, and a portion of the Western Shore. On the Eastern Shore and in those portions of the Western Shore adjacent to the Bay, the Coastal Plain is largely low, featureless, and frequently marshy. The province is a gently rolling upland on the Western Shore and in the northern portions of the Eastern Shore. The Coastal Plain reaches its highest elevation in areas along its western margin.

The Piedmont Plateau is not, as its name implies, a plateau. It is characterized by low hills and ridges which tend to rise above the general lay of the land reaching a maximum height

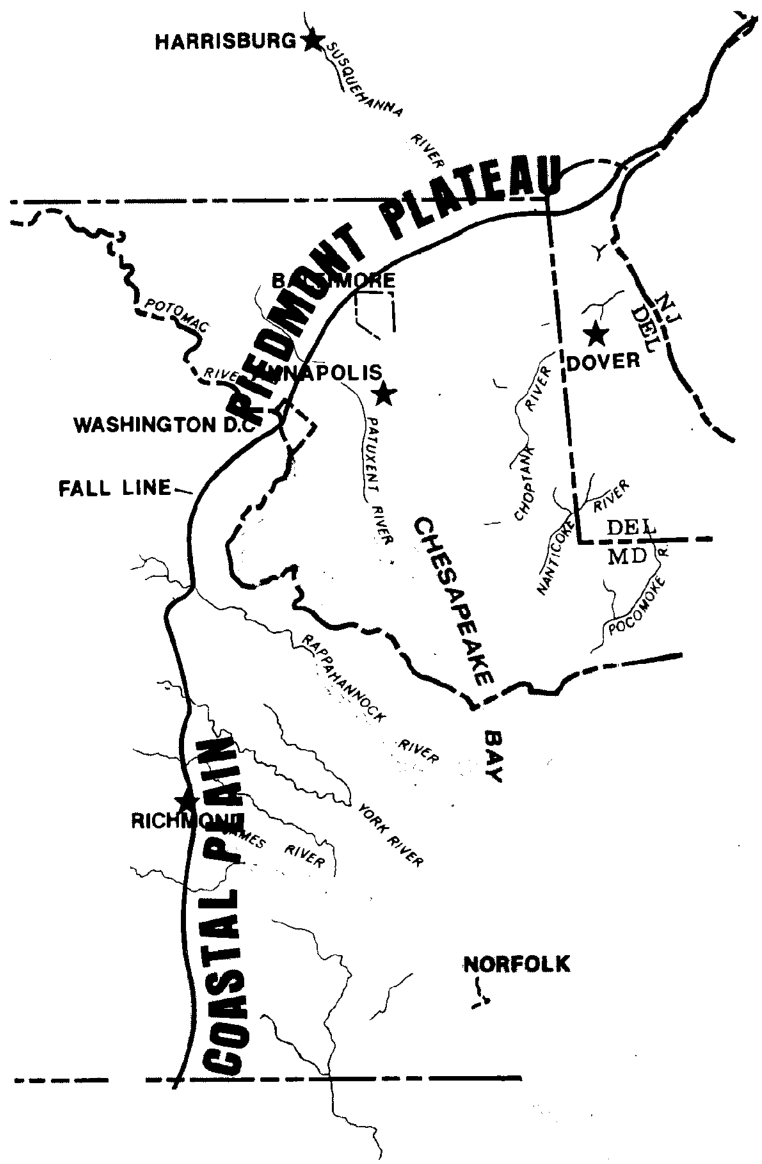



*Figure 4 Physiographic Provinces of the Study Area*

near the Appalachian Province on the west. Many of the stream valleys are quite narrow and steep-sided, having been cut into the hard crystalline rocks characteristic of the province.

## Soils

Soils are a thin layer of material made from broken and decomposed rock with added products of decaying organic matter called humus. The Study Area contains soils produced from the three major types of rock, namely igneous, metamorphic, and sedimentary. The first two types are found primarily in the Piedmont Province. The Coastal Plain is composed of sediments.

The drainage characteristics of the Coastal Plain soils are highly variable. Extensive liming is needed to neutralize their naturally acidic condition. Piedmont soils are medium-grained, easily tilled, and of generally higher fertility than those of the Coastal Plain. A few soils are impermeable when wet, retarding the movement of water and causing water logging. The resulting strong surface runoff can cause serious erosion of slopes.

## Climate

The Chesapeake Bay Study Area is characterized by a generally moderate climate, due in a large part to its proximity to the Atlantic Ocean. The climate is somewhat variable, however, due to the large geographical size of the Bay Region.

Average precipitation for the Study Area is about 44 inches per year, with geographical variations from about 40 to 46 inches per year. Snow fall averages about 13 inches per year and generally occurs between November and March.

Three types of storm activity bring precipitation to the Bay Region. The first type consists of extratropical storms or "lows" which originate to the west, either in the Rocky Mountains, Pacific Northwest, or the Gulf of Mexico. The second is tropical storm or hurricane activity which originates in the Middle Atlantic or the Caribbean Sea region. The third is thunderstorm activity which is almost always on a local scale. It is the last activity which brings about the greatest amount of local variation in precipitation in the Bay Region.

Evapotranspiration, which includes water losses due to evaporation from land and water surfaces and transpiration from plants, amounts to approximately 60 percent of the annual precipitation or about 26 inches per year. Authorities estimate an annual evaporation of 36 to 40 inches from the Bay itself.

The average temperature for the Study Area is approximately 57 °F. The Bay is oriented in a north-south direction, however, and covers a wide latitudinal area, allowing wide temperature variances. As a result, the temperature at the head of the Bay averages less than 55 °F, while at the mouth it averages almost 60 °F.

## Surface and Groundwater Resources

The source of freshwater for the Bay is runoff from a drainage basin covering 64,160 square miles. Approximately 90 percent of this basin is drained by five major rivers, including the Susquehanna, Potomac, Rappahannock, York, and James (see Table 1). Together, these five rivers account for most of the Bay's mean annual inflow of 69,800 cubic feet per second (cfs).

| *Table 1* | *Basin Characteristics of Major Chesapeake Bay Tributaries* | |
|---|---|---|
| *River Basin* | *Drainage Area at Mouth (Sq. Mi.)* | *River Length (Mi.)* |
| Susquehanna | 27,510 | 453 |
| Potomac | 14,217 | 407 |
| Rappahannock | 2,885 | 184 |
| York | 2,857 | 130 |
| James | 10,187 | 434 |

Groundwater aquifiers in the Study Area contain large quantities of high quality freshwater. Water levels in the aquifiers fluctuate according to the balance between precipitation and aquifier recharge on the one hand and evapotranspiration, runoff, and withdrawals on the other hand. Of the average precipitation of 44 inches per year in the Bay Region, an estimated 8.5 to 11 inches actually contributes to the recharge of the groundwater reservoirs.

The most productive aquifiers in the Chesapeake Bay Study Area are the waterbearing formations known as the Columbia Group. Extensive areas on the Eastern Shore and portions of Harford and Baltimore Counties, Maryland, are the principal users. The Piney Point Formation is important in Southern Maryland, portions of Maryland's Eastern Shore and in areas near the Fall Line in Virginia. The Potomac Group provides water to Anne Arundel, Charles, and Prince Georges Counties, Maryland, and is the most important source of groundwater in the Coastal Plain of Virginia.

## Biota

The estuary is extremely productive for a number of reasons. First, the circulation patterns within the Bay create a nutrient trap which acts to retain and recirculate nutrients. Second, water movements in the estuary do a great deal of work removing wastes and transporting food and nutrients, enabling many organisms to maintain a productive existence. Third, the recycling and retention of nutrients by benthic organisms, the effects of deeply penetrating plant roots, and the constant formation of detrital material in the wetlands create a self-enriching system. And last, the estuary benefits from a diversity of producer plant types which together supply year-round energy to the system. Chesapeake Bay has all three types of producers that power productive ecosystems: macrophytes (marsh and sea grasses), benthic microphytes (algae which live on or near the bottom) and phytoplankton (minute floating plants).

## Aquatic Plants

Certain aquatic plants are critical to the health and productivity of Chesapeake Bay. Plants use sunlight and the inorganic nutrients in the water to produce the energy to drive the estuarine ecosystem. These plants, ranging from the microscopic algae to the larger rooted aquatics, are the primary producers—the first link in the aquatic food chain.

Phytoplankton is a general term for free floating, microscopic aquatic plants of both fresh and saline waters. The most important of the phytoplankton are the green algaes, diatoms, and dinoflagellates. The population of these organisms is represented by relatively few species, but when they do occur, they can be present in tremendous numbers. Blue-green algae are another type of phytoplankton. They are not generally considered to be of importance in aquatic productivity and are best known for the nuisance conditions caused when their growth occurs in excess.

Macrophytes are, as the Greek roots of the word indicate, "large plants." Their distribution ranges from entirely freshwater to the open ocean. They are important as food and habitat for fish and wildlife. Unlike the free-floating and minute phytoplankton, the macrophytic aquatic plants are usually either rooted or otherwise fastened to the bottom. Most have defined leaflets which grow either entirely submerged, floating on the surface of the water, or out of the water in direct contact with the atmosphere.

## Fish and Wildlife

Like the plant communities, the aquatic animal communities are not spread homogeneously throughout the Bay. Although the entire estuary serves as nursery and primary habitat for finfish, most spawning areas are concentrated in the areas of low salinity and freshwater in the upper Bay and corresponding portions of the major tributaries. The Bay serves as a spawning and nursery ground for fish caught from Maine to North Carolina. Some of the fish that use the Bay as a nursery include striped bass, weakfish, shad, alewife, blueback herring, croaker, menhaden, and kingfish (see Figure 5).

Oysters are abundant in many parts of the estuary. The numerous coves, and inlets between the Chester and Nanticoke Rivers along the Eastern Shore and the lower portions of the Patuxent, Potomac, York, Rappahannock, and James Rivers account for approximately 90 percent of the annual harvest of oysters. Some species of Chesapeake Bay fish and shellfish thrive in the saltier waters of the estuary. The mouth of the Chesapeake, an area of high salinity, is the major blue crab spawning area.

The marshes and woodlands along the shorelines provide many thousands of acres of natural habitat for a variety of waterfowl, other birds, reptiles, amphibians, and mammals. The marshes and grain fields of the Delmarva Peninsula are particularly attractive to Canada geese and grain-feeding swans, mallards, and black ducks. The Susquehanna Flats, located at the head of the Bay, traditionally support flocks of American widgeon in the early fall, while several species of diving ducks such as canvasback, redhead, ringneck, and scaup winter throughout Chesapeake Bay. While the Bay is primarily a wintering ground for birds that nest further north, several species of waterfowl including the black duck, blue-winged teal, and wood duck find suitable nesting and brood-raising habitat in the Bay Region.

Many other species of birds besides waterfowl are found in the Study Area. Some rely primarily on wetlands for their food and other habitat requirements. These include rails, various sparrows, marsh wrens, red-winged blackbirds, snipes, sandpipers, plovers, marsh hawks, short-eared owls, herons, egrets, gulls, terns, oyster catchers, and curlews. There are numerous other birds which rely more heavily on the wooded uplands and agricultural lands for their basic habitat and food requirements. Among these are many game birds, including wild turkeys, mourning doves, bobwhite qualis, woodcocks, and pheasants. Modest populations of ospreys and American bald eagles also inhabit the Bay Region.

The Chesapeake Bay Region is also home for most of the common mammals native to the coastal Mid-Atlantic region. The interspersion of forest and farmland and the proximity of shore and wetland areas form the basis for a great variety of ecological systems. The abundance of food such as mast and grain crops and the high quality cover vegetation found on the wooded uplands and agricultural lands support good populations of white-tailed deer, cottontail rabbit, red fox, gray fox, gray squirrel, woodchuck, opossum, and skunk. The various vegetation types found in wetland areas also provide indispensible natural habitat for beaver, otter, mink, muskrat, marsh rabbit, and nutria.

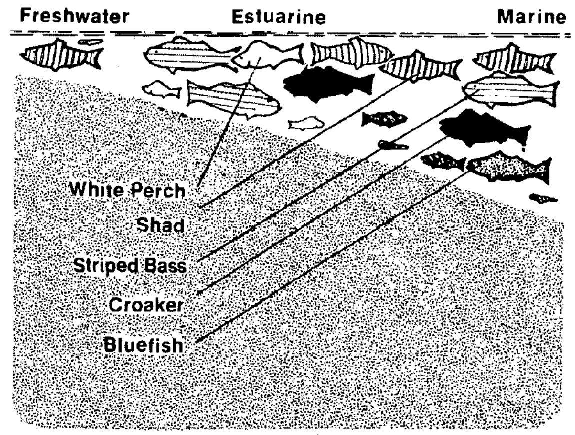



*Figure 5 Fishes: Their Use of the Estuary*

## Important Plant and Animal Organisms

Part of the work on the *Future Conditions Report,* consisted of a survey of prominent Bay Region scientists to determine the most important plant and animal species based on economic, biological, and social criteria. For example, a species would qualify as important if it were either a commercial species, a species pursued for sport, a prominent species important for energy transfer to organisms higher in the food chain, a mammal or bird protected by federal law, or if it exerted a deleterious influence on other species important to humans. The common names and genera of the 124 species identified according to these criteria are presented in Table 2.

## Demographic and Economic Characteristics

Since Captain John Smith first explored Chesapeake Bay in 1608, conditions have changed substantially because of human settlement and activity. Settlers first moved into the Bay Region to take advantage of the soil and climate which was favorable for growing tobacco. Later, major manufacturing and transportation centers developed around the Bay, and the nation's capital was founded at Washington, D.C. From its modest colonial roots, the Bay Region has grown to include nearly 8.5 million people in 1980 and a wide range of economic activity.

## Existing Conditions

Population and Employment

The majority of the inhabitants of the Study Area are concentrated in and around the major cities. In 1980, about 90 percent of the Study Area's population of 8,481,000 resided in one of the Bay Region's seven SMSA's. Economic Areas including both the SMSA and non-SMSA sub-regions are shown on Figure 6. A tabular breakdown of the 1980 population according to these sub-regions is shown in Table 3. In general, Study Area residents have higher levels of education, have higher incomes, and are younger than people in the United States as a whole. Significant variations do occur, however, across the Bay Region.

In 1980, there were approximately 4.1 million people employed in the Study Area, or about 48 percent of the total population. Nine out of every ten people employed worked in one of the seven SMSA's. Between 1970 and 1980, the total number of people employed increased from 3.3 million to 4.1 million, or almost 25 percent. Table 3 also shows a tabular breakdown of the 1980 employment according to the subregions.

Compared to the nation as a whole, the Bay Region has a lower proportion of workers in the blue-collar industries such as manufacturing and mining, and a higher proportion in the white-collar industries such as public administration and services.

Because employment in the white-collar industries tends to be less volatile, the Study Area has had consistently lower unemployment rates over the last several decades than the rest of the nation. Also contributing to these relatively stable employment levels are the large number of workers whose jobs depend on relatively consistent federal government spending.

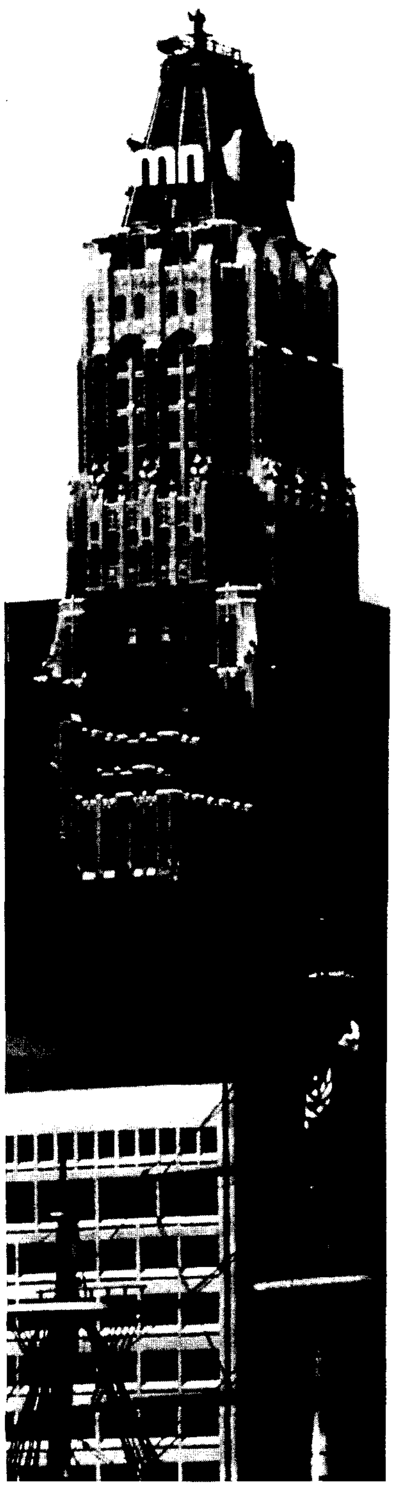


*Table 2*

*Important Chesapeake Bay Plants and Animals*

● *Algae*
- Blue-green alga
- ** Diatom (4 genera)
- Dinoflagellate (3 species)
- Sea lettuce
- Green alga
- Red alga

● *Vascular Plants (Marsh and aquatic)*
- * Widgeongrass
- Saltmarsh cordgrass
- Eelgrass
- Horned pondweed
- Wild rice
- Cattails
- Pondweeds
- Arrow-arum
- Wild celery

● *Cnidaria*
- * Stinging nettle
- ** Hydroid

● *Ctenophora (comb jellies)*
- Comb jelly (2 species)

● *Platyhelminthes (flatworms)*
- Flatworm

● *Annelida (Worms)*
- ** Bloodworm
- Clam worm
- Polychaete worm (4 genera)
- Oligochaete worm

● *Mollusca (Shellfish)*
- Eelgrass snail
- Oyster drill
- Marsh periwinkle
- Hooked mussel
- Ribbed mussel
- Oyster
- Hard shell clam
- ** Coot clam
- ** Brackish water clam
- Baltic macoma
- Stout razor clam
- Razor clam
- * Soft shell clam
- Asiatic clam

● *Arthropoda (Crabs, shrimp, and other crustaceans)*
- Barnacle
- * Copepod (2 genera)
- Opposum shrimp
- Cumacean
- Isopod (2 species)
- Amphipod (5 genera)
- Sand flea
- ** Grass shrimp
- ** Sand shrimp
- ** Xanthid crab (2 species)
- Blue crab

● *Urochordata*
- Sea squirt

● *Pisces (Fish)*
- Cownose ray
- Eel
- ** Shad, herring
- Menhaden
- Anchovy
- Variegated minnow
- Catfish, bullheads
- Hogchoker
- ** Killifish
- Silverside
- ** White perch
- Striped bass
- Black sea bass
- Weakfish
- ** Spot
- Blenny
- Goby
- Harvestfish
- Flounder
- ** Northern puffer
- Oyster toadfish

● *Reptiles*
- ** Snapping turtle
- ** Diamond-backed terrapin

● *Aves (Birds)*
- Horned grebe
- Cattle egret
- Great blue heron
- glossy ibis
- ** Whistling swan
- ** Canada goose
- Wood duck
- ** Black duck
- Canvasback
- Lesser scaup
- ** Bufflehead
- ** Osprey
- Clapper rail
- Virginia rail

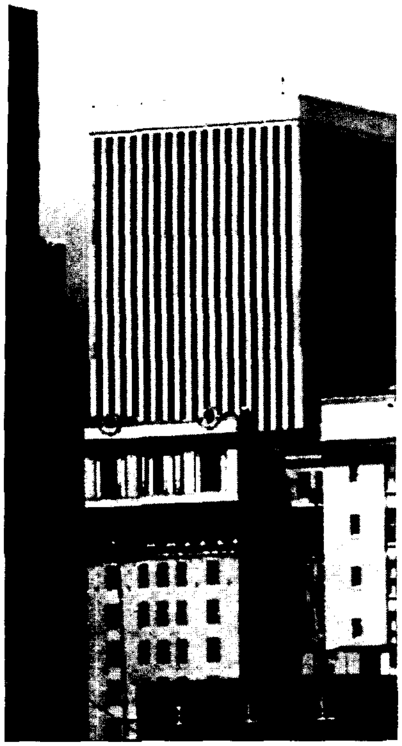


*Table 2 (cont'd)*

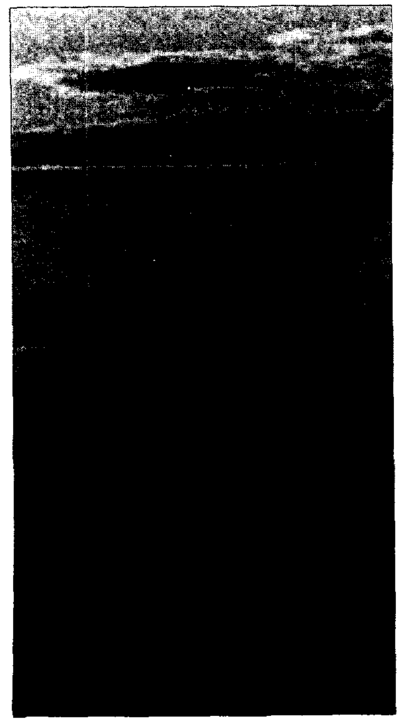
American coot
American woodcock
Common snipe
Semipalmated sandpiper
Laughing gull
Herring gull
Great black-backed gull
Forster's tern
Least tern

- *Mammalia (Mammals)*

Beaver
Muskrat
Otter
Raccoon
White-tailed deer

- *Endangered Species*

Shortnose sturgeon
Atlantic sturgeon
Maryland darter
Southern bald eagle
American peregrine falcon
Ipswich sparrow
Delmarva fox squirrel



* Life histories discussed in the "Biota" Chapter of the Chesapeake Bay *Existing Conditions Report.*

**Life histories discussed in the "Biota" Appendix of the Chesapeake Bay *Future Conditions Report.*

Figure 7 shows a comparison between the Chesapeake Bay Study Area and the nation for employment by major economic sectors. Although the percentages for the Study Area and the nation are similar in many sectors, there are notable exceptions such as in the manufacturing, public administration, and armed forces sectors. A more detailed description of the various economic sectors operating within the Study Area is provided in Supplement A—*Problem Identification.*

## Land Use

The existing land use information for this report was based on remote sensing data obtained from high altitude aerial photography taken in 1970. These data were supplied by the USGS and were part of the Central Atlantic Region Ecological Test Site (CARETS) project. Figure 8 shows the approximate percentages of each major land use type in 1970. Although significant land use changes have occurred in some localized areas since 1970, the area-wide percentages are still reasonable approximations for the overall Study Area.

About 43 percent of the Bay Region is considered to be developed, including 36 percent in agricultural lands and 7 percent in urban lands. Urban land uses are concentrated around the principal urban centers located near the head of tide on the major tributaries of the Western Shore. Many smaller urban centers are found scattered throughout the Study Area, some serving as small ports, retail and wholesale trade centers, or political centers such as state capitals or county seats. Industrial, institutional, and military reservations (of which the Bay Region has many) are also included as urban lands. Most frequently, industries are found in or adjacent to urban areas where good transportation facilities and ample manpower are available.

Land used for the production of farm commodities comprises about one-third of the Chesapeake Bay Region's land area. As such, it constitutes the second largest land use type in the Study Area, second only to forest lands. The major agricultural areas in the Bay Region are located on the Eastern Shore of Maryland, Virginia and Delaware, in rural portions of the Baltimore SMSA, in the northwestern portion of the Washington, DC SMSA, and around Virginia Beach, Virginia.

Forest lands occupy more area in the Bay Region than any other land use type, approximately 54 percent. The Virginia portion of the Study Area accounts for almost two-thirds of the total forest land. Also a high proportion of southern Maryland is woodlands.

The wetlands of the Bay Region, although accounting for only three percent of the total land area, are of crucial importance to the ecosystem of the Bay. Wetlands consist of seasonally flooded basins and flats, meadows, marshes, and swamps. Most of the counties of the Bay Region have some wetland areas of varying types and sizes, although it should be emphasized that not all wetland types are equally valuable to the ecosystem. The major concentration of wetlands in the Chesapeake Bay system is found along the lower Eastern Shore.

Areas of archaeological and historic importance can be found throughout the Region. The primary prehistoric archaeological resources within the Study Area are associated with Indian artifacts. The numerous Indian tribes which inhabited what is now Maryland, Virginia, and Delaware left much evidence of their existence in the form of clay pottery and stone artifacts. The large number of historic sites in the Bay Region provides proof of the region's historic significance and its fundamental role in the development of the nation. Many of the sites relate to the earliest colonial settlements, the winning of national independence, the founding of the Union, the Civil War struggle, and the lives of national leaders.

There are certain other areas of the Bay Region which are of special importance for their ecological or natural significance. Many of these have been identified, and in some cases are being protected. Included are especially important wetlands or other floral habitats, faunal habitats (especially for threatened or endangered species), and naturally

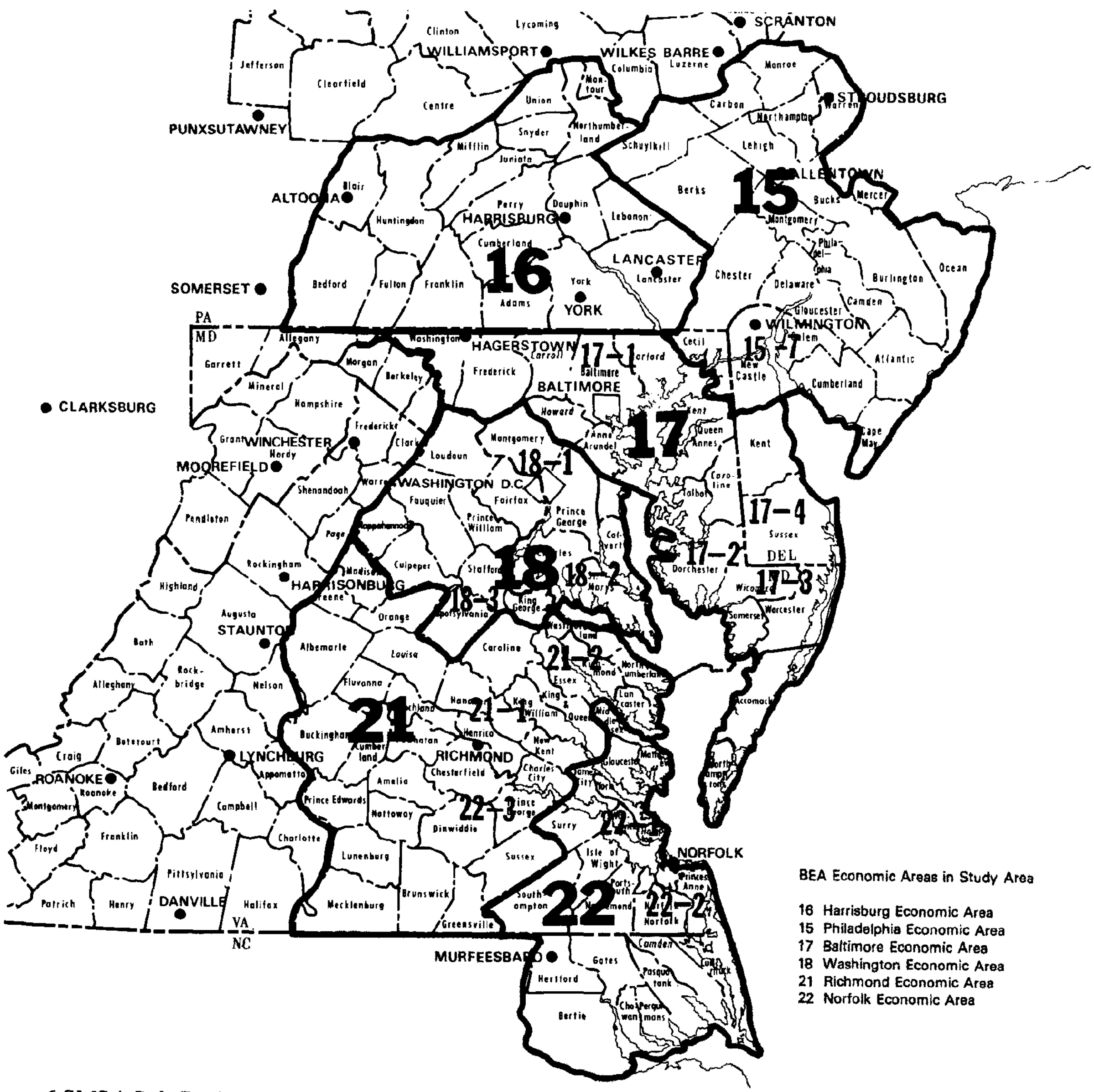



*Figure 6 SMSA Sub-Regions in Chesapeake Bay Study Area*

*Table 3*

*1980 Population and Employment by Sub-Region*
*Chesapeake Bay Study Area*

| *MAJOR ECONOMIC AREA* | *SUB-REGION NAME* | *SUB-REGION NO.** | *1980 POPULATION (1,000's)*** | *1980 EMPLOYMENT (1,000's)*** |
|---|---|---|---|---|
| Wilmington, DE | Wilmington SMSA | 15-7 | 523 | 232 |
| Baltimore, MD | Baltimore SMSA | 17-1 | 2,174 | 994 |
| | Maryland Eastern Shore | 17-2 | 236 | 105 |
| | Virginia Eastern Shore | 17-3 | 46 | 18 |
| | Delaware | 17-4 | 196 | 86 |
| Washington, DC | Washington SMSA | 18-1 | 3,061 | 1,586 |
| | Southern Maryland | 18-2 | 95 | 40 |
| | Virginia Non-SMSA | 18-3 | 101 | 45 |
| Richmond, VA | Richmond SMSA | 21-1 | 607 | 296 |
| | Petersburg-Colonial Heights-Hopewell SMSA | 21-1 | 129 | 57 |
| | Virginia Non-SMSA | 21-2 | 83 | 32 |
| Norfolk, VA | Newport News-Hampton SMSA | 22-1 | 364 | 170 |
| | Norfolk-Virginia Beach-Portsmouth SMSA | 22-2 | 796 | 372 |
| | Virginia Non-SMSA | 22-3 | 70 | 28 |
| STUDY AREA TOTALS | | | 8,481 | 4,061 |

* See Figure 6 for location of each sub-region by number.
**Figures are based on 1980 census.

scenic areas. At present, there are 20 properties within the Study Area designated as national refuges or related properties. There are also about 70 state fish and wildlife management areas and related properties including game farms, sanctuaries, and preserves.

## Future Conditions

A projection of the future conditions in the Chesapeake Bay Study Area was necessary to identify the most probable characteristics in the absence of any water resources management plan. For the purposes of the Chesapeake Bay Study, the target year for planning was established as year 2020. The "without condition" for year 2020 then became the basis for comparing any actions which were proposed during the detailed study phase.

Because the study was conducted over parts of three decades beginning in 1967, the projection of future without conditions progressed through a series of refinements and modifications. Demographic and economic data, for instance, were updated several times, most notably by the decennial censuses of 1970 and 1980. These data, in turn, became the basis for new projections for future years. The assumptions and methodologies for making projections also continued to change as the state-of-the-art evolved. Conceivably, the future without condition could be revised each time a new set of data or new projection methodologies are published.

With this background, it should be noted that a consistent set of projections was prepared for the *Future Conditions Report* using the best information available at that time. These projections were based on the OBERS Series C estimates of population, income, earnings and manufacturing output. OBERS is an acronym reflecting a cooperative effort of the Office of Business Economics (now the Bureau of Economic Analysis) in the U.S. Department of Commerce and the Economic Research Service (now the Economic Statistics and Cooperative Services) in the U.S. Department of Agriculture. The OBERS Series C estimates used data, assumptions, and methodologies which were considered appropriate in the mid-1970's.

## Population and Employment

The total population of the Study Area is expected to increase from about 8.5 million in 1980 to 16.3 million in 2020. This is an increase of about 90 percent over 40 years. Figure 9 shows the expected population increases in each of the five major economic areas. The fastest growing areas will be the Washington, DC, economic areas (portion of Area 18 on Figure 6), the Richmond economic area (portion of Area 21 on Figure 6), and the Wilmington economic area (portion of Area 15 on Figure 6). Slower growing areas include the Baltimore economic area (Area 17 on Figure 6) and the Norfolk-Portsmouth area (Area 22 on Figure 6).

Real per capita income in the Study Area is expected to remain slightly above the national average through the year 2020. There will be some distinct differences, however, among the per capita income averages for the five major economic areas. One of the major driving forces behind the significant increases in population and income will be major increases in manufacturing output. However, the proportion of total output accounted for by the heavy water-impacting industries as a group (i.e., metals, petroleum refining, food and kindred products, chemicals, and paper and allied products) is expected to decline slightly by 2020.

Employment in all economic sectors in the Study Area is expected to reach about 6.8 million persons in year 2020. This is an increase of about two thirds over the 4.1 million workers who were employed in the Study Area in 1980. Figure 10 shows a bar graph which indicates the projected increases in employment by major economic areas. Reflecting existing traits of employment throughout the Study Area, the percentage of job opportunities in the public administration, armed forces, and service sectors will be greater than for the rest of the nation. Conversely, the percentage of job opportunities in the manufacturing sector will be significantly less in the Bay Region than for the nation.

