Chesapeake Bay Tidal Flooding Study

MAIN 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 district 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 Cheseapeake 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. It provides a transportation network on which much of the region's economic development has been based, a wide variety of water-oriented recreation oppor tunities, 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 use of the resources conflict with the natural environment or other intended uses. Thus, the impetus for the Chesapeake Bay Study came from a need to resolve these conflicts, to make uses of the Bay compatible with the Bay ecosystem itself, and to provide an efficient and effective means of managing this diverse, dynamic resource.

For the purposes of this report, the Chesapeake Bay Study Area was defined as the shaded portion shown in Figure 1. The Study Area encompassed all the counties and Standard Metropolitan Statistical Areas (SMSA) adjacent to or directly influencing Cheseapeake 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 represents 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."

AUTHORITY

The authority for the Cheseapeake 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 sections reads as follows:

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

Chesapeake Bay Study

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 the Bay's resources in future years. Within this broad study purpose, three major study objectives were established. These study objectives were identified as follows:

- 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 also included the construction and operation of a hydraulic model. The purpose in using a physical model was to examine complicated hydraulic processes not readily amendable 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, testing was performed between 1978 and 1982. The hydraulic model provided a means of reproducing, at a manageable level, many of the natural events and human changes affecting the Bay. Data were collected from the hydraulic model tests and were then analyzed to assess the consequences of these happenings.

In response to the first study objective, an inventory of existing conditions was completed in 1973. 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 complete 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.

In response to the second study objective, an analysis of future conditions was completed in 1978. Results were published in the 12-volume *Chesapeake Bay Future Conditions Report*. The primary focus of the 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.

Based on the findings of both the *Existing Conditions Report* and the *Future Conditions Report*, a myriad of either existing or emerging water resource related problems in the Chesapeake Bay Region were identified. Because the responsibility for implementing solutions to these problems was either at the local, state, or Federal level, and because there were numerous studies and research programs underway, it was necessary to more specifically define the role of the Chesapeake Bay Study. In defining this role, emphasis was placed on: (1) selecting problems for study that were considered to be high priority and of Bay-wide significance, (2) maximizing use of the Chesapeake Bay Hydraulic Model, (3) avoiding duplication of work conducted under other programs, and (4) being responsive to the original intent of the Congress as specified in the study authorization. A review of the potential studies indicated that at least a portion of the Chesapeake Bay Study and model efforts should be directed toward studies of extraordinary natural events that have Bay-wide impact or significance. These events included: (1) periods of low freshwater inflow from the Bay's tributaries, (2) periods of high freshwater inflow from the Bay's tributaries, and (3) tidal flooding caused by unusual climatological/meteorological conditions.

Two of the most pressing problems identified were tidal flooding along the Chesapeake Bay shorelines and the impacts of low freshwater inflow to the Chesapeake Bay. As recommended in the *Revised Plan of Study* published in 1978 these two problems became the focus of the detailed study phase of the Chesapeake Bay Program. The purpose of this *Main Report* is to discuss the findings of the Tidal Flooding Study.

Tidal Flooding Study

The Tidal Flooding Study had three primary objectives. The first was to provide a better understanding of the tidal flood stage-frequency relationship in the Bay Region as a whole and particularly in those communities subject to tidal flooding. The second major objective was to define the environmental and socio-economic impacts of tidal flooding on the affected communities. The third and final objective was to recommend detailed studies of structural or nonstructural measures for tidal flooding protection in those communities where it was determined to be economically and environmentally feasible as well as socially acceptable.

Study Processes and Report

As discussed in the Foreward to the *Main Report*, tidal flooding was one of two major resource problems addressed during the final phase of the Chesapeake Bay Study. The Tidal Flood Study *Main Report* provides a summary of the investigations and analyses conducted and presents the findings for the communities which were examined. The six tidal flooding appendices listed in Table 1 contain the information supporting the findings which are summarized in the *Main Report*. The identification of tidal flooding as a problem and its general impact on the Bay communities is presented in Appendix A. The formulation of plans to mitigate the flood problem is detailed in Appendix B along with an evaluation of the effects these plans may have on the communities under study. Appendix C profiles the natural and recreational resources of the communities while Appendix D high-

TABLE 1

CHESAPEAKE BAY TIDAL FLOODING STUDY REPORT FORMAT

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

lights their demographic and cultural resources. The flood protection measures considered, and their cost, are presented in Appendix E while Appendix F presents the annualized costs and benefits for each of the plans.

Prior Studies and Reports

There have been several studies accomplished by the Corps that have investi gated specific problems in the communities under study. These studies are discussed in Appendix A — *Problem Identification.* However there has been only one comprehensive Bay-wide tidal flooding study conducted by the Corps in the last three decades. The authorization for this study was contained in Public Law 71, Eighty-fourth Congress, first session, approved 15 June 1955, which read:

> *Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled:* That in view of the severe damage to the coastal and tidal areas of the eastern and southern United States from the occurrence of hurricanes, particularly the hurricanes of August 31, 1954 and September 11, 1954, in New England, New York and New Jersey coastal and tidal areas, and the hurricane of October 15, 1954 in the coastal and tidal areas extending south to South Carolina, and in view of the damages caused by the other hurricanes in the past, the Secretary of the Army, in cooperation with the Secretary of Commerce and other Federal agencies concerned with hurricanes is hereby authorized and directed to cause an examination and survey to be made of the eastern and southern seaboard of the United States with respect to hurricanes with particular reference to areas where severe damages have occurred.
>
> SEC. 2. Such survey, to be made under the direction of the Chief of Engineers, shall include the securing of data on the behavior and frequency of hurricanes, and the determination of methods of forecasting their paths and improving warning services, and of possible means of preventing loss of human lives and damages to property, with due consideration of the economics of proposed breakwaters, seawalls, dikes, dams and other structures, warning services or other measures which might be required.

The above authorization resulted in several studies and subsequent reports which addressed various segments of the tidal shoreline. Specific reports were prepared that considered: (1) the Baltimore Metropolitan Area, Maryland, (2) the Washington, D.C. Metropolitan Area, (3) Colonial Beach, Virginia (4) Garden Creek, Mathews County, Virginia, (5) the tidewater portions of the Patuxent, Potomac and Rappahannock Rivers, including the adjacent Chesapeake Bay Shoreline, and (6) the entire tidal shoreline of the Eastern Shore of Maryland and Virginia and the Western Shore of Maryland from the head of the Bay to the mouth of the Patuxent River. No recommendations for construction of any hurricane protective works resulted from any of the above studies. The following conclusions and recommendations are quoted from House Document No. 176, Eighty-Eighth Congress, first session, 25 November 1963, Chesapeake Bay, Maryland and Virginia, and are considered typical of the findings of these earlier studies.

> On the Eastern shore of the Chesapeake Bay there were no locations at which local interests specifically requested construction of protective structures to prevent tidal flooding. Investigation of the shore showed that there were no locations at which construction of protective structures could be justified although there exist in Dorchester and Somerset Counties large areas that would be flooded by hurricane-induced tides of 10 feet or greater. In these areas serious consideration should be given by local authorities to developing an adequate evacuation plan.
>
> On the Western shore of the Chesapeake Bay there were found no locations at which extensive flooding would occur from high tides since elevations of 20 feet or more exist at shore distances from the new high water shoreline. At some locations along the shore, local interests requested protection from beach erosion. In these locations, it was found that local interests did not desire protection from hurricane-induced tides and since investigations to provide beach erosion protection can be accomplished under existing laws, provision of protection was not investigated for these areas.
>
> Since there appear to be no locations on the east or west shore of the Chesapeake Bay at which protection from hurricane-induced tides could be justified the District Engineer recommends that no further planning or investigation for the provision of hurricane protective works within the study area be undertaken at this time. The District Engineer recommends, however, that this report be published and distributed to appropriate officials in the area who may find the information contianed therein of use in the establishment of flood plain regulatory measures and evacuation procedures.

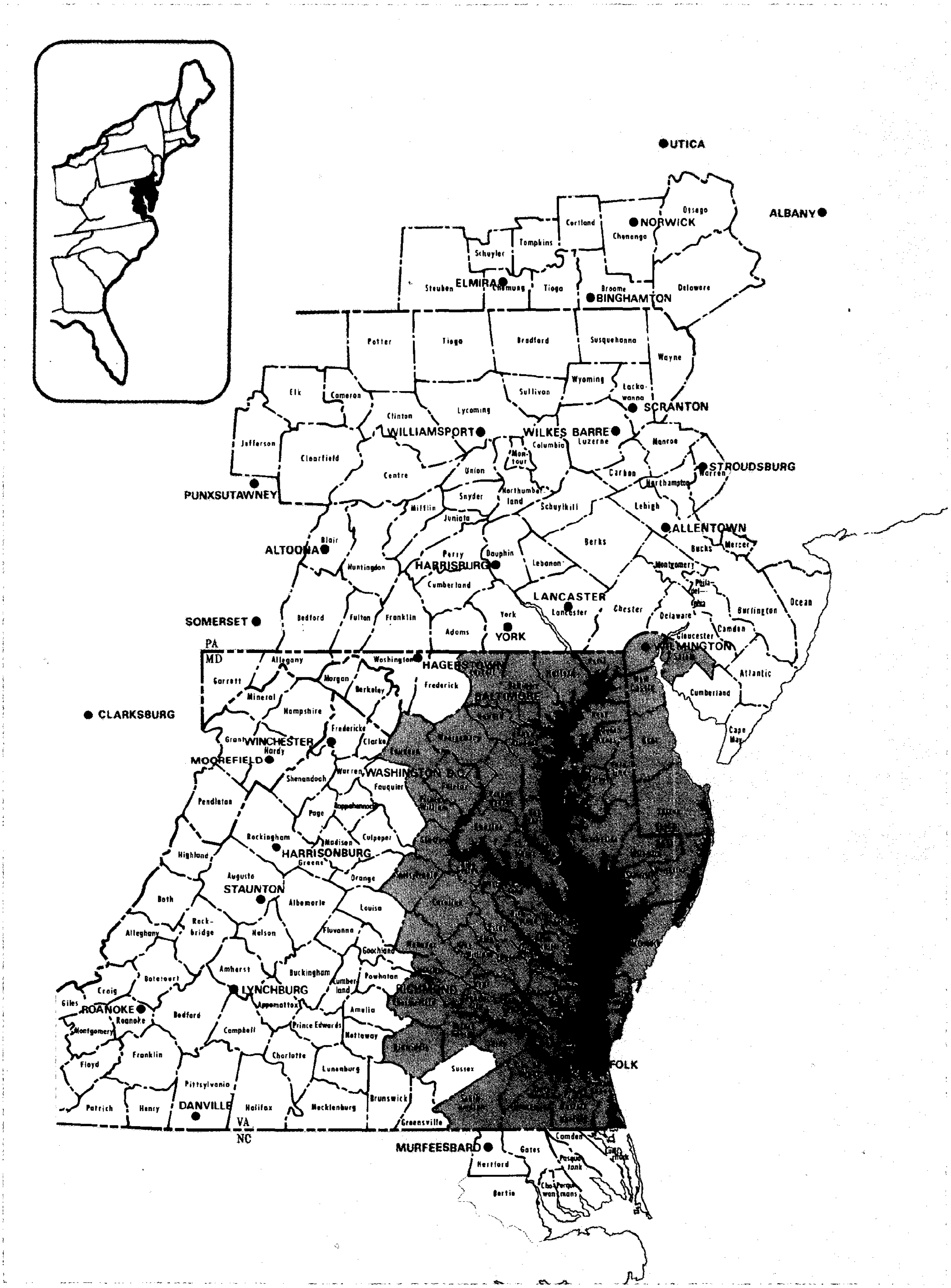


Figure 1 Chesapeake Bay Study Area

Study Participants and Coordination

The problems of 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. Figure 2 illustrates the many agencies involved in the Chesapeake Bay Study. 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.

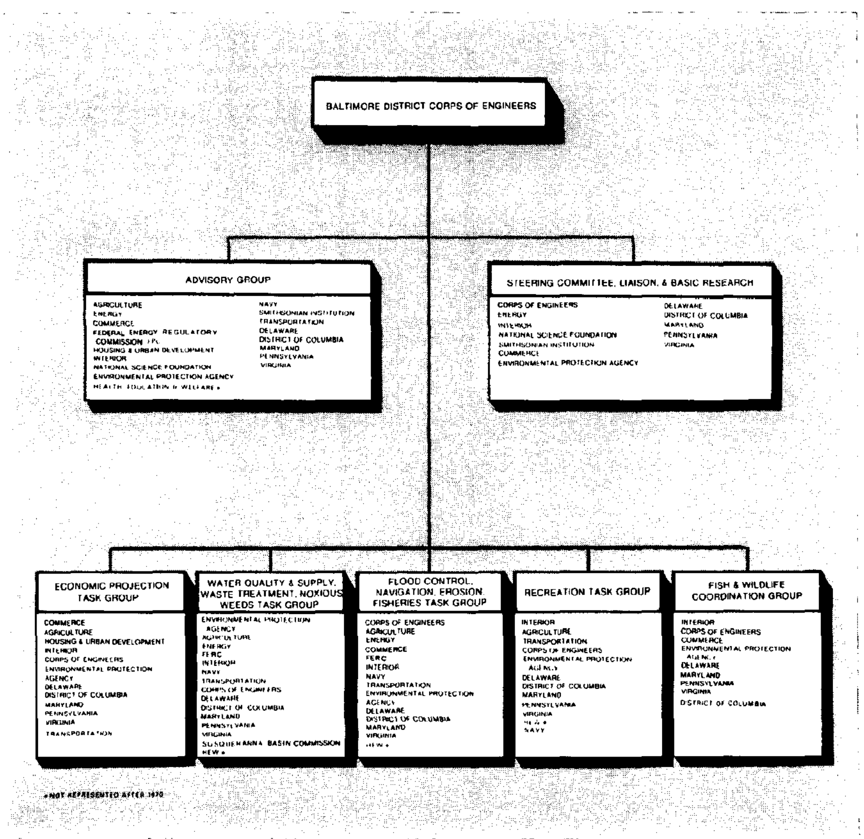
The overall management of the Chesapeake Bay Study was the responsibility of the District Engineer of the Baltimore District, Corps of Engineers. His staff included professionals from the fields of engineering, economics, and the social, physical, and biological sciences. Hydraulic modelling expertise 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. 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*.

Figure 2 Chesapeake Bay Study Organization



CHAPTER II

Problem Identification

Study Area

As stated earlier, the Chesapeake Bay Study Area included all the counties and Standard Metropolitan Statistical Areas (SMSA) contiguous to or directly influencing Chesapeake Bay and its subestuaries. With regard to the detailed problem analysis associated with tidal flooding, only a portion of the Study Area was examined. By its very definition, the tidal flooding study was involved only with those communities that are influenced by the tidal fluctuations in the Bay Estuary. The number of communities, metropolitan areas, and towns considered in the various stages of the study were reduced through consideration of several criteria. The communities selected for detailed study as well as the process used will be discussed later in this chapter. The limits of the area considered in the tidal flooding study are presented in Figure 3.

Existing Conditions

Geology

The Chesapeake Bay Region is divided into geologic provinces — the Coastal Plain and the Piedmont Plateau. These provinces run roughly parallel to the Atlantic Ocean in similar fashion to the Bay itself and join at the Fall Line. 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 portions of the Western Shore adjacent to the Bay, the Coastal Plain is largely low, featureless, and frequently marshy, with many islands and shoals sometimes extending far offshore. It is the low elevation, characteristic of the Coastal Plain, that makes the area particularly prone to flooding from tidal events. 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 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 which are characteristic of the Province.

Climate

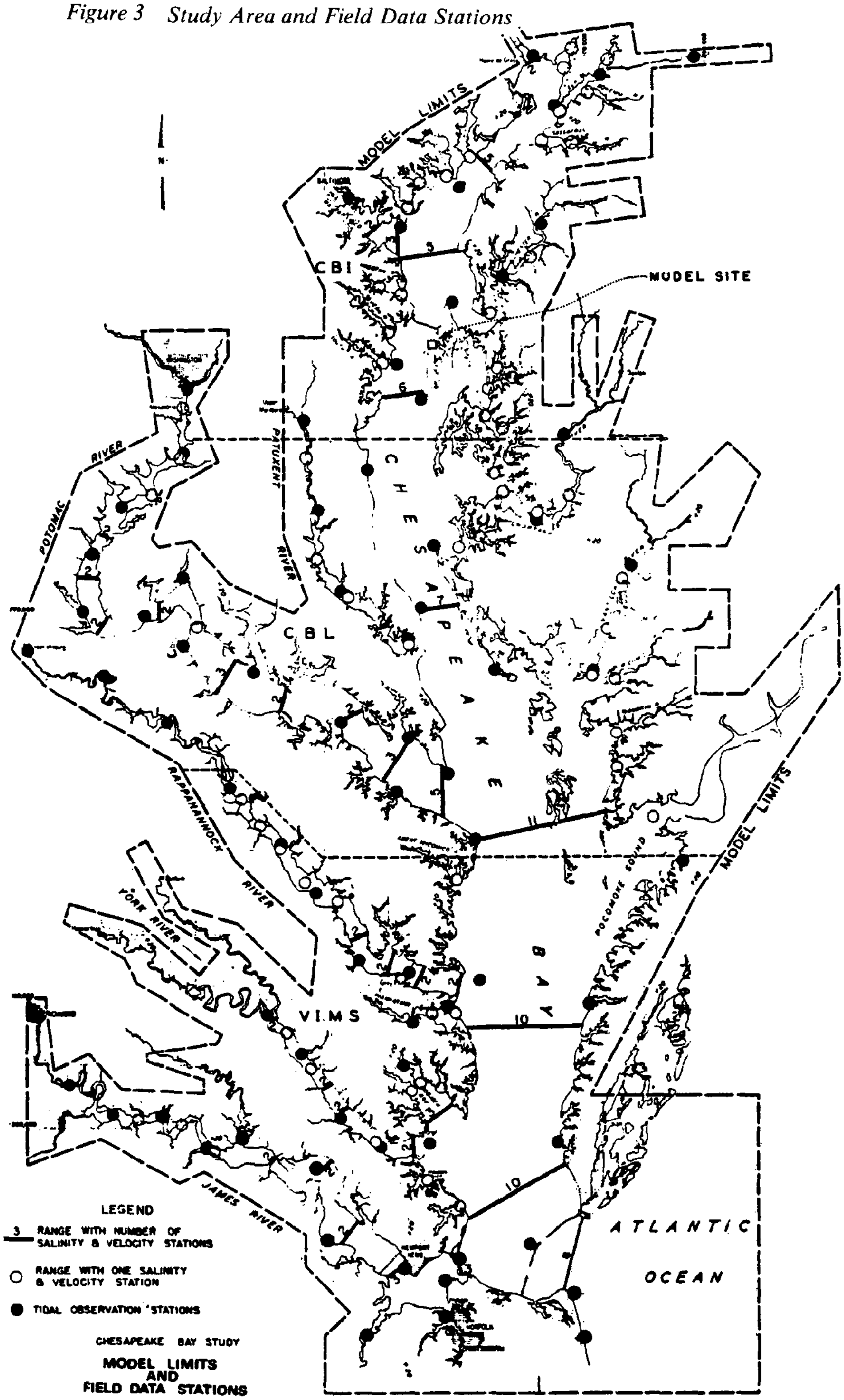
The Chesapeake Bay Study Area is characterized by a generally moderate climate, due in a large part to its proximity to the Atlantic Ocean. Variations occur, however, on a local basis due to the large geographical size of the Bay area. Precipitation for the Study Area averaged 44 inches per year based on the period of record from 1931 to 1960. Evapotranspiration amounts to about 26 inches a year with estimates as high as 36 to 40 inches per year from the Bay itself. Storm activity in the region consists of three types: extratropical storms or "lows", tropical storms or "hurricanes," and thunderstorms. Thunderstorms are responsible for the greatest variation in precipitation in the Bay Region. A discussion of hurricanes and their consequences is found later in this chapter.

Surface Water Hydrology

The source of freshwater for the Bay is runoff from a drainage basin covering about 64,160 square miles. Approximately 88 percent of this basin is drained by five major rivers, including the Susquehanna, Potomac, Rappahannock, York, and James Rivers. These river basins are subject to periodic large, climatic extremes, resulting in large fluctuations in flow (i.e., droughts and floods). Of these, droughts are the more geographically widespread and long-term in nature. The Susquehanna, Potomac, Rappahannock, York, and James Rivers together provide nearly 90 percent of the Bay's mean annual inflow of approximately 69,800 cubic feet per second.

The mixing in the estuary of sea water and freshwater creates salinity variations within the system. In Chesapeake Bay, salinities range from about 33 parts per thousand at the mouth of the Bay near the 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 a comparable area of the Western Shore due to the greater river inflow on the Western Shore and to the earth's rotation. Salinity patterns also vary seasonally according to the amount of freshwater inflow into the Bay system.

Figure 3 Study Area and Field Data Stations



Due to this seasonal variation in salinity and the natural density differences between fresh and saline waters, significant non-tidal circulation often occurs within the Bay's small tributary embayments. In the spring, during the period of high freshwater inflow to the Bay, salinity in the embayments may be greater than in the Bay. Because of this salinity difference, surface water from the Bay flows into the tributaries on the surface, while the heavier, more saline bottom water from the tributaries flows into the Bay along the bottom. As Bay salinity becomes greater through summer and early fall, Bay waters flow into the bottom of the tributaries, while tributary surface waters flow into the Bay.

The natural variations in salinity that occur in the Bay are part of the dynamic nature of the estuary, and the resident species of the plants and animals are ordinarily able to adjust to the 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 content since oxygen is more soluble in cold water than in warm. With spring and higher water temperatures, the dissolved oxygen content decreases. While warmer surface waters stay near saturation, in deeper waters the dissolved oxygen content becomes significantly less despite the cooler temperatures because of increasing oxygen demands (by bottom dwelling organisms and decaying organic material) and decreased vertical mixing. Through the summer, the waters below 30 feet become oxygen deficient. By early fall, as the surface waters cool and sink, vertical mixing takes place and the oxygen content at all depths begins to steadily increase until there is an almost uniform distribution of oxygen. While species vary in the level of dissolved oxygen they can withstand before respiration is affected, estuarine species in general can function in waters with dissolved oxygen levels as low as 1.0 to 2.0 mg/liter. Dissolved oxygen levels of about 5.0 mg/liter are generally considered necessary, however, to maintain a healthy environment over the long term.

The effects of temperature on the estuarine system are also extremely impor tant. Since the waters of Chesapeake Bay are relatively shallow compared to the ocean, they are more affected by atmosphere temperature conditions. Generally speaking, the annual temperature range in Chesapeake Bay is between 0° and 29° C. Because the mouth of the estuary is close to the sea, it has a relatively stable temperature as compared with the upper reaches. Some heat is required by all organisms for the functioning of bodily processes. These processes are restricted, however, to a particular temperature range. Temperatures above or below the critical range for a particular species can be fatal unless the organism is able to move out of the area. Temperature also causes variations in water density which plays a role in stratification and non-tidal circulation as discussed earlier.

Light is necessary for the survival of plants because of its role in photosynthesis. Turbidity, more than any other physical factor, determines the depth light will penetrate in an estuary. Turbidity is suspended material, mineral and/or organic in origin, which is transported through the estuary by wave action, tides, and currents. While the absence of light may be beneficial to some bottom dwelling organisms since they can come out during day-light hours and feed in relative safety, this condition limits the distribution of plant life because of the restriction of photosynthetic activity. This restriction of plant life (especially plankton in the open estuary) will reduce the benthic (i.e., bottom dwelling) and zooplankton populations which in turn will reduce fish productivity.

Nutrients are the minerals essential to the normal functioning of an organism. In Chesapeake Bay, important nutrients include nitrogen, phosphorus, carbon, iron, manganese, and potassium. It is generally believe 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, may cause an increase in the rate of eutrophication which, in turn, can eliminate desirable species, encourage the growth of obnoxious algae, and cause low dissolved oxygen conditions from the decay of dead organisms and other materials. Relatively little is known about the quantities of specific nutrients necessary for the healthy functioning of individual species, or more importantly, of biological communities.

While it is necessary to keep in mind the interactions of these physical and chemical variables when studying Chesapeake Bay, these parameters should not, in fact, cannot be addressed separately. The Bay ecosystem is characterized by the dynamic interplay between many complex factors. As a simple example, the levels of salinity and temperature will both affect the metabolism of an aquatic organism. In addition, both salinity and temperature can cause a drop in the oxygen concentration in the water and thus an increase in the required respiration rate of the organism. While it is true the effects of these variables individually may be of a non-critical nature, the combined (or synergistic) effects of the three stresses may be severe to the point of causing death. These three parameters, in turn, also interact with other physical and chemical variables such as pH, carbon dioxide levels, the availability of nutrients, and numerous others. The subtle variable of time may also become critical in many cases. The important point is that the physical and chemical environment provided by Chesapeake Bay to the indigenous biota is extremely complex and difficult, if not impossible, to completely understand.

THE BIOTA OF CHESAPEAKE BAY

The estuary is biologically a very special place. It is a very demanding environment because it is constantly changing. The resident plants and animals must be able to adjust to changes in physical and chemical parameters. The requirement for adjustment to the almost constant ecological stress limits the number of species of plants and animals that are able to survive and reproduce in the estuary. Despite the fact that relatively few species inhabit the Bay, the Chesapeake, like most estuaries, is an extremely productive ecosystem. This is so for several reasons. Circulation patterns create "nutrient traps" which act to retain and recirculate nutrients. Water movements remove wastes and transport food enabling organisms to maintain a productive existence. The constant formation of detrital material creates a form of "self-enriching" system. Finally, the estuary benefits from a diversity of producer plant types which together provide year-round energy to the system. Chesapeake Bay has all three types of producers that power the ecosystems of the world: macrophytes (marsh and sea grasses), benthic microphytes (algae which live on or near the bottom), and phytoplankton (minute floating plants).

Like the aquatic plant communities, the aquatic communities are not spread homogeneously throughout the Bay. Although the entire estuary serves as nursery and primary habitat for finfish, spawning areas are concentrated in the areas of low salinity and freshwater in the Upper Bay and corresponding portions of the major tributaries. The northern part, including the Chesapeake and Delaware Canal, is probably the largest of all spawning areas in the Bay. This area plus the upper portions of the Potomac, York, Rappahannock, James, and Patuxent Rivers, contains about 90 percent of the anadromous fish (i.e., those which ascend rivers from the sea to reproduce) spawning grounds in the Chesapeake Bay Region. Some of the fish that use the Bay as a nursery include striped bass, weakfish, shad, alewife, blueback herring, croaker, menhaden, and kingfish. In addition to Chesapeake Bay's large resources of finfish and shellfish, the marshes and woodlands in the area provide many thousands of acres of natural habitat for a variety of waterfowl, other birds, reptiles, amphibians, and mammals.

POPULATION

The majority of the inhabitants of the Chesapeake Bay Area are concentrated in relatively small areas in and around the major cities. Approximately 90 percent of the population resided in one of the Region's seven Standard Metropolitan Statistical Areas (SMSA) in 1970. The number of urban dwellers increased by almost 1.5 million during the 1960-1970 decade while the rural population remained virtually the same. People have tended to move out of the inner cities and rural counties and into the suburban counties. Thirty-five of the 76 counties and major independent cities in the Study Area experienced a net out-migration during the 1960-1970 period. On the other hand, most of the suburban counties experienced growth rates in excess of 30 percent and in-migrations of at least 10 percent of their 1960 population. In the Bay Region as a whole, net in-migration accounted for about one-third of the 1.5 million increase in population during the decade of the 1960's. Most of this in-migration was in response to large increases in employment opportunities in the Bay Region.

In 1970, there were approximately 3.3 million people employed in the Study Area. About 91 percent of these worked in one of the Region's seven SMSA's. During the 1960-1970 period, total employment increased by about three-quarters of a million jobs or approximately 30 percent. The National gain during the same period was 19.5 percent.

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. Since 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 Nation as a whole. Also contributing to these stable employment levels are the large numbers of workers whose jobs depended on relatively consistent spending by the Federal government.

This section has provided only a brief overview of the environmental and socio-economic characteristics of the Chesapeake Bay Region. A more detailed discussion of the Bay Region is found in Supplement A of the Summary Report — *Problem Identification*.

PROBLEMS, NEEDS, AND OPPORTUNITIES

Since man first settled on the shoreline of the Chesapeake Bay, he has been subject to the human suffering and millions of dollars of property damage resulting from 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 built up, not only by the force of the wind and the forward movement of the storm wind field, but also by differences in atmospheric pressures accompanying the storm. The actual height reached by a hurricane tidal surge and the consequent damages incurred depend on many factors including shoreline configuration, bottom slope, difference in atmospheric pressures and wind speed. Generally, the tidal surge is increased 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. Tidal surges are greater and the tidal flooding more severe in coastal communities which lie to the right of the storm path 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.

In the course of recorded history, the Chesapeake Bay Region has been subjected to about 100 storms that have caused damaging tidal flooding. The accounts of most of the storms that occurred prior to 1900 are very brief and are usually found only in early newspaper articles and private journals. The elevation and the area inundated by these early tidal floods was seldom accurately documented and it was not until the early part of the 20th century that a program to maintain continuous records of tidal elevations was initiated. The damages and loss of life suffered during these early floods also is not well documented.