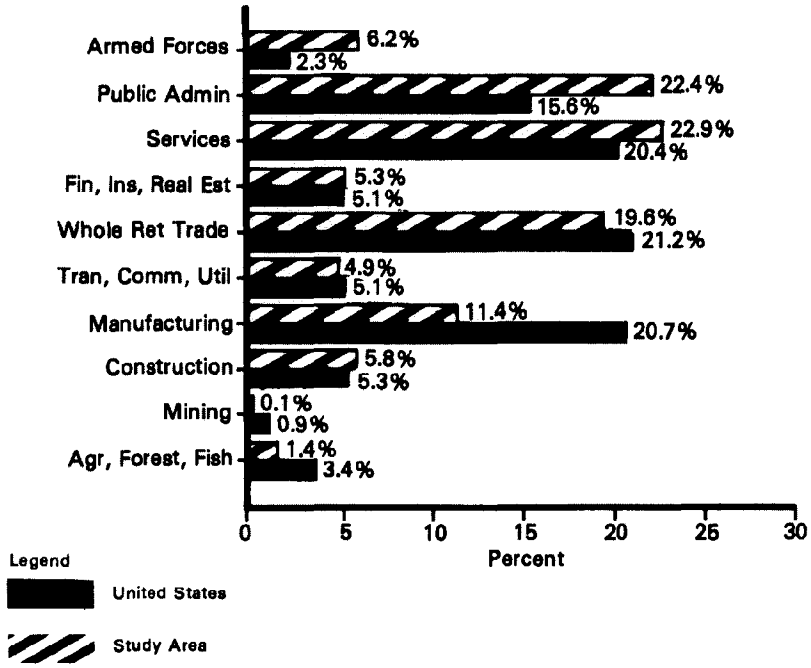



*Figure 7 Employment by Economic Sectors, Chesapeake Bay Study Area and United States (1980)*

## Land Use

The expected future distribution of land uses in the Bay Region was developed from the relevant county, municipal, and regional comprehensive land and water use plans. Numerical estimates of future acreages for urban, agricultural, and forest lands are presented in the following paragraphs.

The portion of land in residential uses in the urban areas can be expected to increase at roughly the same rate as population growth if the assumption is made that population densities will remain at about the same level over the projection period. Using 1970 as the base year, this means that the demand for residential lands will increase approximately 60 percent by the year 2000, and about 110 percent by 2020.

As discussed earlier, manufacturing output in the Chesapeake Bay Region is projected to increase significantly by the year 2020. It is not valid, however, to assume that land needed for industrial purposes will also increase at the same rate since output

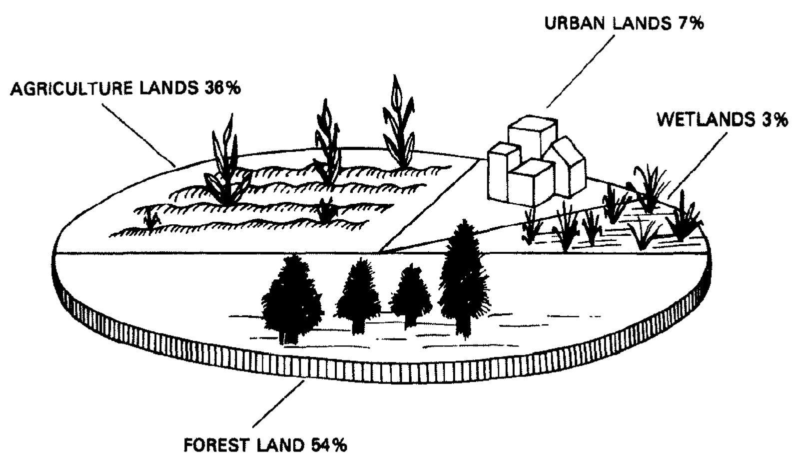



*Figure 8 Major Land Use Types Chesapeake Bay Region (1970)*

per worker and per unit of land will probably increase during this period. If the assumption is made that the productivity of land increases at about the same rate as the productivity of workers (about three percent annually), then the land needed for industrial purposes in the year 2000 can be expected to increase by 28 percent over the 1970 acreage, and by 50 percent in 2020.

The projections of land in crops and miscellaneous farm uses in the Chesapeake Bay Region were derived from OBERS projections. The amount in cropland and miscellaneous farmland is projected to show a steady decline of more than 600,000 acres between 1980 and 2020.

Projections of private commercial forest lands were also disaggregated from OBERS projections. Similar to agricultural land, the projected acreage of private commercial forest land within the Study Area is expected to decline steadily over the projection period. Nearly 700,000 acres are expected to be lost between 1980 and 2020.

Although no projections were prepared for future wetland acreages, it can be stated with a high degree of confidence that the demand for shoreline lands for such uses as marinas, vacation homes, or port facilities will increase in the future. However, more stringent federal and state restrictions on the development or degradation of wetland areas are likely to at least slow down the historic rate of wetlands destruction in the Chesapeake Bay Region.

From an overall perspective, the expected increase in industrial and residential land use will be offset by decreases in agricultural and forest use. The locations in which these land use changes will occur, however, has not been clearly defined. The conflict, then, is not one of enough land for development, but one of where the development should take place. Often the best agricultural lands or the most productive forests are also desirable for urban development. Without proper planning, areas of special ecological, historical, or archaeological significance may be destroyed.

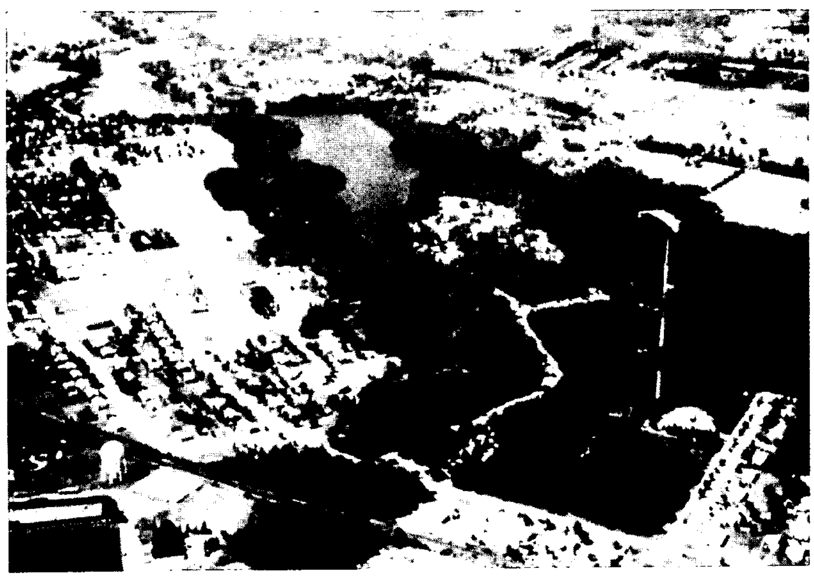


*Table 4*

*Comparison of OBERS Series C and Series E Projections Population and Employment*

| | *Series C* | *Series E* | *% Difference* |
|---|---|---|---|
| 1980* | | | |
| Population | 9,273,100 | 8,875,900 | −4.3 |
| Employment | 3,904,300 | 4,061,200 | 4.0 |
| Percent Employed | 42.1 | 45.8 | 8.8 |
| 2000 | | | |
| Population | 12,489,400 | 11,574,300 | −7.3 |
| Employment | 5,233,000 | 5,457,000 | 4.3 |
| Percent Employed | 41.9 | 47.1 | 12.4 |
| 2020 | | | |
| Population | 16,320,200 | 14,127,400 | −13.4 |
| Employment | 6,825,100 | 6,499,000 | −4.8 |
| Percent Employed | 41.8 | 46.0 | 10.0 |

## Sensitivity Analysis

Although the future without condition has been defined using OBERS Series C information, it is important to recognize that more recent data and projections have been developed. The Bureau of Economic Analysis (BEA, successor of the Office of Business Economics) issued a revised set of projections in 1974 called OBERS Series E. These projections reflected lower population estimates but higher percentages of employment than Series C. In 1981, yet another set of estimates called the 1980 OBERS Regional Projections were published forcasting even lower population levels than the 1974 revisions. Official results of the 1980 census have recently become available confirming the slower rate of population growth and higher employment levels, at least for the decade between 1970 and 1980. In light of these continuing changes the Corps of Engineers elected to evaluate the sensitivity of its earlier OBERS Series C projections (contained in the *Future Conditions Report)* to the new information.

Table 4 displays a comparison between Series C and Series E projections for the two key variables of population and employment. The Series E estimates were based on more conservative assumptions about population growth, resulting in a decrease of about 13 percent from the Series C population forecasts for 2020. Conversely, the employment percentages for the Series E estimates were greater than for the Series C forecasts, reflecting an expectation that a larger proportion of the population would be working.

Even the Series E projections for population are now considered to be too high. The 1980 census revealed that 8,481,000 people lived in the Bay Region. This number is about 400,000 less than the Series E projections and about 800,000 less than the Series C projections. Likewise, the conversion of agricultural and forest lands to urban land (residential and industrial) is not proceeding at the rate projected a few years ago.

In summary, it is clear that population growth and its associated effects are lagging behind the projections

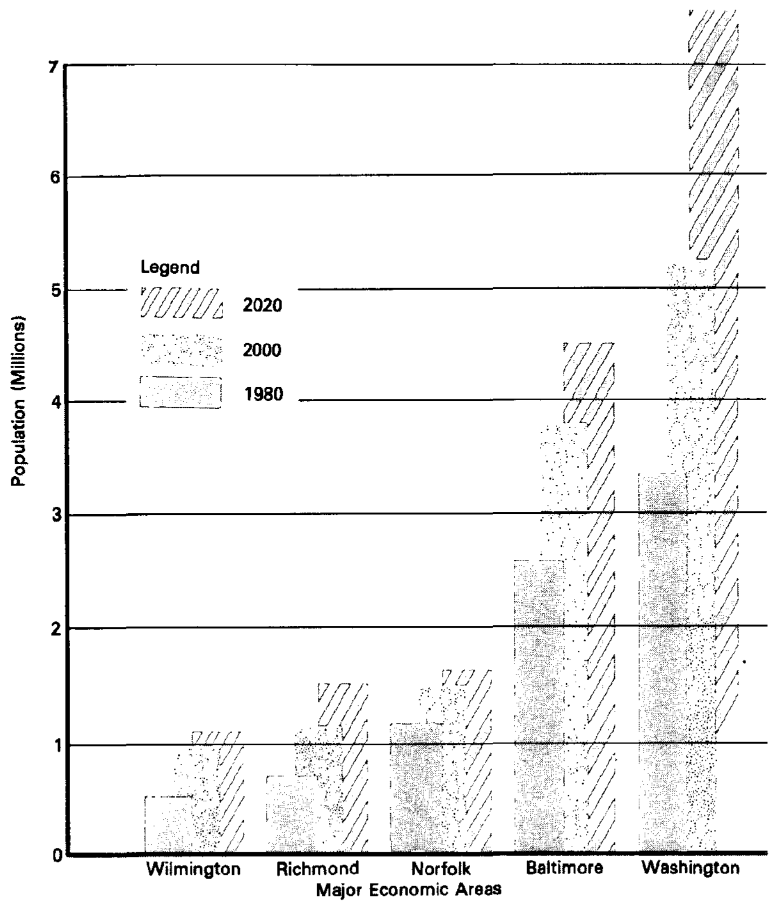



*Figure 9 Series C Projections of Population (1980-2020)*

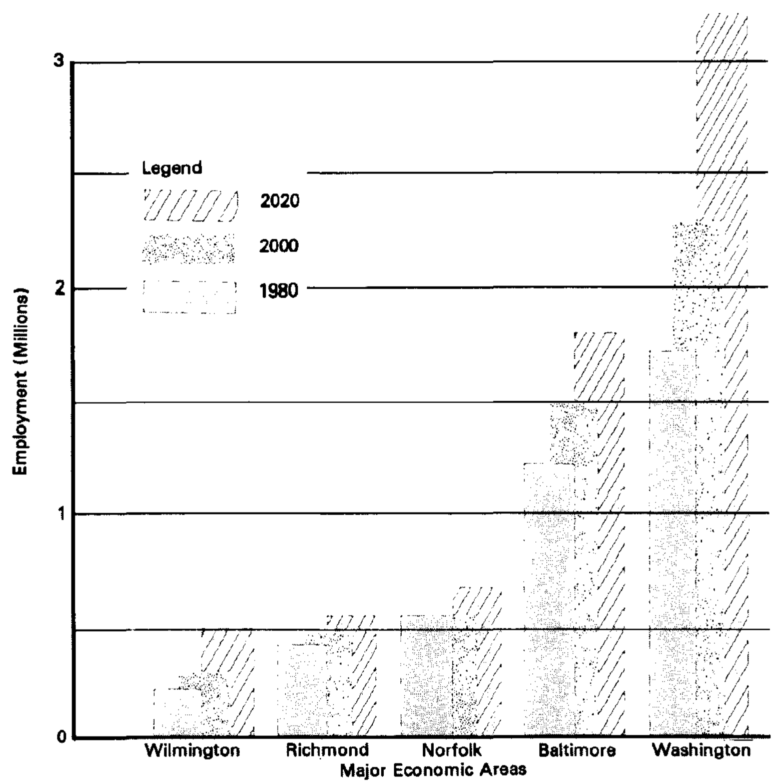



*Figure 10 Series C Projections of Employment (1980-2020)*

available during the 1970's which formed the basis for the *Future Conditions Report*. These lower than projected growth rates, however, do not invalidate any of the Chesapeake Bay Study's findings and conclusions. At worst, they merely mean that the projections have erred on the conservative side and that the project without condition may not be realized until sometime beyond the 2020 target year.

## Institutional Framework

For the purpose of the Chesapeake Bay Study, an institution was defined as an organization which uses certain administrative, political, and social processes to implement and/or manage water resource activities. An institution may be formal (i.e., formed by law or contract) or informal (i.e., formed by a consensus of people, usually with no strict legal basis). Likewise, the process used by the institutions may be either formal (i.e., specified in regulations, by-laws, or charters) or informal (i.e., not written, but customary or assumed methods of operation). For the most part, both the institutions which handle water resource activities and the processes which they use are formal.

Regional planning in the Chesapeake Bay Basin is conducted by three levels of government (federal, state, and local) consisting of three branches within each level (legislative, executive and judicial). This three by three matrix of planning cells has varied in its effectiveness in both planning and managing the water resources of the region. The effectiveness of the planning has generally been a function of the complexity and geographical extent of the problem. Where Bay-wide problems have extended beyond the traditional boundaries of state and local governments, there have often been problems with implementing a solution.

Table 5 contains a list of the major federal, state, and interstate agencies which have water resource responsibilities in the Chesapeake Bay Region. Federal responsibilities are assigned to several different Cabinet level departments and agencies. Some overlap in responsibilities do occur, but most federal organizations

*Table 5*

*Institutions with Water Resources Responsibilities*
*Chesapeake Bay Drainage Basin*

FEDERAL AGENCIES

*Department of Agriculture*
Agricultural Research Service
Soil Conservation Service

*Department of Commerce*
Economic Development Administration

National Marine Fisheries Service

National Oceanographic and Atmospheric Administration

*Department of Defense*
Corps of Engineers

*Department of Interior*
Geological Survey
Fish and Wildlife Service

*Department of Housing and Urban Development*

*Environmental Protection Agency*

STATE AGENCIES

*Delaware*
Department of Natural Resources and Environmental Control

Bureau of Environmental Health

*District of Columbia*

Department of Environmental Services

*Maryland*
Department of Natural Resources

Department of Health and Mental Hygiene

*New York*
Department of Environmental Conservation

Department of Health

*Pennsylvania*

Department of Environmental Resources

*Virginia*

Secretary of Commerce and Resources

Secretary of Human Resources
State Corporation Commission

*West Virginia*

Department of Natural Resources

INTERSTATE/REGIONAL AGENCIES

Susquehanna River Basin Commission

Interstate Commission on the Potomac River Basin

Metropolitan Washington Council of Governments

Atlantic States Marine Fisheries Commission

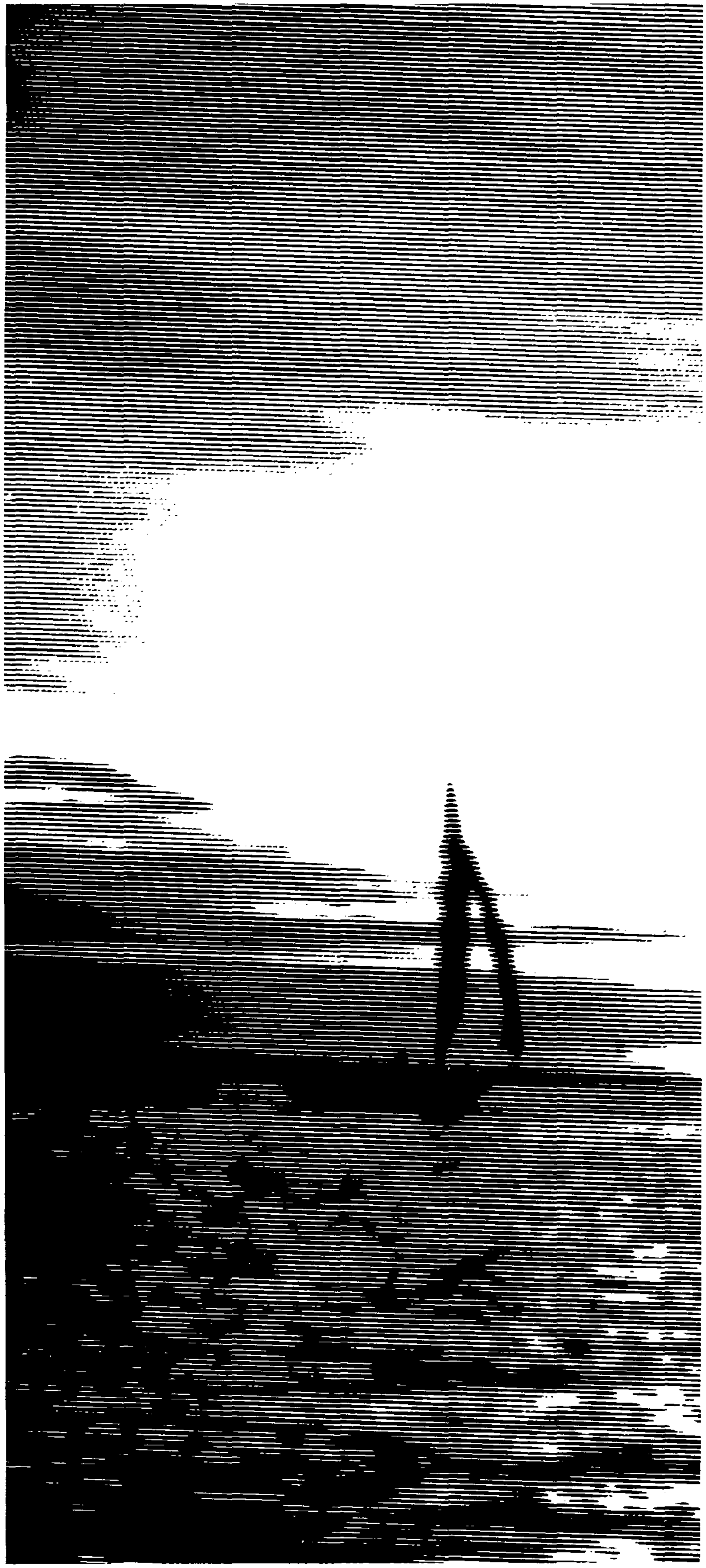
Potomac River Fisheries Commission

Maryland-Virginia Bi-State Working Committee on Chesapeake Bay

Chesapeake Bay Commission (Maryland and Virginia) have specific areas of expertise and jurisdiction. State responsibilities for water resources are generally assigned to an environmental resources department or similar organization. In a few states, the responsibilities for water quality and pollution control are specifically assigned to separate health departments. Interstate and regional agencies with water resources responsibilities also exist within the Chesapeake Bay drainage area. Most of the organizations listed in the third column of Table 5 are organized according to river basin boundaries, but have different degrees or regulatory and enforcement powers. Supplement A—*Problem Identification* provides a more detailed description of the existing institutional framework.

Legal doctrines and principles that govern water and its uses are contained in a variety of sources. Those of primary importance include federal and state constitutions, common law decisions, and statutory enactments. None of these sources alone determine the legal rights pertaining to water law. Each supplements the other, and the composite serves as the basis for the water resources management.

Water use (in the eastern United States) is generally governed by the so-called riparian doctrine. This system emphasizes the rights of water users in common without regard to specific quantities, times, or places of use. Rights under the riparian doctrine are dependent upon ownership of land contiguous to the water source. All such owners have equal right to co-share in the use of the waters, so long as each riparian is reasonable in its use. Riparian rights are further considered usufructuary in nature. That is, they are rights of use, not ownership, of the flowing waters. All states within the Chesapeake Bay drainage area subscribe to the riparian doctrine.



## Chapter III

# Problems, Needs and Opportunities

Forecasts of future population, industrial output, income, and leisure time in the Chesapeake Bay Region all indicate significant growth in coming years. Corresponding increases in demands on the Bay's water and related land resources will almost assuredly accompany such growth. This chapter contains a general discussion of the problems facing Chesapeake Bay, the identification of certain high priority problems for detailed examination, and a statement of national and study planning objectives.

## Problem Inventory

Water resource problems and needs within the Bay Region were identified at length in the *Future Conditions Report*. The major problem categories included: water supply, water quality, outdoor recreation, navigation, flood control, shoreline erosion, fish and wildlife, power, and noxious weeds. In the present report, Supplement A —*Problem Identification* contains a detailed discussion of these problems. The population and economic projections used to determine future needs were based on OBERS Series C forecasts as noted in the previous chapter. Also much of the data presented reflects 1970 conditions unless otherwise noted.

### Water Supply

Water is required to meet the needs of the many communities, industries, and agricultural activities in the Bay Region. As shown on Figure 11, the total volume of water withdrawn from streams, rivers, and reservoirs and subsurface aquifers (ground water) to meet these needs averaged about 2,650 million gallons per day (mgd) in 1970. Approximately 95 percent of the total was used in municipal and industrial systems.

Of the Study Area's 7.9 million residents in 1970, approximately 6.5 million or about 80 percent were served by public water supply systems. These systems ranged in size from those serving as few as 20 persons in small developments to large municipal systems serving commercial, institutional and industrial establishments as well as millions of individuals. The total volume of water furnished through the central systems averaged about 870 mgd in 1970.

Water for use in manufacturing (industrial water supply) totaled 1,620 mgd in 1970, including water from surface fresh and brackish sources, ground water, and public water supply systems. Water use is concentrated within a few specific types of industries. Over 80 percent of total water use is accounted for by three groups of industries; paper and allied products, chemicals and allied products, and primary metals.

Water for livestock and poultry includes the supply necessary for sustenance of beef and dairy cattle, sheep, hogs, horses, chickens, and turkeys as well as that necessary to produce farm products for the market place. In the Chesapeake Bay Region, livestock and poultry water consumption amounted to about 15 mgd in 1967, or less than 1 percent of all uses Bay-wide. The amount of water used for irrigation purposes amounted to 8 billion gallons in 1969. This was applied to only about 2 percent of the total land in crops, indicating the relative unimportance of irrigation to agricultural production in the Bay Region. The major irrigated crops were corn, small grains, cropland/pasture, vegetables, and nursery stock.

Future increases in water demand will occur in the Study Area along with projected population and economic growth. Demands for water supplied through central systems, for example, have been projected to increase by approximately 170 percent Bay-wide by 2020 as shown in Table 6. The Baltimore and Washington, DC, SMSA's are expected to account for the largest share of the centrally supplied water; about 75 percent of the total demand in both 2000 and 2020.

Certain problems are associated with the provision of water for the people, industries, and farms of the Bay Region. Growing affluence and economic development, with accompanying increases in demands for water, will require expansion of water systems and water source development. In most urban areas that are located on or near the tidewater portions of the Bay (such as Baltimore, Newport News, Norfolk, and Portsmouth), nearby sources of freshwater have long since been developed. Increased competition for new sources at greater distances from the urban centers is thus occurring. The economic, institutional, and engineering problems associated with these large-scale projects are substantial.

One of the more significant problems associated with large scale water supply withdrawals is the possibility of reduced freshwater inflows to Chesapeake Bay. Potential increases in future consumptive uses will further depress the natural freshwater inflow. Such reductions may increase the Bay's salinity and cause serious problems for its ecosystem. For example, prolonged periods of depressed inflows may destroy valuable grasses, alter the spawning patterns and range of finfish, change the distribution of shellfish in the Bay, or permit diseases and predators to extend further into the Bay. The location of commercial fishing areas may be altered with higher salinites. This could affect the livelihood of many of the Bay's watermen. Increased salinity regimes may also adversely affect those industries which require water of relatively low salinity for their cooling and processing activities.

Due to the nature and potential severity of the low freshwater inflow problem, it was selected for detailed examination and model testing during the Chesapeake Bay Study. Chapter V of this *Summary Report* and the separate sub-report titled

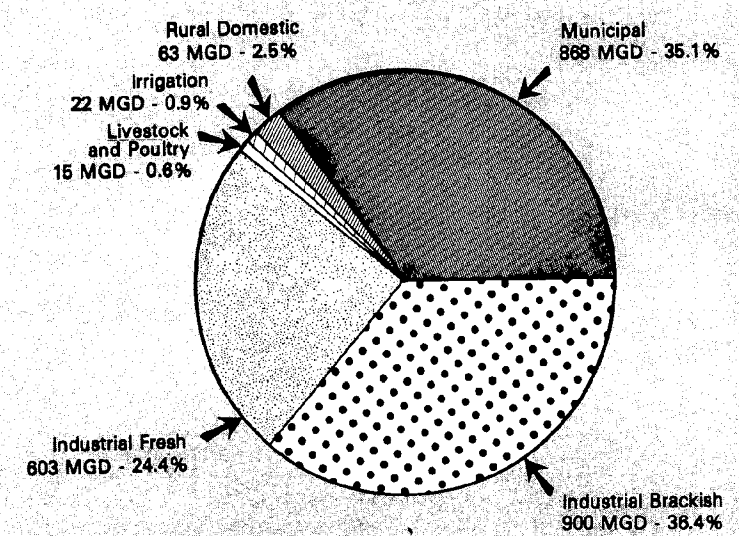


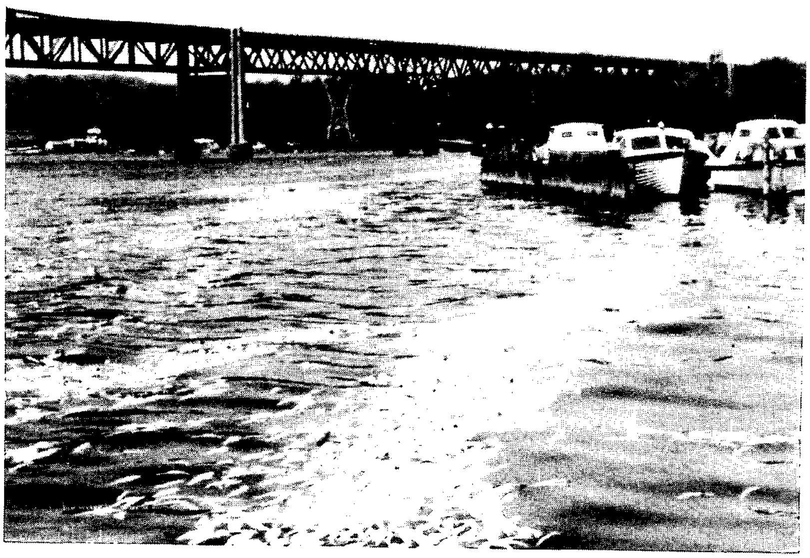

*Figure 11 Average Water Use by Type Chesapeake Bay Region (1970)*

*Table 6*

*Average Water Demands Chesapeake Bay Area (MGD)*

| | *1970* | *1980* | *2000* | *2020* |
|---|---|---|---|---|
| Municipal | 870 | 1,090 | 1,590 | 2,320 |
| Industrial | 1,620 | 1,580 | 1,400 | 1,820 |
| Agricultural* | 160 | 480 | 900 | 1,470 |
| TOTAL | 2,650 | 3,150 | 3,890 | 5,610 |

*Includes irrigation use during a dry year.



*Low Freshwater Inflow* contain more detailed information about the problem and possible solutions.

## Water Quality

Water quality is the term used to describe the biological, chemical, and physical condition of water. What is termed as "good" water quality differs depending on the intended use. Humans require water for drinking that is free of color, pathogenic bacteria, and objectionable taste and odor. Industries which use water primarily for cooling and steam production require water free of materials such as chlorides, iron, and manganese which may be harmful to equipment. Agriculture requires still a different quality of water that is free of degrading materials which are toxic to plant and animal life. Finally, each form of aquatic life requires water of varying qualities in order to assure its healthy existence.

Water quality problems generally arise when the waste loads imposed by cities, farms, and industries exceed the water's capacity to assimilate them. The resulting degradation can be very costly, both economically and ecologically. Increased water treatment, the closing of shellfishing areas, the loss of valuable recreation areas, the corrosion of structures exposed to water, and the destruction of fish and wildlife habitats are some of the costs attributable to poor water quality.

Characterizing the quality of Chesapeake Bay's waters is difficult because of the wide variety of conditions encountered in an area of this size. As quoted from the findings of EPA's Chesapeake Bay Program:

> "Chesapeake Bay Program findings clearly indicate that the Bay is an ecosystem with increasing pollution burdens and declines in desired resources. It is also evident that actions throughout the Bay's watershed affect the water quality of the rivers flowing into the Bay. Degradation of the Bay's water and sediment quality can, in turn, affect the living resources. Thus, effective management of the Chesapeake Bay must be based on an understanding of, and ability to control both point and nonpoint sources of pollution throughout the Chesapeake Bay basin."

The most severe water quality problems occur in the tributaries near areas of high population concentrations. Figure 12 summarizes the major water quality problems of the larger tributaries. In general, municipal and industrial wastes have been found to be the major problems in the populated areas of Baltimore, Washington, Richmond, and Norfolk. Other less populated areas suffer mainly from agricultural and land runoff as well as smaller amounts of municipal discharges. As noted above, the overall system is being impacted by the collective pollutants and nutrients from its tributaries.

It is obvious that much work must be done with regard to water quality improvements if Chesapeake Bay waters are to continue to serve Study Area residents in the manner to which they are accustomed. Since the beginning of the Chesapeake Bay Study in 1967, a number of positive steps have been taken. For instance, Public Laws (PL) 92-500 mandated certain limits on both municipal and industrial wastewater discharges. Some water quality improvements are being noticed around the Bay in response to the construction of better wastewater treatment plants. The EPA's Chesapeake Bay Program also devoted its effort to water quality considerations, and it now appears that both state and federal agencies will initiate stronger Bay management programs based on the findings of that study.

## Outdoor Recreation

The physical characteristics of the Chesapeake Bay region make it an attractive place for water-related recreation activities such as sailing and boating, swimming, camping, and picnicking. From the standpoint of the general public though, Chesapeake Bay is one of the most inaccessible estuaries in the nation. Much of the recreationally desirable land is in competition with other forms of land development such as private homes, industries, or military reservations. For example, in urban areas where recreation opportunities are most urgently needed, the shoreline has often been developed as major port and industrial complexes. A significant percent of the publicly-owned shoreline is unavailable for use by the general public.

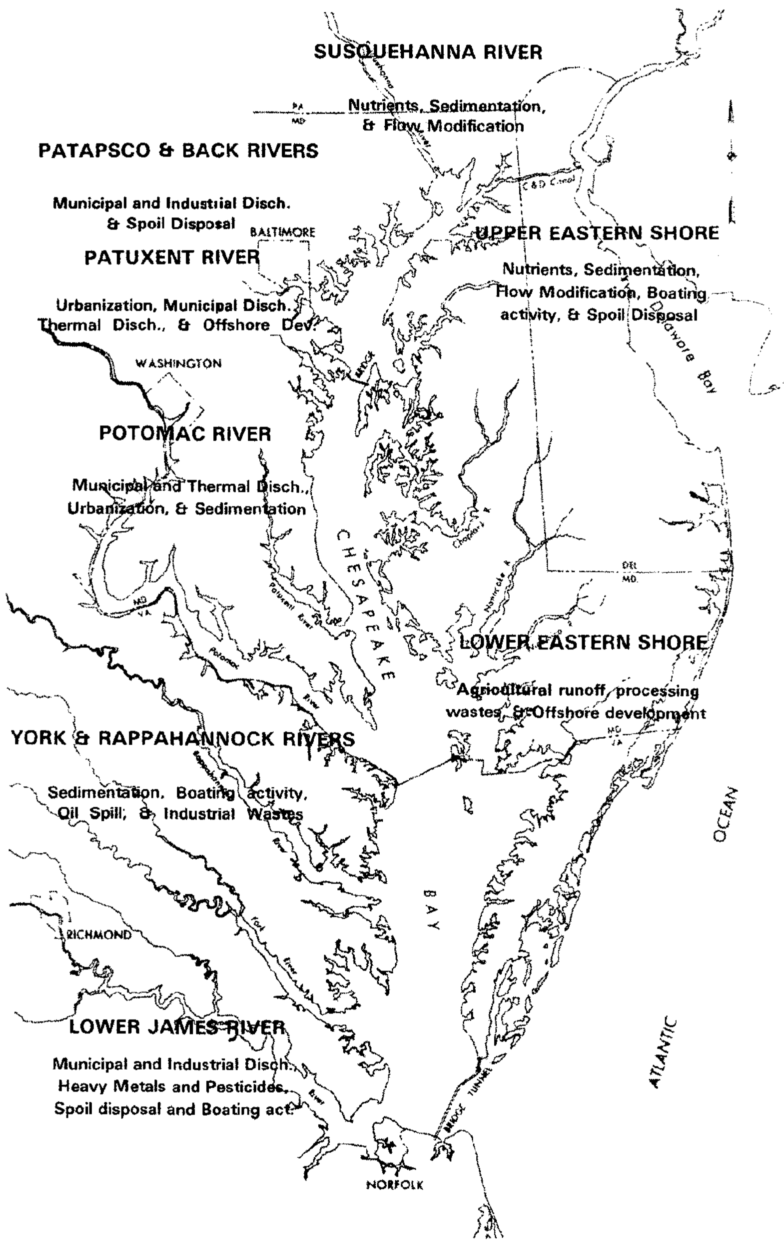
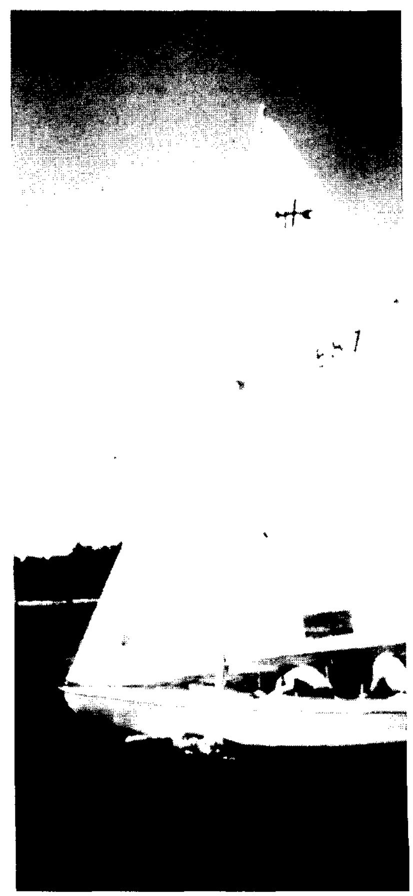
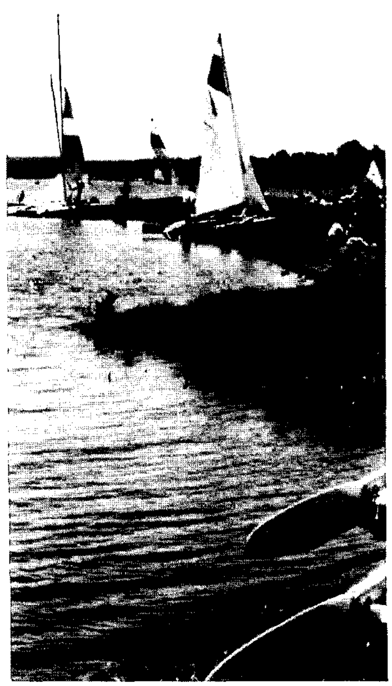



*Figure 12 Water Quality Problems in Chesapeake Bay*

Other factors interfere with the maximum recreational utilization of the Bay and its tributaries. Water quality has deteriorated in many sections of the tributaries precluding body-contact water recreation. This problem is especially severe in the urban areas where recreation demands are the greatest. Recreational use of the Bay and its tributaries has created certain frictions and conflicts in itself. For example, many boaters are responsible for degrading water quality by dumping refuse overboard, discharging sewage effluent, and spilling gas and oil into the water. Recreational boating has also led to overcrowding of certain waterways, particularly those most accessible to the large urban areas. This has created dangerous and undesirable conditions for both boaters and swimmers.