Shown in Table 2 are the recorded tidal elevations at several locations for the most severe floods that have occurred in this century. It should be noted that the relative severity of flooding varies around the Bay since it is a function of changes in storm paths and variances in climatological and astronomical tide conditions.

The hurricane of 23 August 1933 was the most destructive ever recorded in the Bay Region. The hurricane center entered the mainland near Cape Hatteras,

TABLE 2

RECENT CHESAPEAKE BAY STORMS

	Tidal Elevations (Feet Above National Geodetic Vertical Datum)			
Storms	Norfolk	Mid-Bay	Washington	Baltimore
August 1933	8.0	7.3	9.6	8.2
September 1936	7.5	—	3.0	2.3
October 1954 "Hazel"	3.3	4.8	7.3	6.0
August 1955 "Connie"	4.4	4.6	5.2	6.9
August 1955 "Diane"	4.4	4.5	5.6	5.0
April 1966 "Northeaster"	6.5	2.8	4.0	3.3
March 1962 "Northeaster"	7.4	6.0	—	4.7

TABLE 3

TIDAL FLOOD DAMAGES
(Damages in $1,000's, 1979 dollars)

Location	Aug 1933	Oct 1954 "Hazel"	Aug 1955 "Connie"	Mar 1962
Baltimore Metro Area	$32,700	$ 9,600	$16,000	*
Washington Metro Area	16,700	6,700	400	*
Maryland	15,800	12,600	*	
Norfolk Metro Area	11,800	*	*	$ 6,700
Virginia	*	*	*	34,300

*Negligible

TABLE 4

CHESAPEAKE BAY AREA FLOOD-PRONE COMMUNITIES

STATE OF MARYLAND

Anne Arundel County
*Arundel on the Bay
*Avalon Shores (Shady Side, Curtis Pt. to Horseshoe Pt. and West Shady Side)
Broadwater
Columbia Beach
*Deale
Eastport
Franklin Manor on the Bay and Cape Anne
Galesville
Rose Haven

Baltimore City

Baltimore County
Back River Neck
*Dundalk (Including Sparrows Pt.)
*Middle River Neck
*Patapsco River Neck

Calvert County
Cove Point
North Beach on the Bay
Solomons Island

Caroline County
Choptank
*Denton
Federalsburg

Cecil County
Elkton
Northeast

Charles County
Cobb Island

Dorchester County
*Cambridge

Harford County
Haure de Grace

Kent County
*Rock Hall

Queen Anne's County
Dominion
*Grasonville
Stevensville

St. Mary's County
Colton
*Piney Point
St. Clement Shores
St. George Island

Somerset County
*Crisfield
*Smith Island

Talbot County
Easton
Oxford
*St. Michaels
*Tilghman Island

Wicomico County
Bivalve
Nanticoke
*Salisbury

Worcester County
*Pocomoke City
*Snow Hill

COMMONWEALTH OF VIRGINIA

Independent Cities
*Fredericksburg
*Hampton
Newport News
*Norfolk
*Portsmouth Beach
*Virginia Beach
*Chesapeake

Accomack County
Onancock
Saxis
*Tangier Island

King George County
*Dahlgren

King William County
*West Point

**WASHINGTON, D.C.*

Northampton County
*Cape Charles

Westmoreland County
*Colonial Beach

York County
*Poquoson

*Indicates "critically" flood-prone communities.

passed slightly west of Norfolk, Virginia, and continued in a northerly direction passing just east of Washington, D.C. It moved at or near the critical speed for producing the maximum surge, and its time of arrival coincided with the astronomical high tide as it proceeded upstream. The results were tides ranging from 8.0 feet above National Geodetic Vertical Datum (NGVD) at Norfolk to as high as 9.6 feet NGVD at Washington, D.C. In addition to flooding damage, the high winds associated with this storm generated very destructive waves which caused extensive shoreline erosion.

Shown in Table 3 is an estimate of the damages that were caused by the four most damaging storms that have passed through the Bay Region. The estimates reflect the actual physical damages that occurred, updated to reflect 1979 price levels. They do not include allowances for development that has taken place in the flood plain since the storm occurred.

SELECTION OF COMMUNITIES FOR DETAILED STUDY

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 initial step in the analysis was to identify all Bay communities with a population of 1,000 or greater that are located either in total or in part within the Standard Project Tidal Flood (SPTF) Plain. The Standard Project Tidal Flood is defined as the largest tidal flood that is 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 U.S. Weather Bureau (now the National Weather Service) determined that, for the Chesapeake Bay Region, the SPTF would average approximately 13 feet above National Geodetic Vertical Datum (NGVD). The above figure is a static or standing water surface elevation which would occur in conjunction with an astronomical high tide and does not include the effects of waves. Wave heights are dependent upon wind speed and direction, depth of water, fetch (the distance the wind blows over the water in generating the waves) and the length of time the wind blows. Assuming average values for water depth and fetch and superimposing winds characteristic of a hurricane that would produce a tidal surge of 13 feet above NGVD, wave heights on the Bay could be 5 feet. Based on the above combination of tidal surge and wave action the SPTF would inundate all areas up to approximately 18 feet above NGVD. Because average conditions were used in determining the SPTF elevation and for ease in delineating the flooded area, an elevation of 20 feet NGVD was assumed for purposes of the analysis.

The next step in the flooding analysis was to identify those communities that should be classified as "flood-prone." In order for a community to be designated as flood-prone, 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 Bay Region communities indentified as flood-prone are shown in Table 4. Approximately 82,000 acres of land in these communities were located in the Standard Project Tidal Flood Plain.

The last step in the initial screening process was to determine those communities considered to be "critically" flood-prone. The flood problem was considered to be "critical" if 25 acres or more of intensively developed land were inundated by the 100-year flood. Those communities found to be "critical" based on the above criteria are marked with an asterisk in Table 4. It should be noted that the elevations used for the 100-year flood were approximated based on the best available historical information.

During the preparation of the *Revised Plan of Study*, a further screening of those critical communities listed in Table 4 was conducted. This screening eliminated those communities where it was evident that flood protection would not be acceptable to the community. This determination was based on the fact that many strictly residential communities are located along the Bay's shoreline for aesthetic as well as recreational reasons and 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 environment. In these communities, the expressed concern is related to the erosion of land that takes place during tidal storms, instead of the damages that result from temporary inundation of house and property. Application of nonstructural solutions in these same areas, such as floodproofing and relocation, is also inappropriate. Many of the structures are old and not suitable for major floodproofing modifications. Furthermore, these areas were established adjacent to the shoreline to take advantage of the resource, thus making relocation unacceptable.

Based on the above considerations, the communities recommended for detailed study in the *Revised Plan of Study* were limited to those listed in Table 5. All of the recommended communities were considered to have highly developed flood-prone areas where the potential existed for providing some form of flood protection. The *Revised Plan of Study* further recommended that Stage II Studies be conducted and that they concentrate on refinement of environmental, economic, social and hydrologic data and the formulation and evaluation of various flood damage reduction measures.

With the approval of the *Revised Plan of Study*, Stage II studies were initiated for the communities listed in Table 5. As a result of these initial studies several additional communities were eliminated from further consideration. Smith Island, Maryland, and Colonial Beach and Virginia Beach, Virginia, were eliminated as detailed studies of these communities were being conducted under specific study resolutions and any further effort under the Chesapeake Bay Program would have been duplicative. Denton and Salisbury, Maryland, were both eliminated when preliminary stage-damage surveys and more detailed mapping and 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.

Last and most significantly, Baltimore City and the Dundalk area of Baltimore County were also eliminated after preliminary damage surveys and an evaluation of several structural and nonstructural measures. These preliminary evaluations indicated that both structural and nonstructural measures that would provide flood protection for the most flood-prone sections of these two areas would have benefit-cost ratios on the order of only 0.1. These evaluations confirmed the findings of the Baltimore District's Baltimore Metropolitan Flood Study.

TABLE 5

***CRITICAL COMMUNITIES RECOMMENDED FOR DETAILED STUDY (In the* Revised Plan of Study)**

STATE OF MARYLAND

Baltimore County Dundalk (including Sparrows Pt.)	*Somerset County* Crisfield Smith Island
Baltimore City	*Talbot County* St. Michaels Tilghman Island
Caroline County Denton	*Wicomico County* Salisbury
Dorchester County Cambridge	*Worcester County* Pocomoke City Snow Hill
Kent County Rock Hall	

COMMONWEALTH OF VIRGINIA

Independent Cities Chesapeake Fredericksburg Hampton Norfolk Portsmouth	*King William County* West Point *Northampton County* Cape Charles
Accomack County Tangier Island	*Westmoreland County* Colonial Beach *York County* Poquoson

As a result of this screening process, communities were selected for detailed study and are listed by state in Table 6. Because of the areal expanse of the Bay Region, and because of the jurisdictional location of these communities, the Baltimore District, Corps of Engineers requested the Norfolk District to conduct the detailed tidal flooding analyses in the Commonwealth of Virginia while the Baltimore District investigated the Maryland communities. Figure 4 indicates the general location of these communities along the Bay Estuary.

Detailed flood damage surveys were conducted in 1979 in these flood-prone communities. Following the completion of preliminary alternative analyses and other environmental and socio-economic studies, a report was prepared in August

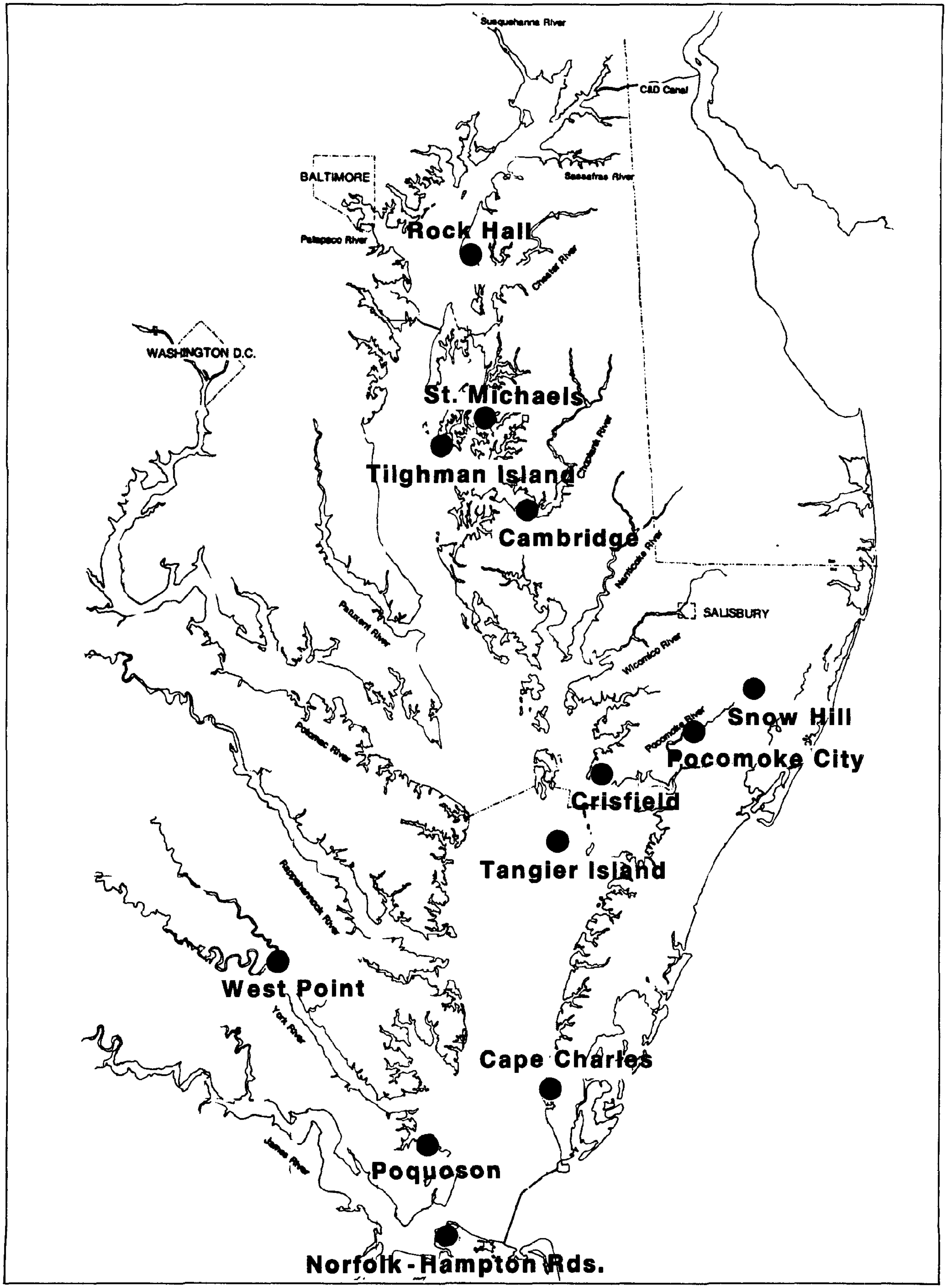


Figure 4 Critical Flood-Prone Communities

TABLE 6

TIDAL FLOOD-PRONE COMMUNITIES EXAMINED

MARYLAND	*VIRGINIA*
Cambridge	Cape Charles
Crisfield	Hampton Roads[1]
Pocomoke City	Poquoson
Rock Hall	West Point
Snow Hill	Tangier Island
St. Michaels	
Tilghman Island	

[1]The Hampton Roads designation includes the cities of Chesapeake, Hampton, Norfolk, and Portsmouth, Virginia.

1980. Based on the findings it was recommended that more detailed studies of several selected communities and the development of Baywide stage-frequency relationships be continued. A Technical Studies Work Plan detailing the stage-frequency related work was prepared and approved. In 1981 work was initiated on the stage-frequency analyses and the support storm surge test was conducted on the hydraulic model in 1982. This test consisted of obtaining surface water elevations throughout the Bay resulting from the ocean tide, a surge wave, a combination of the above two, and fluvial discharge. The results of this test were to be used to adjust and calibrate a numerical storm surge model being developed by the Waterways Experiment Station.

During the development of the Fiscal Year 1984 budget, the decision was made that the Chesapeake Bay Model should be closed and that the study should be completed by the end of Fiscal Year 1984. Because of this, a number of significant modifications were made to the program. The storm surge numerical modeling effort was deleted from the program and all feasibility analyses were based on existing available flood stage-frequency information rather than the refined data expected from the numerical modeling effort.

The major effort remaining on the Tidal Flooding Study consisted of reviewing and revising the 1980 report based on updated information when available. In an effort to verify that the results of the analyses conducted in the 1978-1980 period were still valid, field checks of the damage surveys for each of the 12 critically flood-prone communities were done in the summer and fall of 1983.

PROFILES OF FLOOD-PRONE COMMUNITIES

Cambridge, Maryland

Cambridge is located in Dorchester County in the central part of Maryland's Eastern Shore on the Choptank River: the boundary between Dorchester and Talbot Counties. Elevations in the community range from zero to 30 feet NGVD. Cambridge supports a variable oyster fishery during the fall and winter, and a blue crab fishery during the summer and fall. The Choptank River is one of the more important waterfowl areas in the Upper Chesapeake and supports large populations of several varieties of ducks and geese.

Cambridge had a 1970 population of 11,595 which represented a 5.2 percent decrease from 1960 population totals. The overwhelming majority of industrial employment in Cambridge was in the Manufacturing Sector (39.7 percent) followed by the Wholesale and Retail Trade Sector (17.1 percent). Unemployment in 1970 was approximately five percent.

There are an estimated 3,400 acres within the community of Cambridge. The 100-year flood hazard zone (5.9′ NGVD) covers about 70 acres of the community. Of this area, 76 percent (53 acres) is currently developed. The 500-year flood hazard zone (7.5′ NGVD) covers about 139 acres. Of this amount 88 percent (122 acres) is currently developed.

The Cambridge flood plain is mainly residential in character with the non-residential development located primarily on the waterfront. Table 7 summarizes the type of development in various flood hazard zones. About 80 percent of the structures in the flood plain are residential.

Crisfield, Maryland

Crisfield is the southern most city in Maryland. It is located in Somerset County on the Little Annemessex River, just off Tangier Sound. Elevations in Crisfield range from zero to about 10 feet NGVD. Crisfield abounds with fish and wildlife including waterfowl, rodents, deer, fox, and other species. The grassy water areas in and around Crisfield are important nursery areas for fingerling fish and shellfish.

In 1970, Crisfield had a population of 3,075 with more than 50 percent 35 years of age or older. Population has been declining in this area for several decades. Most of the labor force in the Crisfield area is employed in the Wholesale and Retail Trade sector, the Operatives sector, and the Manufacturing sector. Unemployment in Crisfield is typically above the State average.

The community of Crisfield is approximately 2,100 acres in size and approximately 50 percent of the community is subject to tidal flooding. The community may be subjected to high velocity flooding as a result of the direct assault of waves. With the presence of a major Bay harbor in Crisfield, there is the potential for high debris content in flood waters if boats break loose or if waterfront structures are battered by waves in a major storm.

The 100-year flood hazard zone (5.1′ NGVD) covers about 938 acres of the community. Of this area 73 percent (683 acres) is currently developed. The 500-year flood hazard zone (6.1′ NGVD) covers about 1,283 acres. Of this amount 71 percent (913 acres) is currently developed. The Crisfield flood plain is primarily residential in character with some non-residential development. Table 8 summarizes the type of development in various flood hazard zones. About 85 percent of the structures in the flood plain are residential.

Pocomoke City, Maryland

Located on the Pocomoke River, Pocomoke City is situated in the southwest portion of Worcester County about five miles from the Virginia border. Elevations in Pocomoke City range from about zero NGVD to almost 30 feet above NGVD. Temperatures in the area range from a low of 38 degrees (F) in January to a high of nearly 77 degrees (F) in July. Precipitation averages about 29 inches annually. The Pocomoke River and adjacent wetland areas provide an excellent habitat for numerous waterfowl, wildlife and fish species. Unique to the region are several cypress swamps

TABLE 7

CAMBRIDGE FLOOD PLAIN INVENTORY
(April 1980 Prices)

STAGE (NGVD)	APPROXIMATE FLOOD HAZARD ZONE	NUMBER OF STRUCTURES					AVERAGE ANNUAL DAMAGES
		RESIDENTIAL	COMMERCIAL	INDUSTRIAL	PUBLIC & OTHER	TOTAL	
4 feet	12 year (8.2%)	0	2	2	0	4	$4,000
6 feet	120 year (0.82%)	60	14	2	0	76	$12,000
8 feet	500 year (0.20%)	139	29	3	0	171	$15,000
18 feet	SPTF	359	50	3	0	412	$19,000

TABLE 8

CRISFIELD FLOOD PLAIN INVENTORY
(April 1980 Prices)

STAGE (NGVD)	APPROXIMATE FLOOD HAZARD ZONE	NUMBER OF STRUCTURES					AVERAGE ANNUAL DAMAGES
		RESIDENTIAL	COMMERCIAL	INDUSTRIAL	PUBLIC & OTHER	TOTAL	
4 feet	12 year (8.2%)	57	69	0	3	129	$40,000
5 feet	80 year (1.2%)	564	162	3	13	742	$102,000
6 feet	400 year (0.25%)	1,133	193	4	18	1,348	$129,000
12 feet	500 year (0.20%)	1,679	208	4	31	1,922	$146,000

TABLE 9

POCOMOKE CITY FLOOD PLAIN INVENTORY
(April 1980 Prices)

STAGE (NGVD)	APPROXIMATE FLOOD HAZARD ZONE	NUMBER OF STRUCTURES					AVERAGE ANNUAL DAMAGES
		RESIDENTIAL	COMMERCIAL	INDUSTRIAL	PUBLIC & OTHER	TOTAL	
4 feet	8 year (12%)	2	1	0	0	3	$5,000
5 feet	25 year (4%)	16	4	1	0	21	$8,000
6 feet	70 year (1.4%)	43	8	1	0	52	$12,000
8 feet	500 year (0.20%)	125	30	2	1	178	$20,000
18 feet	SPTF	597	103	3	18	721	$25,000

located along the river. Pocomoke City's 1970 population of 3,573 was a 7.3 percent increase over the 1960 total of 3,329. Pocomoke City is one of the older communities in the State with a median age of 34.5 years compared to the State median age of 27.1 years. Approximately 26 percent of the work force was in the Sales and Clerical category with 27 percent of the industrial employment in the Wholesale and Retail Trade sector. Unemployment in 1970 was relatively low at 4.7 percent of the work force.

There are an estimated 1,080 acres within the community of Pocomoke City. Pocomoke City is subject to tidal flooding from the Pocomoke River. The 100-year flood hazard zone (6.3′ NGVD) covers about 81 acres of the community. All of this area is currently developed. The 500-year flood hazard zone (7.8′ NGVD) covers about 171 acres of which 84 percent (144 acres) is currently developed.

The Pocomoke City flood plain is primarily residential in character with large amounts of non-residential development. Table 9 summarizes the type of development in various flood hazard zones. About 80 percent of the structures in the flood plain are residential.

Rock Hall, Maryland

Rock Hall is located in the southwestern portion of Kent County. Elevations in Rock Hall vary from zero to 25 feet above NGVD. The average summer temperature in the area is approximately 75 degrees (F) and in the winter temperature averages 36 degrees (F). Precipitation in this portion of the Eastern Shore averages about 43 inches per year. Because of water quality problems in several areas around Rock Hall, the biota is rather restricted. Rock Hall is a nursery area for finfish with the saltmarshes on the inside of the breakwaters serving this purpose. Geese and swans constitute almost 90 percent of the waterfowl in the Chester River while ducks account for the remainder.

TABLE 10

ROCK HALL FLOOD PLAIN INVENTORY
(April 1980 Prices)

STAGE (NGVD)	APPROXIMATE FLOOD HAZARD ZONE	NUMBER OF STRUCTURES					AVERAGE ANNUAL DAMAGES
		RESIDENTIAL	COMMERCIAL	INDUSTRIAL	PUBLIC & OTHER	TOTAL	
4 feet	8 year (12%)	29	5	1	0	35	$3,000
6 feet	25 year (4%)	143	17	6	0	166	$17,000
9 feet	140 year (0.7%)	317	22	7	0	346	$47,000
12 feet	500 year (0.2%)	423	24	7	1	455	$63,000
18 feet	SPTF	613	44	8	8	673	$76,000

TABLE 11

SNOW HILL FLOOD PLAIN INVENTORY
(April 1980 Prices)

STAGE (NGVD)	APPROXIMATE FLOOD HAZARD ZONE	NUMBER OF STRUCTURES					AVERAGE ANNUAL DAMAGES
		RESIDENTIAL	COMMERCIAL	INDUSTRIAL	PUBLIC & OTHER	TOTAL	
4 feet	8 year (12%)	1	2	0	0	3	$300
5 feet	25 year (4%)	4	8	1	0	13	$3,000
6 feet	70 year (1.4%)	13	14	1	0	28	$5,000
8 feet	500 year (0.20%)	62	22	3	1	88	$9,000
18 feet	SPTF	414	62	5	14	495	$11,000

TABLE 12

ST. MICHAELS FLOOD PLAIN INVENTORY
(April 1980 Prices)

STAGE (NGVD)	APPROXIMATE FLOOD HAZARD ZONE	NUMBER OF STRUCTURES					AVERAGE ANNUAL DAMAGES
		RESIDENTIAL	COMMERCIAL	INDUSTRIAL	PUBLIC & OTHER	TOTAL	
4 feet	10 year (10%)	1	2	1	9	4	$4,000
5 feet	20 year (5%)	3	2	1	9	7	$6,000
7 feet	100 year (1%)	55	5	5	2	67	$10,000
9 feet	450 year (0.22%)	255	49	6	5	315	$17,000
16 feet	SPTF	713	78	10	12	813	$27,000

TABLE 13

TILGHMAN FLOOD PLAIN INVENTORY
(April 1980 Prices)

STAGE (NGVD)	APPROXIMATE FLOOD HAZARD ZONE	NUMBER OF STRUCTURES					AVERAGE ANNUAL DAMAGES
		RESIDENTIAL	COMMERCIAL	INDUSTRIAL	PUBLIC & OTHER	TOTAL	
4 feet	15 year (6%)	47	4	2	1	55	$8,000
5 feet	40 year (2.5%)	99	10	2	1	112	$15,000
6 feet	90 year (1.1%)	167	11	3	1	182	$21,000
8 feet	500 year (0.20%)	273	13	3	2	293	$31,000
15 feet	SPTF	446	22	4	8	480	$36,000

Population in the Rock Hall area reached 1,101 in 1970 which was a 2.6 percent increase over the 1960 total of 1,073. The median age of 34.9 years also places Rock Hall among the older communities when compared to the State median of 27.1 years. The majority of employment in the area occurs in the Wholesale and Retail Trade sector, followed by the Construction and Manufacturing sectors.

Rock Hall is approximately 860 acres in size and is subject to the tidal flooding of the Chesapeake Bay. The community may be subject to water of high velocity as a result of the direct assault of waves. With the presence of a major Bay harbor in Rock Hall, there is a potential for high debris content in flood waters if boats break loose in a major storm.

The 100-year flood zone (8.7′ NGVD) covers about 466 acres of the community. Of this area 57 percent (266 acres) is currently developed. The 500-year flood hazard zone (11.5′ NGVD) covers about 529 acres. Of this amount 68 percent (329 acres) is currently developed.

The Rock Hall flood plain is mainly residential in character with the non-residential development oriented primarily toward the waterfront. Table 10 summarizes the types of development in the various flood hazard zones. About 90 percent of the structures in the flood plain are residential.

Snow Hill, Maryland

Snow Hill is located 30 miles upstream from the mouth of the Pocomoke River in central Worchester County. Elevations in the Snow Hill area range from zero to 25 feet above NGVD. The average summer temperature of the county is 74.8 degrees (F) while winter temperatures average 38.7 degrees (F). Precipitation in this part of the Eastern Shore averages about 29 inches annually. Biota in the area includes largemouth bass, black crappie, striped bass, branch herring, hickory shad, whiteshad, pickerel, and channel catfish. Puddle ducks use the area for nesting and feeding while wood ducks are also found in the area.

The 1970 population of Snow Hill was 2,201. This represented a 4.8 percent decrease over the 1960 total of 2,311. The median age of the Snow Hill population was 33.3 years which was significantly higher than the State median age of 27.1 years. A large portion of those employed in Snow Hill are in low-skilled, low income occupations such as the Operatives and the Sales and Clerical categories. A large portion of the work force is employed in the Manufacturing sector.

Snow Hill is approximately 750 acres in size and is subject to tidal flooding from the Pocomoke River. The 100-year flood hazard zone (6.3′ NGVD) covers about 92 acres of the community. Of this area 21 percent (19 acres) is currently developed. The 500-year flood hazard zone (7.8′ NGVD) covers about 141 acres. Of this amount 28 percent (39 acres) is currently developed. The Snow Hill flood plain is primarily non-residential in character. Table 11 summarizes the type of development in various flood hazard zones. About 45 percent of the structures in flood plains less than the 100-year flood plain are residential.

St. Michaels, Maryland

St. Michaels is located in the eastern part of Talbot County on the Miles River. Elevations in the St. Michaels area range from zero to 15 feet above NGVD. Because of its location in the middle latitudes, St. Michaels' climate is moderate. Summer temperatures average 75.2 degrees (F) while the winter season temperatures average 36.7 degrees (F). Precipitation in this area averages 41.7 inches annually.

Significant wildlife habitat is located in the areas adjacent to the more than 600 miles of county shoreline. Principal finfish species found in the waters around St. Michaels are striped bass, spot, weak fish, white and yellow perch. Oyster bars lie just outside the entrance to St. Michaels Harbor. Waterfowl in the area consist of puddle ducks, Canada geese, and whistling swans. Osprey are also known to utilize the area with mourning doves and woodcock among the migratory game birds.

St. Michaels 1970 population of 1,470 was a 0.9 percent decrease from the 1960 total of 1,484. The median age of the St. Michaels population was 35.8 years which was significantly higher than the State figure of 27.1 years. The majority of industrial employment in St. Michaels is the Manufacturing and Wholesale and Retail Trade sectors. Unemployment in St. Michaels in 1970 was very low at only 2.9 percent of the work force.

St. Michaels is approximately 620 acres in size and is subject to tidal flooding from the Miles River. The 100-year flood hazard zone (7.2′ NGVD) covers about 73 acres of the community. One hundred percent of this area is currently developed. The 500-year flood hazard zone (9.2′ NGVD) covers about 292 acres. Of this amount 76 percent (222 acres) is currently developed.

The St. Michaels flood plain is mainly residential in character with the non-residential development located primarily on the waterfront and a main commercial street. Table 12 summarizes the type of development in various flood hazard zones. About 80 percent of the structures in the flood plain are residential.

Tilghman Island, Maryland

Tilghman Island, in Talbot County, Maryland, is about 3.5 miles long and 1 mile wide. It is separated from the mainland by Knapps Narrows. Elevations on Tilghman Island range from zero NGVD to approximately 10 feet above NGVD. Important commercial finfish species include striped bass, spot, weakfish, and white perch. The area also serves as an important concentration area for a great variety of waterfowl and supports the greatest local concentration of breeding black ducks in the region.

The 1970 census indicated that the population of Tilghman Island was 1,180. The median age of the population was 34.6 years reflecting a population older than the State median age of 27.1 years. Approximately 40 percent of the work force was employed in the Operatives category and at least 25 percent of the industrial workforce was employed in the Manufacturing sector.