In terms of future recreation demands, the former Bureau of Outdoor Recreation (BOR) projected the need for swimming beaches and pools to increase significantly by year 2020 with the largest supply deficiencies occurring in the Baltimore, Washington, and Richmond areas. On the other hand, large supply surpluses were projected for the Maryland and Virginia Eastern Shore, Delaware, and Hampton Roads where sizable expanses of ocean beach exist. In similar fashion, the supply of campsites, boat ramps, and picnic tables is expected to be deficient in the large metropolitan regions. A surplus is expected in the less populated regions and small urban areas.





## Navigation

Approximately 160 million short tons of cargo was shipped on Chesapeake Bay during 1974. About 80 percent of this freight passed through the ports of Baltimore or Hampton Roads. Approximately 70 percent of the total freight traffic in these two ports is foreign in origin or destination. Baltimore is basically an importing port, while Hampton Roads is an exporting port.

The major commodities going into Baltimore are metalic ores and concentrates, petroleum and petroleum products, gypsum, sugar, iron and steel products, salt, and motor vehicles and equipment. The port is one of the nation's leaders in the importing of automobiles and ore. Most of the total freight tonnage passing through Hampton Roads is coal and lignite. Hampton Roads also conducts important trade in the exporting of corn, wheat, soybeans, tobacco leaf, and grain mill products, as well as in the importing of petroleum products, gypsum (limestone), lumber and wood products, and chemicals.

Although Baltimore and Hampton Roads are the only major international deepwater ports in the Chesapeake Bay Study Area, there is also a significant amount of traffic in the harbors of some of the smaller ports such as Richmond, Yorktown, Hopewell, Petersburg, and Alexandria, Virginia; Piney Point, Annapolis, Salisbury, and Cambridge, Maryland; and Washington, DC. The major commodities shipped through these ports are petroleum and petroleum products, construction materials, fertilizers, and seafood. In addition, the Chesapeake and Delaware (C&D) Canal handles large quantities of general cargo and petroleum products.

Due to the increasing size of ocean-going vessels during the past 100 years and the economies involved in the use of these ships, repeated deepenings and widenings of Chesapeake Bay's ship channels have been necessary. The present main channel depth in Baltimore Harbor is 42 feet, although in December of 1970 Congress authorized a deepening of the channel to 50 feet. In Hampton Roads, the main channel was deepened to 45 feet in 1965. The Norfolk District of the Corps of Engineers has completed a report recommending that the channel be further deepened to 55 feet. Table 7 provides a list of the major federally authorized channels and the corresponding channel depths.

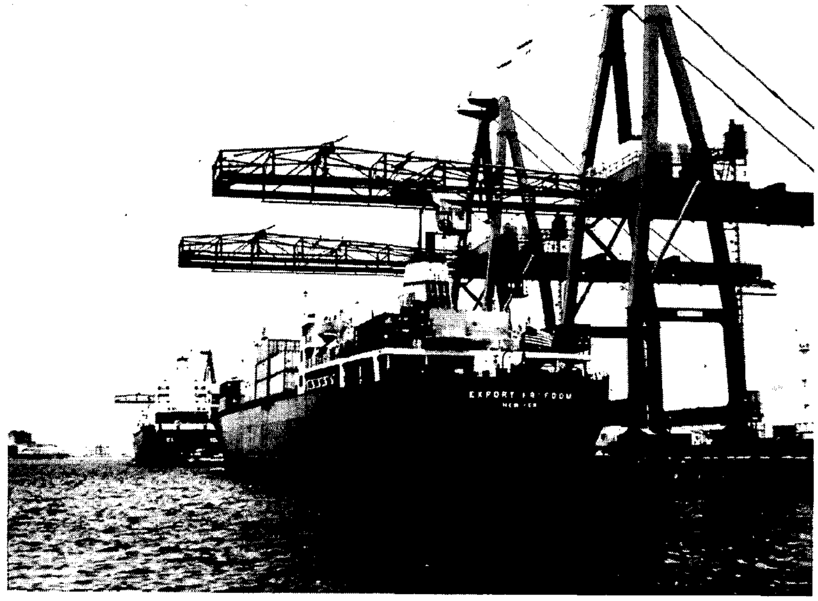


*Table 7*

*Federally Authorized Main Channel Depths*
*Chesapeake Bay Region*

| *Port or Waterway* | *Authorized Depth (feet)* |
|---|---|
| Baltimore Harbor and Channels | 50* |
| Hampton Roads | 45 |
| York River (to West Point) | 22 |
| James River (to Richmond) | 35** |
| Wicomico River (to Salisbury) | 14 |
| Nanticoke River (to Seaford) | 12 |
| Rappahannock River (to Fredericksburg) | 12 |
| Choptank River (to Cambridge) | 25 |
| Tred Avon River (to Easton) | 12 |
| Chesapeake and Delaware Canal | 35 |

*Existing depth in main channel is 42 feet.
**Existing depth maintained at 25 feet.

In the future, the bulk commodities (i.e., metallic ores, coal, petroleum, and grain) are projected to continue to dominate waterborne traffic in the port complexes of Baltimore and Hampton Roads. General cargo movements in both ports, however, are also expected to increase a very high rate over the projection period. Waterborne commerce on the "smaller" waterways is also expected to increase over the projection period. It will continue to be dominated by bulk oil movements. Generally speaking, the level of traffic and the rates of increase for the waterways on the Western Shore will be greater than those on the Eastern Shore.

Several significant navigation and waterborne commerce problems face the Study Area in future years. These problems and needs were identified in the *Future Conditions Report,* and are summarized as follows:

- A need to accommodate large bulk vessels which are expected to dominate the world trade in petroleum, coal, and iron ore. Serious economic inefficiencies will result if the larger vessels are unable to fully load.
- A need for economically and environmentally acceptable methods of dredge material disposal, especially for the larger ports.
- A need to alleviate potential congestion problems in port, channel, and anchorage areas. Waterway congestion increases the likelihood of accidents, with a potential for the spill of hazardous substances into the water.
- A need to minimize the potential conflicts between commercial and recreational users of the Bay.
- A need to minimize erosion damage from waves caused by passing vessels.
- A need to provide additional lands to accommodate expanding port facilities.

## Tidal Flooding

Serious tidal flooding along Chesapeake Bay is caused either by hurricanes or "northeasters." Hurricanes usually occur in the summer or early fall months while northeasters usually occur in the winter months. Since records were first kept in the late 1800's, there have been about 100 storms which have caused tidal flooding damage. Table 8 contains estimates of tidal flood damages caused by four of the worst storms that passed through the Bay Region. The estimates reflect the actual physical damages that occurred, updated to reflect 1983 price levels. Due to the changes in the degree of development in the flood plain, these figures do not reflect the damages that would result from a recurrence of these storms under today's conditions.

Existing and future flood problem areas were identified initially by considering the degree of tidal flooding that would be experienced by those communities located along the shoreline of the Bay and its tributaries. The analysis was limited to communities or urbanized areas because residential, commercial, and industrial development would suffer the greatest monetary losses as a result of a tidal flood. Through a screening and evaluation process described more fully in Chapter IV, critically flood-prone communities were subsequently identified. Table 9 contains the initial list of both the existing and future critical problem areas. The communities on this list were further screened and evaluated as discussed in Chapter IV and in the separate sub-report titled *Tidal Flooding*.

## Shoreline Erosion

The shorelands of Chesapeake Bay are composed of three physiographic elements—fastland, shore, and nearshore (see Figure 13). The fastland is that area landward of normal water levels. The shore is the zone of beaches and wetlands which serve as a buffer between the water body and the fastland. The nearshore extends waterward from the mean low water level to the 12-foot depth contour.

While the causes of shoreline erosion are complex and not completely understood, the primary processes responsible for it are wave action,

*Table 8*

*Tidal Flood Damages*

| *Location* | *Storms and Damages in Millions of Dollars (1983 Dollars)* | | | |
|---|---|---|---|---|
| | *Aug 1933* | *Oct 1954 "Hazel"* | *Aug 1955 "Connie"* | *Mar 1962* |
| Baltimore Metro Area | $43.5 | $12.8 | $21.3 | Neg |
| Washington Metro Area | 22.2 | 8.9 | 0.6 | Neg |
| Maryland Tidewater Area | 21.1 | 16.8 | 3.3 | Neg |
| Norfolk Metro Area | 15.7 | Neg | Neg | 8.9 |
| Virginia Tidewater Area | Neg | Neg | Neg | 45.7 |

*Neg—Negligible

tidal currents, and ground water. Waves generated by wind, especially during hurricanes or other large storms, are the cause of most of the shoreline erosion in the Bay Region. In some busy harbors and waterways, the wakes of passing ships are also a significant erosive force.

The natural processes of shoreline erosion have claimed thousands of acres of land around Chesapeake Bay and its tributaries. One estimate places the amount of shoreline erosion at 45,000 acres over the past 100 years. Futile attempts to arrest the rate of erosion through either poorly designed or constructed protective measures have frustrated property owners. In many cases, landowners have accelerated the rate of erosion by eliminating natural protective devices such as vegetative cover.

Sediment, the product of erosion, has also had significant impacts on both the natural environment and man's use of the resource. Sediment from shoreline erosion may eventually be deposited in either natural or man-made navigation channels requiring maintenance dredging and the problems associated with dredged material disposal. In addition, sediment also has a considerable impact on water quality and the biota of the Bay. The sediment can cover productive oyster beds and valuable aquatic plants. Reduced light penetration into the turbid waters can also be very detrimental to aquatic life.

In order to define those areas or reaches of tidal shoreline along the Bay and its tributaries that are suffering critical losses of land, an inventory of historical erosion rates and the adjacent land use was compiled. Using these erosion rates together with the land use information, approximately 400 miles of shoreline (260 miles in Maryland and 140 miles in Virginia) were identified as existing critical erosion reaches. In addition, nearly 45 more miles of Bay shoreline have the potential to become critical erosion reaches in the future.

## Fish and Wildlife

The fish and wildlife of Chesapeake Bay contribute in many ways to making the Bay what it is today, in terms of both commercial markets and re-

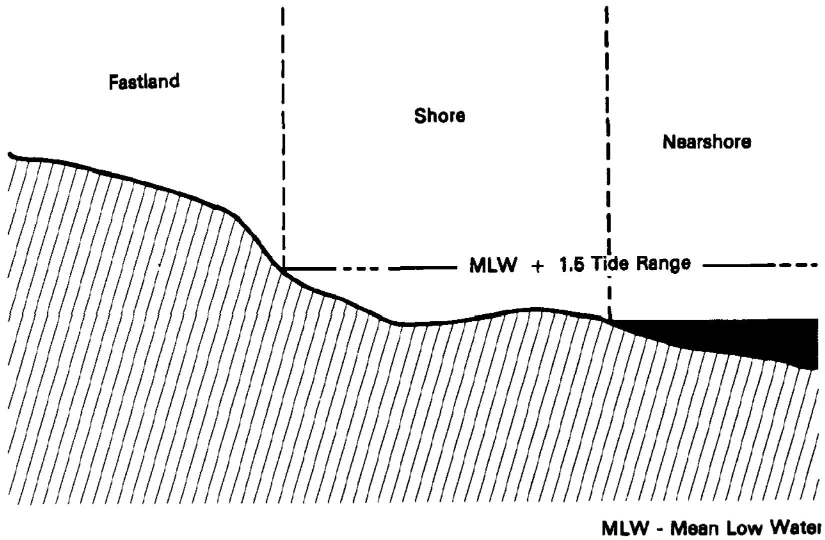
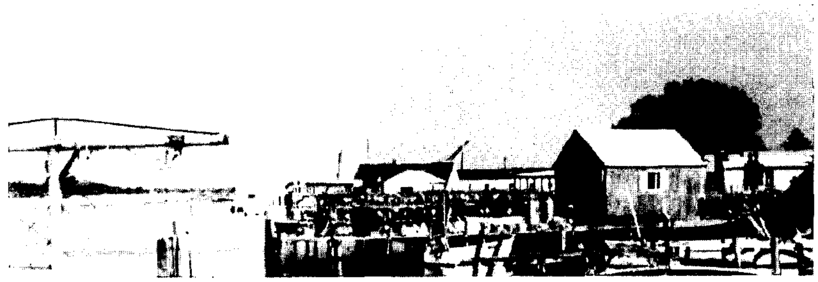



*Figure 13 Shorelands of Chesapeake Bay*

*Table 9 Critically Floodprone Communities*

| *STATE OF MARYLAND* | *COMMONWEALTH OF VIRGINIA* |
|---|---|
| *Anne Arundel County* | *Independent Cities* |
| Arundel on the Bay | Fredericksburg |
| Avalon Shores (Shady Side, Curtis Pt. to Horseshoe Pt. and West Shady side) | Hampton |
| Deale | Norfolk |
| *Baltimore City* | Portsmouth |
| *Baltimore County* | Virginia Beach |
| Dundalk (Including Sparrows Pt.) | Chesapeake |
| Middle River Neck | Poquoson |
| Patapsco River Neck | *Accomack County* |
| *Caroline County* | Tangier Island |
| Denton | *King George County* |
| *Cecil County* | Dahlgren |
| Elkton | *King William County* |
| Northeast | West Point |
| *Dorchester County* | *Northampton County* |
| Cambridge | Cape Charles |
| *Kent County* | *Westmoreland County* |
| Rock Hall | Colonial Beach |
| *Queen Anne's County* | *WASHINGTON, DC* |
| Grasonville | |
| Stevensville | |
| *St. Mary's County* | |
| Piney Point | |
| *Somerset County* | |
| Crisfield | |
| Smith Island | |
| *Talbot County* | |
| St. Michaels | |
| Tilghman Island | |
| *Wicomico County* | |
| Salisbury | |
| *Worcester County* | |
| Pocomoke City | |
| Snow Hill | |

creational enjoyment. Increasingly, people are turning to the out-of-doors for use of their leisure time, and fish and wildlife contribute both directly and indirectly to the value of the outdoor experience. Sport hunting and fishing, for example, are major activities of outdoor enthusiasts, as are birdwatching and nature photography. In addition, commercial interests rely on fish and wildlife resources as an important source of income and employment.



Commercial landings of finfish include striped bass, weakfish, shad, catfish, bluefish, menhaden, alewife, spot, white perch, croaker, flounder, and herring. Shellfish, which are commonly harvested commercially, include crabs, oysters, soft clams, and hard clams. The shellfish harvest usually represents the large money crop in Chesapeake Bay as it sometimes comprises up to 80 percent of the total commercial harvest value. The fishermen responsible for catching the finfish and shellfish constitute the harvesting sector of the commercial fishing industry. Employment in the harvesting sector varies between 16,000 and 20,000. About 7,000 more people work in the processing sector of the commercial fishing industry.

Catches of finfish and shellfish by recreationists in the Bay Region make up the balance of the total fishery harvest. Species of fish particularly sought by the recreational fisherman, include spot, striped bass, white perch, weakfish, shad, croaker, flounder, yellow perch, catfish, and bluefish. It is estimated that landings of all of these but striped bass, flounder, and catfish actually exceed the commercial catch, demonstrating the importance of recreational fishing in the Bay. Shellfish are also taken by a considerable number of recreationists.

Projections of future demands for finfish and shellfish resources are a function of the maximum harvest for each species that can be sustained over time. Continued harvesting beyond this "Maximum Sustainable Yield" (MSY) would result in eventual decline in the species population. Most of the commercially and recreationally important species are expected to experience harvesting pressures in excess of their MSY before

2020, and some before 2000 if present practices are continued. In some cases, commercial catches of recreationally important species will decline over the projection period. An associated reduction in employment in the commercial fisheries harvesting and processing sectors is also expected.

Wildlife are trapped for commercial purposes in the Bay Region. Furbearing species commonly trapped are beaver, gray fox, red fox, mink, muskrat, opossum, otter, raccoon, skunk, weasel, and bobcat. The muskrat is of primary economic importance since it provides approximately 70 percent of the total income of Bay trappers.

Hunting in the upland forests, farms, wetlands, and open water areas of the Bay Region is a widely practiced form of recreation. Animals such as deer, rabbit, squirrel, woodchuck, raccoon, and opossum, and game birds such as turkey, quail, and dove are hunted in uplands. In the open water and wetland areas, waterfowl such as ducks and geese and other birds such as rails and woodcock are the most significant game species.

Future hunting effort in the Bay Region for big game and waterfowl is seen primarily as a function of the amount of land available as quality habitat for wildlife and the degree of access to it by the public. Hunting effort by 2020 is projected to increase by 70 percent for waterfowl and 140 percent for big game over the 1970 amounts. Small game hunting is projected to decline over the study period. Based on the hunting demand analysis, land access requirements for hunting should increase by 60 percent by 2020 over the amount available in 1970.

The wetlands and uplands of the Bay Region are also inhabited by plants and animals which are enjoyed strictly for their presence. Wild untrampled areas provide a source of recreation to large numbers of people who enjoy birdwatching, nature walking, and photography.

Non-consumptive wildlife utilization (excluding nature walking) is projected to increase at a slightly higher rate than the population. Nature walking is expected to increase at a rate equal to population growth. The factors most affecting the provision of a quality non-consumptive recreational experience are the availability of suitable habitats for wildlife and access by the public. Compared with the 814,000 acres of public land in the Study Area available in 1970, about 1.9 million acres of public land will be required by 2020 for non-consumptive outdoor activity.

## Electric Power

The Chesapeake Bay Region is served by about 75 electric utilities covering parts of Maryland, Virginia, Delaware, West Virginia, North Carolina, and Washington, DC. These utilities are of varied ownerships: private corporations, municipalities, consumer cooperatives, and the federal government.

With the exception of hydropower, most electric generating processes (coal, oil, gas, nuclear, and combustion) use water as a means to remove waste heat from the power generating process. The heated water is then pumped into cooling towers or returned to its source (in this case, Chesapeake Bay or one of its tributaries). Possible detrimental effects can occur. In those processes which use once-through cooling, waste heat is discharged to a receiving water body for assimilation. Undesirable fish and aquatic plants may predominate near the discharge point. The immediately surrounding water body may also become undesirable for other uses as well, particularly in the summer. Most thermal discharges are now regulated by federal and state standards which establish a maximum allowable temperature increase. In generating processes which use cooling towers, a significant amount of cooling water may be lost to evaporation. This loss, termed a consumptive use, represents water which is withdrawn but not returned to the source.

Electric use is expected to grow substantially in coming years, although not nearly as much as was estimated just a decade ago. With increased electric use, additional generating facilities will be needed and obsolete plants must be replaced. It is further expected that waste heat will be dissipated almost entirely by wet cooling towers in the future, irrespective of the generating process.

The gradual move to wet cooling towers portends an increase in consumptive use. Water withdrawals are expected to decrease over the projection period. Water consumption, on the other hand, is expected to increase substantially. This apparent discrepancy is due to the fact that once-through cooling systems, which have high withdrawal rates, will slowly be replaced by cooling towers which have high consumptive use rates. The result of this increase in water consumption will be reduced freshwater inflows to the Bay. If allowed to continue unabated, declining freshwater inflows could cause severe environmental damage. Adverse social and economic effects would likely accompany such changes.

In addition to the water quantity and quality problems, electric power plants and their associated facilities pose other problems. These include siting of new plants, compatible land uses adjacent to large plants, impingement and entrainment of fish in plant facilities, air pollution, radiological effects, disposal of nuclear wastes, and routing of transmission lines.

## Noxious Weeds

The aquatic plants which inhabit Chesapeake Bay waters are very important as they serve as the primary producers or vital life line for other species. However, as with any resource, an overabundance can also lead to problems. Excessive growth or heavy concentrations can actually restrict the use of other resources. Problems arise when the plants occur in such a place or to such an extent that they limit other beneficial water related uses such as navigation, recreation, fish and wildlife, water quality, and public health. At this point, they become a hindrance and are termed "noxious weeds."

The three types of aquatic plants which have, in the past, caused the most widespread problems in Chesapeake Bay include Eurasian watermilfoil, water chestnut, and sea lettuce. Eurasian watermilfoil, a submerged aquatic plant which flourishes in water ranging from fresh to 15 ppt salinity, caused problems in the late 1950's and early 1960's in the Gunpowder and Middle River areas of the northern Bay and in tributaries of the Potomac and Rappahannock Rivers in the lower Bay. Water chestnut problems, which occur near tributary headwaters (as the plant can tolerate no salinity), were documented in the Gunpowder and Sassafras Rivers in the early 1960's. Finally, sea lettuce, growing in saline waters over 12 ppt, caused problems in tributaries of the Potomac River and near the Norfolk area in the mid-1960's.

While the aforementioned aquatic plants have caused problems in the Bay Region in the past, today only an occasional isolated report of these can be found. They are still present in the Bay waters, but none in sufficient numbers to require comprehensive control measures. The potential does exist, however, for these plants to cause problems in future years should certain favorable conditions exist.

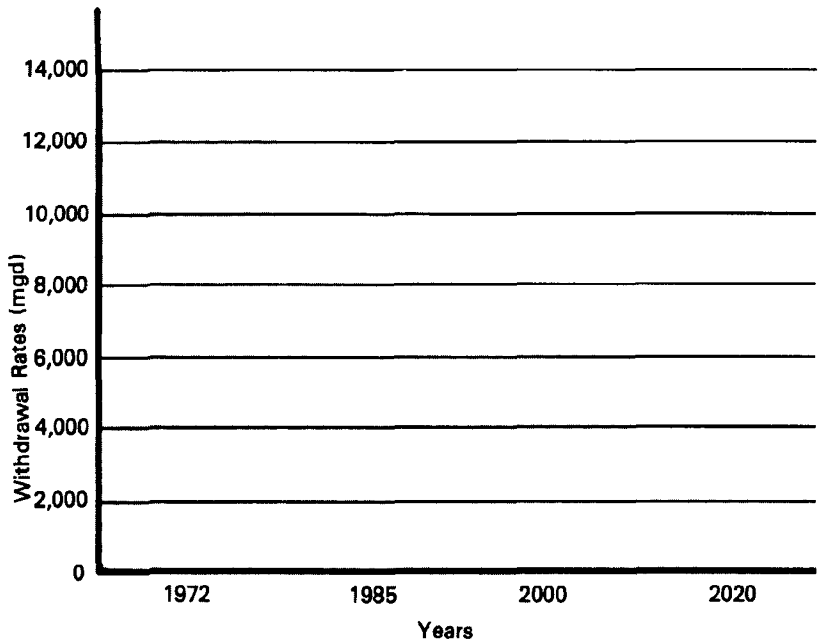
An emerging aquatic plant problem is the increase of *Hydrilla verticillata* (hydrilla) in the Washington, D.C. area. The Potomac River and several freshwater impoundments in the Washington area are becoming infested with hydrilla at an alarming rate. Planning efforts are presently underway to address the problem.

## Problems Selected for Study

As is evident from the preceding sections, there are many existing and emerging problems facing Chesapeake Bay. The responsibility for addressing a particular problem may rest at the federal, state, or local government level, depending on the nature of the problem and its areal extent. In this regard, there are numerous studies and research programs underway at all levels of government that are investigating various Bay-related problems.

The Corps of Engineers, therefore, had to establish its role at the study outset within this spectrum of ongoing studies and research. To better define a productive effort for both the study and testing programs, the Corps generally adhered to the following four guidelines:

- Selecting problems for study that were considered of high priority and that had Bay-wide significance.
- Maximizing the use of the Chesapeake Bay Hydraulic Model.
- Avoiding duplication of work being conducted under other existing or proposed programs.
- Being responsive to Congress' original intent in the authorization.



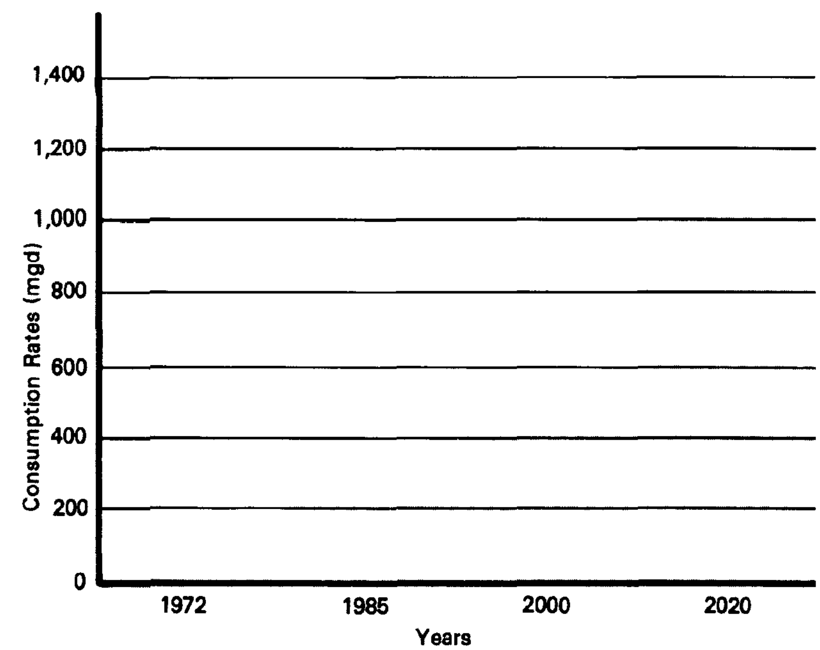




*Figure 14 Projected Energy Requirements for the Chesapeake Bay Market Areas*

## Relation Between Model Tests and Resource Studies

Before continuing, it is important to understand that two categories of "studies" were defined within the context of the overall Chesapeake Bay Study. The first category, called "model study" or "model test" refers to examinations which were to be conducted using the Chesapeake Bay Model. A model test typically addressed only the physical aspects of a particular water resource problem. The second category, called "resource study," refers to the Corps traditional planning process of plan formulation, assessment, and evaluation. A resource study typically addressed one or more problems, and considered economic, environmental, social, and institutional effects along with the physical parameters.

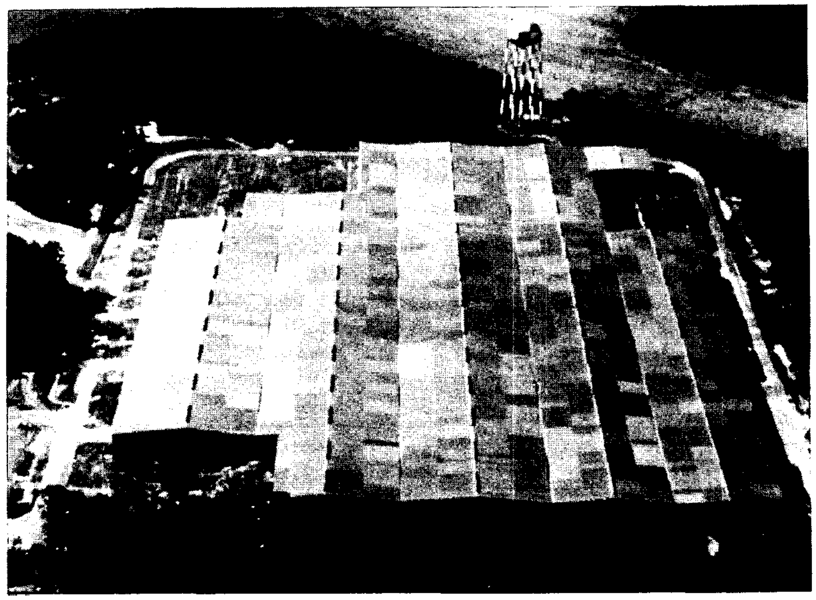


Figure 15 shows a schematic diagram outlining the relationship between the resource studies and hydraulic model tests which were conducted for the Chesapeake Bay Study. The *Existing Conditions Report* and the *Future Conditions Report* served as the primary means to identify problems. Once the problems were defined, they were separated into those which were suitable for hydraulic model testing and those which required the broader efforts associated with a resource study. Naturally, several of the model tests provided information directly to the resource studies; this important link is shown on Figure 15. Other model tests were performed in support of related Corps studies and in support of investigations by other agencies.

## Initial Model Testing Program

A list of problems having potential for testing on the hydraulic model is shown in Table 10. This list was generated from information contained in the *Existing Conditions Report,* the *Future Conditions Report*, correspondence, meetings with the Advisory Group and Steering Committee, and specific inquiries from others as to model applications. At the beginning of the study, it was assumed that the Corps would conduct only one year of testing using the Chesapeake Bay Model. Therefore, it became necessary to screen

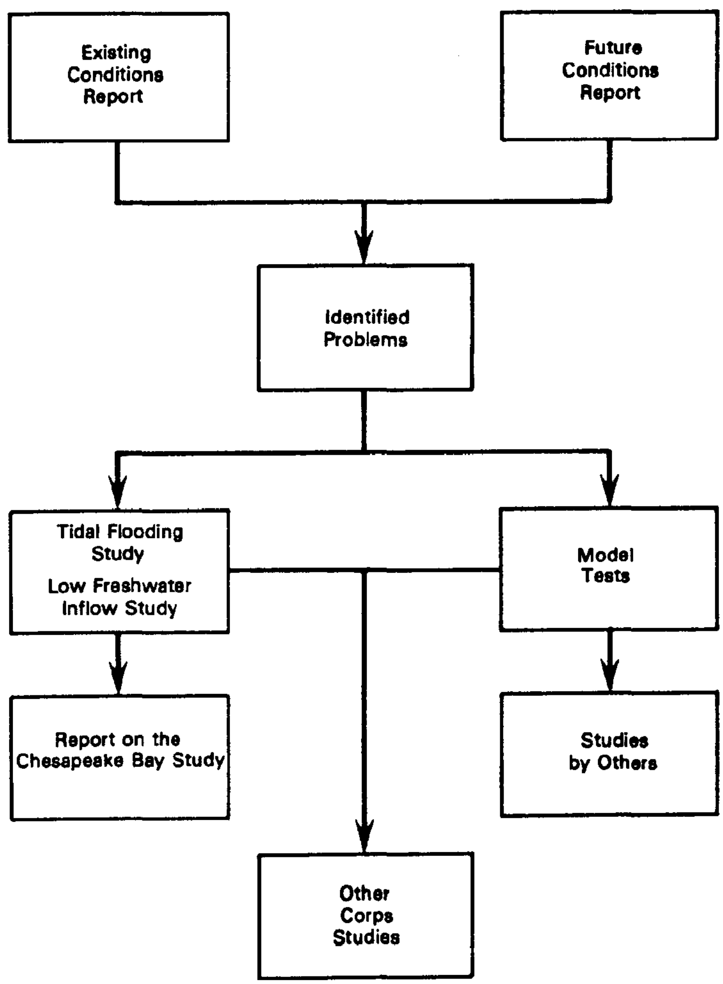



*Figure 15 Relation between Resource Studies and Hydraulic Model Testing*

the list of potential model tests to identify those having the highest priority. This screening and ranking was accomplished with the help of the Steering Committee and the Advisory Group.

Three problems were selected for testing during the model's initial year of operation. First, an examination was to be made of the effects of decreased inflows on salinity regimes within Chesapeake Bay (Low Freshwater Inflow Study). Second, an investigation was to be made of the effects on the estuarine system of dredging the Baltimore Harbor Channels to a depth of 50 feet (Baltimore Harbor Study). Third, a study was to be made of the effects on salinity and current patterns of using the upper Potomac Estuary as a supplemental water supply source for Washington, DC (Potomac River Estuary Water Supply and Wastewater Dispersion Study).

It should be noted that this initial model testing program did not include any in-depth analysis of the data to be collected. Furthermore, the hydraulic model was to be closed after one year of testing.

## Expanded Study and Testing Program

During the development of this first year program, it became apparent that there were many problems in Chesapeake Bay which could be examined only in the context of a hydraulic model testing program far beyond that which could be accomplished in a one year period. It was also apparent that if such a model testing program were undertaken, it should be formulated in the context of a resources study. Further, the model testing data should be used in the resources study as an aid in formulating solutions. In 1975, the Corps prepared a revised scope of work recommending an expanded study program and a total of four years of model testing.