The community of Tilghman is approximately 1,530 acres in size. Tilghman Island is subjected to tidal flooding from the Chesapeake Bay. The community may be subjected to high velocity flooding as a result of the direct assault of waves on development. With the presence of a major Bay harbor and waterfront development in Tilghman, there is the potential for high debris content in flood waters if the boats break loose in a major storm or if waterfront property is demolished. The 100-year flood hazard

TABLE 14

CAPE CHARLES AVERAGE ANNUAL DAMAGES
(January 1983 Price Levels)

Total Damage $1,000	*Flood Stage Elevation*	*Probability in Years*	*Interval*	*Average Interval*	*Annual Loss to Stage Noted*
11,753.00	12.00	*0.00*			*$37,423*
5,247.00	10.00	*1,000.00*	*0.100*	*$8,500*	*28,923*
2,748.00	9.00	*300.00*	*0.233*	*9,328*	*19,595*
610.00	8.00	*100.00*	*0.667*	*11,193*	*8,402*
238.00	7.40	*50.00*	*1.000*	*4,240*	*4,162*
131.00	7.00	*35.00*	*0.857*	*1,581*	*2,581*
40.00	6.50	*20.00*	*2.143*	*1,832*	*748*
4.00	6.00	*12.00*	*3.333*	*733*	*15*
0.00	5.90	*11.00*	*0.758*	*15*	*$0*

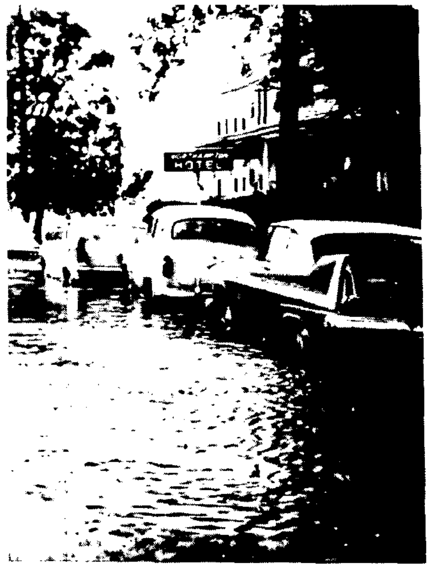


FIGURE 5 CAPE CHARLESFLOOD SCENE SEPTEMBER 1960 HURRICANE

zone (6.1′ NGVD) covers about 1,108 acres of the community. Of this area 21 percent (236 acres) is currently developed. The 500-year flood hazard zone (7.9′ NGVD) covers about 1,397 acres. Of this amount 25 percent (355 acres) is currently developed.

The Tilghman Island flood plain is primarily residential in character with the non-residential development oriented toward the waterfront. Table 13 summarizes the type of development in various flood hazard zones. About 90 percent of the structures in the flood plain are residential.

Cape Charles, Virginia

Cape Charles is an incorporated town located in Northampton County on the western shore of the Delmarva Peninsula approximately 11 miles from the entrance of Chesapeake Bay. The area is relatively flat with elevations ranging from zero to 12 feet NGVD with most below eight feet. Cape Charles is the largest town in the county in both land area and population. Most of the development in Cape Charles has taken place on the low ground near the water's edge. Almost the entire town is below the level of the standard project tidal flood which is at elevation 12 feet NGVD. A field survey performed for this community included an inventory of 538 structures. Of this total, 445 were residential, 85 were commercial; and eight were public structures. Average annual damage estimates are presented in Table 14. The area has a temperate climate, with a 30-year average annual temperature of 57.8 degrees (F). Precipitation averages 42 inches annually with the heaviest rainfall occurring between June and September.

Several salt marsh habitats are located in the vicinity of Cape Charles. The waters in the area are highly productive and contain a variety of living natural resources of commercial and recreational importance. The surrounding land includes agricultural fields, natural woodlands, a golf course, and a limited amount of residential, municipal, and industrial development beyond the immediate Cape Charles vicinity.

Cape Charles' 1980 population of 1,512 represents about 10 percent of the County population. The town's economy is based on farming, fishing, some tourism, and light industry. The greatest amount of manufacturing or industrial employment is in fish and shellfish harvesting. According to the National Marine Fisheries Service (NMFS), over 50 percent of Virginia's total surf clam landings were from Northampton County. Retail Trade and Services are the two other large employment sectors.

The 100-year tidal flood stage is esti- would be inundated by the 100-year stage still water level. Wave action would raise the stage by four feet. Storm tides have penetrated several blocks into the developed sections of the town on a number of occasions. The water level of the 1933 storm reached a maximum elevation of 7.0 feet in Cape Charles. The tidal surge created by the northeaster of May 1962 reached an elevation of 7.2 feet. Figure 5 shows flooding in Cape Charles resulting from the September 1960 hurricane while Figure 6 presents views of the bulkhead and beach areas immediately after the March 1962 storm and after emergency restoration.

Hampton Roads, Virginia

The Hampton Roads region of Virginia represents a multiple city complex in southeastern Virginia centered about Hampton Roads Harbor. This harbor is surrounded by the largest urban population concentration in Virginia. As one of the finest harbor complexes in the United States, the area contains two major railroad terminals, shipbuilding and drydock installations, military bases, industrial companies, several deep water terminals for shipping and unloading cargo, and various other supportive enterprises for a major harbor. Terminals are serviced by an extensive rail-

Cape Charles Beach and Promenade following March 1962 Storm

Cape Charles Beach and Promenade after Emergency Retoration

FIGURE 6 BEACH, BULKHEAD AND PROMENADE AT CAPE CHARLES — MARCH 1962 STORM

road and trucking system for inland transport.

The shorelands of Chesapeake, Norfolk, and Portsmouth have elevations less than 20 feet, of which 75 percent is classified as low shore (20 ft. or less of relief) and 25 percent being artificial fill (Owen, et al., 1976). The artificial fill is associated with the various large docking facilities and the Craney Island Disposal Area which is located at the entrance of the Elizabeth River. Owen, et al. (1966) characterizes the shoreline as being 38 percent artificially stabilized, but includes in his figures a stabilized portion of the Norfolk beach area outside the harbor entrance along the low Chesapeake Bay. However, a high percentage of stabilized and/or bulkheaded shoreline frontage is found within Hampton Roads Harbor, especially in the industrialized and downtown areas of Norfolk and Portsmouth.

Along the north shore of Hampton Roads is the city of Hampton with a land area of 55 square miles and an inland water area of 17.3 square miles. Hampton is boardered along its western side by the city of Newport News and to the east by the Chesapeake Bay. Several small creeks and the Hampton River enter Hampton Roads from the city's shoreline. Thirty-five percent of Hampton's entire shoreline has bulkheads or seawalls. Combinations of shore protective structures including riprap, groins, and bulkheaded property are common along the shoreline.

Existing marshes within the Hampton Roads complex are predominantly composed of salt marsh cordgrass (*Spartina alterniflora*), salt grass (*Distichlis spicata*) and other wetlands flora to a lesser degree. A variety of small mammals may be found associated with the wetland sites. These areas will also have significant populations of resident and migratory waterfowl and other birds. Population densities vary and become more diversified where marshes are bordered by undisturbed woodland sections. The marshes and adjacent sand (and mud) flat areas also contain a variety of invertebrate types, including shellfish. A variety of fish are also present.

The ports of Hampton Roads and the services and activities associated with them have a profound influence on the area's economy. Hampton Roads is the leader in export tonnage and second only to the port of New York in export-import tonnage in the United States. The value of these exports increased from $1.8 billion in 1970 to $8.85 billion in 1981.

The greatest increases in population are anticipated for Chesapeake and Virginia Beach. Based on census data for 1970 and 1980, Chesapeake grew by 27.8 percent and Virginia Beach grew by 52.3 percent. By comparison, Hampton grew by only 1.5 percent while Norfolk and Portsmouth both lost residents. The Virginia Department of Planning and Budget expects the study area to grow by 44.7 percent from 1980-2030 while Chesapeake and Virginia Beach are expected to grow 81.3 percent and 122.7 percent, respectively, during the same period.

Historical unemployment rates in the study area have remained below U.S. levels. In 1982, the rate was 6.6 percent for the Norfolk-Virginia Beach-Portsmouth SMSA and 7.2 percent for the Newport News-Hampton SMSA. Employment within the area is related to the major economic activities of the two SMSA's. These will continue to be port, military/Federal government, and manufacturing operations. Also the services industry is expected to experience the most growth in the period 1980 to 2030.

Norfolk

Norfolk is located on the south shore of Hampton Roads and Chesapeake Bay. It is bound by water on three sides and is penetrated by smaller estuaries making interior areas vulnerable to tidal flooding.

Approximately 75 percent of the land in Norfolk is below elevation 13.0 (the standard project flood) and 20 percent is below elevation 9.0. Minor flooding up to elevations of four to five feet is associated with periods of moderately high sustained winds from the northeast, north, and northwest and may be experienced several times within any one year. Flooding of this magnitude is not serious and goes unnoticed except for the temporary difficulties which may be experienced by the boating interests due to rough seas. The main source of concern is the large and infrequent floods which are associated with major storm events such as hurricanes or severe northeaster-type storms. Storm surges which, together with the normal astronomical tide, produce elevations of six feet or higher cause widespread flooding in the city. Wave action has been responsible for most of the structural damage along the shore front.

The disastrous hurricane of 23 August 1933 inundated about 600 acres in the downtown Norfolk area. The greatest concentration of damage occurred in the Central Business District where 52 acres, containing streets, stores, and business offices were flooded from 1 to 4.5 feet by salt water, polluted by industrial and sanitary wastes. High water blocked practically all movement to and from the central business district. Other sections of the downtown area flooded included 150 acres in the Hague area, 140 acres in th Tidewater Drive area, and 72 acres in the waterfront area. The exposed beach resorts of Willoughby and Ocean View felt the full fury of the storm.

During the March 1962 northeaster, more than 1,000 persons were evacuated from the area along Chesapeake Bay. A few were also evacuated from other areas. The flow of automobile traffic was impeded by the flooding of streets, including access roads to tunnels. A photograph of one of the many areas flooded during the March 1962 storm is shown in Figure 7. In Norfolk there are numerous other areas that experience occasional flooding. These areas lie along rivers and creeks and are scattered throughout the city. There is no plan to eliminate this situation that would be economically feasible.

Portsmouth

Portsmouth is located near the confluence of the Western and Southern Branches of the Elizabeth River tidal estuary. Forming a part of the greater Hampton Roads Harbor, Portsmouth is a major port of call for oceangoing vessels.

Typical of Virginia's coastal plain, the topography of Portsmouth is flat and featureless with land elevations seldom exceeding 15 feet above NGVD. While some developments on the flood plain are more susceptible to flood damage than others, experiences gained particularly in the March 1962 northeaster storm and the August 1933 hurricane, have shown that the flood problem is serious and that damage can be widespread throughout the city. The August 1933 hurricane produced flooding to elevation eight throughout most of the city.

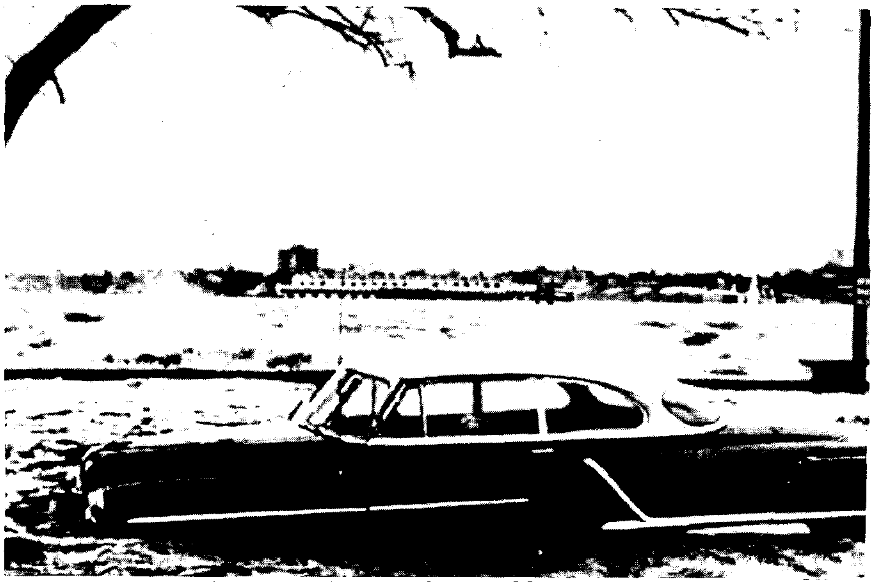
FIGURE 7 FLOOD SCENE, MARCH 1962 "NORTHEASTER" AT NORFOLK, VIRGINIA

Damage during smaller floods under elevation five is confined to streets. Resulting traffic problems are created. Also, there would be some minor flooding of other low-lying property. However, between elevations 5 and 10, there are large concentrations of commercial, residential, and industrial buildings. It is within this zone that serious flood damage has been suffered during past tidal floods and where the potential exists for even greater loss in future floods.

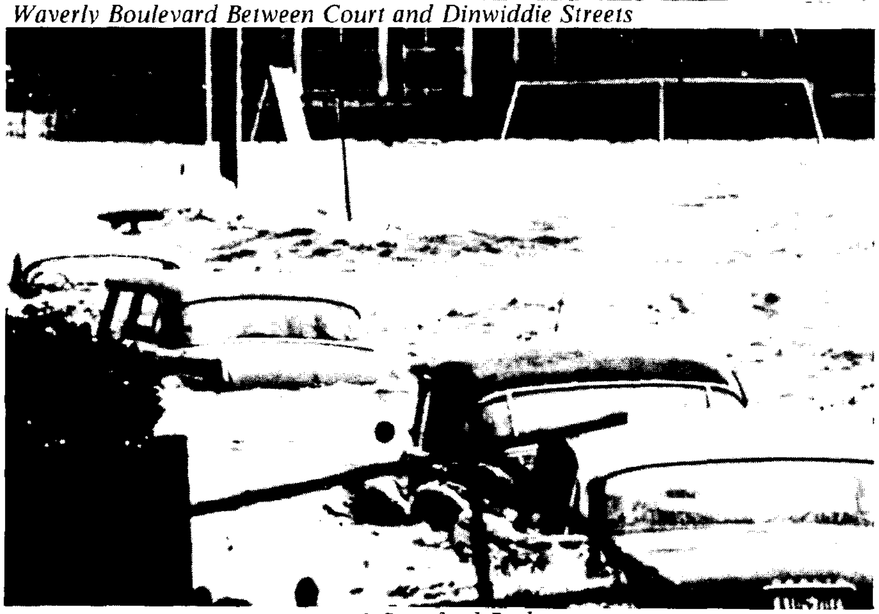
The city sustained a great deal of damage during the 1962 northeaster, primarily from flooding in several low areas bordering on the Elizabeth River and Southern Branch. Three hundred and twenty houses and 20 commercial and industrial businesses received damage in various degrees from flooding to a depth of water as much as 4-½ feet. One thousand automobiles were inundated. Federal, state, and local agencies were active during the emergency and in removing debris after the water subsided. Emergency operations consisted mainly in evacuating children and other personnel from the school at 5th and Jefferson Streets. Also, many persons including entire families, were evacuated from their homes on First and Second Streets. A number of roads were rendered impassable for 2 days. Telephone and electric power services were disrupted. Along the Western Branch of Elizabeth River, much of the damage was sustained by boats and facilities. Several homes and businesses were flooded and one industry suffered additional loss from having to suspend operations for the duration of the storm. Flood scenes typical of the March 1962 northeaster in Portsmouth are shown in Figure 8. The August 1933 storm caused extensive damage, inundating hundreds of acres of the city including downtown commercial and industrial areas as well as residential areas.

Since then, the City of Portsmouth has closed streets, raised roads, and constructed a floodwall that extends for a distance of 3,500 feet along the waterfront. The floodwall does provide some protection to the downtown area. Surface drainage behind the protective works includes a number of openings through the wall which have been provided with flap gates. However, there are questions as to whether the flap gates in the floodwall would perform as designed during a major tidal storm.

During discussions with the superintendent of surveys in Portsmouth, one problem area was discovered. It is landward of Crawford Bay where many homes have been restored. The concrete



Waverly Boulevard Between Court and Dinwiddie Streets



Corner of Washington Street and Crawford Parkway

FIGURE 8 FLOOD SCENES, MARCH 1962 "NORTHEASTER" AT PORTSMOUTH, VIRGINIA

bulkhead here is below elevation six. The city also has a problem with sand depositing in Crawford Bay which blocks the drainage outlets and must be dredged periodically.

Chesapeake

The topography of Chesapeake is typical of the flat Tidewater coastal plain in which the city is located. Development consists generally of residences along the northern boundary and is a continuation of the urban growth of the cities of Norfolk and Portsmouth.

Flooding of that portion of the city affected by the level of water in Chesapeake Bay occurs as a result of high water in the Elizabeth River and its Southern and Western Branches. Storm surges, which together with the normal lunar tide produce a water level of elevation five or higher in the northern section of the city, cause widespread flooding and produce damage. Floods this high and higher have occurred many times in the past. Also most major roads and bridges would have areas wherein flooding will occur during both the intermediate regional tidal flood (100-year, elevation 8.5), and standard project tidal flood (elevation 13).

High tides during the March 1962 storm entered into the Eastern and Southern Branches of Elizabeth River in Chesapeake. No mass evacuation of people was required. However, many were forced to abandon their homes and businesses to avoid the high water.

Hampton

Hampton is located on the shores of Hampton Roads and Chesapeake Bay. Much of the land is below elevation 10 and there are developments in areas as low as elevation five. Generally, the ter rain slopes fairly uniformly from the higher elevations to sea level. There are no protective barriers such as sand of elevation five or higher, cause widespread flooding in the city. Many times in surrounding water areas. Consequently, an increase in the level of Chesapeake Bay and other bodies of water (which practically encompass the city) cause flooding of land masses to the same level.

More than two-thirds of the land area of the city would be inundated by the standard project tidal flood (elevation 13) and approximately one quarter of the land area would be inundated by the 100-year tidal flood (elevation 8.5). It is estimated that about 20,000 people are located within the area affected by the latter flood. The Federal Emergency Management Agency has conducted a wave height study for Hampton. Wave heights that can be expected with the 100-year flood on both the Chesapeake Bay and the Hampton Roads sides would reach elevation 13.

The main source of concern is the large and infrequent floods which are associated with major storm events such as hurricanes and severe northeast storms. Storm surges which, together with the normal lunar tide, produce water levels of elevation five or higher, cause widespread flooding in the city. Many times in the past, the city has been essentially paralized with practically all normal functions within the area brought to a standstill because of such flooding. An important factor to shorefront areas is that high water is generally associated with high waves which have inflicted structural damage to shorefront structures and eroded sand and other mate-

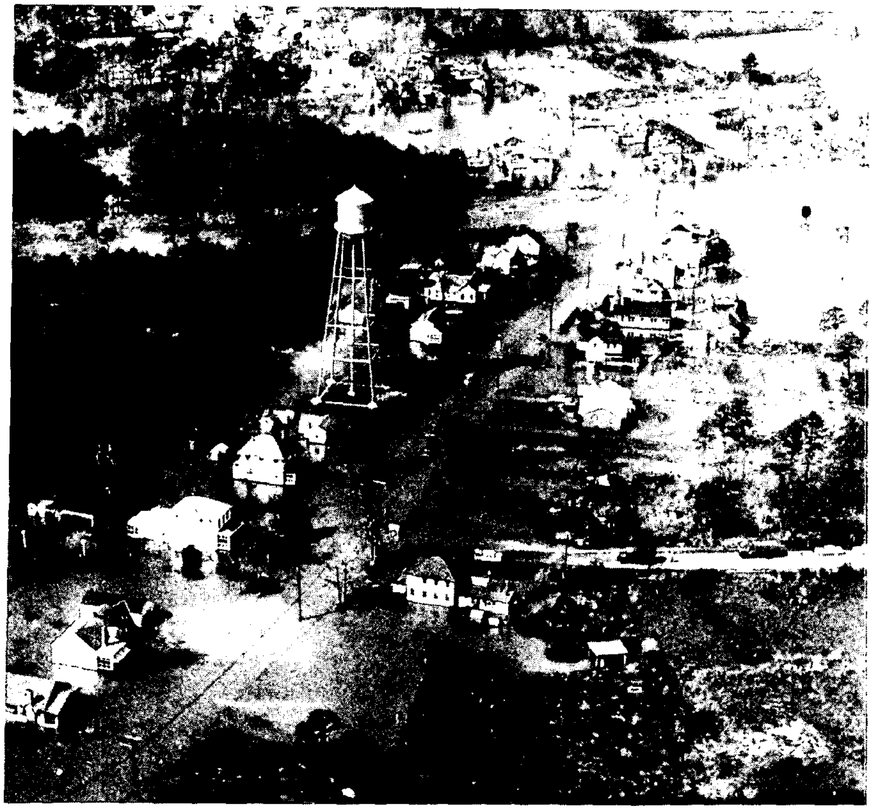


FIGURE 9 FLOODING IN HAMPTON-FOX HILL SECTION, MARCH 1962

TABLE 15

HAMPTON-FOX HILL AREA AVERAGE ANNUAL DAMAGES (January 1983 Price Levels)

Total Damage $1,000	*Flood Stage Elevation*	*Probability In Years*	*Interval*	*Average Interval*	*Annual Loss To Stage Noted*
1,805.10	11.00	0			*$100,098*
1,702.80	10.50	1,000.00	0.100	$1,754	*98,344*
1,583.80	10.00	600.00	0.067	1,096	*97,249*
1,532.50	9.80	500.00	0.033	519	*96,729*
1,271.70	9.00	180.00	0.356	4,985	*91,744*
1,093.00	8.50	100.00	0.444	5,255	*86,489*
903.50	8.00	60.00	0.667	6,655	*79,834*
544.10	7.00	26.00	2.179	15,775	*64,059*
514.80	6.90	25.00	0.154	815	*63,245*
256.90	6.00	12.00	4.333	16,720	*46,524*
75.60	5.00	4.60	13.406	22,287	*24,237*
3.10	4.00	1.20	61.594	$24.237	*$0*

rial from the beaches. Figure 9 shows flooding that occurred in theHampton-Fox Hill area as a result of the March 1962 northeaster.

One area typical of Fox Hill was selected for analysis. The data for the 61 structures located in this area were evaluated through the use of a computer program and stage-damages were determined for existing conditions. These figures were updated to January 1983 price levels. The damage-frequency relationship was based on the stage-damage curve compiled for the area and the stage-frequency curve presented in Appendix E — *Engineering Design and Cost Estimates*. The resultant average annual damages up to any tidal flood stage are presented in Table 15.

Poquoson, Virginia

The City of Poquoson is located on the western shore of Chesapeake Bay in the area known as the Lower Peninsula of Virginia. The city is bounded on the north by the Poquoson River, a tidal inlet of Chesapeake Bay. There are numerous creeks along the northern shoreline, with Bennett Creek being the largest and most significant harbor. The eastern shore is bounded by a tidal marsh bordering the Chesapeake Bay. This marsh, referred to as Plum Tree Island is about 1.1 miles wide and has ground elevations of less than five feet. On the south, the city is bounded by Back River and its Northwest Branch. The mean range of tide is 2.4 feet.

The city is typical of most coastal communities in that practically all of the existing development has taken place on the low ground near the edge of the water. Three-fifths of Poquoson is below elevation 5.0 including many developed areas. Eighty-five percent of the city is below elevation 7.0 which is the level of the 25-year flood, exclusive of wave action. There are no tidal flood protection measures in the city nor are there any dunes along the Poquoson shoreline.

Poquoson has been one of the fastest growing cities in the State, its population increasing from 4,278 in 1960 to 5,441 in 1970. The most recent census showed a 1980 population of 8,726. The city is primarily residential in character. Poquoson mainly serves as a residential base for citizens who commute to jobs in the nearby larger cities, military bases, and Government installations.

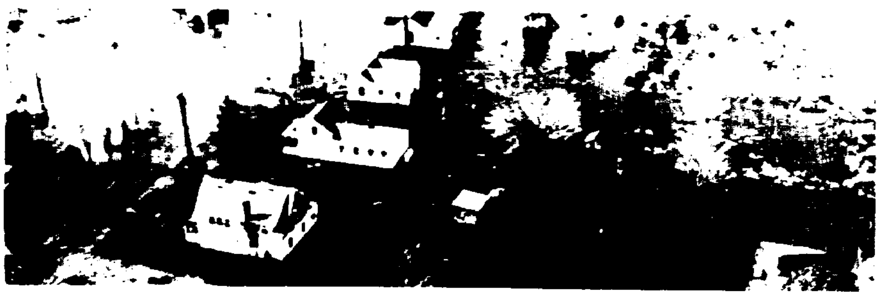


FIGURE 10 FLOOD SCENE OF MARCH 1962 "NORTHEASTER" AT POQUOSON, VIRGINIA

TABLE 16

POQUOSON AREA I
AVERAGE ANNUAL FLOOD DAMAGES
(January 1983 Price Levels)

Total Damage $1,000	Flood Stage	Probability In Years	Interval	Average Interval	Annual Loss To Stage Noted
588.10	11.00	0			$3,258
278.80	10.00	1,000.00	0.100	$433	2,824
257.40	9.80	500.00	0.100	268	2,556
167.10	9.00	175.00	0.371	788	1,768
79.20	8.50	100.00	0.429	528	1,240
27.30	8.00	60.00	0.667	355	885
17.00	7.00	25.00	2.333	517	368
0	6.00	12.00	4.333	$368	$0

TABLE 17

POQUOSON AREA II
AVERAGE ANNUAL FLOOD DAMAGES
(January 1983 Price Levels)

Total Damage $1,000	Flood Stage	Probability In Years	Interval	Average Interval	Annual Loss To Stage Noted
1,112.80	11.00	0			$15,021
867.60	10.00	1,000.00	0.100	$990	14,030
782.10	9.80	500.00	0.100	825	13,206
563.10	9.00	175.00	0.371	2,498	10,707
415.80	8.50	100.00	0.429	2,098	8,610
280.80	8.00	60.00	0.667	2,322	6,288
80.00	7.00	25.00	2.333	4,209	2,078
11.50	6.00	12.00	4.333	1,983	96
0	5.80	10.00	1.667	$96	$0

As previously stated, Poquoson is bordered by the Poquoson River to the north, the Plum Tree Island Wildlife Refuge to the east, and the Northwest Branch of the Back River to the south. This area contains numerous creeks, coves, and an extensive salt marsh. Beginning at Poquoson Shores at Hunts Neck, there is an extensive tidal flat with fringing marsh areas scattered along the shoreline. Scattered sandy beaches and occasional piers may be seen. This pattern extends into Roberts Creek where the prominent wetlands vegetation is saltmarsh cordgrass (*Spartina alterniflora*), saltmeadow hay (*Spartina patens*), and salt grass (*Distichlis spicata*).

Poquoson is bordered on the west by an extensive acreage of natural woodland. The city is scattered over a large area with no central core or city complex. This condition results in acreage of woodland and land in various types of agricultural use between parts of the city. However, the city is in a phase of burgeoning growth with numerous residential homes under construction throughout the city which infringe into the wooded sections. Of major significance is the Plum Tree Island Wildlife Refuge. Vast in size, this area is mainly salt marsh with stretches of well established pine growth on the higher ridges within the refuge.

Large sections of Poquoson have been subjected to tidal flooding in varying degrees of intensity many times in the past. Past flooding indicated by high water marks has been as high as elevation 9.0. Many developed areas are at elevation 5.0 or below. During periods of high tidal flooding, the shoreline is subject to wave action across the low marsh areas and shallow inlets and creeks.

The greatest known flood in the Poquoson area occurred in August 1933. It was the result of a hurricane which swept northward past Poquoson on a path along the axis of Chesapeake Bay. Maximum tide heights during this flood reached elevation 9.0, based on high water marks, with an average height of about 8.3.

Another great flood in March 1962, the result of a northeaster, was the second largest ever recorded at Poquoson. This flood, although the second largest in height of stage reached, was the most severe of record in terms of monetary damage along the Virginia coast.

TABLE 18

POQUOSON AREA III
AVERAGE ANNUAL FLOOD DAMAGES
(January 1983 Price Levels)

Total Damage $1,000	*Flood Stage*	*Probability In Years*	*Interval*	*Average Interval*	*Annual Loss To Stage Noted*
2,437.80	11.00	0			$66,477
2,142.80	10.00	1,000.00	0.100	$2,290	64,187
2,079.00	9.80	500.00	0.100	2,111	62,076
1,666.80	9.00	175.00	0.371	6,956	55,119
1,366.20	8.50	100.00	0.429	6,499	48,620
1,080.70	8.00	60.00	0.667	8,156	40,464
556.40	7.00	25.00	2.333	19,100	21,364
145.30	6.00	12.00	4.333	15,204	6,161
118.80	5.80	10.00	1.667	2,201	3,960
0	5.00	6.00	6.667	$3,960	$0

TABLE 19

POQUOSON AREA II
AVERAGE ANNUAL FLOOD DAMAGES
(January 1983 Price Levels)

Total Damage $1,000	*Flood Stage*	*Probability In Years*	*Interval*	*Average Interval*	*Annual Loss To Stage Noted*
11,287.60	11.00	0			$416,631
9,814.50	10.00	1,000.00	10.100	$10,551	406,080
9,306.00	9.80	500.00	0.100	9,560	396,519
7,732.70	9.00	175.00	0.371	31,643	364,876
6,633.00	8.50	100.00	0.429	30,784	334,092
5,380.80	8.00	60.00	0.667	40,046	294,046
3,107.40	7.00	25.00	2.333	99,029	195,017
1,403.40	6.00	12.00	4.333	97,734	97,283
425.30	5.00	6.00	8.333	76,196	21,087
20.20	4.00	4.00	8.333	18,562	2,525
0	3.00	2.00	25.000	$2,525	$0

Hundreds of homes were flooded, some by as much as two to four feet. By the nature of its development, damages were widely dispersed in the area, and the flood losses amounted to $500,000. One scene of flooding in this area is shown in Figure 10.