Following approval of the concept of an expanded study and model testing program, a study program was identified and documented in the *Revised Plan of Study* published in October 1978. During the development of this

*Table 10* *Potential Model Tests*

**ESTUARINE PROCESSES STUDIES**

Low Freshwater Inflow Study
High Freshwater Inflow Study
Water Exchange Among Tributaries
Determination of Circulation Patterns
Tidal Flooding Study
Movement of Hydrogen Sulfide in Lower Bay

**MUNICIPAL WATER SUPPLY STUDIES**

Potomac River Estuary Water Supply
Baltimore-Susquehanna River Diversion
Rappahannock River Estuary Study
Susquehanna-Potomac Water Diversion
Upper James River (Hopewell and Richmond) Water Supply
James-Appomattox Diversions
James-York Diversions

**POWER PLANT EFFECTS STUDIES**

Proposed Upper Bay Power Plant Thermal Effects Study
Proposed Lower Bay Power Plant Thermal Effects Study
Upper Bay Power Plants Cumulative Thermal Effects Study
Lower Bay Power Plants Cumulative Thermal Effects Study
Potomac River Power Plants Thermal Effects Study
James River Power Plants Thermal Effects Study
York River Power Plants Thermal Effects Study
Rappahannock River Power Plants Thermal Effects Study

**NAVIGATION STUDIES**

Baltimore Harbor Channel Enlargement Study
North Bay Dredged Material Containment Area Study
Norfolk Harbor Channel Enlargement Study
South Bay Dredged Material Containment Area Study
Bay-Wide Dredged Material Containment Area Study
York River Channel Enlargement Study
Crisfield Harbor Construction Study
Cape Charles Harbor Channel Enlargement Study

**WASTEWATER STUDIES**

Upper and Lower Bay Wastewater Dispersion Study (EPA)
Potomac River Estuary Wastewater Dispersion Study
Patuxent River Estuary Wastewater Dispersion Study
James and Elizabeth Rivers Wastewater Dispersion Study
Patapsco River Estuary Wastewater Dispersion Study
Back River Wastewater Dispersion Study
Chester River Wastewater Dispersion Study
Choptank River Wastewater Dispersion Study
York River Wastewater Dispersion Study
Rappahannock River Wastewater Dispersion Study
Upper and Lower Bay Nutrient Equilibrium Study

**DEVELOPMENT OF NUMERICAL MODELS**

Determination of Dispersion Coefficients
Verification of Numerical Tidal Model
Determination of Water Masses in Three Dimensions
Determinations of Mass Exchanges at Open Boundaries
Calibration of Numerical Hydrodynamic Model

**SEDIMENT TRANSPORT STUDIES**

Sediment Transport in Upper Bay
Sediment Transport in Potomac River Estuary
Sediment Transport in Rappahannock River Estuary
Sediment Transport in York River Estuary
Sediment Transport in James River Estuary
Sediment Transport in Chester River Estuary

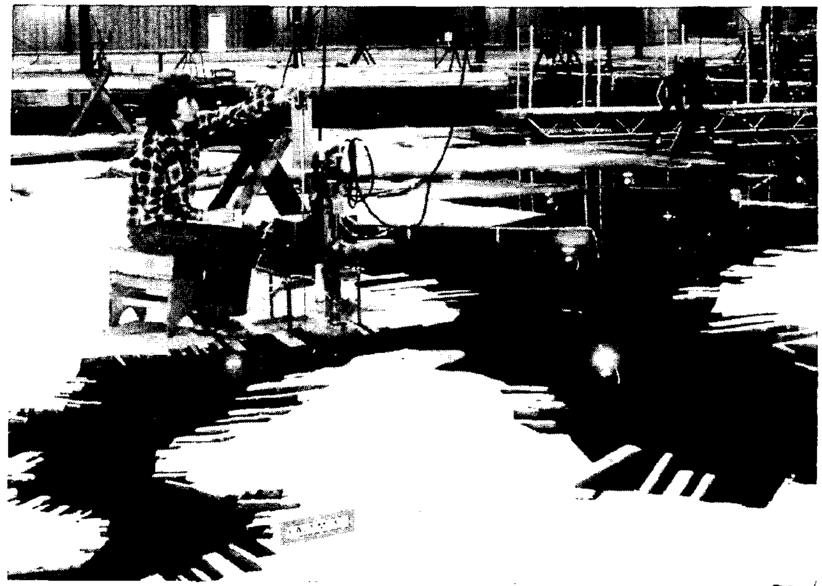
program, the potential study candidates listed in Table 10 were again reviewed. Based on this review, it appeared that at least a portion of the future study and model effort to be funded by the Chesapeake Bay Study should be directed toward studies of extraordinary natural events that have Bay-wide significance. More specifically, these rare natural events included: periods of prolonged low freshwater inflow from the Bay's tributaries, periods of high freshwater inflow from the Bay's tributaries, and tidal flooding caused by unusual climatological/meteorological conditions.

In considering the desirability of conducting additional studies of these rare events, the following points were germane to the selection process.

- These events all have significant Bay-wide impacts on the natural resources.
- The effects of these rare events are intensified because of people's use of the Bay and its resources.
- There is a lack of data/understanding of the physical changes that occur in the estuarine system as a result of these rare events. Further, the effect on both the resources themselves and people's use of the resources is not well defined.
- There is no existing federal or state program that is addressing these rare events on a Bay-wide basis.
- The resource problems and conflicts associated with these events were ranked as high priority by the Steering Committee.
- All of these rare events could be duplicated and evaluated using the Chesapeake Bay Hydraulic Model.

Based on a formulation process which considered the above points, the need for testing for others, and the overall priority of need for the testing, it was recommended that the expanded study and testing program be composed of the following:

- Baltimore Harbor Channel Enlargement Test
- Comprehensive Low Freshwater Inflow Test Study



- Potomac River Estuary Water Supply and Wastewater Dispersion Test
- Proposed Upper Bay Power Plant Thermal Effects Test for Maryland
- Upper Bay Cumulative Thermal Effects Test for Maryland
- Tidal Flooding Test and Study
- High Flow Test and Study
- Bay-wide Wastewater Dispersion Test for EPA

The Low Freshwater Inflow, Tidal Flooding, and the High Flow tests and studies were the three programs selected for detailed analysis as part of the Chesapeake Bay program. The other tests were to be conducted in support of other Corps' studies or the programs of others.

### Revisions to Expanded Study Program

For a number of reasons, the most significant of which was the lack of sufficient funding, the study and testing program as recommended in the 1978 *Revised Plan of Study* was not completed. Rather, the expanded study program was limited to the Low Freshwater Inflow Study and the Tidal Flooding Study. Both of these studies were also somewhat reduced in scope from that originally planned. A more complete description of these studies is provided in Chapters IV and V of this *Summary Report*. Further, a complete subreport with accompanying technical appendices has been prepared for each of these two studies. The testing that was conducted for others is discussed in more detail in *"Supplement C — Chesapeake Bay Hydraulic Model."*

## National Objective

Guidelines for the formulation and evaluation of water resource plans by federal agencies are contained in the "Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies." These guidelines were published by the Water Resources Council (WRC) on March 10, 1983 pursuant to Section 103 of the Water Resources Planning Act (PL 89-80) and Executive Order 11747.

The federal objective for water and related land resources planning is to contribute to national economic development (NED). Planning to achieve the NED objective must be consistent with protecting the nation's environment in accordance with national environmental statutes, applicable executive orders, and other federal planning requirements. Contributions to the NED objective are defined as increases in the net value of the national output of goods and services, expressed in monetary units. Contributions to NED are the direct net benefits that accrue in the planning area and the rest of the nation, both in terms of goods and services that are marketed and also those that may not be marketed.

Federal planning efforts are also to develop alternatives to the one that reasonably maximizes net NED benefits. In evaluating and displaying the effects of alternative plans, four accounts are employed. These four accounts include NED, environmental quality (EQ), regional economic development (RED), and other social effects (OSE). The EQ account shows effects on ecological, cultural, and aesthetic attributes of significant natural and cultural resources that cannot be measured in monetary terms. The RED account shows the regional incidence of NED effects, income transfers, and employment effects. The OSE account shows urban and community effects on life, health, and safety.

## Planning Objectives

Planning objectives are expressions of public and professional concerns about the future use of water and related land resources. They are derived through an analysis of the existing resource base and the expected future conditions within a study area. The purpose in defining planning objectives is to establish targets which guide the formulation of alternative plans and to enable evaluations of the plan effectiveness. Planning objectives may sometimes conflict with each other, reflecting different perceptions of how the water resource should be managed in the future.

Planning objectives were developed for the Chesapeake Bay Study through various Advisory Group and Steering Committee meetings, public meetings, workshops, agency correspondence, and individual discussions. Additionally, the *Existing Conditions Report* and the *Future Conditions Report* along with the *Revised Plan of Study* helped to put into focus the important planning objectives. The planning objectives are listed as follows:

- Preserve, restore, and enhance the integrity of the Chesapeake Bay ecosystem.
- Manage, preserve, and enhance areas of significant natural, historical, cultural, or scientific interest.
- Assure sufficient quantities of water to meet the needs of domestic, municipal, industrial (including power plants), and agricultural users.
- Assure water of suitable qualities for all intended or potential water resource uses.
- Maintain, enhance, and/or increase water-based recreational opportunities.
- Maintain, enhance, and/or increase the commercial and sport fishing opportunities and resources.
- Maintain or improve water navigation facilities which provide service advantageous to the nation's transportation system.
- Reduce tidal flooding damages.
- Reduce damages due to shoreline erosion.
- Develop power facilities where they can contribute to a needed increase in power supply.
- Control the occurrence of certain aquatic plants where they interfere with people's use of the Bay.
- Maintain or improve adequate outlets for approved on-farm drainage systems for surface water management.

## Planning Constraints

Planning constraints are those physical, environmental, social, economic, and institutional boundaries which define the limits of study. The broad constraints on any planning process conducted at the federal level are embodied in a large volume of law, regulation, and policy such as the "Principles and Guidelines." These constraints form the framework in which water resource projects are conceived, developed, and evaluated. The technical, economic, environmental, and social constraints and criteria for the resource studies selected for detailed analysis are discussed in the following chapters.

# Tidal Flooding Study

Tidal flooding of low lying areas adjacent to the Chesapeake Bay shorelines is an occasional natural phenomenon. Over the years, tidal flooding has caused significant human suffering and millions of dollars of damage for those people living along the shorelines. Table 8 in the previous chapter displays monetary losses associated with some of the worst tidal floods.

As discussed earlier, the Chesapeake Bay Tidal Flooding Study was one of two priority studies selected for detailed analysis because of the magnitude and Bay-wide nature of the problem. The Tidal Flooding Study had three primary objectives (1) to provide a better understanding of the tidal flood stage-frequency relationship; (2) to define environmental and socio-economic impacts of tidal flooding; and (3) to recommend structural or non-structural measures for tidal flood protection.

This summary chapter includes a description of the screening process used to identify communities subject to tidal flooding, a discussion of potential solutions, and a presentation of the plan formulation and evaluation rationale which was used for communities facing critical tidal flooding problems. Details concerning the Tidal Flooding Study are contained in the separate report titled *Chesapeake Bay Tidal Flooding Study*.

## Identification of Problem Communities

### Cause of Tidal Flooding

Serious tidal flooding in the Chesapeake Bay Region is caused by either hurricanes or "northeasters." Hurricanes which reach the Middle Atlantic states are usually formed either in the Cape Verde region or the western Caribbean Sea and move westerly and northwesterly. In most cases these storms change to a northerly and northeasterly direction in the vicinity of the East Coast of the United States.

As a hurricane progresses over the open water of the ocean, a tidal surge is created. This tidal surge is caused not only by the force of the wind and the forward movement of the storm wind field, but also by differences in atmospheric pressure accompanying the storm. The actual height reached by a hurricane tidal surge depends on many factors including shoreline configuration, bottom slope, difference in atmospheric pressure, and wind speed. Generally the tidal surge increases as the storm approaches land because of both the decreasing depth of the ocean and the contours of the coastline. An additional rise usually occurs when the tidal surge invades a bay or estuary and hurricane winds drive waters to higher levels in the more shallow areas. Tidal surges are greater and the tidal flooding more severe in coastal communities which lie to the right of the storm path. This phenomenon is due to the counterclockwise spiraling of the hurricane winds and the forward movement of the storm.

"Northeaster" is a term given to a high intensity storm which almost invariably develops near the Atlantic Coast. These storms form so rapidly that an apparently harmless weather situation may be transformed into a severe storm in as little as six hours. Most northeasters occur in the winter months when the temperature contrasts between the continental and maritime air masses are the greatest. The East Coast of the United States has a comparatively high incidence of this type of storm, with the area near Norfolk, Virginia, being one of the centers of highest frequency.

### Existing Tidal Flooding Areas

Existing flood problem areas were identified by considering the degree of tidal flooding that would be experienced by those communities located along the shoreline of the Bay and its tributaries. The analysis was limited to communities or urbanized areas.

The initial step in the analysis was to identify all Bay communities having a population of 1,000 or greater that were located either in total or in part within the "Standard Project Tidal Flood Plain." The Standard Project Tidal Flood (SPTF) was defined as the largest tidal flood that would be likely to occur under the most severe combination of meteorological and hydrological conditions that are considered reasonably characteristic of the geographic region.

The Corps of Engineers, in cooperation with the National Weather Service, determined that the SPTF would average approximately 13 feet above mean sea level (msl) for the Bay Region. The above figure is a static or standing water surface elevation which would occur in conjunction with an astronomical high tide. It does not include the effects of waves. Wave heights of approximately five feet could be expected during a hurricane. Based on the above combination of tidal surge and wave action, the SPTF would inundate areas up to approximately 18 feet above msl. However, for ease in delineating the flood area, an elevation of 20 feet above msl was assumed for the SPTF elevation.

The next step in the analysis was to identify those communities that should be classified as "floodprone." In order for a community to be designated as floodprone, at least 50 acres of land that were developed for intensive use had to be inundated by the SPTF. Intensive land use was defined as residential (four dwelling units/acre or greater), commercial (including institutional), or industrial development. The sixty Bay Region communities identified as floodprone are listed in the first column of Table 11. Approximately 82,000 acres of land in these communities were located in the SPTF flood plain.

The next step was to further examine the communities designated as floodprone and classify each as to whether or not the tidal flood problem was considered to be "critical." The

flood problem was considered to be critical if the Intermediate Regional Tidal Flood (IRTF) inundated 25 acres or more of intensively developed land and also caused significant physical damage. The IRTF was defined as that tidal flood which has a one percent chance of occurrence in any one year, generally referred to as the 100-year flood. Elevations for the 100-year tidal flood were approximated for points around Chesapeake Bay based on historical records. The flood heights were found to range between 6 and 11 feet above msl. Approximately 27,000 acres of land in 32 communities were found to be in the 100-year tidal flood plain. The 32 critically floodprone communities are designated in the second column of Table 11.

## Future Tidal Flooding Areas

The criterion used for designating an area as floodprone in the future was that 50 acres or more of land proposed for intensive land use fall within the Standard Project Tidal Flood Plain. Areas were considered to be "critically" floodprone if 25 acres or more of land proposed for intensive land use were within the 100-year flood plain. The communities found to be critically floodprone in the future are designated in the third column of Table 11.

Based on a comparison of the existing and future acreage, it was noted that an additional 58,000 acres of land are proposed for intensive development within the Standard Project Tidal Flood Plain with 19,000 acres of that land being within the 100-year flood plain.

## Screening of Communities for Detailed Analysis

During the preparation of the *Revised Plan of Study,* a further screening of those critical communities listed in columns 2 and 3 of Table 11 was conducted. This screening eliminated those communities where it was evident that flood protection would not be feasible. This determination was based on the fact that many residential communities are located along the Bay's shoreline solely for aesthetic and recreational reasons. A structural solution would require, in most cases, a flood wall of excessive height. This type of structure would impact upon the use of the shoreline for recreation and would cause visual disruption of the shoreline's environment. Application of non-structural solutions such as flood proofing and relocation, would also be inappropriate. Many of these structures are old and not suitable for major flood proofing modifications. Relocation away from the shoreline would likewise be unacceptable because the houses were built adjacent to the water to take advantage of the resource.

Further screening eliminated several additional communities from further consideration. Smith Island, Maryland, Virginia Beach, Virginia, and Colonial Beach, Virginia were eliminated as detailed studies of these communities were being conducted by the Corps of Engineers under specific study resolutions. Any further effort under the Chesapeake Bay Program would have been duplicative. Denton and Salisbury, Maryland, were eliminated when preliminary stage-damage surveys and more detailed flood plain delineation indicated that the flood problem was limited to only scattered development at frequencies in excess of once in 100 years. Likewise, Fredericksburg, Virginia, was eliminated when fluvial rather than tidal flooding was found to be the problem.

Lastly and most significantly, Baltimore City and the Dundalk area of Baltimore County were eliminated after preliminary damage surveys and an evaluation of several struc-

*Table 11*

*Tidal Flooding*
*Critical Problem Areas*

| *Communities Facing Floodprone Communities** | *Communities With Critical Existing Problems*** | *Communities Facing Additional Critical Problems in Future**** | *Communities Designated For Detailed Study* |
|---|---|---|---|
| *Maryland* | | | |
| Anne Arundel County | | | |
| Arundel on the Bay | X | X | |
| Avalon Shores | X | | |
| Broadwater | | | |
| Columbia Beach | | | |
| Deal | X | | |
| Eastport | | | |
| Franklin Manor on the Bay & Cape Anne | | | |
| Galesville | | | |
| Rose Haven | | | |
| Baltimore City | X | | |
| Baltimore County | | | |
| Back River Neck | | | |
| Dundalk | X | X | |
| Middle River Neck | X | | |
| Patapsco River Neck | X | | |
| Calvert County | | | |
| Cove Point | | | |
| North Beach on the Bay | | | |
| Solomons Island | | | |
| Caroline County | | | |
| Choptank | | | |
| Denton | X | | |
| Federalsburg | | | |
| Cecil County | | | |
| Elkton | | X | |
| Northeast | | X | |
| Charles County | | | |
| Cobb Island | | | |
| Dorchester County | | | |
| Cambridge | X | | X |
| Harford County | | | |
| Havre de Grace | | | |
| Kent County | | | |
| Rock Hall | X | X | X |
| Queen Anne's County | | | |
| Dominion | | | |
| Grasonville | X | X | |
| Stevensville | | X | |

*Table 11 (cont'd)*

| *Communities Facing Floodprone Communities** | *Tidal Flooding Critical Problem Areas* — *Communities With Critical Existing Problems*** | *Communities Facing Additional Critical Problems in Future**** | *Communities Designated For Detailed Study* |
|---|---|---|---|
| St. Mary's County | | | |
| Colton | | | |
| Piney Point | X | | |
| St. Clement Shores | | | |
| St. George Island | | | |
| Somerset County | | | |
| Crisfield | X | | |
| Smith Island | X | X | X |
| Talbot County | | | |
| Easton | | | |
| Oxford | | | |
| St. Michaels | X | X | X |
| Tilghman Island | X | | X |
| Wicomico County | | | |
| Bivalve | | | |
| Nanticoke | | | |
| Salisbury | X | X | |
| Worcester County | | | |
| Pocomoke City | X | X | X |
| Snow Hill | X | | X |
| *Virginia* | | | |
| Independent Cities | | | |
| Chesapeake | X | X | X |
| Fredericksburg | X | | |
| Hampton | X | X | X |
| Newport News | | | |
| Norfolk | X | X | X |
| Poquoson | X | X | X |
| Portsmouth | X | | X |
| Virginia Beach | X | X | |
| Accomack County | | | |
| Onancock | | | |
| Saxis | | | |
| Tangier Island | X | | X |
| King George County | | | |
| Dahlgren | X | | |
| King William County | | | |
| West Point | X | | X |
| Northampton County | | | |
| Cape Charles | X | | X |
| Westmoreland County | | | |
| Colonial Beach | X | | |
| *Washington, D.C.* | X | | |

*Communities having at least 50 acres of existing development within the Standard Project Tidal Flood Plain.

**Communities having at least 25 acres of existing development within the 100-year tidal flood plain.

***Communities having at least 25 acres of additional proposed development within the 100-year tidal flood plain.

tural and non-structural measures. These preliminary evaluations indicated that both structural and non-structural measures which would provide flood protection for the most floodprone sections of these two areas would have benefit-cost ratios on the order of only 0.1.

The fourth column of Table 11 provides a list of the floodprone communities which were retained for detailed examination. Figure 16 shows the locations of these communities. (It should be noted that the independent cities of Hampton, Norfolk, Chesapeake, and Portsmouth were considered as a single area during the detailed examination.)

## Detailed Problem Definition

Having identified those communities which are subject to serious tidal flooding, the next step in the investigation was to examine each community in detail to determine the magnitude and frequency of the flood damages. Detailed flood damage analyses were conducted in 1979 to establish the relationship between flood stages (heights) and corresponding damages in the floodprone communities. Field surveys were undertaken to determine the number of structures subject to tidal flooding. These structures were then classified according to residential, commercial, industrial, or public uses. Damage estimates were assigned to each structure according to its use, its contents, its condition, and its location. Generally, greater damages were found to be associated with the higher tidal flood stages.

At the same time that the flood damage surveys were being conducted, the Corps was proceeding with the planning necessary to develop Bay-wide stage-frequency relationships. A numerical tidal surge model was to be used to develop the stage-frequency information. The hydraulic model was then to be used to calibrate and verify the numerical model by simulating several storm surges of different frequencies in conjunction with tidal fluctuations and fluvial inflows. Unfortunately, funding constraints and problems with the hydraulic model indefinitely delayed the stage-frequency examination, and it was necessary to proceed without such information. Therefore, the tidal flooding analysis was conducted using existing stage-frequency relationships rather than the refined data expected from the combined hydraulic and numerical modeling effort.

The stage-damage information and the stage-frequency data were combined to produce a damage-frequency relationship for each floodprone community. From this relationship, average annual damages, shown in Table 12, were developed for each community. These numbers represent the average damages which could be expected in any year under existing conditions (i.e., no improvements) when considering the entire hydrologic record. Average annual damages are an economic tool used by the Corps of Engineers and other federal agencies to evaluate the relative seriousness of flood problems. They are also used to compare the cost of flood reduction measures against the reduced damages (benefits) that would be expected from a project.

## Plan Formulation and Evaluation

Once the severity and frequency of the tidal flooding problem in each community had been defined, alternative plans for reducing the damages were formulated. Potential structural and non-structural measures were first examined in general terms. Later, these measures were combined

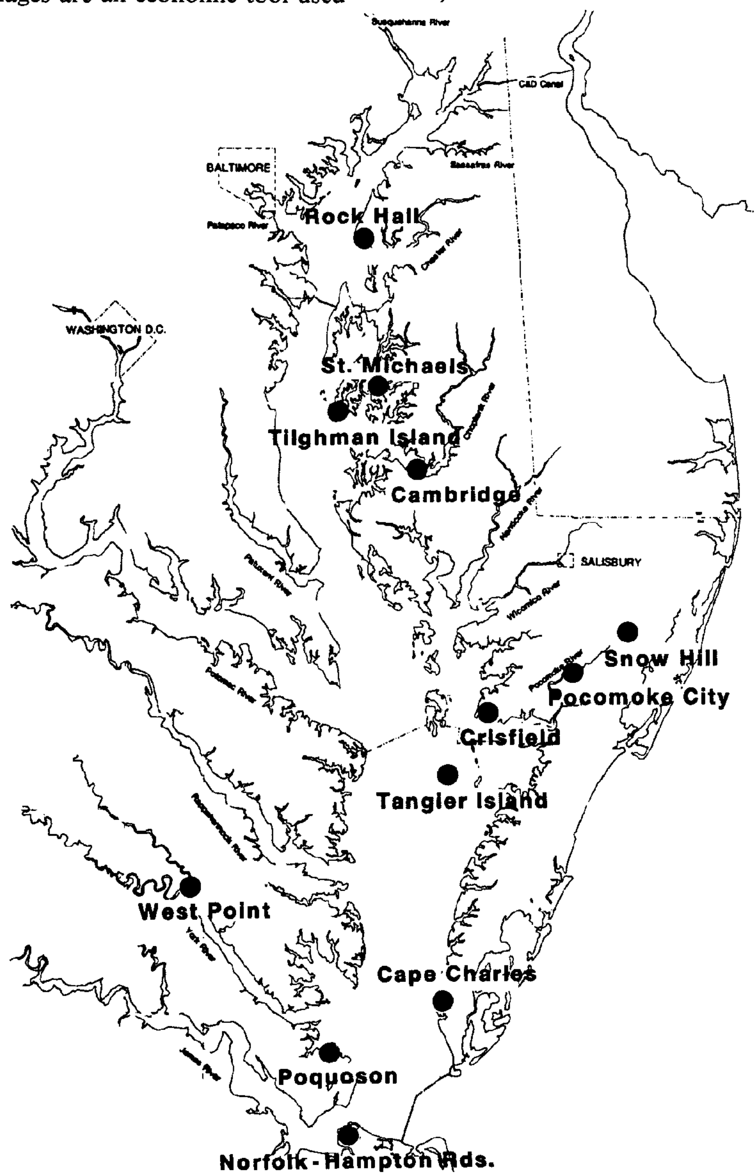



*Figure 16 Floodprone Communities Designated for Detailed Study*

into specific plans according to the conditions in each floodprone community.

## Survey of Potential Management Measures

### Structural Solutions

Structural solutions are defined as those man-made structures that are designed to protect an area from tidal flood damages. Flood walls and levees are two examples of these types of structures. While differing in design, appearance, and cost, flood walls and levees serve essentially the same purpose. Both are constructed near the shoreline to protect landside development from inundation by tidal flood waters.

Flood walls are generally concrete and may have vertical, curved or stepped faces. Flood walls may be used where the close proximity of the development to the shoreline precludes the construction of levees. Levees are usually earth embankments having a top width of approximately 10 feet and side slopes that vary between 1 on 2 and 1 on 4. Levees are generally less expensive than flood walls. They are particularly applicable in areas where construction materials are nearby and there is sufficient area between the shoreline and the development for their construction.

*Table 12*

*Average Annual Damages Due To Tidal Flooding*

| Community | Average Annual Damages |
|---|---|
| *Maryland** | |
| Cambridge | $ 18,000 |
| Crisfield | $142,000 |
| Pocomoke City | $ 24,000 |
| Rock Hall | $ 74,000 |
| Snow Hill | $ 11,000 |
| St. Michaels | $ 26,000 |
| Tilghman Island | $ 35,000 |
| *Virginia*** | |
| Cape Charles | $ 30,000 |
| Hampton/Norfolk/Chesapeake/ Portsmouth*** | $ 79,000 |
| Poquoson | $398,000 |
| Tangier Island | $382,000 |
| West Point | $ 49,000 |

*Average annual damages are shown at July 1979 price levels.
**Average annual damages are shown at January 1983 price levels.
***Based on results of studies at one selected sample area (Fox Hill).

Due to the high cost of this type of protection, the use of levees and flood walls in the Bay Region is generally limited to those floodprone areas where there is extensive residential, commercial, or industrial development. It should also be noted that providing a levee or flood wall of sufficient height to protect against a major tidal flood could severely restrict the use of the shoreline for recreational, transportation, or shipping purposes. Also, the protection may be considered unacceptable from an aesthetic standpoint if the view of the water body is restricted.

A breakwater is another type of flood protection structure. It is designed to break the force of storm waves and thus reduce the damage that would be experienced by storm waves breaking on shoreline development. The design of an effective breakwater includes consideration of the expected height and direction of storm waves, the selection of size and type of construction materials based on expected wave forces, the availability of construction materials in the project area, the effect of the breakwater on commercial and recreational boating, and the environmental effects.

Breakwaters can be either shore-connected or located offshore. They are generally classified by either the construction materials or the method of construction. Breakwaters can be constructed of stone or concrete blocks (rubble-mound breakwaters), stone-asphalt mixtures, reinforced concrete shells filled with stone or sand, steel sheet piling cells filled with sand, or timber cribs filled with rubble. They can also be mobile or floating breakwaters which may be moved into place when a tidal flood is predicted. The most common type of breakwater in the Chesapeake Bay Region is the shore-connected, rubble-mound breakwater. In the sheltered waters of the Bay and the sub-estuaries, this type of protection is very effective and usually can be constructed with materials that are available locally.

Recreational and commercial craft are particularly susceptible to damage caused by the large waves associated with tidal flooding. Harbors of refuge provide areas of calm water for the safe mooring of all types of craft. Harbors of refuge can be naturally sheltered areas such as coves or inlets, or existing marinas and mooring areas protected through the use of breakwaters.

Other possible structural measures include bulkheads, revetments, groins, and beach nourishment. These measures, however, are used primarily for the control of shoreline erosion and have only limited applicability as tidal flood control solutions.

### Non-Structural Solutions

Non-structural solutions include regulatory actions by communities or individual measures by property owners to either prevent tidal flood damage or to avoid land use patterns which conflict with tidal flooding. Some of the more common types of non-structural measures include flood proofing, relocation, aquisition and demolition, flood forecasting, evacuation, zoning and land use controls, and public awareness programs.

Flood proofing is actually a combination of minor structural changes and adjustments to properties subject to flooding. Flood proofing is recommended where traditional types of flood protection are not feasible and where moderate flooding having low stages, low velocity, and short duration is expected. Flood proofing measures can be classified into three broad types. First, there are permanent measures which become an integral part of the structure. Second, there are standby measures which are used only during floods, but which are constructed or made ready prior to any flood threat. Third, there are emergency measures which are carried out during a flood according to a predetermined plan.

Permanent measures usually involve either the elimination of openings through which water can enter a building. For example, unnecessary doors and windows can be permanently sealed with brick; valves can be installed on basement sewer pipes to prevent flood water from backing up into the basement; or boilers, air-conditioning units, and other immobile machinery can be moved to high elevations and replaced with movable furniture or stock. Adjustments such as these can be most easily undertaken in existing buildings during periods of remodeling or expansion. Raising the entire structure above the tidal flooding level is another method of permanent flood proofing.

Standby measures are most desirable when it is necessary to maintain access to structures at points below selected flood protection levels. For example, display windows at commercial structures must not be blocked in order to serve their main purpose. These types of openings cannot be permanently flood proofed, but they can be fitted with removable flood shields. Since the placement and installation of such devices requires several hours, a flood warning system has to be established before such flood proofing measures can become effective.

Emergency measures are carried out during an actual flood experience. These measures may be designed to keep water out of buildings and are intended only to protect equipment and stock. A widely used emergency measure is the planned removal of contents to higher locations when a certain flood stage is expected. Again, an effective flood warning system is crucial to the effectiveness of this type of measure.

Relocation of a structure involves moving the building to a new site which is not in the tidal flood plain. Although classified as a "non-structural" measure, relocation includes several construction-type activities such as preparing a new site, readying the structure for transport, transporting the structure to a new location, and razing the former site. Typically, relocation is an expensive and somewhat time-consuming operation. Provided the new site is above the tidal flooding zone, though, the solution is a permanent one. A similar procedure is for some public agency to acquire the flood prone property, relocate the owner/resident to a different building, and demolish the former structure.

Reliable and accurate forecasts of floods and flood stages can be coupled with well-planned evacuation procedures to save lives and reduce property losses. Unlike fluvial flooding along small inland streams, tidal flooding along the Bay's shorelines can usually be predicted several hours to sometimes several days in advance. These types of forecasts are normally prepared and released by the National Weather Service. If conditions warrant temporary abandonment of buildings in low-lying areas, the local civil defense offices and Red Cross chapters can conduct the evacuation according to a predetermined plan. Some communities have even practiced flood evacuation procedures in simulated exercises. Advance flood warnings also permit home-owners and businesses to move household goods and equipment to upper floors or higher ground.

Until recently, insurance against flood losses was virtually non-existent. Now, however, flood insurance is available in floodprone communities under the Federally-subsidized National Flood Insurance Program. A cooperative effort of the Federal Government and the private insurance industry, the program is operated by the Federal Insurance Administration of the U.S. Department of Housing and Urban Development (HUD). In return for making low cost insurance available for existing floodprone properties, the program places certain obligations upon the community. It is required to adopt and enforce certain land use, zoning, and building code regulations which will govern development in the floodprone areas. The emphasis of these regulations is generally on discouraging intensive development and encouraging instead land uses such as parks, ball fields, and picnic areas which do not suffer significant permanent losses from temporary flooding.

The potential hazards of tidal flooding are not always evident to a prospective developer or homeowner. In other instances, the hazard may be apparent, but the preventative action taken to avoid the problem is either ill-conceived or constructed. In either case, the individual would benefit from additional information relative to tidal flooding. A public awareness program would serve to advise the public as to the location of the flood plain and expected flood heights. The program could also provide information as to the structural and non-structural measures that could be used to cope with tidal flooding. The success of a public awareness program that is directed toward "self-help" is highly dependent on the publicity which it receives. Distribution of information should be supplemented by public meetings to explain the purpose and intent of the program and where further technical advice can be secured.

## No Action

One other option that must be considered is the "no action" or "do nothing" plan. Certain segments of a community or, in fact, entire communities may not be well suited for the application of flood damage reduction measures. Additionally, some communities may not desire any kind of planned flood protection, perhaps for aesthetic reasons. Still other communities may consider the risk associated with the expected level, frequency, and duration of flooding to be within acceptable limits and thereby choose to do nothing.

## Development of Alternative Plans

Having completed the survey of potential management measures, a range of alternative plans was developed for each floodprone community. The plans were comprised of different combinations of structural and non-structural measures aimed at reducing or eliminating tidal flooding damages. Depending on the frequency of flooding, the real extent of damages, and the estimated economic severity, different levels of flood protection were also considered within each community. Costs for each alternative plan were developed and then annulized for comparison to the reduced average annual damages. Benefit to cost ratios were then computed for each plan, and the environment effects were investigated.

Several formulation criteria were used to guide the development of the alternative plan. These criteria are listed below:

- Flood protection should be designed to provide protection against the 100-year tidal flood (approximately equal to the flood of record) and up to the 500-year tidal flood, if practicable.