A flood that may be expected once in 100 years (although it could occur more often and in any year) would inundate almost the entire city. In some residential areas of the city, there would be four feet of water or more that would be standing in the yards and on the roads. The danger of becoming trapped in one's home in this type of flood is very real.

In 1980, a field survey was made of this community. This included a field investigation, a study of the available maps, and an inspection of the city. A damage-frequency relationship was developed based on the stage-damage curves compiled for the area, and the Corps stage-frequency curve. The total average annual damages for any tidal flood stage for the four areas of Poquoson that were investigated are shown in Tables 16-19.

Tangier Island, Virginia

Tangier is an island, 3.5 miles long and 1 mile wide, located in the lower half of Chesapeake Bay. The town is part of Accomack County. The 771 inhabitants live on three ridges on the island known as West Ridge, Main Ridge, and Canton Ridge. Their homes are wood frame construction or trailers. The residents usually earn their living from the sea. This includes sportfishing and shell fishing was well as an extensive crab industry.

Tangier Island is triangularly shaped and is composed of three distinct bodies of land. The two larger components lie along a north-south axis, approximately 2.8 miles long, divided about mid-point by the Tangier North Channel, with the entire island 1.6 miles in width. To the east and adjacent to Mailboat Harbor is the third portion, identified as East Point Marsh.

East Point Marsh is a small marsh island of about 110 acres. It contains a few buildings, a large dredge-material disposal area, and approximately 67 to 80 acres of saltmarsh interspaced with numerous standing ponds and small creeks. Along the northeastern side of this island, severe shore erosion has been taking place. Waters that are of shallow and intermediate depth along the island's eastern margin became deeper within a mile, with depths increasing into Tangier Sound.

The most developed and populated portion of the Tangier Island group is that area located south of the Tangier North Channel (Tangier South). Consisting of approximately 385 acres, Tangier South is characterized by three parallel ridges that are bordered and separated by low land saltmarsh. The roads, various buildings, and all the houses have been constructed on these higher elevated ridges. Between the three ridges are two

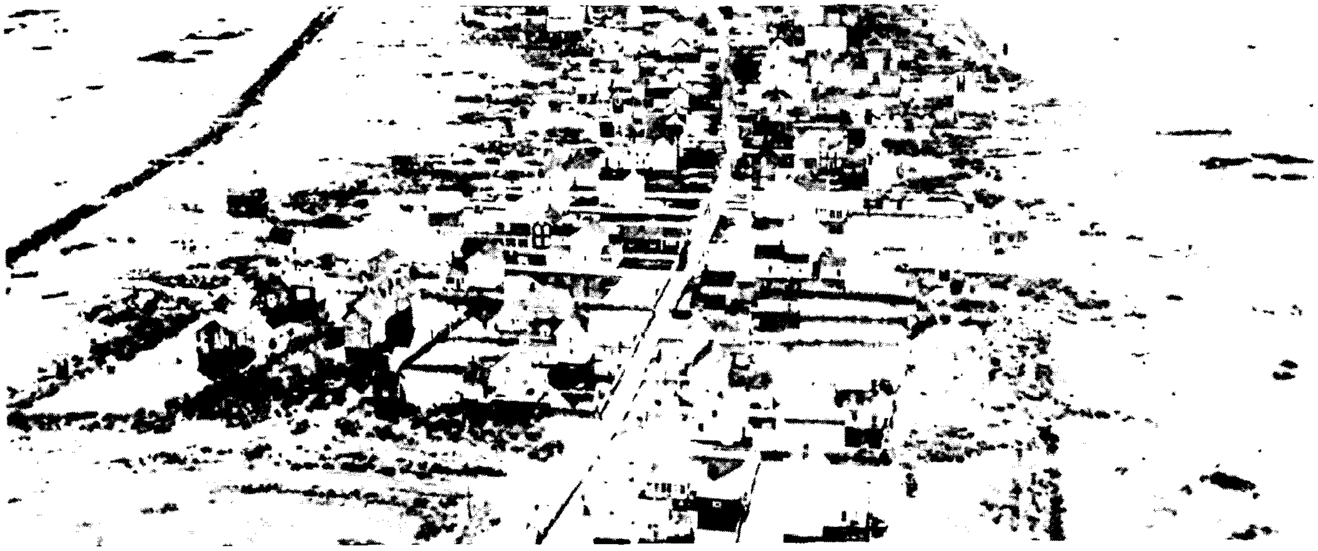


FIGURE 11 FLOOD SCENE AT TANGIER ISLAND, MARCH 1962

TABLE 20

TIDAL STAGE-DAMAGE DATA FOR TANGIER ISLAND
(Corps of Engineers Frequencies)
January 1983 Price Levels

Total Damage $1,000	Flood Stage	Probability In Years	Interval	Average Interval	Annual Loss To Stage Noted
7,643.00	11.00	0.00			$481,734
6,978.00	10.00	1,000.00	0.100	$7,310	474,423
6,811.00	9.80	500.00	0.100	6,894	467,529
6,023.00	9.00	175.00	0.371	23,835	443,694
5,445.00	8.50	100.00	0.429	24,574	419,120
4,708.00	8.00	60.00	0.667	33,843	385,277
3,315.00	7.00	25.00	2.333	93,602	291,675
1,940.00	6.00	12.00	4.333	113,858	177,817
1,683.00	5.80	10.00	1.667	30,192	147,625
847.00	5.00	6.00	6.667	84,333	63,292
246.00	4.00	4.00	8.333	45,542	17,750
28.00	3.00	3.00	8.333	11,417	6,333
12.00	2.00	2.00	16.667	3,333	3,000
0.00	1.00	1.00	50.000	$3,000	$0

creeks that extend across the length of the island. These creeks further divide into various waterways into the marsh. The southern end of this island is basically all saltmarsh and tidal flats with a sand spit extending from the western margin to form Code Harbor.

The people of Tangier indicated that they do not mind the high tide that comes up to the roads. The last time that they had an unusually high water level was during the March 1962 storm, a scene of which is shown in Figure 11. Very few houses were flooded during this storm. In 1980, a diligent search was made by the staff of the Norfolk District Office for high water data on past tidal floods. As can best be ascertained, the 1933 tidal flood reached an elevation of about 7.0 feet above mean sea level. According to the U.S. Geological Survey, the three ridges that are inhibated now are below elevation 5.0 as are the salt marshes that surround the island. Thus, a major storm that would inundate the entire island (south) would threaten the safety and lives of the entire population. Escape by boat, helicopter, or plane to the mainland would not be practical.

Tangier Island is subject to tidal flooding — the extent of which is dependent on the still water stage. Stage-frequency relationships for the Island have been developed by both the Corps and the Virginia Institute of Marine Science (VIMS). Based on the Corps data, the 100-year tidal flood elevation of 8.5 would inundate the entire island and all structures would be damaged. Damage to residential and commercial property would exceed $1.3 million. Based on the VIMS frequency relationship which was developed using a two dimensional depth integrated numerical model, the 100-year tidal flood would have a stage of 4.1 and cause only $68,000 in damage. Using the Corps frequency data, events exceeding the 100-year tidal flood would create a serious problem. The lives of some islanders would be threatened and 298 residential, 25 commercial and seven public buildings would receive major damage.

Based on field surveys, the stage-damage relationship was established for all structures on Tangier Island. The damage-frequency relationship was developed based on the stage-damage relationship and the Corps stage-frequency curves. The average annual flood damages for Tangier Island are presented in Table 20.

West Point, Virginia

West Point, an incorporated town with a 1980 population of 2,725, is located in King William County on the west side of Chesapeake Bay. It lies at the confluence of the Mattaponi and Pamunkey Rivers and the upper end of York River, 33 miles upstream from Chesapeake Bay. The mean range of tide is 2.8 feet.

West Point is a wholesale and retail trading center. It is also the nucleus of an industrial complex which includes a large paper manufacturing plant — The Chesapeake Corporation of Virginia. This plant occupies the left bank of the Pamunkey River from 14th Street north for about 0.8 mile.

West Point connects with Interstate 64 by Virginia Highway 33, a four-lane concrete road eight miles long that crosses both the Mattaponi and Pamunkey Rivers. Water to the town and to the Chesapeake Corporation is supplied by wells. The sewerage system includes secondary treatment for both the Town of West Point and Chesapeake Corporation. Power is supplied by the Virginia Electric and Power Company.

A large portion of the city is surrounded on three sides by water. To the north and landward, there exists a general rural setting with woodlands, agricultural lands, a few roads, and limited resi dential development. Common field crops include corn, soybeans, wheat, and other grains. Local timerland owners develop large amounts of Loblolly and Virginia pine, which are sold as sawtimber, piling, and pulpwood. The low land bordering the river systems contains large areas of wetlands. The shoreline around the city also contains patches of wetlands marsh, plus stretches of bulkheaded property. Piers and docking facilities are also scattered around the shoreline.

Fringe and more extensive marsh acreage is present to West Point Creek and beyond to Lord Delaware Bridge on Virginia Highway 33. Moving farther up the Mattaponi River, large stands of salt marsh vegetation and fringe sections occur on both sides of the river. Considerable marsh development is also present along the Pamunkey and upper York Rivers. At these sites, alternate sections of fringe marsh with broad patches of salt marsh vegetation are common. A few pound net stakes may be seen in both the lower Mattaponi and Pamunkey Rivers, but no extensive fishery was noted. Accretion at a rate of approximately 1.3 feet per year, is estimated along the eastern shoreline of West Point. However, along the western shoreline, there is slight erosion of 0.8 foot per year between Eltham Bridge and the southern end of the City (Hobbs, et al., 1975).

Data on the heights of past major storms at West Point are lacking. The Virginia State Water Control Broad installed a gage in September 1968, but it was removed recently.

The U.S. Coast and Geodetic tide gage at Gloucester Point has been in existence since 1952. The highest tide observed was about 7.9 feet during the northeaster on 7 March 1962 or 6.46 feet above mean low water or 5.5 feet above mean sea level. According to the Coast and Geodetic Survey, the height of flooding at West Point is somehwat higher than at Gloucester Point. In a storm tide of the 1962 magnitude, it is difficult to determine the exact height at West Point. The range for this storm is estimated to vary from 5.7 to 6.4 feet with an average of about 6 feet above mean sea level.

The plant engineer for The Chesapeake Corporation resided in West Point during the August 1933 hurricane. He stated that the water reached a stage from 11 to 12 feet at The Chesapeake Corporation plant. This is based on a depth of 5 to 6 feet of water over the basement floor of the power plant which is at elevation 6.41 feet. Undoubtedly, this unusual height was due to the 1-to 2-mile width and 22-foot depth of the York River with wind driving the waters upstream in the 33-mile fetch of river to West Point.

TABLE 21

WEST POINT AVERAGE ANNUAL FLOOD DAMAGES (CORPS FREQUENCY)
— January 1983 Price Levels —

Total Damage $1,000	*Flood Stage*	*Probability In Years*	*Interval*	*Average Interval*	*Annual Loss To Stage Noted*
3,505.80	11.00	0			$62,477
2,072.30	10.00	1,000.00	0.100	$2,789	59,688
1,821.60	9.80	500.00	0.100	1,947	57,741
1,149.60	9.00	175.00	0.371	5,518	52,223
910.80	8.50	100.00	0.429	4,415	47,808
699.70	8.00	60.00	0.667	5,368	42,440
363.10	7.00	25.00	2.333	12,399	30,040
205.10	6.00	12.00	4.333	12,311	17,729
84.00	5.00	6.00	8.333	12,046	5,683
13.10	4.00	4.00	8.333	4,046	1,638
0	3.00	3.00	25.000	$1,638	$0

TABLE 22

WEST POINT AVERAGE ANNUAL FLOOD DAMAGES (VIMS FREQUENCY) — January 1983 Price Levels —

Total Damage $1,000	*Flood Stage*	*Probability In Years*	*Interval*	*Average Interval*	*Annual Loss To Stage Noted*
1,148.40	9.00	0			$25,591
542.50	7.60	1,000.00	0.100	$845	24,745
364.30	7.00	500.00	0.100	453	24,292
205.90	6.00	120.00	0.633	1,806	22,486
198.00	5.90	100.00	0.167	337	22,150
130.70	5.40	50.00	1.000	1,644	20,506
83.20	5.00	21.00	2.762	2,954	17,552
11.90	4.00	3.00	28.571	13,586	3,967
0	3.00	1.00	66.667	$3,967	$0

Elevations were established by the Corps at street intersections at and below 15th Street. The Chesapeake Corporation plant, practically all of the area (240 acres) at and below elevation 10.0 feet is located downstream from 15th Street. About 70 acres and 25 buildings are on ground which is at or below the 5-foot contour. Approximately 100 buildings are located on the 40 acres between the 5-and 10-foot contours. The remaining land located in this urbanized area below 15th Street is not more than a foot above elevation 10.0 feet.

The probable future damage from tidal flooding was estimated exclusive of the damage to be sustained by The Chesapeake Corporation. A damage-frequency relationship was developed based on the state-damage by the Corps and/or VIMS. The total average annual damages for any tidal flood stage for West Point are presented in Tables 21 and 22.

Statement of Planned Objectives

Planning objectives were established to guide the formulation and evaluation of flood protection plans. Simply stated, the objectives provided the yardstick against which the alternative plans were measured. Two levels of objectives were considered important for the Chesapeake Bay Tidal Flooding Study: National planning objectives and study planning objectives.

National Planning Objectives

Guidelines for the formulation and evaluation of plans of improvement for all Federal water and related land resource activities were contained in the Water Resources Council's "Principles and Standards for Planning Water and Related Land Resources," established pursuant to Section 103 of the Water Resources Planning Act (P.L. 89-80). These Principles and Standards required that Federal and Federally-assisted water and land activities be planned toward achievement of National Economic Development (NED) and Environmental Quality (EQ) as co-equal national objectives. The components of the NED objective included:

- The value of increased output of goods and services resulting from a plan.
- The value of output resulting from external economies associated with a plan.

The components of the EQ objective included:

- Management, protection, enhancement, or creation of areas of natural beauty or human enjoyment.
- Management, preservation, and/or enhancement of especially valuable or outstanding archaeological, his torical, biological, or geological resources and ecological systems.
- Enhancement of quality aspects of water, land, and air by control of pollution or prevention of erosion and restoration of eroded areas.
- Avoiding irreversible commitments of resources to future needs.