- Flood protection design criteria such as freeboard requirements and design features of a structure's typical cross section should be compatible with the existing site conditions, available materials, and the type of structure selected.

- The plans developed should be engineeringly feasible.

- Tangible and intangible benefits should exceed costs.

- Benefits and costs should be expressed in comparable quantitative economic terms based on either a 50 or 100-year project life and the applicable federal interest rate.

- Loss of life and property and hazards to health and safety should be eliminated.

- Archaeological, historical, aesthetic, geological and ecological resources should be preserved, maintained or enhanced.

- Community cohesion and desirable community growth should be preserved, maintained or enhanced.

The character of the flood plain communities in Maryland is somewhat different from those in Virginia. The Maryland communities, for the most part, were found to be older village centers with relatively stable populations. The economics in most of them are tied to the seafood industry and other Bay-related trades. Little growth is projected for coming years. The Virginia communities, on the other hand, were generally found to be somewhat larger and of a broader economic base. Significant growth is expected in future years in some of them. The Virginia communities, of course, are also closer to the Atlantic Ocean and exposed to potentially greater damages as storms move along the coastline.

## Maryland Communities

Table 13 contains a list of the Maryland communities and a summary of the structural and non-structural measures which were considered. Some plans contained only structural elements, some plans contained only nonstructural measures. Alternative plans for a given community sometimes differed only in the level of protection provided. In other communities, alternative levee and/or floodwall alignments were examined to furnish protection to different sections within the town.

Adverse environmental effects were found to range from minimal for most of the non-structural measures to significant for the structural components. Adverse social effects would occur if structures were relocated, or if certain buildings were acquired and demolished. Economic information was developed for each alternative plan and is shown in the last several columns of Table 13. As is evident from the data in the table, the economic costs of providing tidal flood damage protection far outweighed the potential economic benefits. In no instance did the ratio of benefits to costs exceed the 1.0 necessary for economic justification.

Most of the flood damage surveys for the Maryland communities were performed in 1978 and 1979 and reflect conditions at that time. A reconnaissance level survey of these same communities was undertaken in 1983, however, to determine if any of them had experienced major growth in areas subject to tidal flooding. The conclusions reached from this survey were that some minor growth had occurred in nearly all communities, but not to the degree necessary to substantially alter any of the earlier findings. Thus, no additional work was performed for any of the Maryland communities when preparing the report on the Chesapeake Bay Study.

## Virginia Communities

Similar to the plan development process for the floodprone Maryland communities, alternative plans were formulated for each of the Virginia communities facing critical tidal flooding problems. These plans also included both structural and nonstructural measures in various combinations as indicated in Table 14. (It should be noted that the intense level of development in the Hampton/Norfolk/Chesapeake/Portsmouth region precluded a detailed examination of the area during this study. Instead, only the selected sample area of Fox Hill was examined to determine if tidal flood reduction measures might be feasible.)

Environmental and social effects of the various flood reduction measures were found to be similar to those in the Maryland communities. In several of the Virginia communities, though, the preliminary examinations conducted in 1978 and 1979 revealed that some of the alternative plans were economically justified. Consequently, the Norfolk District, Corps of Engineers conducted additional investigations in 1983 to determine if any of the tidal flood reduction plans still appeared to be feasible. These investigations included reexaminations of the average annual damages, new computations for the first costs and annual costs of the alternative plans and recomputation of the benefit to cost ratios. The results of this recent iteration of economic

*Table 13*

## *Plans for Tidal Flood Protection*
## *Maryland Communities*

| Community | STRUCTURAL MEASURES Earth Levee | Concrete Floodwall | Flood Proofing | NON-STRUCTURAL MEASURES Utility Room Addition | Acquisition & Demolition | Relocation | Raising | Average Annual Damages | ECONOMIC INFORMATION* First Cost Of Plans | Annual Cost** Of Plans | Annual Benefits Of Plans | Benefit To Cost Ratios |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cambridge (8 Plans) | X | X | X | X | X | | | $ 18,400 | $556,300 to $9,120,600 | $55,150 to $706,700 | $13,500 to $103,800 | 0.1 to 0.5 |
| Crisfield (6 Plans) | X | X | X | X | X | X | X | $142,500 | $676,300 to $7,333,200 | $49,800 to $567,200 | $33,000 to $172,000 | 0.3 to 0.7 |
| Pocomoke Cty (5 Plans) | X | X | X | X | X | X | X | $ 23,900 | $259,700 to $4,322,700 | $19,100 to $335,300 | $10,100 to $18,000 | 0 to 0.5 |
| Rock Hall (10 Plans) | X | X | X | X | X | X | X | $ 73,500 | $1,093,000 to $13,513,800 | $80,450 to $1,046,300 | $22,500 to $194,500 | 0.2 to 0.3 |
| Snow Hill (7 Plans) | X | X | X | | X | | X | $ 11,400 | $303,500 to $3,741,600 | $22,300 to $290,000 | $3,400 to $9,100 | 0 to 0.2 |
| St.Michaels (4 Plans) | X | X | X | X | X | | X | $ 26,300 | $730,000 to $11,970,800 | $53,700 to $926,600 | $8,200 to $16,000 | 0 to 0.2 |
| Tilghman Is (7 Plans) | X | X | X | | X | X | X | $ 34,700 | $120,500 to $8,896,360 | $8,900 to $689,300 | $400 to $21,000 | 0 to 0.3 |

*Economic information is based on July 1979 price levels and the fiscal year 1980 interest rate of 7 1/8 percent.

**Figures for annual costs include operation and maintenance as well as interest and amortization.

*Table 14*

## *Plans for Tidal Flood Protection*
## *Virginia Communities*

| Community | STRUCTURAL MEASURES Earth Levee | Concrete Floodwall | Dikes Flapgates | Flood Proofing | NON-STRUCTURAL MEASURES Utility Room Addition | Acquisition & Demolition | Relocation | Raising | Average Annual Damages | ECONOMIC INFORMATION* First Cost Of Plans | Annual Cost** Of Plans | Annual Benefits Of Plans | Benefit To Cost Ratios |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cape Charles (5 Plans) | | | X | | X | | | X | $ 37,300 | $103,000 to $502,000 | $9,300 to $45,400 | $200 to $5,200 | 0.02 to 0.13 |
| Hampton/ Norfolk/ Chesapeake/ Portsmth*** (3 Plans) | | X | | | | | | X | $100,100 | $904,000 to $3,184,000 | $81,800 to $352,000 | $62,000 to $108,600 | 0.3 to 0.8 |
| Poquoson (8 Plans) | | | | | | X | X | X | $501,400 | $199,000 to $8,754,000 | $18,100 to $792,800 | $15,000 to $362,000 | 0.2 to 1.2 |
| Tangier Is. (4 Plans) | | X | | | | | | X | $481,700 | $180,000 to $24,891,000 | $16,300 to $2,503,300 | $23,800 to $534,100 | 0.2 to 1.5 |
| West Point (4 Plans) | | | | | | | | X | $ 62,500 | $90,000 to $1,048,000 | $8,200 to $94,900 | $9,400 to $40,200 | 0.4 to 1.2 |

*Economic information based on January 1983 price levels and fiscal year 1983 interest rate of 7 7/8 percent.

**Figures for annual costs include operation and maintenance as well as interest and amortization.

***Figures are for the Fox Hill sample area only.

analyses are shown in the last several columns of Table 14. Confirming the earlier work, certain combinations of tidal flood reduction measures appear to be *economically justified for* Poquoson, Tangier Island, and West Point.

## Findings and Conclusions

Several significant findings and conclusions were derived from the Chesapeake Bay Tidal Flooding Study just described. The first and most obvious finding is that periodic tidal flooding is a problem that affects all of Chesapeake Bay's shorelines at one time or another. Nearly 60 communities around the Bay were identified as having existing or potentially serious tidal flooding problems. Less obvious, perhaps, is that significant monetary loss from tidal flooding is incurred by only a small number of these communities which because of topography and land use patterns, are especially susceptible to damage in developed sections. The twelve communities noted in Table 11 and shown on Figure 16 were identified for detailed examination during the Tidal Flooding Study.

Both structural and non-structural measures are available to reduce or prevent the adverse effects of tidal flooding in these communities. Structural measures include projects such as earth levees and concrete flood walls. For some communities, these measures are the most effective means of flood protection. These structural solutions, however, usually have adverse environmental effects and are very expensive. In addition, residents are often opposed to structural solutions on aesthetic grounds and because direct access to the Bay's shoreline is hindered.

Non-structural measures include programs such as flood proofing, utility room additions, acquisition and demolition of floodprone structures, relocation, and raising of buildings. Non-structural solutions are usually less expensive and less environmentally damaging than structural projects. Voluntary participation by nearly all residents and businesses is required, though, to make a non-structural tidal flood protection program effective on a community-wide basis. Furthermore, non-structural solutions usually require direct monetary outlays by these same residents and businesses.

Combinations of structural and non-structural measures are perhaps the best plans for tidal flood protection. Economic information developed during the Tidal Flooding Study, however, indicated that tidal flood protection programs were economically, justified in only a few communities. Of those 12 communities which were investigated, only three Virginia communities (Poquoson, Tangier Island, and West Point) were found to have plans with benefit to cost ratios greater than 1.0. The value and intensity of development in most floodprone areas was not great enough to warrant a full-scale tidal flooding protection program. A further observation is that many residents of floodprone communities view tidal flooding as a temporary inconvenience which is a tolerable tradeoff for the benefit of living and working close to the water of Chesapeake Bay.

Although flood protection plans for the Hampton Roads complex (Hampton, Norfolk, Chesapeake, and Portsmouth) would not be economically justified based on the findings of the Fox Hill sample area, further detailed studies of the entire area are warranted. Existing flood damage surveys in the Hampton Roads area are over 20 years old, and much new development along with substantial redevelopment has occurred in this particular area. Detailed flood damage surveys reflecting current conditions should also be undertaken for Poquoson, and Tangier Island, before any firm commitments to tidal flood protection plans are made in these communities. While there was economic justification for one of the plans for West Point, the limited scope of the plan (three residential and one industrial property) and the intent of the property owners to undertake their own improvements precludes the need for additional study.

Any further investigation of tidal flooding along Chesapeake Bay shorelines should also include development of a storm surge model, as discussed earlier in this chapter. Such a model would permit more accurate forecasts of tidal flooding stages. A storm surge model would also be useful in developing a better stage-frequency relationship on which to base the computation of average annual damages used in the economic evaluation of flood reduction plans.

In spite of the finding that few tidal flooding protection plans are justified, certain steps can be taken to reduce inconvenience and damage in a community. Perhaps one of the most promising steps is the development of an accurate tidal flood forecasting and warning system. This system could be developed through the coordinated efforts of the National Weather Service and local civil defense departments. Included in the flood forecasting and warning system would be items such as the following: advance weather and tidal stage forecasts, communication networks to inform communities and residents of potential flooding, permanent markets in critical areas to indicate tidal flood heights, planned evacuation routes from low-lying areas, and designation of municipal buildings not in floodprone areas for temporary shelter during flood events. While such actions alone will not reduce the incidence or magnitude of tidal flooding, human suffering and inconvenience would at least be reduced. Another step is the encouragement of land use patterns in the floodprone areas which are compatible with periodic tidal flooding. These patterns could be established at the local level through comprehensive planning documents, zoning ordinances, or land use regulations.

# Chapter V

## Low Freshwater Inflow Study

Chesapeake Bay is dependent upon the inflow of freshwater to maintain its salinity regime. Decreases in the amount of freshwater entering the Bay have had serious environmental, social and economic impacts in the past and are expected to have even more severe impacts in the future.

As discussed earlier, the Low Freshwater Inflow Study was one of two priority problems selected for detailed analysis. This selection was based on the severity and Bay-wide nature of the low freshwater inflow related problems. The Low Freshwater Inflow Study had three primary objectives: (1) to provide a better understanding of the relationship between the salinities in Chesapeake Bay and the magnitude of freshwater inflow from its tributaries; (2) to define the socio-economic and environmental impacts of both short and long term reductions of freshwater inflow; and (3) to identify the promising alternative solutions to the problems caused by reductions in freshwater inflow to Chesapeak Bay.

This chapter includes: (1) a description of the problem identification process to include the selection of priority problem species, (2) a discussion of the alternative measures that could be employed to solve the problems and (3) a presentation of the plan formulation and evaluation rationale used to select the most promising alternatives. Details concerning the Low Freshwater Inflow study are contained in the report and appendices titled *Chesapeake Bay Study — Low Freshwater Inflow Report.*

## Problem Identification

Like all estuaries, Chesapeake Bay is dependent on the inflow of freshwater to maintain its salinity regime. The many species that live in the Bay year round and others that utilize it only in various portions of their life cycle are generally able to survive in the natural variations in salinity. But, drastically reduced freshwater inflows during a period of drought or reductions of less magnitudes over a longer period of time can impose environmental stress by threatening the health or even the survival of species sensitive to particular ranges of salinity. Changes in freshwater inflow can also alter existing estuarine flushing characteristics and circulation patterns. In short, the character of Chesapeake Bay and the health and well being of the ecosystem are dependent on established physical, chemical, and biological patterns in the Bay. These are, in turn, intimately related to the volumes and seasonal variations in freshwater inflows.

The Chesapeake Bay and its tributaries are a large source of water supply for the communities, industries, and farms located along or near its shores. People use the water from the Bay and its tributaries for a variety of domestic purposes. Industries use it in their manufacturing processes while farmers irrigate crops and water live stock. Most of this water is returned to the Bay or its tributaries after it has been used. The part that is not returned is called the consumptive loss. Consumptive losses occur nearly every time water is used. The amount of the consumptive loss varies with each use and may include up to as much as 75 percent of the water withdrawn. Most importantly, recent studies show that consumptive losses have increased over the years and are expected to continue to increase over the next fifty years.

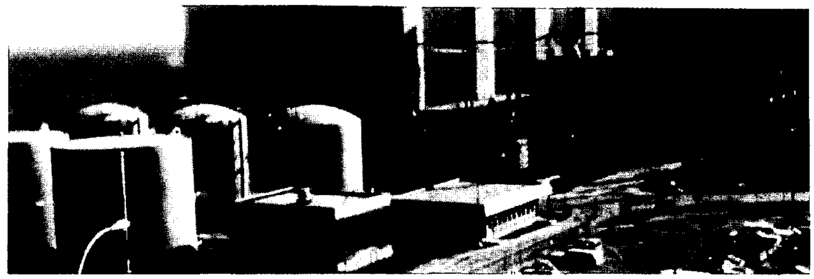
In the future, every tributary to Chesapeake Bay will be subjected to the consequences of a rapidly increasing consumptive use of water. This means that by the year 2020 there will be a marked reduction in the amount of fresh water flowing into Chesapeake Bay. The result of this will be an increase in the Bay's salinity levels. The magnitude of these increased salinities and their socio-economic and environmental consequences was the focus of the problem identification stage of this study. The problem identification process was conducted in the following four steps:

1. Develop existing and expected future water supply demands.

2. Develop existing and future consumptive loss projections.

3. Conduct testing on the Chesapeake Bay Hydraulic Model to determine changes in salinity caused by reduced freshwater inflows.

4. Determine the socio-economic and environmental impacts of changes in salinity.



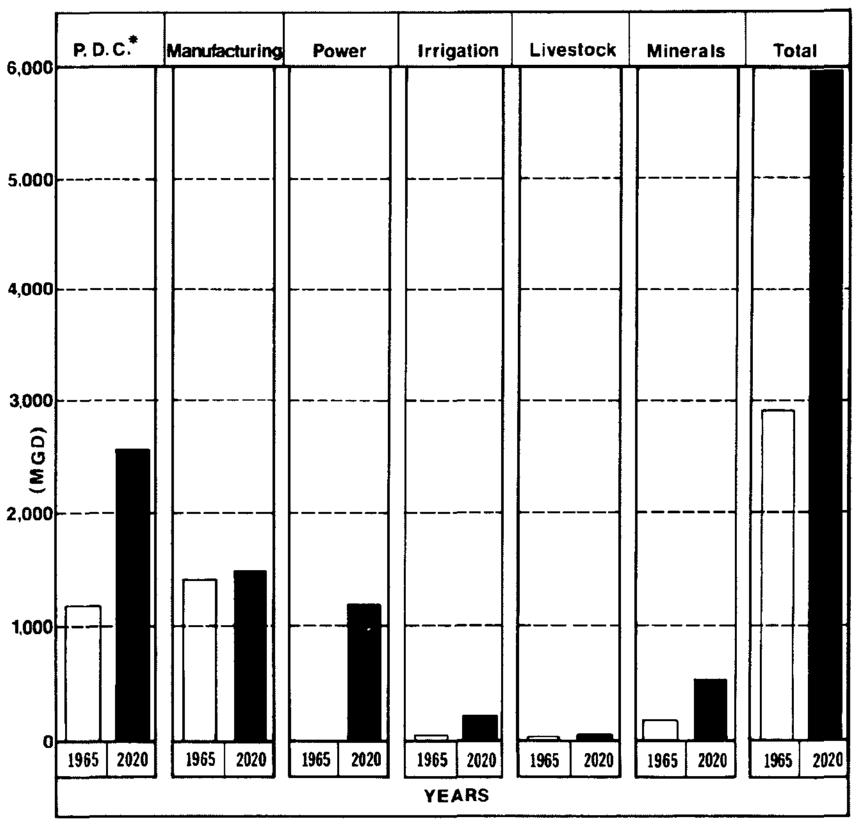



*Figure 17 Water Supply Demands*

## Water Supply Demand and Consumptive Losses

Water supply demands were projected to the year 2020 in six use categories to include public, manufacturing, power, irrigation, livestock and minerals. As shown on Figure 17 water use is expected to increase substantially in all categories except manufacturing and livestock.

More significant to Chesapeake Bay are the projected increases in consumptive losses of water. As shown on Figure 18 a five-fold increase in consumptive losses is expected by 2020. As noted on the figure the largest increases will be in the power and manufacturing categories. By 2020 a significant portion of the freshwater inflow to the Bay will be lost because of consumptive losses. Figure 19 shows a comparison of the consumptive losses with both long term average inflows and average monthly inflows during the 1960's drought. The losses are relatively small (maximum of 11%) when compared with average values, however, even this small a change can have significant impacts on Bay salinities. When consumptive losses are compared with inflows expected during droughts, the losses may equal over 50% of total inflow to the Bay and are very significant.

## Problem Identification Hydraulic Model Test

The primary purpose of the hydraulic model test was to determine how future consumptive losses of water would effect both drought and long term average salinities in the Bay and its tributaries. In order to accomplish this, the test was divided into two parts; a base test and a futures test. In the base test, the freshwater inflows that occurred during the 1963 to 1966 drought were simulated. The drought was followed by several repetitions of an average inflow year. In the futures test, both the average and drought hydrographs were reduced by the expected increase in consumptive losses between the years 1965 and 2020.

It was found that consumptive losses in general cause a saltier Chesapeake Bay. The magnitude and structural variations in salinity as a result of these losses are dependent on the

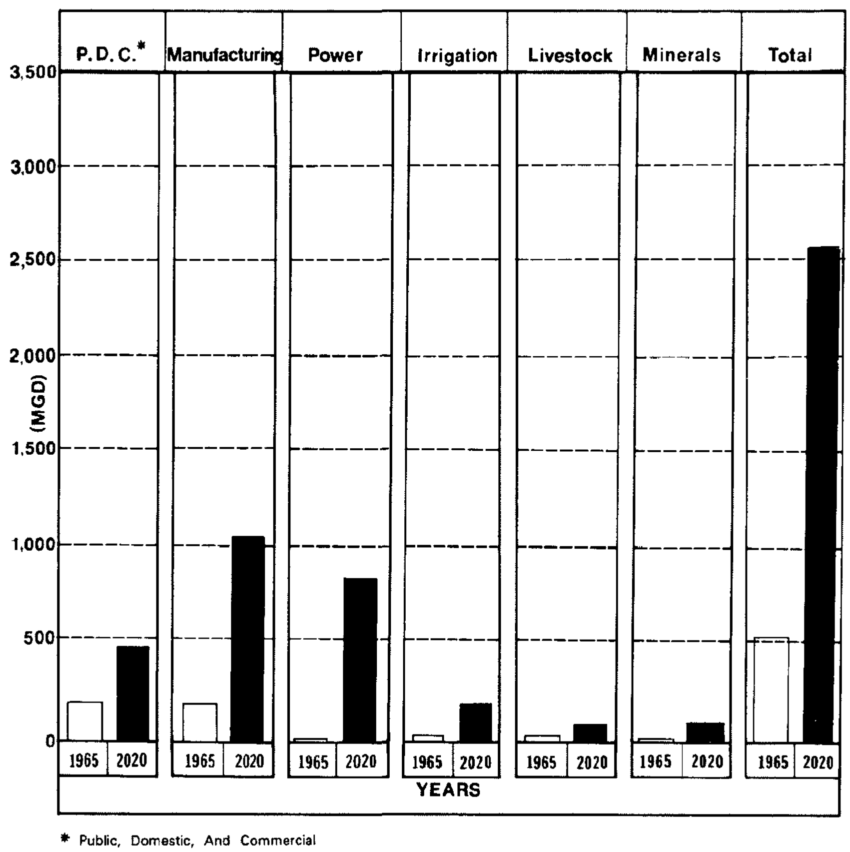



*Figure 18 Consumptive Losses*

specific hydrodynamic characteristics of a given area and its proximity to the riverine system or the ocean. On the average however, it appears that the Chesapeake Bay salinities increased a maximum of 2 to 4 parts per thousands due to consumptive losses of water. Also, it appears that drought salinities are as much as 5 parts per thousand higher than long term averages.

Of particular significance in the test results, is the penetration of higher level salinities into the estuary. This phenomena is illustrated on the accompanying isohaline maps (Figures 20 and 21). These maps compare both base and future seasonal average salinity conditions for two different seasons of the year. Particular note should be taken of how the lines of equal salinity are located much further upstream in the futures test than they are in the base test. For more detail on the conduct and results of the hydraulic model test, the reader is referred to Appendix D of the *Low Freshwater Inflow Study*.

## Problems and Needs

The data from the hydraulic model test provided an understanding of how changes in freshwater inflow affected the Bay's salinity regime. The next step was to identify the nature and severity of the problems associated with the increasing salt levels. Based on a preliminary examination, the two areas of concern were changes in the populations of important Bay biota and adverse impacts on those using the estuary as a water supply source.

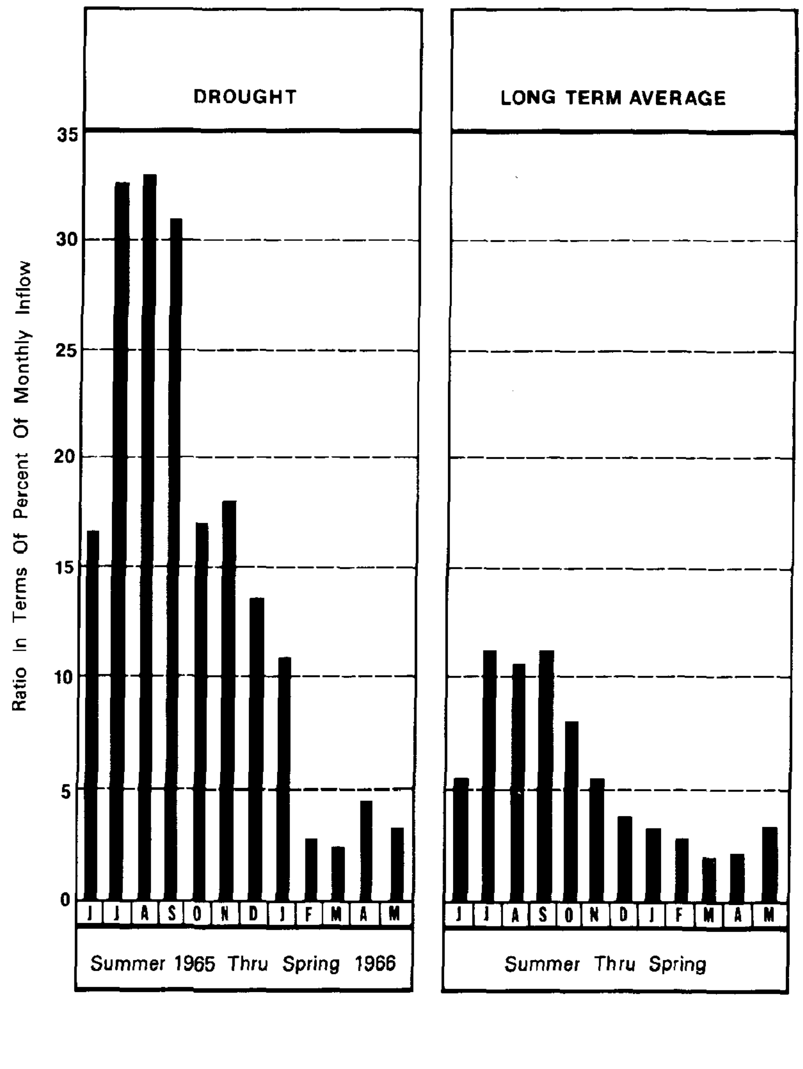



*Figure 19 Ratio of Incremental Consumptive Losses to Freshwater Inflows*

Of the two areas of concern, the biota related impacts were considered to be the most important. The biota impacts had to be addressed from not only an eco-system perspective, but also as the impacts related to commercial fishing and recreation. Identifying the impacts on the Bay biota was a complex and challenging endeavor. The assessment methodology that was developed is considered to be "state-of-the-art" and was a cooperative effort among the Steering Committee, the Fish and Wildlife Service, the Corps and the Corps contractor Western Eco-System Technology, Inc. (WESTECH).

The first step of the assessment methodology was to identify a small group of organisms which would be representative of the over 2700 species indigenous to the Bay. Through the cooperative efforts of WESTECH, the Fish and Wildlife Service and the scientific community the 57 species shown on Table 15 were chosen.

The next step of the process was to determine how the potential habitat of these 57 species was affected by changes in salinity. The potential habitat for each species was mapped for each of the four inflow conditions simulated in the hydraulic model testing. The criteria used in mapping included not only salinity, but substrate, depth and the critical seasons for the individual organisms.

Given the habitat mapping, the Fish and Wildlife Service formed a panel of experts (Biota Evaluation Panel) to determine how the changes in habitat would affect the populations of the study species. The Panel evaluated the changes in habitat between the base, future, average and drought conditions and prepared an assessment of the expected population changes. The Panel also gave consideration, where appropriate, to such other factors as species interactions, recovery time, recruitment and recolonization.

In trying to summarize the findings of the Panel, it should be noted that while changes in habitat due to long term average increases in consumptive losses are small, the impacts can be significant. Large losses in populations of oysters, soft clams and a brackish water clam *(Macoma* *balthica)* may be expected with the long term decreases in freshwater inflow.

Much larger losses are expected during both Base and Future Drought events. Plants and animals particularly affected include anadromous fish, low salinity submerged aquatic vegetation (SAV), soft clams, *Macoma* and oysters. Certain species will be more affected by reductions in food supply (ducks) or increases in predation or disease (oysters) than by direct losses in habitat. Also, some organisms will recover much more rapidly from the effects of a drought. Small, rapidly growing organisms such as plankton would be expected to repopulate affected areas rather quickly. On the other hand, it could take as long as a decade or more for some of the benthics and SAVs to recover from the effects of a drought.

The anticipated decline in oysters under all three reduced freshwater inflow conditions is particularly disturbing. Although oysters generally thrive in areas where salt levels are high, so do diseases such as dermo and MSX. The problem is that oysters move into new areas and recolonize very slowly while its diseases and parasites can spread rapidly; especially where salt levels are greater than 15 ppt. The Panel has estimated that the oyster mortalities due to the phenomenon would be very large and could approach 80% in the Future Drought Condition. It should be noted that these conclusions have been partially substantiated during the past several years. Freshwater inflows to Chesapeake Bay have been low and salinities have been high. Along with this has been a rapid increase in MSX related mortalities and a marked intrusion of the disease into new upstream areas.

The Panel estimated that the acreage of many of the low salinity varieties of submerged aquatic vegetation will be significantly reduced by decreases in inflow. Losses of these species are significant in that they serve as a valuable food for waterfowl and provide valued habitat for many other species. As reported in the recent Environmental Protection Agency reports, the SAV populations are severely reduced. Further

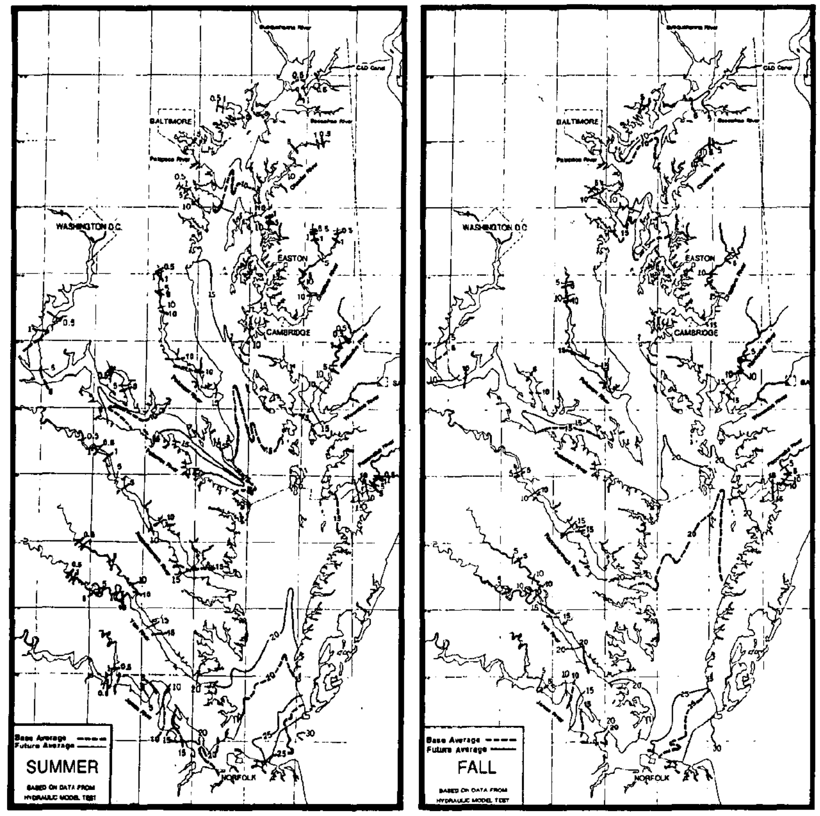



*Figure 20 Intrusion of Salinity—Long Term Average*

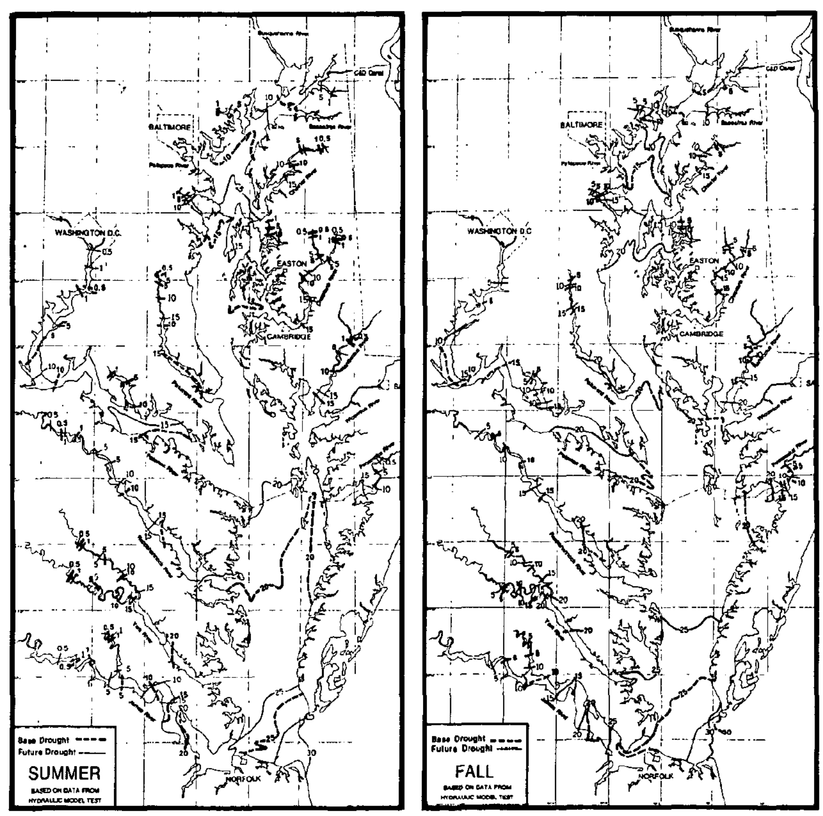



*Figure 21 Intrusion of Salinity During Drought*

declines caused by reduced inflows could result in the total disappearance of some species.

The Canvasback Duck would also be adversely affected by reduced inflows. The canvasback is very dependent on both the SAV and *Macoma balthica* to supplement its diet. *Macoma* is expected to decline markedly and with that decline, there would be an attendent reduction in the population of canvasback ducks.

The Panel also addressed the impacts of salinity changes on specific zones within the estuary. Based on the Venice System developed in 1958, the estuary is divided into zones which generally correspond to the breakpoints in organism distribution. These zones are as follows:

| | |
|---|---|
| Tidal Freshwater | 0.0 to 0.5 ppt |
| Oligohaline | 0.5 to 5.0 ppt |
| Mesohaline | 5.0 to 18.0 ppt |
| Polyhaline | 18.0 to 30.0 ppt |
| Euhaline | over 30.0 ppt |

Salinity is the factor that determines the boundaries of these zones. As freshwater inflows decrease and salinities increase, these zones move further upstream and the size of the lower salinity areas are generally compressed. For example, under the Future Drought Condition the areas of the oligohaline and tidal freshwater zones are reduced by approximately 80 and 50 percent, respectively. The large loss in the oligohaline zone is one of the most significant impacts of reduced freshwater inflow. The tendency in the estuary is for nutrients and detrital material to concentrate at the interface between salt and freshwater. During spring and summer, the low salinity areas become the site of prodigious growths of plankton which provide food for important species of juvenile fish. As shown on Table 16, there are many other important species that are dependent on the low salinity waters. In summary the role of the oligohaline zone in the life histories of this wide spectrum of organisms, as well as its role in overall ecosystem function, makes imperative its protection and, if possible, enhancement under all conditions of freshwater inflow.

*Table 15* *Final Study Species List*

PHYTOPLANKTON ASSOCIATIONS

| | |
|---|---|
| Winter/Spring | *Cyclotella meneghiniana/ Melosira granulata* tidal freshwater association |
| | *Katodinium rotundatum/Skeletonema costatum* oligohaline, low mesohaline association |
| | *Asterionella japonica/Skeletonema costatum* dominated mesohaline association |
| | *Nitschia pungens atlantica/Skeletonema costatum/Chaetoceros* spp. dominated polyhaline association |
| Summer/Fall | *Anacystis/Microcystis* tidal freshwater association |
| | *Gymnodinium* spp. */Prorocentrum minimum* dominated oligohaline, low mesohaline associations |
| | *Gymnodinium/Chaetoceros/Skeletonema* dominated high mesohaline polyhaline associations |

SUBMERGED AQUATIC VEGETATION

| | |
|---|---|
| *Ceratophyllum dermersum* | hornwort |
| *Potamogeton* | pondweeds |
| *Ruppia maritima* | widgeon grass |
| *Zanichellia palustris* | horned pondweed |
| *Zostera marina* | eelgrass |

EMERGENT AQUATIC VEGETATION ASSOCIATIONS

Tidal Freshwater Associations

*Spartina* spp.
dominant, brackish tidal marsh
*Juncus roemerianus*
dominant, brackish tidal marsh

ZOOPLANKTON

| | | |
|---|---|---|
| Ctenophora | *Mnemiopsis leidyi* | ctenophore |
| Cnidaria | *Chrysaora quinquecirrha* | sea nettle |
| Rotifera | *Brachionus calcyiflorus* | rotifer |
| Crustacea | *Acartia clausi* | copepod |
| | *Acartia tonsa* | copepod |
| | *Eurytemora affinis* | copepod |
| | *Scottolana canadensis* | copepod |
| | *Bosmina longirostris* | cladoceran |
| | *Evadne tergestina* | cladoceran |
| | *Podon polyphemoides* | cladoceran |

BENTHOS

| | | |
|---|---|---|
| Annelida | *Limnodrilus hoffmeisteri* | oligochaete worm |
| | *Heteromastus filiformis* | polychaete worm |
| | *Pectinaria gouldii* | polychaete worm |
| | *Scolecolepides virdis* | polychaete worm |
| | *Streblospio benedicti* | polychaete worm |
| Mollusca | *Urosalpinx cinerea* | oyster drill |
| | *Crassostrea virginica* | oyster |
| | *Macoma balthica* | Baltic macoma |
| | *Mercenaria mercenaria* | hard clam |
| | *Mulinia lateralis* | coot clam |
| | *Mya arenaria* | soft clam |
| | *Rangia cuneata* | brackish clam |
| Crustacea | *Ampelisca abdita* | amphipod |
| | *Balanus improvisus* | barnacle |
| | *Callinectes sapidus* | blue crab |
| | *Cyathura polita* | isopod |
| | *Gammarus daiberi* | amphipod |
| | *Leptocheirus plumulosus* | amphipod |
| | *Palaemonetes pugio* | grass shrimp |

FISH

| | |
|---|---|
| *Alosa sapidissima* | American shad |
| *Alosa pseudoharengus* | alewife |
| *Brevoortia tyrannus* | menhaden |
| *Anchoa mitchilli* | bay anchovy |
| *Leiostomus xanthurus* | spot |
| *Menidia menidia* | Atlantic silverside |
| *Micropogon undulatus* | Atlantic croaker |
| *Morone saxatilis* | striped bass |
| *Morone americana* | white perch |
| *Perca flavescens* | yellow perch |

WILDLIFE (BIRDS)

| | |
|---|---|
| *Anas platyrhynchos* | mallard |
| *Anas rubripes* | black duck |
| *Aythya valisineria* | canvasback |

*Table 16*

*Important Species Dependent on Tidal Freshwater and Oligohaline Zones*

Phytoplankton
- Tidal Freshwater Assoc.
- Oligo/low meso. Assoc.

*Ceratophyllum demersum* (SAV)
Tidal freshwater marsh assoc.
*Brachionus calcyiflorous* (rotifer)
*Eurytemora affinis* (copepod)
*Scottolana canadensis* (copepod)
*Bosmina longirostris* (cladoceran)
*Limnodrilus hoffmeisteri* (Oligochaete worm)
*Scolecolepides Viridis* (polychaete worm)
*Cyathura polita* (isopod)
*Gammarus daiberi* (amphipod)
*Alosa sapidissima* (Am. shad)
*Alosa pseudoharengus* (alewife)
*Morone saxatilis* (striped bass)
*Morone Americana* (white perch)
*Perca flavescens* (yellow perch)

Consideration was also given to the impacts on those municipalities, agricultural interests and industries that use the Bay as a source of potable, irrigation or cooling process water. They were surveyed to determine the likely impacts of increased salinities at their respective intakes. Sufficient data were collected during the surveys to assess the damages that could be expected in the event of droughts or long term reductions in inflow. As will be discussed in subsequent paragraphs the economic impacts, i.e., damages, were not found to be sufficient to warrant further consideration during the formulation stage of the study.

Given the aforementioned findings of the Biota Evaluation Panel relative to biological impacts, further analyses were conducted to determine the implications to commercial fishing, sport fishing, water contact recreation and other resources. These analyses, together with the results of the water users surveys, were then used by a Corps multi-disciplinary study team to make an overall assessment of the socio-economic and environmental impacts. The following paragraphs summarize the findings of the study team. Tables 17, 18 and 19 also provide a summary of environmental, economic and social impacts, respectively.

In addition to the environmental impacts on the biota itself as defined by the Biota Evaluation Panel, consideration was also given to aesthetic values. Chesapeake Bay is well known for its aesthetic values. Many hours are spent by the thousands of people enjoying the reflection of the sun and moon on its waters, watching the waterfowl in their mass migrations and in just quiet solitude. The reductions in freshwater inflow caused by consumptive losses of water is not expected to markedly change these experiences. There are, however, four factors that could contribute to a small to moderate intrusion on the aesthetic experience. These are, a degrading of water quality, a loss in the numbers of waterfowl, an increase in the density of sea nettles and a degradation of boating docks by wood borers.

Most of the economic impacts caused by reductions in inflow will be im-

*Table 17*

*Summary of Environmental Impacts*

| *Environmental Category Account* | *Impact Criteria* | *Magnitude of Adverse Impacts* | | | *Extent of Effects* | | |
|---|---|---|---|---|---|---|---|
| | | *Future Average* | *Base Drought* | *Future Drought* | *Local* | *Regional* | *National* |
| AQUATIC RESOURCES | | | | | | | |
| •Tidal Fresh Phyto. | habitat loss | — | VL | VL | X | | |
| •Mesohaline Phyto. | habitat loss | M | L | L | X | | |
| •*Prorocentrum minimum* | habitat loss | — | M | L | X | | |
| •*Ceratophyllum demersum* & other low salinity SAV | habitat loss | S | L | L | X | X | |
| •Tidal Fresh Marsh | habitat loss | S | M | L | X | | |
| •*Brachionus calcyiflorus* | habitat loss | — | L | L | X | | |
| •*Eurytemora affinis* | habitat loss | — | L | L | X | | |
| •*Scottolana Canadensis* | habitat loss | — | VL | VL | X | | |
| •*Bosmina longirostris* | habitat loss | — | VL | VL | X | | |
| •*Limnodrilus hoffmeisteri* | habitat loss | — | L | VL | X | | |
| •Oyster (MSX & Dermo.) | habitat loss | L | VL | VL | X | X | X |
| •*Macoma balthica* | habitat loss | M | L | L | X | | |
| •Soft Clam | habitat loss | L | VL | VL | X | | |
| •Shad | habitat loss | — | M | L | X | X | X |
| •Alewife | habitat loss | — | M | M | X | | |
| •White perch | habitat loss | — | M | M | X | | |
| •Striped bass | habitat loss | — | M | L | X | X | X |
| •Yellow perch | habitat loss | M | M | M | X | | |
| •Canvasback | habitat loss | M | L | L | X | X | X |

*Table 17 (cont'd)*

*Summary of Environmental Impacts*

| *Environmental Category Account* | *Impact Criteria* | *Magnitude of Adverse Impacts* *Future Average* | *Base Drought* | *Future Drought* | *Extent of Effects* *Local* | *Regional* | *National* |
|---|---|---|---|---|---|---|---|
| ECOSYSTEM | Net adverse effect | S | M | M-L | X | X | X |
| AESTHETICS | | | | | | | |
| •Water quality | Poor flushing in subestuaries | — | M | M | X | | |
| •Canvas back | Few ducks | — | S | S | X | | |
| •Boat-docking facilities | Collapsing boat docks | S | M | M | X | | |
| •Sea nettle | effect on recreationists | — | S | S | X | | |
| RARE AND ENDANGERED SPECIES | Habitat loss | — | M | M | X | X | X |

LEGEND
— Insignificant
S Small
M Medium
L Large
VL Very Large
EX Extreme

posed on the commercial fishing industry, recreation, and those that use the Bay as a source of water supply. The average commercial fishing harvest in the Bay during the period of 1952 to 1980 was worth approximately $73 million annually. The economic losses associated with both long term decreases in inflows and drought events are significant. The losses associated with the long term decrease are estimated at $15.2 million, while the Future Drought Condition could result in losses in excess of $300 million. Over 90 percent of these losses would be in the shellfish harvest, most particularly oysters and soft clams. There would also be significant impacts related to such finfish as striped bass and shad. Clearly, further consideration of important commercial species was necessary.

Changes in the habitat of several species will affect man's recreation activity and cause some economic impacts. Increased boat/marina maintenance will result from further intrusion of shipworms and barnacles. Losses in water contact recreation will accompany increased infestations of sea nettles. Lastly, sport fishing and waterfowl hunting will be degraded because of the reduced numbers of preferred species. Despite these adverse impacts however, the recreation related problems were not considered sufficient to warrant further study.

Similar to the recreation related problems, a more detailed analysis found that increased salinities would not have a major economic impact on Bay water users. Only two communities (Havre de Grace, Maryland and Hopewell, Virginia) would have damages associated with their use of Bay waters for municipal purposes. Both communities are expected to take local actions to eliminate these problems. Similarily, the industries affected are also likely to take the necessary action to eliminate any salinity related problems.

A change in the habitats and abundances of Bay organisms can cause impacts other than economic and environmental. Among these are health and safety, special traditions, science and education, and such ethereal things as recreation experience. Of these, only recreation, and traditions are felt to have significance in planning for low freshwater inflow. Moderate impacts would be sustained by swimmers and water skiers in their increased encounters with sea nettles. Potential health risks could also be involved for persons who experience allergic reactions. Sport fishing and hunting will also suffer significant impacts. The loss of such species as striped bass, shad and canvasback ducks would be a loss of not only recreation potential, but a detriment to people's concept of the Bay.

Lastly, the activities of Bay waterman convey an image of tonging for oysters or manning trotlines for crabs. This way of life dates from the Bay's first settlement with some communities changing little since their founding over 300 years ago. Loss of traditional harvesting grounds, especially for a species such as the oyster, would encourage a decline in the waterman and his unique way of life. The importance of finfish in the waterman's way of life is less easily quantified. But, using oysters as the principal barometer, traditions associated with commercial fishing in Chesapeake Bay could be very significantly affected.

The previous paragraphs provide a brief overview of the socio-economic and environmental impacts of reduced freshwater inflows. It is clear that many of the species that live in the Bay will be seriously adversely affected and that significant damages will occur. Included as Table 20 is a list of those priority problem species that were selected as the focus of the plan formulation efforts. Of particular importance are oysters and those species that depend on the oligohaline and tidal freshwater zones. Of nearly equally importance are the low salinity SAVs, soft clam and *Macoma*.

*Summary of Economic Impacts*

| *Economic Category Account* | *Impact Criteria* | *Magnitude of Adverse Impacts* *Future Average* | *Base Drought* | *Future Drought* | *Extent of Effects* *Local* | *Regional* | *National* |
|---|---|---|---|---|---|---|---|
| COMMERCIAL FISHERIES | | | | | | | |
| •Oyster | Lost harvest values | L | L | VL | X | X | X |
| •Striped Bass | Lost harvest values | S | M | L | X | X | |
| •Shad | Lost harvest values | S | M | L | X | X | |
| •Soft Clam | Lost harvest values | L | VL | VL | X | X | |
| RECREATION | | | | | | | |
| •Swimming (Sea Nettle) | Reduced expenditures | — | — | — | X | | |
| •Boating *(Teredo & Bankia)* | Reduced expenditures | M | EX | EX | X | X | |
| •Waterfowl Hunting (Canvasback and other ducks) | Reduced expenditures | — | S | S | X | X | |
| •Sportfishing | Reduced expenditures | — | — | — | X | X | |
| BAY WATER USERS | | | | | | | |
| •Municipal | Increased treatment costs | — | — | — | X | | |
| •Industrial | Increased treatment costs | — | — | — | X | | |
| •Power | Increased treatment costs | — | — | — | X | | |

LEGEND
- — Insignificant
- S Small
- M Medium
- L Large
- VL Very Large
- EX Extreme

*Table 19*

*Summary of Social Impacts*

| *Social Category Account* | *Impact Criteria* | *Magnitude of Adverse Impacts* | | | *Extent of Effects* | | |
|---|---|---|---|---|---|---|---|
| | | *Future Average* | *Base Drought* | *Future Drought* | *Local* | *Regional* | *National* |
| HEALTH & SAFETY | | | | | | | |
| •Sea nettle | Effect on swimmers | — | — | S | X | | |
| •Public water systems | Effect of salt on public health | — | — | — | X | | |
| RECREATION EXPERIENCE | | | | | | | |
| •Sport fishing | Loss of preferred species | — | S | M | X | X | |
| •Waterfowl hunting | Population loss of favored waterfowl | S | M | L | X | X | |
| •Swimming and waterskiing | Increased densities loss sea nettle | — | M | M | X | | |
| •Boating | Effect of borers | — | S | S | X | X | |
| TRADITIONS | | | | | | | |
| •Ches Bay watermen | Loss of oysters | M | L | VL | X | X | X |

LEGEND
— Insignificant
S Small
M Medium
L Large
VL Very Large

*Table 20*

*Priority Problem Species*

1. Oyster (including drills and MSX)
2. Oligohaline/Tidal Freshwater Zone
3. Low Salinity SAV
4. Sea Nettle
5. Soft Clam
6. *Teredo/Bankia*
7. *Macoma balthica* and Canvasback Duck

# Plan Formulation

## Planning Objectives and Assumptions

Guidelines for the formulation and evaluation of plans for improvement for all federal water and related land resource activities are contained in the *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies,* March 1983. As stated therein, "The single federal objective of water and related land resource planning is to contribute to national economic development consistent with protecting the Nation's environment, pursuant to national environmental statutes, applicable executive orders, and other federal planning requirements."

The primary objective of the Chesapeake Bay Low Freshwater Inflow Study was to formulate those alternative freshwater inflow related actions which would lead to the preservation or enhancement of the socio-economic and environmental values of Chesapeake Bay and the estuarine portion of its tributaries.

Within this very broad objective, more specific objectives have been adopted through interactions with the scientific community and the public to further define the planning setting and the subsequent constraints on plan formulation. These objectives provide a focus for development of plans to protect highly valued habitats and reduce the short and long term adverse impacts of droughts and consumptive losses. These objectives which are specific to individual aquatic resources are as follows:

1. Protect productive oyster beds from incursions of disease organisms and predators, or otherwise alleviate these damages, for purposes of long-term commercial fishery productivity and Bay traditions.

2. Maintain the size of tidal freshwater and oligohaline salinity zones for their value in ecosystem functions and as a spawning and nursery area for numerous commercially and recreationally important species such as striped bass, shad, spot, menhaden, and alewife.

3. Maintain and/or enhance the productivity of striped bass and shad which are important in commercial harvests, recreation, and Bay traditions.

4. Contribute to the propogation of submerged aquatic vegetation for benefit of waterfowl (important components of recreational hunting and Bay traditions) and ecosystem processes.

5. Contribute to the productivity of the clam, *Macoma balthica,* as an essential food for canvasback duck (an important component of recreational hunting and Bay traditions).

6. Contribute to the productivity of the soft clam, *Mya arenaria,* for its commercial harvest values.

7. Reduce the potential for incursion of wood borers *Bankia* and *Teredo* to avoid economic losses at boating harbors.

8. Moderate the proliferation of sea nettles to contribute to water contact recreation experience and aesthetic environmental values.

Limitations on the full array of options available for successful response to the planning objectives (i.e., "constraints") are imposed on the planning setting by technical, environmental, and institutional factors and definitive public views. Based on recommendations of the Biota Evaluation Panel, certain guidelines and procedures were adopted for use in guiding the planning process. These are:

1. Pursue a highly conservative policy toward alterations in the quantity of freshwater inflow, recognizing the high biological value of Chesapeake Bay and acknowledging the limits of predictive capability.

2. Retain the fundamental seasonal freshwater inflow pattern of low flows in the fall and high flows in the spring.

3. Recognize that upstream shifts of species will frequently move them into lower valued habitat.

Major assumptions made in plan formulation include:

1. The use of salinity tolerance alone, in conjunction with knowledge of the habitat variables substrate and depth, is sufficient to permit meaningful alternative plan development and evaluation.

2. The selected "study species" provide a sufficiently adequate representation of all Bay biota to permit the formulation of generalized problem solutions.

3. By the year 2020, the goals of the 1976 Amendments to the Water Pollution Control Act would be met. Therefore, water quality other than salinity would not be a plan evaluation variable.

## Potential Measures

A variety of measures were considered to reduce or eliminate the effects of reduced freshwater inflows. The measures can generally be classified as either "flow supplementation" or "Chesapeake Bay related". Flow supplementation measures are those means which can be employed in the Bay's tributary drainage basins to provide increased freshwater inflow. Included in this category are both structural and nonstructural measures such as reservoir storage, importation of water from outside the Bay drainage area, development of groundwater, conservation, pricing, drought emergency measures, and growth restrictions.

The second category of measures considered are those Chesapeake Bay related alternatives which can be implemented in the Bay area directly in order to eliminate adverse impacts. Included in this category are fisheries management (catch restrictions and nursery/restocking programs), oyster bed restoration and salinity barriers.

## Preliminary Screening

Given the aforementioned alternative measures, a preliminary screening was conducted to eliminate those measures which were not considered to be feasible from a technical or institutional viewpoint. Also, some of the Bay related measures were selected as most promising alternatives without conducting more detailed analyses. Detailed studies of these selected alternatives were not conducted because of either the limited state of the art or the analysis/implementation of the alternative was clearly not within the scope of this study. Reservoir storage and conservation, however, were subjected to a detailed screening. The following paragraphs provide a brief description of the measures considered and the results of the preliminary screening.

*Reservoir Storage*—Upstream water storage would be provided through the construction of reservoir projects or reallocation of storage in existing projects in the drainage basins tributary to Chesapeake Bay. Water would be stored during periods of surplus stream flows for release during low flow periods. Upstream storage is well proven in its potential for supplementing stream flow and therefore was retained for further investigation.

*Interbasin Importation of Water*—The importantion of water into the Bay drainage from other basins was considered only briefly. It was eliminated from further consideration in light of high cost, potential adverse socio-economic and environmental impacts in other basins and potential implementation difficulties.

*Groundwater Development*—Large scale groundwater development could be used to supplement the freshwater inflows to Chesapeake Bay. This measure was also dropped due to potential high cost and the likely adverse impact of large withdrawals on local groundwater users.

*Conservation*—Conservation measures are normally instituted in order to reduce the amounts of water needed for water supply for communities, farms and industries. In most cases this will reduce the amount of water that is used consumptively, although a few conservation measures such as recirculating cooling processes can actually increase consumptive losses. While these types of measures can take many forms, conservation for this study was defined as those permanent measures such as pressure reducing valves, plumbing code regulations, consumer education and other water saving devices that, once implemented, save water year round. It also included adoption of water saving manufacturing process.

Three levels of water savings through conservation were considered. The medium level was the only one addressed in detail as it was considered the most reasonable and cost effective of the three levels.

*Pricing*—Water pricing is a demand controlling measure that assumes that the price of water can be regulated to control demand. A major study of pricing in the Metropolitan Washington Area found that the demand for water by Potomac River users could not be further reduced by pricing policies, at least in the immediate future. This measure was therefore eliminated from further consideration.

*Drought Emergency Measures*—These measures normally consist of actions taken during a water shortage to temporarily reduce the water use. They often include bans on such activities as lawn sprinkling or the washing of automobiles. Although the savings in consumptive losses associated with these measures are small, they were retained for further consideration.

*Growth Restrictions*—Broadly defined, growth restrictions would take the form of population, land use and industrial activity controls that would reduce the rate of growth of water demands. In theory, consumptive losses could be reduced. Due to the many levels or combinations of measures that could be implemented, specific plans for growth restrictions were not formulated. However, growth restrictions were retained as a most promising alternative from a conceptual viewpoint.

*Fisheries Management*—Given the importance of commercial and sport fishing to the Chesapeake Bay Region, it is not surprising that the involved states all have comprehensive fisheries programs and attendant research and resource study programs. The alternative to be considered is modifying the existing programs of the states in order to be more responsive to the problems/needs identified in the Low Freshwater Inflow Study. Given the problem species and areas, the state resource agencies will be better able to target catch restrictions, minimum length requirements, hatchery programs and other measures to aid those commercially and recreationally important fin and shellfishes that are adversely impacted by low flows. Although the present relationship of fishery management measures to fish populations in the estuary are largely unproven or unknown, there have been some apparent successes attributed to catch restrictions and finfish restocking. Due to this and the potential for these measures to help alleviate drought and long term average problems, fisheries management has been identified as one of the most promising alternatives.

*Oyster Bed Restoration*—Oyster bed restoration or repletion is the process of transferring seed oysters and shell to both low production and new oyster bars. The seed oysters are then allowed to mature before they are harvested about two or three years later. The repletion program has largely been credited with helping to sustain the State of Maryland's oyster production since 1960. The Commonwealth of Virginia has a similar long-established and reasonably successful program. This apparent success was justification for identifying this program as one of the most promising alternatives.

*Salinity Barriers*—Salinity barriers, in the form of solid structures constructed across a portion of the Bay or one of the subestuaries, could effectively prohibit the intrusion of high salinity waters. While effective in reducing salt water intrusion, potential negative effects include: (1) reducing the normal flushing action of a subestuary, (2) interrupting the normal migratory movements of various species of finfish, and (3) disrupting commercial and recreational boating. Further, a detailed analysis of barrier plans would probably require model testing. Thus, due to the degree of adverse impact and inability for additional model testing, salinity barriers were dropped from further consideration.

## Formulation of Flow Supplementation Plans

### Conservation

The potential for accumulation of large benefits through the institution of conservation measures is small. This may be surprising in view of the large reductions in water demands that often result from conservation. For the most part, however, conservation measures that are presently used are more oriented to reducing water demands than consumptive losses. This is reflected on Table 21 where potential savings in consumptive losses through both permanent conservation measures and emergency drought measures are compared with year 2020 consumptive losses. The many blank spaces on this table indicate that the savings in a particular river basin are less than one mgd.

Implementation of conservation plans would be very difficult and costly in an area as large and diverse as the Chesapeake Bay Basin. Because communities and industries are, for the most part, already established, large amounts of replumbing, retrofitting and perhaps changes in manufacturing processes may be required. Also, the responsibility for instituting these measures would rest with the hundreds of local political subdivisions.

In view of these factors, there is some question whether the benefits associated with conservation measures are sufficient to justify their costs. But, conservation is the only feasible measure that would decrease long term average consumptive losses. Also, conservation does have recognized benefits beyond those resulting from reductions in consumptive losses. In view of these factors, it was decided to retain for further analyses conservation measures in only those river basins where average annual reductions in consumptive losses are 10 percent or greater. These basins are the:

- Susquehanna River Basin
- Potomac River Basin
- York River Basin
- Rappahannock River Basin
- Patuxent River Basin
- Chester River Basin
- Choptank River Basin

## Reasonable Storage

The initital step in the storage analysis was to develop an inventory of those existing federal and non-federal projects that have a total storage in excess of 10,000 acre-feet. It was at first assumed that up to 50 percent of the conservation storage that was not already committed for low flow augmentation storage could be allocated for releases for the Bay. It was further assumed that any flood control storage above three inches could also be reallocated for low flow augmentation. While reallocation for this purpose would have beneficial impacts, there would likely be major adverse recreation and fish and wildlife impacts within the reservoir areas of most of the projects. Further, the loss of flood control storage would likely be perceived as a major adverse impact even if the loss of benefits is minor. After consideration of the various reallocation assumptions, it was decided that a practicable reallocation level would be 20 percent of the present conservation storage. Further, no flood control storage would be reallocated for low flow purposes.

Consideration was also given to the construction of new storage projects. The potential projects initially identified included those federal and non-federal projects that were under construction, authorized, recommended for construction, or found to have merit in recent comprehensive basin studies. This initital inventory was then screened and those projects which appeared to have the most merit were selected and the total storage was summed for each of the major basins. Only reservoir sites in the Susquehanna, Potomac, James and Rappahannock Rivers were retained.

*Table 21*

*Conservation Potentials*

| *Point* | *Basin* | *Year 2020 Consumptive Losses (mgd)* | *Potential Medium Conservation (mgd)* | *Drought Emergency Measures (mgd)* |
|---|---|---|---|---|
| 15 | Susquehanna | 992 | 178 | 54 |
| 1 | Nansemond | 105 | 2 | 7 |
| 2 | Chickahominy | 4 | —* | — |
| 3 | Appomattox | 25 | — | — |
| 4 | James | 226 | 4 | 15 |
| 5 | York | 98 | 14 | 5 |
| 6 | Rappahannock | 50 | 5 | 4 |
| 11 | Patuxent | 14 | 2 | 1 |
| 12 | Severn | 13 | — | — |
| 13 & 14 | Upper Western Shore | 389 | 27 | 25 |
| 16 | Bohemia | 14 | — | — |
| 17 | Chester | 30 | 6 | 3 |
| 18 | Wye | — | — | — |
| 19 | Choptank | 72 | 17 | 5 |
| 20 | Nanticoke | 34 | 2 | 2 |
| 21 | Pocomoke | 18 | — | — |
| 7 | Lower Potomac | 6 | — | — |
| 8 | Occoquan | 9 | — | — |
| 9 | Anacostia | 2 | — | — |
| 10 | Potomac (D.C. and Above) | 472 | 50 | 35 |

*—Conservation is less than 1 mgd.

*Table 22*

*Potential Reasonable Upstream Storage*
*Chesapeake Bay Drainage Area*

| *Basin* | *Implementable Storage (Acre-Feet)* | *Storage Based on 5% of Average Annual Flow (Acre-Feet)* |
|---|---|---|
| Susquehanna | 1,200,100* | 1,418,800 |
| Potomac | 395,800* | 449,000 |
| James | 1,115,000 | 370,000* |
| Rappahannock | 713,000 | 106,000* |
| York | 0* | 96,000 |

One other factor was considered in the development of reservoir storage criteria. One of the plan formulation goals is the retention of the natural seasonal patterns of freshwater inflow to Chesapeake Bay. In order to assure achievement of this goal, storage in each basin was limited to five percent of the average annual discharge of the river or stream. Thus, the reasonable upper limit of reservoir storage considered in plan formulation was a function of either the availability of reservoir sites or the limits to flow modification. Shown on Table 22 are potential upstream storages for each major basin. The lower of the values are those considered reasonable. These are marked with an asterisk.

## Storage Requirements

The salinity levels of the Chesapeake Bay are a function of many factors including the time history, magnitude, and location of freshwater inflows, ocean salinities, antecedent salinities, and tidal amplitudes. The possible combinations of these factors is nearly infinite. Because of this, it is not possible to select one set of minimum freshwater inflows which will assure that the plan formulation goals are met under all possible conditions. Rather, target salinities must be specified at critical locations and the required freshwater inflows computed based on the unique hydrographic and salinity conditions which exist, or are projected to exist, during the period of interest. Real time salinity monitoring, historic freshwater inflow records, and both estaurine and riverine models would be needed to accomplish this.

The Chesapeake Bay Study staff had intended to develop the sophisticated methodologies necessary to compute the amount of storage required to meet plan formulation goals under the unique hydrographic and salinity conditions addressed in this study. Three model tests were to be done in order to gather the data necessary to do this. But, it was possible to conduct only one of these tests meaning that much of the information needed was not available. It was decided, however, that it would be remiss to produce this report without addressing storage requirements at all. Therefore, the rather simplistic two-step methodology described in *Appendix B, Plan Formulation*, was developed to give at least some insight to the amount of reservoir storage needed to meet the various plan formulation goals. A short summary of this methodology is below. For clarity, it is described by illustrating its application in the situation where the goal is to maintain summer Base Drought salinity conditions during a Future Drought event. Storages for other conditions were computed in a similar manner.

1. Antecedent conditions must be satisfied if salinities are to be at Base Drought levels at the beginning of summer. It was determined from the hydraulic model test that, depending on the location in the estuary and the magnitude of inflow, it takes from 60 to 150 days for salinities to adjust to a change in freshwater inflow. Therefore, if Base Drought salinities are to be met at the beginning of summer, the Base Drought hydrograph must be in place 60 to 150 days prior to summer. The amount of storage needed to accomplish this was computed by determining the average difference (expressed in mgd) between Future Drought and Base Drought freshwater inflows during the antecedent period and multiplying this difference by the number of days in the period.

2. The second step involved determining the amount of storage required to maintain Base Drought salinities during the summer (the target season). This was done by multiplying by 90 days the difference (in mgd) between the Future Drought and Base Drought summer seasonal average freshwater inflow.

## Phase I Plan Development

Phase I of the planning effort addressed only the Susquehanna River and the Main Bay. Its purpose was to identify the potentials for solving through flow supplementation the full range of identified problems. A series of plans were formulated for each problem species or species group. The first set of plans was designed to eliminate long term average damages. Sufficient freshwater inflow was provided to bring Future Average salinities back to Base Average salinities. The storage requirements were those needed to achieve salinity goals during one season of the year.

Early in the evaluation process, the feasibility of accomplishment of "long-term average" plans through the use of storage became doubtful. Practical considerations arose regarding the monitoring necessary to determine release schedules to accomplish long-term average goals. Thus, except for conservation plans, which would directly reduce future consumptive losses, long-term average plans were dropped. Conservation was looked at more closely in later iterations of plan formulation.

The second set of plans was designed to eliminate drought related damages. Sufficient freshwater inflow was provided to decrease salinities from Future Drought Levels to a series of predetermined goals. These goals ranged from Base Drought to Base Average levels of protection.

Inspection of Table 23 indicated that very large amounts of water would be needed to meet the Future and Base Average goals. It is clear that the storages required are far beyond that considered reasonable. In addition, seasonal salinities greater than long-term average ones are not necessarily detrimental. These are part of the natural cycle and it is only during extreme drought events that high salinities have been specifically identified as a multi-resource problem. Of course, the effects of MSX and dermo on the oyster is of concern

*Table 23*

*Storages Required to Reduce Drought Salinities in Main Bay*

| *Salinity Goal* | *Storage 1000 (Acre-Feet)* Low | High | *Supplemental Flow (mgd)* |
|---|---|---|---|
| Future Drought (no action) | 0 | 0 | 0 |
| Base Drought | 920 | 1,200 | 900 |
| Future Average | 9,500 | 12,300 | 10,100 |
| Base Average | 10,800 | 14,000 | 11,300 |

under all conditions. Any further penetration of them into the estuary should be prevented if at all possible. But, there is some question whether this should be done if the result is an upsetting of the balance of nature. Thus only a slight enhancement of Base Drought salinities is deemed feasible. In effect, the major objectives of the flow supplementation alternatives became restricted to furnishing sufficient water to make up for consumptive losses and to slightly enhance the Base Drought.

## Phase II Plan Development

In Phase II of plan development, the focus was expanded to include all major tributaries to Chesapeake Bay. Early in this phase, however, permanent conservation in the upper western shore and in such important rivers as the Patuxent, York, Choptank, and Chester were eliminated from further consideration. It was obvious that increases in habitat resulting from either of these measures would be too small to produce meaningful benefits. Thus, storage and permanent conservation were addressed in detail only in the Susquehanna, Potomac, James, and Rappahannock Rivers in Phase II of plan development.

Emergency drought restrictions were also eliminated as independent alternatives because institution of these measures would produce only very small increases in habitat for short periods of time. Also, they would be difficult to implement and enforce in an area as large as the Chesapeake Bay Basin. Drought emergency measures do, however, have some potential in reducing the amount of reservoir storage that may be required.

Four alternative plans were developed for each of the four seasons of the year. There are therefore, a total of 16 plans for each major river. Each of these plans were oriented to achieving during the Future Drought the salinities associated with one of the following four flow conditions.

1. No Action—Future Drought Salinities

2. Conservation—The salinities resulting from a "medium" level of conservation

3. Base Drought—Base Drought Salinities

4. Base Drought Enhancement—A salinity condition one-half way between Base Drought and Future Average.

The organisms selected for consideration in the evaluation were restricted to those ranked as high priority by the Steering Committee. These were oysters, submerged aquatic vegetation, soft clams, *Macoma,* and those species dependent upon the oligohaline and tidal freshwater zones. No specific plans were formulated for sea nettles and wood borers (bankia and teredo). These species, however were included in the evaluations of the effects of each flow supplementation plan.

Two criteria were established for evaluation and screening of the alternative plans:

1. Change in habitat—to be retained, a plan must provide at least a 25 percent incremental increase in habitat for one of the six major species. This applied to both storage and conservation plans.

*Table 24*

*Results of Phase II Screening*

| *Basin* | *Plan* | *Species Significantly Enhanced* | | | | |
|---|---|---|---|---|---|---|
| | | *Oysters* | *Oligohaline/Tidal Freshwater Zones* | *Low Salinity SAV* | *Soft Clam* | Macoma |
| Susquehanna | Summer Base Drought | X | X | — | X | — |
| | Fall Base Drought | — | X | — | — | X |
| | Conservation | — | X | — | X | — |
| Potomac | Summer Base Drought | X | X | X | X | — |
| | Fall Base Drought | — | X | — | — | X |
| | Spring Base Drought | — | — | X | — | — |
| | Conservation | — | X | — | X | X |
| James | Summer Base Drought | X | X | — | — | — |
| | Fall Base Drought | — | X | — | — | — |
| | Spring Base Drought | — | X | X | — | — |
| Rappahannock | Summer Base Drought | X | — | — | — | — |
| | Fall Base Drought | — | X | — | — | X |
| | Spring Base Drought | — | X | — | — | — |

X-Plan Retained

The Steering Committee, during its review of the problem identification process,established a set of priorities to be considered in plan formulation. It ranked the problem species or associations as follows:

Priority 1. Oysters, Oligohaline Zone, Tidal Freshwater Zone

Priority 2. Low Salinity, SAV, Soft Clam, *Macoma*

Priority 3. *Bankia, Teredo* and Sea Nettle

2. Required Storage—the volume of storage required will not exceed that which has been defined as reasonable.

These criteria were applied to each plan to identify the most promising flow supplementation plans.

The reservoir storage and conservation plans that were retained after these criteria were applied are shown on Table 24. As can be seen, conservation in the Rappahannock River was deleted. Many of the reservoir storage plans were also eliminated. This included all of the Winter plans, the Spring plan for the Susquehanna River, and all of the Base Drought Enhancement Plans. This meant that Base Drought levels of protection are the most that can be achieved within the established criteria. Although storage plans providing less than this level of protection are feasible, they have not been specifically addressed in the remainder of this report.

Of the remaining plans, only the Summer Base Drought plans provide benefits to all three priority 1 species. In addition, benefits are provided by these plans for two out of the three priority 2 species with only the *Macoma* being omitted. Clearly the Summer Base Drought plan provides more benefits than any of the other plans and should be retained as a most promising alternative. Because available storage is sufficient to provide protection for only one season, individual plans for spring and fall were effectively eliminated from further consideration.

The next step in the process was to assess the potential for developing multi-season plans. The advantage of these plans is clear if it is recognized that once the Summer plan is implemented, only the amount of water needed to make up for the consumptive losses during the added season is required. The antecedent flow supplementation conditions are already met. This is illustrated on Table 25 where the storage required for both summer and multi-season plans are shown under three assumed levels of conservation.

A comparison of the storage required (both with and without conservation measures) for each of the multi-season plans reveals that only the plans for the Rappahannock, James and Susquehanna Rivers are implementable. Therefore, multi-season plans for the Potomac Basin were dropped from further consideration.

It is clear that supplementing the freshwater inflows to Chesapeake Bay through reservoir storage would produce substantial benefits in the estuary. But, it should be emphasized that like the other most promising alternatives, the reservoirs addressed in this study are not being recommended for construction; rather, they are measures that need to be further analyzed before any recommendation can be made. In particular, the upstream socio-economic and environmental impacts must be identified in detail to determine if the total benefits of reservoir storage outweigh the total costs. An important ingredient in these analyses are the local, regional, and National perspectives.

Another point that should be emphasized is the meaning of the word

*Table 25*

*Storage Requirements for Multi-Season Plans (1000's Acre-Feet)*

| | | *No Conservation* | | *With Conservation* | | *With Conservation & Drought Emergency* | | *Assumed Reasonable* |
|---|---|---|---|---|---|---|---|---|
| *River* | *Plan* | *low* | *high* | *low* | *high* | *low* | *high* | *Storage* |
| Susquehanna | SU-3 | 920 | 1200 | 710 | 930 | 650 | 870 | 1,200 |
| | SUFA-3 | 1360 | 1630 | 1050 | 1270 | 930 | 1150 | 1,200 |
| Potomac | SU-3 | 440 | 560 | 390 | 500 | 360 | 470 | 400 |
| | SPSU-3 | 620 | 760 | 560 | 680 | 530 | 650 | 400 |
| | SUFA-3 | 640 | 760 | 570 | 680 | 520 | 630 | 400 |
| James | SU-3 | 200 | 240 | 190 | 230 | 170 | 210 | 370 |
| | SPSU-3 | 310 | 350 | 300 | 340 | 280 | 320 | 370 |
| | SUFA-3 | 310 | 350 | 300 | 340 | 250 | 290 | 370 |
| Rappahannock | SU-3 | 45 | 60 | 40 | 50 | 35 | 45 | 106 |
| | SPSU-3 | 65 | 80 | 60 | 70 | 55 | 65 | 106 |
| | SUFA-3 | 65 | 80 | 60 | 70 | 50 | 60 | 106 |

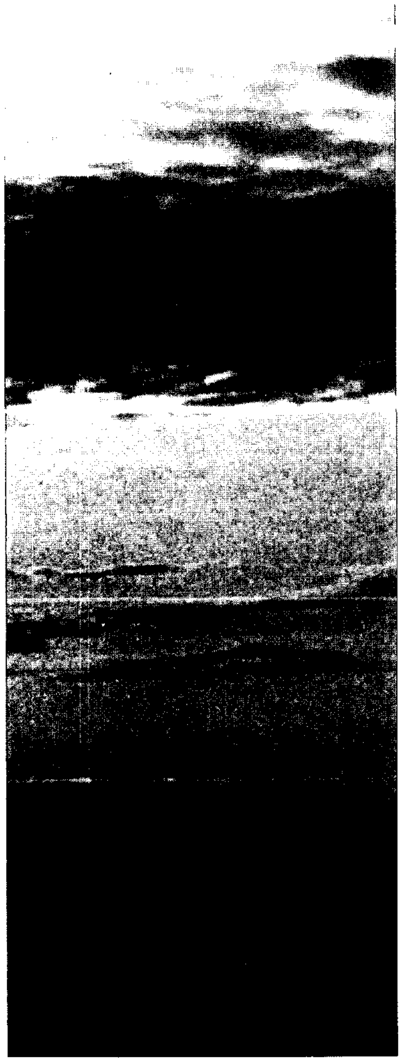


*Table 26*

*Most Promising Alternatives*

| *ALTERNATIVE* | *AREA WHERE IMPLEMENTED* |
|---|---|
| *Flow Supplementation Measures* | |
| Conservation | Susquehanna and Potomac River Basins |
| Reservoir Storage | Susquehanna, Potomac, Rappahannock and James River Basins |
| Growth Restrictions | Entire Chesapeake Bay Drainage |
| *Chesapeake Bay Measures* | |
| Fisheries Management | Chesapeake Bay and Tributaries |
| Oyster Bed Restoration | Chesapeake Bay and Tributaries |

"reasonable" as it relates to quantities of storage. This determination was based solely on technical considerations and experience in previous studies. For the most part, it is a function of the amount of water that can be stored without materially affecting the natural variability of flows in the main stem of the rivers. The work associated with this study appears to indicate that the storage of a quantity of water equivalent to the amount of consumptive losses that will accumulate in two seasons during a severe drought in the year 2020 is the outer limit of technically feasible "reasonable" storage. Certainly more detailed studies are needed to ascertain if this level of storage can be economically, socially, and environmentally justified or if some lesser level of storage is more appropriate.

## Most Promising Alternatives

In summary, the plan formulation process found that the measures shown in Table 26 are the most promising alternatives for solving the problems associated with reductions in the freshwater inflow to Chesapeake Bay.

The above alternatives were developed in varying levels of detail. Conservation and reservoir storage were evaluated in a rather rigorous three phase screening process that identified the habitat protected by each measure. On the other hand, no specific plans were developed for growth restrictions and the Chesapeake Bay measures. The present state of the art knowledge for these measures was not sufficient to permit development of these plans beyond conceptual levels.

The benefits produced by each of the most promising alternatives are summarized on Table 27. The table indicates the level of protection provided by each measure and that portion of the estuarine system receiving the benefits. The benefits are characterized as either environmental or socio-economic as appropriate.

*Table 27*

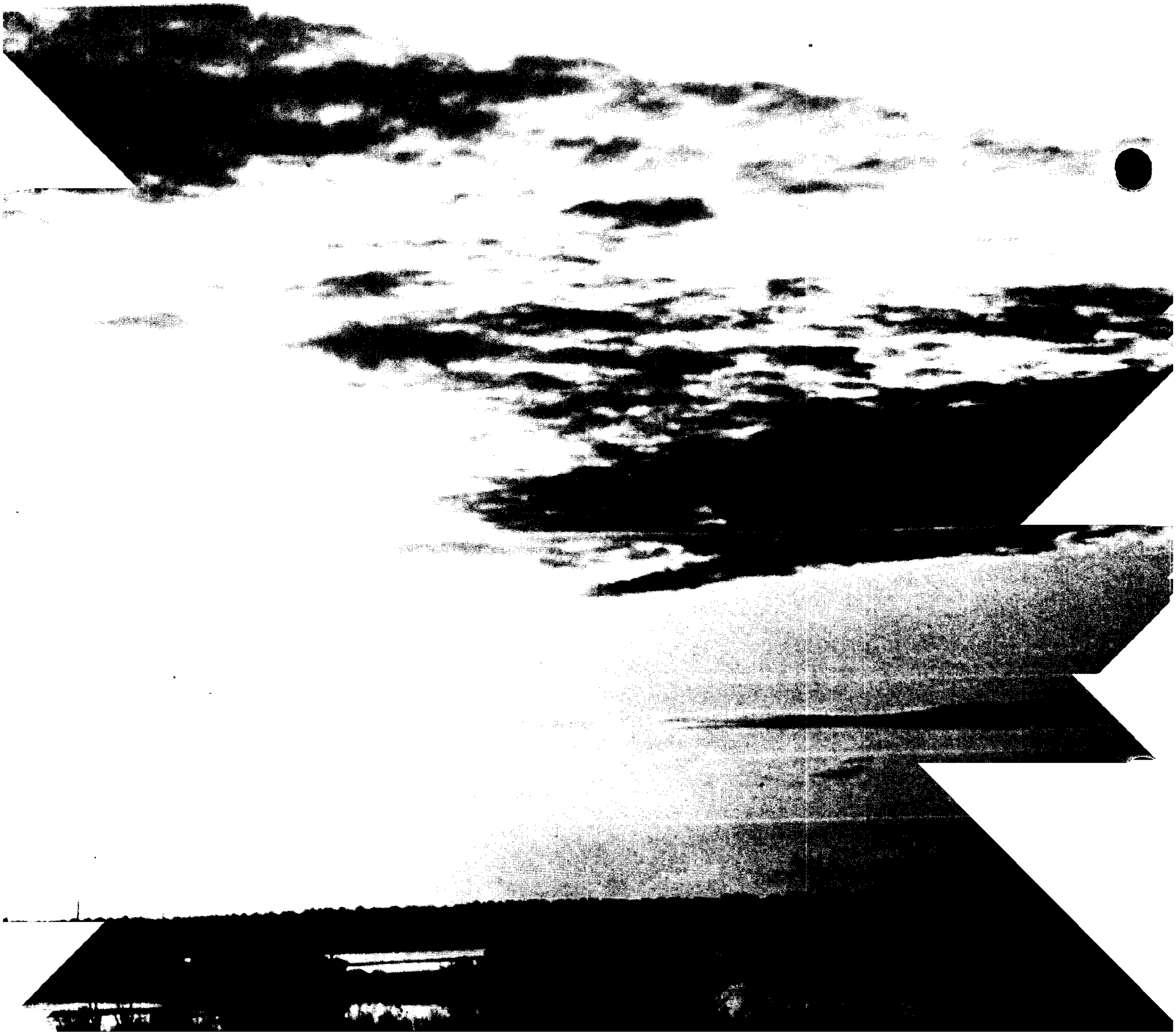
## *Benefits of Most Promising Alternatives*

| | FLOW SUPPLEMENTATION MEASURES | | | | | CHESAPEAKE BAY MEASURES | | |
|---|---|---|---|---|---|---|---|---|
| | RESERVOIR STORAGE (Drought Only) | | | CONSERVATION | GROWTH RESTRICTIONS | OYSTER BED RESTORATION | FINFISH RESTOCKING | CATCH LIMITATIONS |
| | SUMMER | SPRING-SUMMER | SUMMER-FALL | (Drought & Average) | (Drought & Average) | (Drought & Average) | (Drought & Average) | (Drought & Average |
| AREA BENEFITED | Main Bay, Potomac, Rappahannock, James | James, Rappahannock | Main Bay, James, Rappahannock | Main Bay, Potomac | Assumed Bay-wide | Bay-wide | Bay-wide | Bay-wide |
| LEVEL OF PROTECTION | Base Drought | Base Drought | Base Drought | 23% of BD (MB)<br>9-12% of BD (P) | Unknown | Unknown | Unknown | Unknown |
| ENVIRONMENTAL BENEFITS | | | | | | | | |
| Problem Species or Groups* | Oysters, Oligo Zone, SAV, Soft Clam (MB, P) | Oyster (SU)<br>O-Zone (SP & SU)<br>SAV (SU) | Oyster (SU)<br>O-Zone (SU & FA)<br>SAV (SU), Soft Clam (SU) *Macoma* (FA-MB, J) | Oyster (SU)<br>O-Zone (All seasons)<br>SAV (SP & SU)<br>Soft Clam (SU)<br>*Macoma* (FA) | Oysters (SU)<br>O-Zone (All seasons)<br>SAV (SP & SU)<br>Soft Clam (SU)<br>*Macoma* (FA) | Oysters | Striped, Bass, Shad | Oysters, Soft clam Striped Bass, Shad |
| Other Species | Will benefit all species adversely affected by increased salinities in summer (See Table V-3) | Will benefit all species adversely affected by increased salinities in spring & summer (See Table V-3) | Will benefit all species adversely affected by increased salinities in summer & fall (See Table V-3) | Will benefit all species adversely affected by increased salinities (See Table V-3) | Will benefit all species adversely affected by increased salinities (See Table V-3) | None | None | None |
| SOCIO-ECONOMIC BENEFITS | | | | | | | | |
| Commercial Fishery | Oysters, soft clams striped bass, shad | Oysters, striped bass, shad, soft clam | Oysters, striped bass, shad, soft clam | Oysters, striped bass, shad, soft clam | Oysters, striped bass, shad, soft clam | Oysters | Striped bass, shad | Oysters, striped bass, shad, soft clam |
| Recreation | Less boat slips exposed to *Bankia* (MB & P); Less nettles for swimming; improved sport fishing (striped bass & shad); improved hunting due to more food (SAV) for waterfowl (MB, P, R) | Less nettles for swimming; improved sport fishing (striped bass shad); improved hunting due to more food (SAV) for waterfowl (R) | Less boat slips exposed to *Bankia* (MB); less nettles for swimming; improved sport fishing (striped bass & shad); improved hunting due to more food (SAV & *Macoma*) for waterfowl (MB, R) | Less boat slips exposed to *Bankia*; less nettles for swimming; improved sport fishing (striped bass & shad); improved hunting due to more food (SAV & *Macoma*) for waterfowl | Less boat slips exposed to *Bankia*; less nettles for swimming; improved sport fishing (striped bass & shad); improved hunting due to more food (SAV & (*Macoma*) for waterfowl | None | Improved sport fishing (striped bass & shad) | Improved sport fishing (striped bass & shad) |
| Water Users | Slight benefit in summer (MB, P, J) | Slight benefit in spring & summer (J) | Slight benefit in summer & fall (MB, J) | Slight benefit all seasons | Slight benefit all seasons | None | None | None |
| OTHER BENEFITS | Will slightly reduce salinities at boundary with other tributaries during summer | Will slightly reduce salinities at boundary with other tributaries during spring & summer | Will slightly reduce salinities at boundary with other tributaries during summer & fall | No discernable change | Unknown | None | None | None |

LEGEND

| Seasons when benefits occur | Seasons where benefits occur |
|---|---|
| SP — Spring | MB — Main Bay |
| SU — Summer | P — Potomac |
| FA — Fall | J — James |
| | R — Rappahannock |

*Oligo Zone — Includes species in both Tidal Freshwater and Oligohaline Zones (See Table V-2)
Benefits occur in all areas if not noted.



# Chapter VI

## Public Involvement

Obtaining the views of the public and incorporating their preferences into the planning process are integral parts of any study, especially one as complex as the Chesapeake Bay Study. To encourage participation, a structured public involvement program was established and maintained throughout the study. A concerted effort was made to keep the lines of communication open so that information could be provided to any suggestions received from the public. For the Chesapeake Bay Study, the "public" was defined as any non-Corps of Engineers entity. Thus, the public included other federal agencies, state agencies, and local governments as well as private organizations, civic groups, and individual citizens.

The following sections briefly describe the nature of the public involvement program and the activities that accompanied it. A detailed discussion is contained in Supplement B—*Public Involvement.*

## Overview

### Purpose

The overall purpose of the public involvement program was to furnish an organized set of activities which would encourage two-way communication between the Corps of Engineers and the many publics in the Bay Region. Within this broad purpose, several specific objectives were established for the public involvement program. They included the following:

- To further identify all those elements of the public that were affected by any interested in Chesapeake Bay.
- To identify, as a continuing effort, the most effective means of involving the public in the Chesapeake Bay Study.
- To inform the public about the progress of the Chesapeake Bay Study, especially the conduct on the various resource studies and the hydraulic model testing program.
- To obtain the public's comments and suggestions concerning problems, potential solutions, and related impacts concerning the Bay's resources.
- To incorporate the public's desires and preferences into the final recommendations whenever possible.

### Public Involvement Measures

Three basic measures were used to initiate and sustain public participation throughout the study. They provided for general information, interaction-dialogue, and review-reaction. Each measure was designed to reach different levels of the public in the study area as shown on Figure 22. Likewise, each measure was geared to evoking a different degree of involvement or response from each level of the public.

### General Information

This measure was used to distribute information about study progress to as many people as possible. It usually provided for only one-way communication with the public. Mechanisms such as newsletters, newspaper articles, special publications, public displays, movies, press releases, and announcements through the media were used to reach most levels of the public.

### Interaction-Dialogue

Interaction-dialogue provided for a two-way communication between the Corps and the public. It required a certain amount of involvement by the interested public to obtain a better knowledge about the study, as well as a certain amount of involvement by the Corps to find out public needs and desires. Interaction-dialogue mechanisms such as workshops, planned educational programs, speeches, to organized groups, interviews, and tours of the hydraulic model were techniques that were employed to reach those who were either interested, involved, or decision-makers.

### Review-Reaction

Review-reaction was used to obtain feedback from those who were directly involved with the study. Special committees or advisory groups were formed to accomplish this purpose. Committee meetings, formal public meetings, progress reports, interim reports, and draft and final reports were used to garner the important opinions and values of the involved public and the decision-makers.

### Relationship to the Planning Process

Over the course of the Chesapeake Bay Study which spanned nearly two decades, the formal procedures which govern how federal agencies are to conduct water resource investigations have undergone periodic revisions. The most recent set of procedures was published by the U.S. Water Resource Council in March 1983 ("Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies"). Despite the numerous revisions through the years, though, the underlying concepts for planning have remained essentially the same. A sequential process of problem identification, plan formulation, and evaluation is to be followed. In addition, the process is to be a repetitive one with as many iterations as necessary to arrive at an acceptable plan of action. The iterative process can sharpen the planning focus, change the emphasis as new data are obtained, or redirect the effort as problems become more clearly defined. Public review and comment can occur at any time during this process.

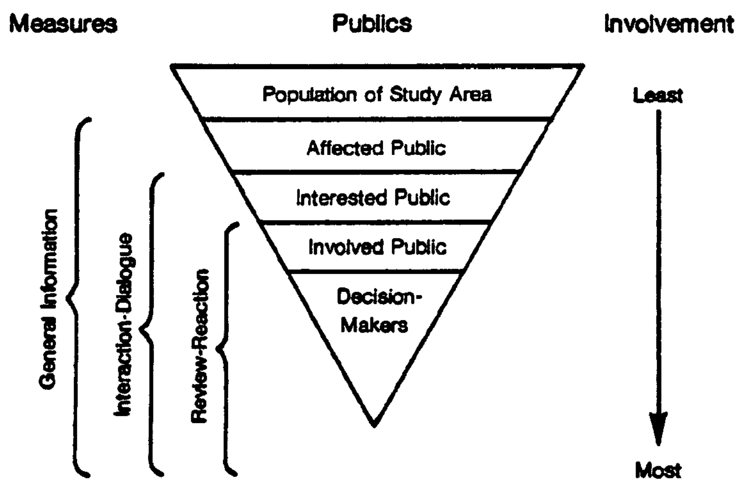



*Figure 22 Gearing Public Involvement Measures to the Public*

The Chesapeake Bay Study was conducted within this broad planning framework. The major study phases included the Initital Study Phase, the Existing and Future Conditions Phase, and the Detailed Study Phase. Within each study phase, numerous opportunities were provided to the public for review-reaction, interaction-dialogue, and general information. This continuous public involvement process permitted the participants to become fully aware of the study's basic assumptions, the data which were being generated or gathered, the areas of risk and uncertainty, the implications of the proposals being considered, and the progress of the hydraulic model testing program. Such a procedure also allowed certain decisions to be tempered by the public's input, at key points during the study.

## Description of Public Involvement Program

### Organizational Structure

The Chesapeake Bay Study was conducted under the general direction of the District Engineer, Baltimore District. Because of the important nature of the study, the District Engineer had a high degree of involvement in the study activities. The routine coordination of study activities was conducted under the supervision of the Chief, Planning Division and the Chief, Chesapeake Bay Study Branch. A multi-disciplinary staff was assembled within the Chesapeake Bay Study Branch to conduct the necessary investigations. Hydraulic modeling expertise was provided by the Waterways Experiment Station.

The nature and magnitude of the study, however, demanded extensive coordination among all of the agencies and institutions concerned with water resources planning in the Bay Region. To maximize participation by these organizations, each was charged with exercising leadership and providing information in those disciplines in which it had special competence. Several interagency committees were formed to open the necessary avenues for participation. These committees included an Advisory Group, a Steering Committee, and five Task Groups. Figure 23 displays a schematic view of the study's organizational structure.

### Advisory Group

The Advisory Group was established in 1967 as the principal coordinating mechanism for the study. It was composed of representatives from 11 federal agencies, the Commonwealths of Pennsylvania and Virginia, the States of Delaware and Maryland, and the District of Columbia (see Figure 23). The individuals serving on the Advisory Group were designated by the heads of their respective federal agencies or the governors of the involved states.

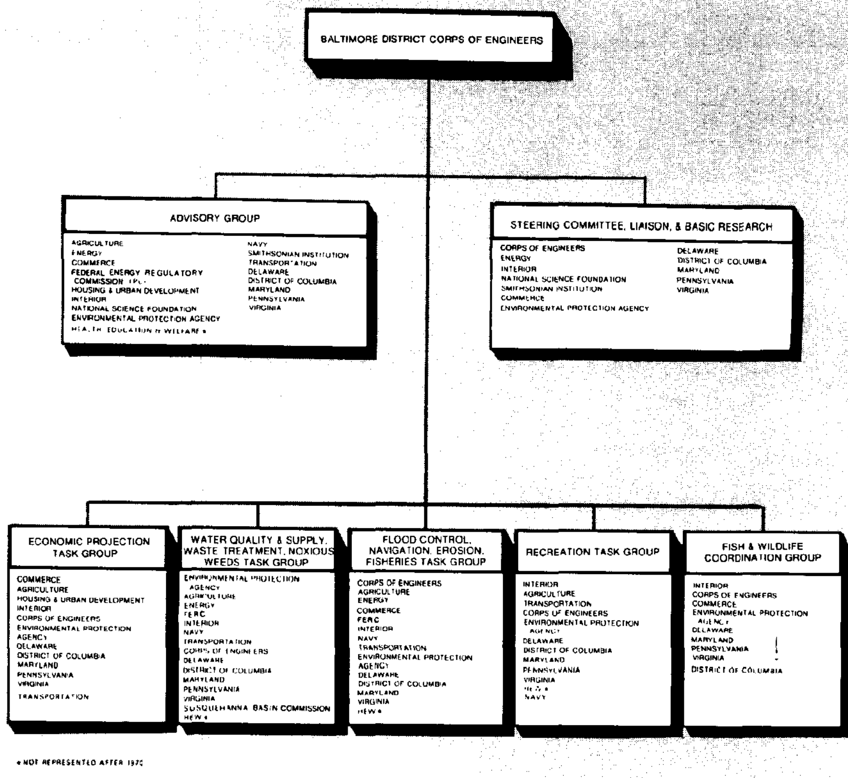



*Figure 23 Chesapeake Bay Study Organizatoin*

The Advisory Group advised the District Engineer regarding study policy and provided general direction under which all study participants operated. More specifically, the duties of the Advisory Group were:

- To advise the District Engineer in the coordination of study efforts.
- To consider the views of all participants as reported to the Group and make recommendations to the District Engineer.
- To review reports from all participants.
- To assist the District Engineer in providing information to the public and encourage participation by the public at hearings and other meetings.

Generally speaking, the Advisory Group convened whenever it was necessary to coordinate study efforts, to review and comment on study results, or to determine future study direction and activities. Numerous meetings of the Group were held over the course of the study. In addition to these official meetings, continuous coordination among the members was maintained on an individual basis.

## Steering Committee

The Steering Committee for Liaison and Basic Research was established in 1968 as a group of eminent scientists having specialized expertise concerning Chesapeake Bay. The Steering Committee was viewed as a high level technical committee which could furnish direction to the working Task Groups and provide scientific recommendations to the Advisory Group and the District Engineer. Some of the duties of the Steering Committee were:

- To develop study work plans for the scientific investigations being conducted by the Task Groups.
- To furnish scientific guidance, as necessary, to the Task Groups and the Corps of Engineers.
- To keep the Task Groups, the Advisory Committee, and the District Engineer informed of the latest technological advances in the study of the Bay's hydrodynamics and environmental values.
- To review and comment on the reports which were prepared by the various participants.

As with the Advisory Group, the Steering Committee met on an as needed basis throughout the study.

## Task Groups

Five Task Groups were originally established for the Chesapeake Bay Study. These groups included the following: Economic Projections Task Group; Water Quality and Supply, Waste Treatment, and Noxious Weeds Task Group; Flood Control Navigation, Erosion, and Fisheries Task Group; Recreation Task Group, and Fish and Wildlife Coordination Group.

Each task group was concerned with related study categories and functioned as a basic work group. The chairman designated for each task group was from the federal agency most closely associated with that particular field of study. The agencies serving on each of these original groups are shown on Figure 23.

At a January 1980 meeting of the Advisory Group, a discussion was held concerning the five original Task Groups and the role that they would have in the final phase of the study. Although these groups had served well during the first two phases of the study, it had become apparent that a reorganization was desirable. It was agreed that the groups, as then organized, would have little meaning for the final study phase. The work could best be accomplished by groups organized along specific resource study lines. It was therefore recommended by the Advisory Group, and so adopted by the Corps, that the five original Task Groups be replaced by two new groups—the Tidal Flooding Task Group and the Freshwater Inflow Task Group.

## Coordination Process

The specific responsibilities of the Advisory Group, the Steering Committee, the Task Groups, and the general public were all part of the coordination and review process. This was an iterative process that flowed between the Corps of Engineers and the various publics.

The District Engineer, who was responsible for management of the study, established broad goals based on study authority, budget limitations, and advice from the Advisory Group and Steering Committee. The Advisory Group and Steering Committee, in turn, suggested the types of investigations that should be conducted by the Task Groups in order to achieve the goals. The Task Groups were then charged with conducting the specific work assignments for the investigations within their particular areas of responsibility.

Following completion of a work assignment by a Task Group member, other members of the Task Group reviewed the report. After any necessary revisions, the report was forwarded to the Advisory Group and Steering Committee for further review. Again, comments were offered and appropriate revisions were made before sending the report to the District Engineer for final review.

Numerous opportunities were also provided for general public comment as well. These opportunities included forums such as public meetings, workshops, and civic group discussions. The Corps was also assisted in its involvement with the general public through the Citizens Program for Chesapeake Bay, Inc. (CPCB). This committee, although not created by the Corps of Engineers, included representatives from civic and environmental organizations throughout the Study Area.

## Public Involvement Activities

The following paragraphs provide an overview of the most significant public involvement activities which occurred during the study. The discussion addresses the three major time periods of the study. The Initial Study Phase is defined as the time period between study initiation (1967) and approval of the *Plan of Study* in 1970. The Existing and Future Conditions Phase covers the period between 1970 and the publication of the *Revised Plan of Study* in 1978. The Detailed Study Phase covers the period from 1978 to completion of this final report. Also included as part of the following discussion is a short description of the public involvement activities associated with the construction and operation of the Chesapeake Bay Hydraulic Model. Plate B-1 in Supplement B — *Public Involvement* shows chronologically the most significant public involvement and study activities. Pertinent correspondence for all study phases is included in Supplement B as Attachment B-4.

## Initial Study Phase

In the Initial Study Phase, the organizational structure described earlier was formally established by the District Engineer and several meetings of the various committees were conducted. These meetings were geared primarily to identifying study tasks, to developing work plans, and to assigning study responsibilities. A series of public meetings were held in late 1967 in Maryland and Virginia to inform the general public of study initiation. These public meetings were also used to obtain the general public's views about water resource problems confronting the Bay Region. The first major document was the *Plan of Study* published in June 1970. The *Plan of Study* outlined the study's scope, defined the study area, proposed study objectives, and described how the study was to be conducted.

## Existing and Future Conditions Phase

The Existing and Future Conditions Phase began when the *Plan of Study* was approved. This phase eventually produced the *Existing Conditions Report* in 1973 and the *Future Conditions Report* in 1978. These reports were the result of many meetings by the Advisory Group and Steering Committee, and sometimes lengthy investigations by the Task Groups.

In 1973, a specially prepared film was completed which provided an overview of the Chesapeake Bay Study and the hydraulic model. This film furnished the means to reach large numbers of people. The film was shown on television and was used over the next several years for hundreds of presentations throughout the Study Area.

During this phase, the Corps of Engineers adopted the existing Citizens Program for Chesapeake Bay, Inc. as an informal citizens advisory committee. Members of CPCB reviewed and commented on both the *Existing Conditions Report* and the *Future Conditions Report.* In addition, another series of public meetings were conducted in mid-1976. The purposes of these meetings were to inform the public about the study's progress, to discuss the preliminary findings of the *Future Conditions Report,* and to again solicit the public's views on Chesapeake Bay's problems. A News Circular (the first in a series) describing the study's progress was published in 1978; it was distributed to about 10,000 individuals within the Study Area.

Last, a *Revised Plan of Study* was published in 1978. During the course of the Existing and Future Conditions Phase, it became apparent that the study and hydraulic model testing program which was proposed in the original *Plan of Study* would not adequately address the many problems facing Chesapeake Bay. Thus, the Corps of Engineers, together with the Advisory Group and the Steering Committee, devised an expanded program for the final phase of study. The expanded program described in the *Revised Plan of Study* proposed four years of hydraulic model testing in concert with five years of resource studies.

### Detailed Study Phase

Public involvement activities during the final phase of the study were similar to those conducted during the first two phases. Advisory Group and Steering Committee meetings were held to seek advice on the conduct and findings of the Tidal Flooding Study and the Low Freshwater Inflow Study. Three additional News Circulars were published to keep the general public advised of study progress and findings. It should be noted, however, that because the schedule for completing the study was advanced several years, there was little opportunity for participation by a citizens advisory committee in the detailed study phase.

In cooperation with EPA, the State of Maryland, and the Commonwealth of Virginia, two large portable displays were prepared in 1979. These displays consisted of a discussion with appropriate photos and graphics of the Bay related programs of the Corps, EPA, and the two states. The displays were circulated throughout the Bay Region for exhibit in public buildings, schools, festivals, and other appropriate Bay-related events. Also in 1979, the Corps and the Chesapeake Research Consortium, Inc., jointly sponsored an educational seminar to discuss the Bay and the capabilities and potential uses of the hydraulic model.

Western Eco-Systems Technology held three conferences during the course of its study. The first seminar was at the Chesapeake Bay Hydraulic Model on November 15, 1979 and the second in Colonial Beach, Virginia, on March 20, 1980. Working papers were presented at each seminar on the selection of species, the habitat classifications, and the biota assessment study methodology. The third seminar was a scientific conference held on October 29, 1981 at the Naval Academy. At this conference, information was presented showing the rationale and basis for the biota assessment and the preliminary findings.

Last, the draft of the final report was distributed for review to all committee members, local and state governments, federal agencies, Citizens Program for Chesapeake Bay, and interested individuals. A synopsis of public views and comments concerning the draft report and the overall study will be provided later in this chapter.

### Hydraulic Model

The Chesapeake Bay Hydraulic Model at Matapeake, Maryland, provided the focus for perhaps the most beneficial series of public involvement activities as far as the general public was concerned. A groundbreaking ceremony for the hydraulic model was held in 1973 and a formal dedication ceremony was held in 1976. Both of these were sponsored by the Commissioners of Queen Annes' County. United States Congressmen, Senators, and local officials attended both of these events and accompanying media coverage was extensive.

About three years prior to the completion of the hydraulic model visitor center in 1979, regularly scheduled tours of the model began. The lobby of the visitor center had numerous displays which explained the Bay and the hydraulic model. The visitor could then enter an auditorium for a 20 minute slide show which further described the Bay, its problems, and the Corps' study. Lastly, the visitor received a 30 minute guided tour of the model with an even more detailed discussion of how the model operated and a description of the testing being conducted at that time. Generally speaking, the tours were provided three times a day during the week for the entire period between June 1976 and August 1983. The model was also open on selected weekends for such events as Chesapeake Appreciation Days. During the period when the model was open, it is estimated that approximately 200,000 people from every state and numerous foreign countries visited the model and received some appreciation and understanding of the Bay and the Corps' program. It should be noted that effective August 1984 the State of Maryland has assumed the maintenance on the hydraulic model pending the transfer of the model to the State.

## Public Views and Comments

The last step in the Chesapeake Bay Study public participation program involved a review of the draft of the final report by the agencies, institutions, and organizations that participated in the conduct of it. Their comments are addressed in detail in Supplement B — *Public Involvement*. In general, many of the comments were editorial or otherwise could be easily incorporated. The more important of the issues raised related to the vintage of the data base and the feasibility of reservoir storage.

In this regard, there was concern and some confusion about the information shown in the summary of the *Future Conditions Report.* This report was completed in 1978 and reflected conditions and projections made in the early 1970's. In the final report, these were updated where information was readily available or when it was not, statements were added to clarify the vintage of the information. In addition, it was recommended that the *Future Conditions Report* be updated.

There was also concern about the water supply and consumptive loss projections used in the Low Freshwater Inflow Study. These were based on OBERS Series "E" data, the most current projections available at the time the work was done in the mid-1970's. In 1983, a new projection set was published that was somewhat less optimistic. However, since the Series E data were used in the hydraulic model test, it was not possible to use this new data base in the evaluations. Rather, sensitivity analyses have been prepared comparing the data sets.

The feasibility of the reservoir storage alternative was also questioned. To accommodate this, the final report was revised to emphasize that the reservoir alternatives were evaluated from only the hydrologic and in estuary biologic perspectives and that reservoir construction is not being recommended. Rather, the recommendations call for further studies of both upstream and in estuary socio-economic and environmental impacts.

# Chapter VII
# Summary and Findings

## Summary

Historically, measures taken to control and use the Chesapeake's water and related land resources were oriented toward solving individual problems. A comprehensive examination had not been undertaken of the Bay's complex interrelationships. The Chesapeake Bay Study was initiated in 1967 to fill this gap. Its overall purpose was to conduct a comprehensive investigation of the entire Bay Region so that the most beneficial uses could be made of the Bay's resources.

The study was accomplished in three distinct developmental phases. Each of these phases was responsive to one of the following study objectives:

- To assess the existing physical, chemical, biological, economic, and environmental conditions of the Chesapeake Bay.
- To project the future water resource needs of the Bay Region to the year 2020.
- To formulate and recommend solutions to priority problems using the Chesapeake Bay Hydraulic Model.

The initial or inventory phase of the program responded to the first objective. It was completed in 1973 and the findings were published in a document titled *Chesapeake Bay Existing Conditions Report.*

Included in that seven-volume report is a description of the existing physical, economic, social, biological, and environmental conditions of the Chesapeake Bay. This was the first published report that presented a comprehensive survey of the entire Bay Region and treated Chesapeake Bay as a single entity. Most importantly, the report contains much of the basic data required to project the future demands on the Bay and to assess the ability of the resource to meet those demands.

The findings of the second or future projections phase of the program are contained in the *Chesapeake Bay Future Conditions Report.* The primary focus of that report was the projection of water resources needs to the year 2020 and the unrestrained growth and use of the Bay's resources. This report, therefore, provided the basic information necessary to proceed into the final or detailed study phase of the program. It should be emphasized that, by design, the *Future Conditions Report* addressed only needs and problems. No attempt was made to identify or analyze solutions to specific problems.

As directed in the authorization, the study included the construction and operation of a hydraulic model. The purpose in using a physical model was to examine complicated hydraulic processes not readily amenable to analysis by other analytical methods. The Chesapeake Bay Hydraulic Model was constructed between 1973 and 1976 near Matapeake, Maryland. Following adjustment and verification, testing was performed between 1978 and 1982. The hydraulic model provided a means of reproducing, to a manageable scale, many of the natural events and man-made changes affecting the Bay.

Given the hydraulic model and the array of existing and potential problems identified in the *Future Conditions Report*, the third and final phase of the study addressed the analysis of two priority problems: tidal flooding and reductions in freshwater inflow to the Bay. Both of these problems were the subject of detailed analyses to both better define the problem and evaluate potential solutions. The hydraulic model was used to develop the physical data needed in the detailed analyses. Given the time and funding constraints imposed on the study however, the scope of the Tidal Flooding and Low Freshwater Inflow Studies was limited to only a framework nature. This the final report of the Chesapeake Bay Study is therefore not an authorization document, but does provide recommendations for specific authorization studies as well as actions or promising alternatives that should be considered by others.

## Significant Findings

The following paragraphs provide a brief synopsis of the most pertinent findings of the many analyses that were undertaken during the study. The findings are categorized as they relate to either the various substudies that were conducted as part of the overall study or the overall study and model testing program. The findings address the physical, environmental and socio-economic condition of the resources; problem definition; important planning issues; and alternatives for future resources planning.

### Existing and Future Conditions Reports

Chesapeake Bay is a vast natural, economic, and social resource. Along with its tributaries, the Bay provides a transportation network on which much of the economic development of the Region has been based, a wide variety of water-oriented recreational opportunities, a home for numerous fish and wildlife, a source of water supply for both municipalities and industries, and the site for the disposal of many waste products. The natural resources and processes of the Bay and man's activities interact to form a complex and interrelated system. Unfortunately, problems often arise when man's intended use of one resource conflicts with either the natural environment or man's use of another resource.

In 1970, approximately 7.9 million people lived in the Chesapeake Bay Region. By the year 2020, population is expected to more than double reaching a level of approximately 16.3 million persons. Employment is projected to grow at approximately the same rate as population; per capita income is projected to nearly quadruple; and manufacturing output is expected to increase by nearly 600 percent.

Chesapeake Bay is one of the largest estuaries in the world, having a surface area of about 4,400 square miles, a length of nearly 200 miles, and over 7,000 miles of shoreline. Like many coastal plain estuaries, the Bay is a broad, shallow expanse of water varying from 4 to 30 miles in width, but having an average depth of less than 28 feet. Its maximum depth is 175 feet near Bloody Point, Maryland.

The marshes, woodlands, and the Bay itself, provide an extremely productive natural habitat for over 2,700 different species. The sheer number of species alone forecasts the complexity of Bay biota in terms of partitioning species to communities and determining functional relationships that will aid in understanding the Bay as an ecosystem.

More than half of the land in the Chesapeake Bay Region is covered by woodlands, forests, or wetlands. An additional one-third is in agricultural uses. Only about 7 percent of the land is used for residential, commercial, or industrial purposes.

The land needed for residential purposes will nearly double between 1970 and 2020. The amount of land needed for industrial purposes will increase by about 50 percent if industry is to meet the projected increase in manufacturing output. Conversely, the land in crops and miscellaneous farmland is expected to decrease by approximately 22 percent. Although there is sufficient land in the Bay Region available for residential and industrial development, conflicts between competing land use types in preferred areas is expected to continue to be a problem in the future.

In 1970 there were 49 central water supply systems in the Bay Region which served 2500 or more people. These systems served about 76 percent of the people in the Region, as well as many industries, providing a total of 872 million gallons of water per day (mgd). By the year 2020, 31 of these 49 systems are expected to have average water demands which will exceed presently developed sources of supply. The projected demands for water supplied through central systems will total approximately 2320 mgd by the year 2020. It is questionable whether or not new sources of water can be developed without placing undue stresses on the Bay system.

Assuming significant increases in recycling rates, water intake by all Bay Region industry (i.e., centrally-supplied and self-supplied) is projected to experience only modest increases of about 13 percent. Water consumption, however, is expected to increase by nearly 800 percent over the same period. As a result of these factors, the volume of industrial discharge is projected to decrease by 24 percent.

Total agricultural water demand, which includes uses for livestock and poultry, irrigation, and the rural domestic population, is expected to quadruple between 1970 and 2020, with over 90 percent of the increase due to a rise in the demand for irrigation water. Available supplies are expected to be sufficient to meet the future demand.

Water quality conditions in the Bay vary widely due to a variety of factors: proximity to urban areas, type and extent of industrial and agricultural activity, stream-flow characteristics, and the amount and type of upstream land and water use.

Between 1970 and 2020, boating and sailing activity is projected to increase by more than five times, swimming by four and one-half times, picnicking by a factor of three and one-half, and camping by almost six times. As a result of these increases, major deficits in the number of boating ramps, picnic tables, and camping sites are expected by the year 2020. Total Regional swimming pool and beach acreages are considered to be sufficient to meet demands through 2020 although there are acute existing deficits in most of the major urban areas.

In the major ports of Baltimore and Hampton Roads, the movement of such bulk commodities as petroleum, coal, grain, and in the case of Baltimore, iron ore, are expected to continue to dominate waterborne commerce. Bulk oil traffic is expected to approximately double by the year 2020 in Baltimore and remain at about the 1972 level throughout the projection period in Hampton Roads. The increasing size of bulk carriers, along with the projected general increase in bulk traffic, will intensify the need for deeper channels in the major harbors of the Region. Foreign general cargo traffic is projected to increase by a factor of approximately six in both Baltimore and Hampton Roads between 1972 and 2020.

Bulk oil is projected to continue to dominate waterborne traffic movements through the minor ports and waterways around Chesapeake Bay. The largest increases are expected on the Western Shore due to the larger growth in population and income predicted for this area. The level of petroleum traffic is critical because of the potential for environmentally damaging oil spills.

Based on the damage that could be expected from a 100-year tidal flood, the tidal flooding problem is considered to be "critical" in 31 communities in the Bay Region. An additional 20,000 acres of land within the 100-year tidal flood plain has been proposed for future intensive development.

Approximately 410 miles of Chesapeake Bay shoreline were identified as having "critical" erosion problems (based on intensity of development and existing rate of erosion). Over the last 100 years, approximately 25,000 and 20,000 acres of shoreline have been lost to erosion in Maryland and Virginia, respectively. An additional 44.4 miles of shoreline have the potential to become critical erosion problem areas in the future.

In 1973, the total harvest of finfish and shellfish from Chesapeake Bay and its tributaries totaled 565 million pounds valued at approximately $47.9 million at the dock. When the combined recreational and commercial catches are taken into account, maximum sustained yields (i.e., the greatest harvest which can be taken from a population without affecting subsequent harvests) are projected to be exceeded for blue crabs, spot, striped bass, white perch, shad, weakfish, flounder, and the American eel by the year 2000. By 2020, catches of oysters, softshell clams, menhaden, and alewife are also expected to exceed their maximum sustainable yields.

There are numerous areas in the Region which are of significant historical, archaeological, or ecological interest. These include nearly 800 properties which are included in the National Register of Historic Places or have been nominated for that distinction, 20 properties designated as National Wildlife refuges or research centers, and thousands of recorded archaeological sites.

Waterfowl hunting in the Chesapeake Bay Region is predicted to increase by 70 percent during the projection period. Big game hunting will increase 141 percent while small game hunting is expected to decrease by about 13 percent. Existing hunting land access problems are expected to be aggravated by the increases in waterfowl and big game hunting.

The demand for non-consumptive wildlife uses including bird watching, bird and wildlife photography, and nature walking is expected to approximately double over the projection period. Because of this, an additional one million acres of publicly accessible land will be required to maintain the quality level that existed in 1970.

The total demand for electricity in the geographical area containing the electric utilities serving the Bay is projected to increase by a factor of more than 5 by the year 2000 and a factor of approximately 13.5 by 2020. More and larger power plants will be required to meet this demand. By the year 1985, nuclear power is projected to account for approximately 44 percent of the Chesapeake Bay Region's power pool requirements. By 2020, the percentage is expected to increase to 72 percent.

Water withdrawal by power plants is expected to decrease significantly from 12,660 mgd in 1972 to 2,250 mgd in the year 2020, due to projected increases in water recycling. Water consumption, however, is projected to increase dramatically.

Aquatic plants are vital elements of the Chesapeake Bay ecosystem and form the basis in the food chain for the Bay's productive fish and wildlife resources. There has been in recent years a marked reduction in the numbers of some of the more beneficial aquatic plant species.

Although noxious weeds such as Eurasian watermilfoil, water chestnut, and sea lettuce have caused widespread problems in Chesapeake Bay in the past, present populations are well below troublesome levels. The potential remains, however, for a reemergence of high concentrations of these plants in the future as evidenced by the recent establishment of hydrilla in the Potomac estuary.

The above findings, as presented in the *Existing and Future Conditions Reports,* represent the results of the first detailed comprehensive assessment of the Bay and its resources and as such provide an excellent set of baseline data. Periodic reassessments should be made to update the baseline information and monitor any changes in the Bay and its resources.

## Tropical Storm Agnes Study

In June 1972, Tropical Storm Agnes moved through the mid-Atlantic states causing extensive damage to the resources of Chesapeake Bay. Public Law 92-607, the *Supplemental Appropriations Act of 1973* included $275,000 for studies of the storm's effect on Chesapeake Bay. This special study was conducted as part of the overall Chesapeake Bay Study and the findings of it are presented in the following paragraphs.

Chesapeake Bay is a dynamic and highly complex system influenced by many factors. When one or more of these factors are altered, the ramifications are felt throughout the system. Some are immediate and obvious. Others are felt after the event and are subtle, but nonetheless significant.

Massive freshwater inflows from the basin's tributaries can significantly lower salinity levels in the tributary estuaries and in the Bay proper. The freshwater inflows depress the surface salinities first, and then the salinities at the lower depths. After freshwater inflows return to normal, pre-storm conditions, the Bay will also return to its pre-storm conditions.

The Bay life most affected by massive freshwater inflows are those species, such as oysters and clams, that have no or limited means of locomotion and have a low tolerance to changes of salinity. Finfish and shellfish that are able to move to areas where their necessary salinity levels are present are less affected. When the estuarine system returns to its pre-storm conditions, the mobile species will return to their original habitats.

The direct and immediate Bay-related economic impacts are damages to boats and the cleaning up of debris that is washed into the Bay with the floodwaters. The fishery and recreation industries suffer both immediate and long-term economic impacts. The economic losses are due to fish kills, bans on harvesting certain species, health reasons, and the curtailment of boating activities because of floating debris.

Floodwaters introduce large amounts of nutrients into the Bay. This results in massive growth of algae blooms, which in turn depress dissolved oxygen levels in the water.

When floodwaters in the drainage basin inundate or overtax sewage treatment plants, raw and partially treated sewage are washed into the Bay. This could present a major health hazard which may require bans on harvesting of fishes and water-contact recreation.

The major geological implication to the Bay of fluvial flooding is the deposition of sediment on the Bay bottom. Erosion of the Bay's shoreline areas is slight.

There were changes in the bottom geometry of the Bay's tributaries in some areas. It could not be determined, however, if the changes were directly attributable to Agnes since much of the pre-Agnes base line data were based on surveys taken years before. The changes to the bottom geometry are not sufficiently significant to warrant a redesign of the Bay model.

Historically, hurricanes and tropical storms are recurring phenomena in the Bay basin. It can be readily assumed that, in the future, the region will again be subjected to devastating storms and flooding. Chesapeake Bay demonstrated its intricateness and delicacy during Agnes. But the Bay also demonstrated its resiliency by absorbing the storm's impact and returning, for the most part, to pre-storm conditions shortly after Agnes subsided.

The physical and biological consequences of high freshwater inflows to the Bay are not fully understood. Further studies to include the development of models are needed to understand events similar to Tropical Storm Agnes.

## Chesapeake Bay Hydraulic Model

The Chesapeake Bay Model proved to be a valuable and effective tool for developing the physical data needed for the full range of studies conducted for both the Chesapeake Bay Study and others.

The following tests were performed on the Chesapeake Bay Hydraulic Model:

- Baltimore Harbor Channel Enlargement Test
- Nanticoke River Toxic Material Dispersion Test
- James River Oil Dispersion Test
- Cuyahoga Victim Recovery Test
- Patuxent and Chester River Prototype Survey Design
- Lafayette River Wastewater Dispersion Test
- Low Freshwater Inflow Problem Identification Test
- Potomac Estuary Water Supply and Wastewater Dispersion Test
- Storm Surge Test
- Norfolk Harbor Channel Deepening Test
- Air-Florida Debris Recovery Test

## Tidal Flooding Study

Periodic tidal flooding is a problem that affects all of the Bay's shoreline. Nearly 60 communities around the Bay were identified as having existing or potential flooding problems.

Because of their topography and land use patterns, twelve communities were found to be susceptible to significant monetary losses from tidal flooding. These twelve communities were studied in detail in the Tidal Flooding Study.

Both structural and non-structural measures can be used to reduce or prevent the adverse effects of tidal flooding. Structural measures were generally found to be very expensive, have adverse environmental effects, and were less acceptable to local residents. Non-structural solutions were usually less expensive and less environmentally damaging. Combinations of structural and non-structural plans were found to be the best alternatives for providing tidal flood protection in the Bay area.

Of those communities investigated, only Poquoson, Tangier Island, and a portion of Hampton Roads (Hampton, Norfolk, Chesapeake and Portsmouth) were found to have sufficient economic justification to warrant more detailed authorization studies.

Given the lack of historical tidal flood stage and frequency information, a coordinated Bay-wide program should be instituted to collect and record stage related data.

Any further investigation of tidal flooding in the Bay Region should include the development of a storm surge model to be used to provide stage-frequency related information.

In order to reduce the adverse effects of tidal flooding, a Bay-wide coordinated tidal flood forecasting and warning system should be developed.

Local jurisdictions that are subject to tidal flooding should be encouraged to adopt flood plain zoning regulations, display potential flood height markers and generally make more prudent use of flood prone areas.

## Low Freshwater Inflow Study

Chesapeake Bay is a complex estuarine system that is dependent on the freshwater inflow from its tributaries to maintain the salinity regime that characterizes its ecosystem.

Increasing population and economic growth in the Bay drainage area is predicted to result in increased water supply demands and attendant increases in the amount of water used consumptively. Increased consumptive use is expected to cause a marked reduction in freshwater inflow to the Bay and result in higher salinities throughout the Bay system. In the long term, salinities would be expected to increase by as much as 2 to 4 ppt just from increased consumptive losses alone.

The occurrence of long term drought events results in large reductions in freshwater inflow to the Bay. Over the course of the drought, salinities may be up to 5 ppt higher than average. Increasing consumptive losses will further exacerbate future drought events.

The relationship between freshwater inflow and salinities in the Bay system is very complex. At the present time, physical modeling is the only means available that can accurately predict changes in salinity levels caused by variations in freshwater inflows. The testing conducted on the Chesapeake Bay Model was considered to be on appropriate representation of the changes in salinity distribution resulted from droughts and decreases in inflow caused by increasing consumptive losses.

The Chesapeake Bay Model low freshwater inflow test also demonstrated that: (1) no perceptible changes in water surface elevations or velocities were caused by freshwater inflow changes of the magnitude addressed in this study, (2) the Bay returned to "normal" 6 to 9 months after a drought, (3) salinities could vary significantly across the Bay and (4) spring tides have a marked influence on vertical salinity stratification.

Although several studies have been conducted, the effects of the C & D Canal on Chesapeake Bay salinities are still not well understood.

The Low Freshwater Inflow Study methodology involved selecting representative species for study, mapping potential habitat under various conditions, using expert scientists to interpret the significance of habitat change, and assessing socio-economic and environmental impacts of the changes. This methodology proved to be a valid technique for both defining problems and evaluating alternatives. It was developed because the state of the art knowledge relative to the physical and biological interactions in the Bay system are not sufficiently advanced to use comprehensive ecosystem models.

The changes in habitat caused by reductions in freshwater inflow can have both beneficial and adverse effects. The adverse effects were found to far outweigh the beneficial ones.

The most serious adverse impacts would be to the oyster which would suffer from the intrusion of disease and predators. The net loss of oysters could exceed 85 percent of present stocks under drought conditions. The economic impact of this magnitude of loss would approach $60 million annually.

Other organisms suffering significant adverse impacts include all those species dependent on the oligohaline and tidal freshwater zones, soft clams, low salinity submerged aquatic vegetation, Baltic clams, and several important sport fish and waterfowl to include striped bass and canvasback ducks.

In addition to significant economic losses, the losses to the commercial fishery and recreation industries could have far reaching social impacts on many of the Bay's traditions.

The impacts of decreasing inflows on the municipalities and industries that use the estuary as a water supply source are small. Likewise, the increase in the number of beaches affected by the further intrusion of sea nettles would be small.

It is realized that demographic and economic projections more recent than those used in this study indicate that the magnitude of consumptive losses used as the bases for the foregoing analyses may not be realized in the year 2020. It is believed, however, that under any circumstances, the magnitude of increases in consumptive losses will be sufficient to be of real concern and that the Low Freshwater Inflow Study provides a framework for the development of corrective actions.

In order to reduce or eliminate the adverse effects of decreasing freshwater inflows, consideration was given to both flow supplementation and Chesapeake Bay measures. Flow supplementation measures are upstream measures that provide additional flow in the tributaries and contribute to the health of all species. Chesapeake Bay measures are remedial actions that are oriented to restoring specific species that were destroyed or reduced.

While no specific plan was developed to solve the problems caused by reduced freshwater inflows, several alternatives were identified as "most promising." These include reservoir storage, conservation, growth restriction, oyster bed restoration, and fisheries management.

It should be emphasized that no recommendations are being made for the immediate implementation of any of these alternatives. Rather, further analyses are needed that will lead to the development of specific plans for coping with the consequences of decreases in freshwater inflows to Chesapeake Bay. In the meantime, it would be prudent to consider these consequences in all future actions related to the use, preservation, and enhancement of the Bay.

Bay salinities are a function of many factors to include freshwater inflow, antecedant salinities and tidal amplitude to name a few. Because of this complexity, it is not possible to select one minimum inflow that will insure that target salinities will not be exceeded. In order to implement flow supplementation alternatives, a predictive system must be developed to insure that the volume and timing of flow releases produce the desired Bay salinities.

Programs for the preservation and enhancement of Chesapeake Bay are presently being formulated and implemented. The success of these programs could be dependent, in part, on full consideration of the consequences of reduced freshwater inflows to the Bay.

Both the physical and biological processes of Chesapeake Bay are very complex and in many cases, not well understood. While it would not be prudent to defer management decisions until there is a full understanding of the Bay, continued advances in our knowledge of the system must be pursued. Of particular concern are a better understanding of the interactions among organisms and the role of freshwater inflows in biological and physical processes.

With the many studies conducted on the Chesapeake Bay there has been an enormous amount of data and information collected. At the present time it is nearly impossible to determine what studies have been conducted much less recover the information contained in them. There is an important need for a comprehensive data information and retrieval system for Chesapeake Bay.

## Recommendations

In light of the findings discussed in the foregoing chapters and in the best interest of the long term productivity of Chesapeake Bay and its resources, I recommend that Congress authorize the Corps of Engineers to:

1. Conduct survey scope tidal flooding studies in the Poquoson, Tangier Island and Hampton Roads areas of Virginia to include the development and verification of a storm surge model capable of forecasting tidal flood stages and developing stage—frequency relationships.

2. Conduct a comprehensive water supply and drought management study that will identify those measures required to optimize the use of existing water supplies in the Bay drainage basin and minimize reductions in freshwater inflow to the Bay.

3. Conduct a comprehensive Baywide study to develop plans for dredged material disposal for the maintenance and improvement of all major harbors and approach channels to include, but not limited to, Baltimore and Norfolk Harbors and the Chesapeake and Delaware Canal.

4. Conduct further studies to determine the effects of the Chesapeake and Delaware Canal on the salinities of the Bay.

5. Conduct a periodic update of the information contained in the *Chesapeake Bay Future Conditions Report* to insure that the information will serve as a water resources data base for Chesapeake Bay.

I also recommend that Congress support other agencies, institutions and individuals in their endeavors to:

1. Conduct appropriate local floodplain planning and develop a tidal flood forecasting and warning system, including warning and evacuation plans, designation of shelters, marking of flood prone areas and other measures.

2. Refine those low freshwater inflow alternatives found to be the most promising and develop a definitive plan for eliminating or reducing the adverse effects of both droughts and the increasing consumptive losses of water.

3. Conduct research to develop and refine ecosystem models that would provide a better understanding of the hydrodynamics and biological resources of Chesapeake Bay with emphasis on the interactions among organisms and those processes that are controlled by or related to freshwater inflow to Chesapeake Bay.

4. Conduct further studies to determine the physical and biological consequences of high freshwater inflows on Chesapeake Bay.

5. Establish and maintain a data information and retrieval system to be used as a central repository for all Chesapeake Bay related studies and data.

Martin W. Walsh, Jr.

MARTIN W. WALSH, Jr.
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# GLOSSARY

**acre-foot:** a measure of water volume, equivalent to an acre of water surface one foot deep.

**aquifer:** a saturated underground geologic formation of sand, gravel, or other porous material, capable of transmitting water to wells or springs.

**aesthetics:** people's perceptions of beauty or artistic values in the environment.

**algae:** group of plants, variously single celled, colonial, or filamentous.

**anadromous:** a type of fish that ascends rivers from the sea to spawn — examples in Chesapeake Bay include shad and alewife; striped bass are considered semi-anadromous.

**aquatic:** of or pertaining to fresh or salt water; growing or living in or upon water.

**Base Average:** long-term average freshwater inflow conditions; also, salinity conditions resulting therefrom, as determined by hydraulic model testing.

**Base Drought:** historical freshwater drought inflow conditions from 1963 to 1966; also, salinity conditions resulting therefrom, as determined by hydraulic model testing.

**Bay Region:** the geographical area which includes those counties or SMSA's which are located on Chesapeake Bay, approximately to the head-of-tide; same as "Study Area."

**benefit-cost ratio:** the arithmetic proportion of estimated average annual benefits to average annual costs, insofar as the factors can be expressed in monetary terms. The relation of benefits to costs represents the degree of tangible economic justification of a project.

**benthic:** of or pertaining to the bottom of a water body.

**benthos:** those organisms living on or in the bottom of a water body.

**biomass:** the living weight of a plant or animal population, usually expressed on a unit area basis.

**biota:** the plant and animal life of a region.

**bloom:** an unusually large number of organisms per unit of water, usually algae, made up of one or a few species.

**brackish water:** a mixture of salt water from the ocean and freshwater from land drainage; usually considered to have a salinity greater than 1 part per thousand.

**cfs:** cubic feet per second.

**combustion plant:** a type of electrical generating facility which uses the power of combustion instead of steam to drive the turbine.

**consumptive loss:** the portion of the water used for public, agricultural, industrial and electric power cooling usage that is lost from streamflow because of evaporation, incorporation into products, etc. (equivalent to "withdrawal" minus "discharge")

**copepods:** any of a subclass of small crustaceans of fresh or saline waters; a component of the zooplankton.

**critically flood-prone:** for purposes of the Tidal Flooding Study, when 25 acres or more of intensively developed land are inundated by the 100-year flood.

**crustacean:** any of a class of arthropods, including shrimp, crabs, and barnacles.

**detritus:** a non-dissolved product of disintegration or decay; organic detritus forms the basis of the estuarine food chain.

**dissolved oxygen (DO):** oxygen gas dissolved in water — necessary for life of fish and other aquatic organisms.

**dissolved solids:** a measure of the amount of organic and inorganic material which has been chemically dissolved in water.

**dockside value:** in commercial fishing, the value of a harvest to the fishermen before it is resold to distributors and wholesalers.

**drainage basin:** the area of the land from which all precipitation, less evapotranspiration and other losses, eventually discharges to a river or Bay.

**drought:** a prolonged period of dry weather or lack of rain; in this study it generally refers to a period similar to the drought of the mid-1960's that resulted in some of the lowest recorded streamflows in the Bay area.

**ecosystem:** the interacting system of living things and their physical and chemical environment.

**endangered species:** a plant or animal in danger of extinction throughout all or a significant portion of its range; currently listed under the provisions of the Endangered Species Act of 1973.

**epifauna:** aquatic species which live attached, on or above the bottom.

**epiphytic:** living on the surface of plants.

**estuary:** a partially enclosed body of water, with a connection to the ocean, in which freshwater from overland drainage is mixed with saline water moving in from the ocean; also that portion of a stream or river influenced by the tide of the body of water into which it flows.

**euhaline:** of or pertaining to waters of greater than 30 ppt salinity.

**euryhaline:** able to exist in a wide range of salinities; as opposed to "stenohaline."

**eutrophic:** abundant in nutrients and having high rates of productivity, frequently resulting in oxygen depletion below the surface layer.

**evapotranspiration:** the combined loss of water from a given area during a specified period of time by evaporation from the soil or other surface and by transpiration from plants.

**Extratropical Storm:** see Northeaster.

**fall line:** the geological boundary line where sedimentary formations of the Coastal Plain thin out as they come into contact with the harder crystalline rocks of the Piedmont Plateau; generally coincides with the head-of-tide on western shore tributaries.

**finfish:** that portion of the aquatic community made up of the true fishes as opposed to invertebrate shellfish.

**flood:** an overflow of lands not normally covered by water and that are used or are usable by man. Floods have two essential characteristics: the inundation of land is temporary; and the land is adjacent to and inundated by overflow from a river or stream or an ocean, bay, or other body of standing water.

**flood plain:** the relatively flat area or low lands adjoining the channel of a river, stream or watercourse or ocean, bay, or other body of standing water, which has been or may be covered by flood water.

**flood-prone:** for purposes of the Tidal Flooding Study, having at least 50 acres of land developed for intensive use inundated by the SPTF.

**juvenile:** a fully developed but immature life stage.

**larva:** an early developmental stage of an animal which changes structurally to become an adult (e.g., caterpillars, tadpoles).

**life cycle:** the series of life stages in the form and mode of life of an organism, i.e., between successive recurrences of a certain primary stage such as the spore, fertilized eggs, seed, or resting cell.

**marsh:** low, wet, soft land; in the Bay, often synonymous with wetlands.

**mesohaline:** of or pertaining to salinities which range between 5 and 18 ppt.

**mgd:** millions of gallons per day.

**motile:** capable of spontaneous movement.

**neap tide:** tide of decreased range which occurs about every two weeks.

**neckton:** the actively swimming aquatic animals (e.g., fish).

**non-tidal current:** any current that is caused by other than tide producing forces; includes currents generated by wind and water density differences.

**Northeaster:** a cyclonic type storm which develops near the Atlantic Coast and is most common during the winter months and early spring. Wind speeds are not as great and central pressures are not as low as ordinary hurricanes, but winds cover a considerably greater area.

**nutrients:** organic and inorganic chemicals necessary for the growth and reproduction of organisms.

**oligohaline:** of or pertaining to low salinity concentrations; in this study, relates to the salinity range of 0.5 to 5.0 ppt.

**organism:** any individual plant or animal.

**photosynthesis:** the process in plants of production of carbohydrates from carbon dioxide and water, using sunlight as energy, and chlorophyll as a mediator.

**phytoplankton:** small, freely floating forms of aquatic life (e.g., algae, diatoms, etc.).

**piscivorous:** feeding on fishes.

**plankton:** the passively drifting or weakly swiminging organisms in marine or fresh waters.

**polyhaline:** of or pertaining to salinities which range between 18 and 30 ppt.

**power pool:** two or more interconnected electric systems planned and operated on a coordinated basis.

**ppt:** parts per thousand.

**predator:** an organism living by capturing and feeding upon other animals.

**primary consumer:** an organism which consumes green plants.

**productivity:** the rate of production of organic matter produced by biological activity in an area (measured in units of weight or energy per unit volume or area and time).

**recycling rate:** the ratio of water intake to gross water use.

**riparian doctrine:** unwritten law historically recognized in the Eastern States, guaranteeing stream flows be undiminished in quantity or quality due to unreasonable upstream uses.

**risk:** the chance of injury, damage or loss; often quantifyable as a probability of occurrence, such as the risk of a drought.

**salinity:** a measure of the dissolved solids content of water. The amount of chlorinity or electrical conductivity in a sea water sample is used to establish salinity; seawater is about 35 parts per thousand salinity (by weight); drinking water standards allow a maximum of 0.25 ppt salinity.

**secondary consumer:** an organism which consumes the primary consumer.

**shellfish:** aquatic animals having a shell or exoskeleton, usually mollusks (clams and oysters).

**spawn:** to produce or deposit eggs, sperm, or young.

**species:** a distinct kind; a population of plant or animal all having a high degree of similarity and that can generally only breed among themselves.

**spring tide:** tide of increased range which occurs about every two weeks when the moon is new or full.

**stage:** in hydrology, the height of the water surface above or below an arbitrary datum; a gage height.

**Standard Metropolitan Statistical Area (SMSA):** a designation of the U.S. Bureau of the Census which is defined as containing a city, or "twin" cities, with a population of 50,000 or more, and the socially and economically contiguous counties.

**Standard Project Tidal Flood (SPTF):** the largest tidal flood that is likely to occur under the most severe combinations of meteorological and hydrological conditions that are considered reasonably charactertistic of the geographic region.

**steam power plant:** a type of electrical generating facility which uses steam to drive an electrical generator. The steam is generated by heat from burning fossil fuels or from the fissioning of nuclear fuel.

**stenohaline:** of/organisms which can endure only a narrow range of salinities.

**substrate:** bottom sediments — mud, sand, clay, silt, etc.

**suspended solids:** undissolved material in water, includes both organic and inorganic substances.

**synergistic:** interactions of two or more substances or organisms producing a result that any was incapable of independently.

**tidal flooding:** the inundation of land by tides higher than those usually caused by hurricanes or "northeasters."

**trophic level:** all organisms in a complex community that derive their food a common step away from the primary producers (green plants).

**Tropical Storm:** a cyclonic wind storm of tropical origin with winds from 39 to 74 mph.

**uncertainty:** lack of certainty; doubt; relates in this study to estimates of such variables as future population growth, fishery productivity, etc.

**vertebrate:** those animals possessing a backbone or spinal column, i.e., fishes, birds, reptiles, amphibians, and mammals.

**waterfowl:** birds frequenting water, including game birds such as ducks and geese.

**wetlands:** areas characterized by high soil moisture and high biological productivity, where the water table is at or near the surface for most of the year.

**withdrawal:** water taken from a surface or groundwater source for an offstream use (equivalent to "intake").

**zooplankton:** the animal forms of plankton, including certain types of protozoans, crustaceans, jellyfishes, etc., and the eggs and larvae of many benthic and necktonic animals.

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