The NED objective sought to achieve the maximum net benefits from a National viewpoint, while the EQ objective sought to maximize environmental benefits (and the least amount of adverse impacts) measured primarily in nonmonetary units. In formulating alternative plans to maximize these National objectives, trade-offs occurred. These trade-offs were considered with reference to the without condition. When plans were to be finalized, the impacts and trade-offs of each were tabulated to aid decision-makers in selecting a program for further consideration.

The Principles and Standards promulgated by the Water Resources Council provided the basis for the water resources planning procedures followed during the Tidal Flooding Study. The Tidal Flooding Study was initiated and conducted under these guidelines and the findings and conclusions presented reflect the Principals and Standards. It should be noted, however, that on 9 September 1982, the WRC repealed the Principles and Standards and, in their place, established new "Principles and Guidelines."

The major change resulting from the implementation of the Principles and Guidelines is that the co-equal national objectives of NED and EQ have been combined into one Federal objective. The Federal objective of water and related land resources 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.

Study Planning Objectives

Within the framework of National objectives, a second level of planning objectives was developed which related to the problems, needs, concerns, and opportunities of the specific study area. Study planning objectives are expressions of public and professional concerns about the future use of water and related land resources. They were derived through an analysis of the existing resource base and the expected future conditions within the study area. The purpose in defining study planning objectives was to establish "targets" to guide the formulation of alternative plans and to enable evaluations of the plan effectiveness. Planning objectives sometimes conflicted with each other, reflecting different perceptions of how the water resources should be managed in the future.

During the early phase of the planning process, the planning objectives were general in scope and often many in number. Based on the existing and future problems, needs, and opportunities identified during the initial iterations of the planning process, including the preparation of the Chesapeake Bay Existing Conditions and Future Conditions reports, the following were recommended as planning objectives for the Chesapeake Bay Study program:

- Preserve, restore, and enhance the integrity of the Chesapeake Bay ecosystem.
- Manage, preserve, and enhance areas of significant natural, historical, cultural, and scientific interest for the inspiration, enjoyment, and education of man.
- 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 sportfishing opportunities and resources.
- Maintain or improve water navigation facilities which provide transportation advantageous to the Nation's transportation system.
- Reduce tidal flooding damages.
- Reduce damages due to shoreline erosion.
- Develop power facilities where its provision can contribute to a needed increase in power supply.
- Control the occurrence of certain aquatic plants where they interfere with man's use of the Bay.
- Maintain or improve adequate outlets for approved on-farm drainage systems for surface water management.

As they related more directly to the tidal flooding problem, which is the subject of this report, the following are the specific planning objectives that were identified for the communities under study.

- Protect life and property.
- Reduce flood damages and health hazards due to flooding.
- Minimize adverse impacts on cultural resources and the natural environment.
- Minimize adverse impacts on aesthetic values and community cohesion.
- Avoid inducing any additional flood plain damages.

Planning constraints are those physical, environmental, social, economic, and institutional boundaries which define the limits of study. The broad institu tional constraints on the planning process are embodied in a large volume of law, regulation and policy. These constraints form the framework in which water resources projects are conceived, developed and evaluated. As it related to the Chesapeake Bay Study, the study authority which was quoted in Chapter I provides the basic constraints as to the scope and geographic area of study. Based on the findings presented in the Existing and Future Conditions Reports, the scope of the final phase of the study was further limited to studies of tidal flooding and low freshwater inflow as recommended in the *Revised Plan of Study* and as discussed in previous paragraphs.

Formulation of Flood Protection Plans

Plan Formulation Rationale

The analysis of plans considered in preliminary planning was based primarily on technical and economic criteria to facilitate early identification of those plans which were not justified. Subsequent plan formulation was based on technical, economic, and intangible criteria, including beneficial and detrimental effects on the environment. These criteria permitted the development of plans of improvement which represented the best response to the stated planning objectives.

Technical Criteria

The following technical criteria were adopted for use in formulating the plans considered in those communities under study:

1. 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.

2. Flood protection design criteria, such as freeboard requirements and design features, should be compatible with the existing site conditions, available materials and the type of structure selected.

3. The plans developed should be engineeringly feasible.

Economic Criteria

The economic criteria which were a plied in the plan formulation studies included the following:

1. Tangible and intangible benefits should exceed costs.

2. Benefits and costs should be expressed in comparable quantitative economic terms based on either a 50- or 100-year project life and the appropriate Federal interest rate of 7⅛ percent (FY 1980) or 7⅞ percent (FY 1983).

3. Interest during construction was not included in the economic analysis because it was either not applicable or it would not effect the economic feasibility of a plan.

Environmental and Social Well-Being Criteria

Environmental and social well-being criteria considered in the plan formulation process included the following:

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

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

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

The following sections of this chapter provide a general presentation of the management measures considered in plan formulation and an analysis of all plans considered. Included is a general overview of the criteria used in developing the plans as well as descriptions of the plans. For additional information on the development of these plans, refer to Appendix B — *Plan Formulation, Assessment, and Evaluation;* Appendix E — *Engineering Design and Cost Estimates;* and Appendix F — *Economics.*

Management Measures

As required by the *Principles and Standards*, co-equal consideration was given to both structural and nonstructural protection measures as a means of solving flood-related problems. In an effort to identify potential measures which could address one or more of the specific planning objectives, a broad range of measures was identified during development of the *Plan of Study* and early in Stage II. Most of the measures were carried forward in the Stage II planning.

The following sections discuss those management measures which were investigated in detail. Several of the measures presented were quickly eliminated based on engineering and/or economic criteria and are so noted. Further discussion of these structural and nonstructural measures can be found in Appendix E — *Engineering Design and Cost Estimates*.

Levees and Floodwalls

Levees and floodwalls, while differing in design, appearance and cost, serve essen tially the same purpose. Both are constructed near the shoreline to protect landside development from inundation by tidal floodwaters. A substantial reduction in both nuisance and major tidal flooding problems can be realized with these structural measures. The levees examined consisted of earth embankments having a top width of approximately 10 feet and side slopes of 1 on 3. The waterside face of the levee is armored with stone where appropriate to prevent wave damage. Levees are generally less expensive than floodwalls and are particularly applicable where construction materials are available and there is sufficient area between the shoreline and the area to be protected. Floodwalls are generally concrete with vertical faces and, because of their cost, are used in areas where close proximity of the development precludes the construction of levees.

Seawalls, Bulkheads, and Revetments

Seawalls, bulkheads, and revetments are structures placed parallel to the shoreline to separate a land area from a water area. These structures serve to both retain the land behind them and provide protection from wave damage. Generally, these structures are used where it is necessary to maintain the shore in an advanced position relative to that of adjacent shores, where there is little or no protective beach or where it is desired to maintain a certain depth of water along the shoreline.

Other Structural Measures

Other types of structural measures that can be employed along coastal areas to provide protection from tidal flooding include sand dunes and breakwaters. Dunes along the coast can prevent the movement of storm tides and waves into the area behind the beach. Breakwaters can serve to provide protection from waves thus creating harbors of refuge and protection for harbor facilities. Given both the nature of the tidal flooding and the communities under study, further consideration was not given to these two measures.

Floodproofing

Floodproofing is a combination of structural changes and adjustments to structures and building contents which are designed to reduce flood damages. Although it is more simply and economically incorporated into new construction, floodproofing is also applicable to existing structures that are structurally sound. A preliminary inventory of the communities under study revealed that most residential and some older commercial buildings that may require floodproofing were of metal or wood frame construction and therefore not able to withstand the hydrostatic forces. Conversely, several of the new commercial buildings constructed of concrete block were capable of incorporating floodproofing measures rather easily. Therefore, consideration was given to only basement floodproofing of residential structures and commercial floodproofing of structurally sound structures. Basement floodproofing consists of raising the superstructure of residential structures, removal of the existing foundation including basement walls, construction of a new reinforced concrete substructure with waterstops, provision of check valves in the storm and sanitary lines, and landscaping. Commercial floodproofing includes the floodproofing of the first floor and/or basement by provision of a floodwall, flood shields, waterproofing compounds, back flow valves and sump pumps.

Raising

This alternative consists of raising the elevation of the basement and/or first floor of a damage-prone structure. Depending on the type of structure, foundation composition, and height of raising, various measures may have to be employed. These measures may include such items as physically raising the superstructure, provision of a new foundation and basement walls, utility additions, and landscaping.

Utility Room Addition

This alternative consists of relocating all basement utilities to a wood-frame utility room constructed adjacent to the home at the first floor level. This addition reduces part of the damages in the basement by moving those utilities subject to damage to a less frequently flooded location.

Relocation

Relocation of a structure to a site out of the flood plain involves physically moving the structure a reasonable distance to a prepared flood-free site of comparable value. The costs of house relocation have been developed on the premise that the Corps will administer all the necessary contracts to include moving the superstructure, razing the abandoned site, preparation of a new site, and modifying the house as necessary to accommodate the move.

Acquisition and Demolition

Acquisition and demolition includes relocation of the homeowner, the purchase of a particular structure at a fair and reasonable price, demolition of the structure and restoration of the site by filling, grading and seeding where required. It should be noted that the estimates developed for this alternative include an allowance for costs associated with the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970.

Flood Warning and Evacuation

Early in the study, a flood warning and evacuation plan was identified as a potential tidal flood control alternative. Hurricane tidal-flood damages can be reduced by the provision of improved forecasting and warning services, and the establishment of evacuation plans. A hurricane warning system, combined with emergency mobilization, would aid in the prevention of loss of life and of damage to items which are readily movable, but would not prevent the actual flooding of properties. Further study revealed that the National Weather Service has a "self-help" program for coordinating and developing flood warning systems in conjunction with local governments. In addition, it was found that the National Ocean Survey has received the authority to study, in detail, flood warning and evacuation along the coastal regions of the United States under the NOAA Coastal Hazards Program. Accordingly, detailed investigation of flood warning and evacuation plans was not deemed appropriate.

Flood Insurance

Although flood insurance does not reduce flood damages, it does provide some compensation for flood damages which have been suffered. All the communities under study in the Bay area became eligible for flood insurance in 1974 under either the regular or the emergency programs authorized by the Flood Disaster Protection Act of 1973 and administered by FEMA. Residents of the communities may purchase flood insurance under this program and accordingly, there was no need to investigate this measure.

No Action

One nonstructural option that must obviously be considered is that of "NO ACTION." There will be numerous flood-prone structures that, because of their structural condition, level and frequency of expected flooding or other factors, will not be recommended for any type of structural or nonstructural flood protection.

Description of Plans Considered

Cambridge, Maryland

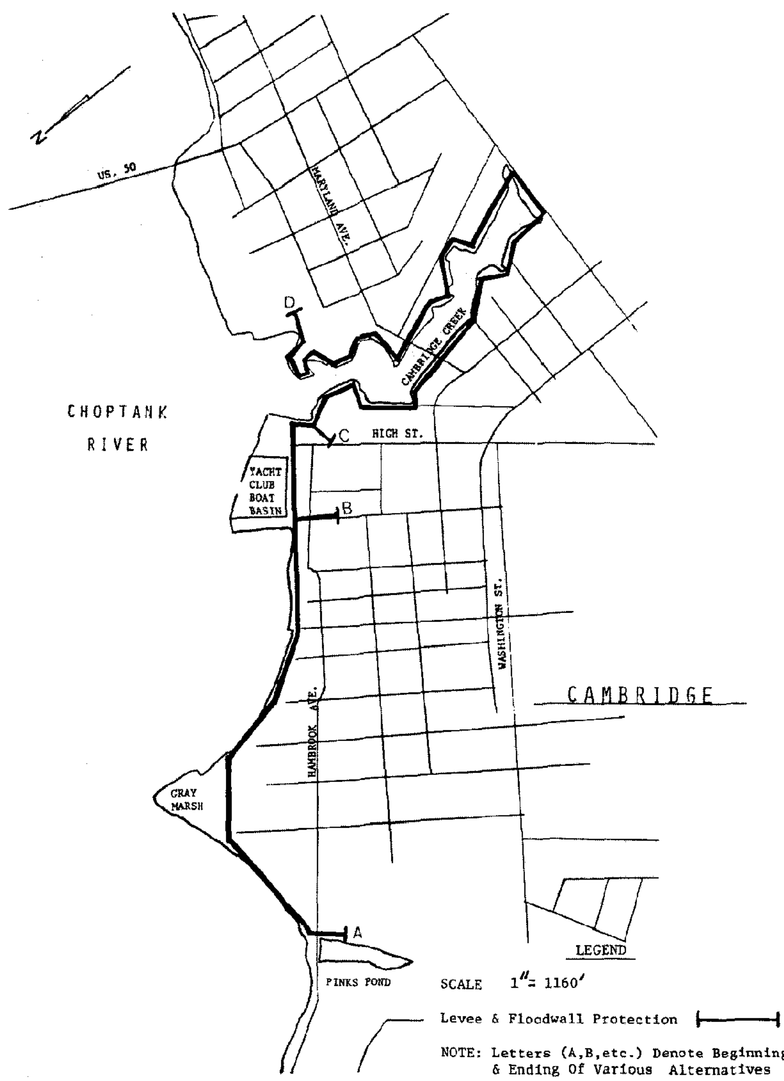
A total of eight plans of protection were considered for Cambridge. Six of the plans were structural and the remaining two were nonstructural. The structural plans consisted of combinations of earth levees and concrete floodwalls which provide two degrees of flood protection to the urban area between Pinks Pond (Point A) and the eastern shore of Cambridge Creek (Point D) as shown in Figure 12. These structural plans were designed to provide protection with three feet of freeboard against either the 120-year flood or the event approximating the 500-year flood. The two nonstructural plans were designed to provide protection against the 40- and 120-year flood events in the same area as the structural plans. The nonstructural measures which comprised these plans include floodproofing, provision of utility additions and acquisition and demolition of some structures. Approximately 16 and 30 structures are impacted for the 40- and 120-year plans, respectively.

Crisfield, Maryland

Four structural and two nonstructural plans of protection were considered for Crisfield. The structural plans were combinations of earth levee and floodwall totaling approximately four miles in length. As shown in Figure 13, one line of protection would reach from the Route 380 — Johnson Creek Road junction (Point A) to the vicinity of the junction of Route 358 and Crisfield Park Road (Point C). A shorter plan (Point A to Point B) was also considered. These structural plans were designed to provide protection with freeboard against either the 80-year (5.0 ft. NGVD) or the 400-year flood (6.0 ft. NGVD).

The two nonstructural plans consist of utility additions, relocation, acquisition and demolition, and floodproofing. Nearly 200 structures would be involved. These nonstructural plans would be undertaken in the same area as the structural plans. Protection to both elevation 4.0 feet NGVD (12-year flood) and elevation 5.0 feet NGVD (80-year flood) was considered.

Figure 12 Cambridge Plans of Improvement



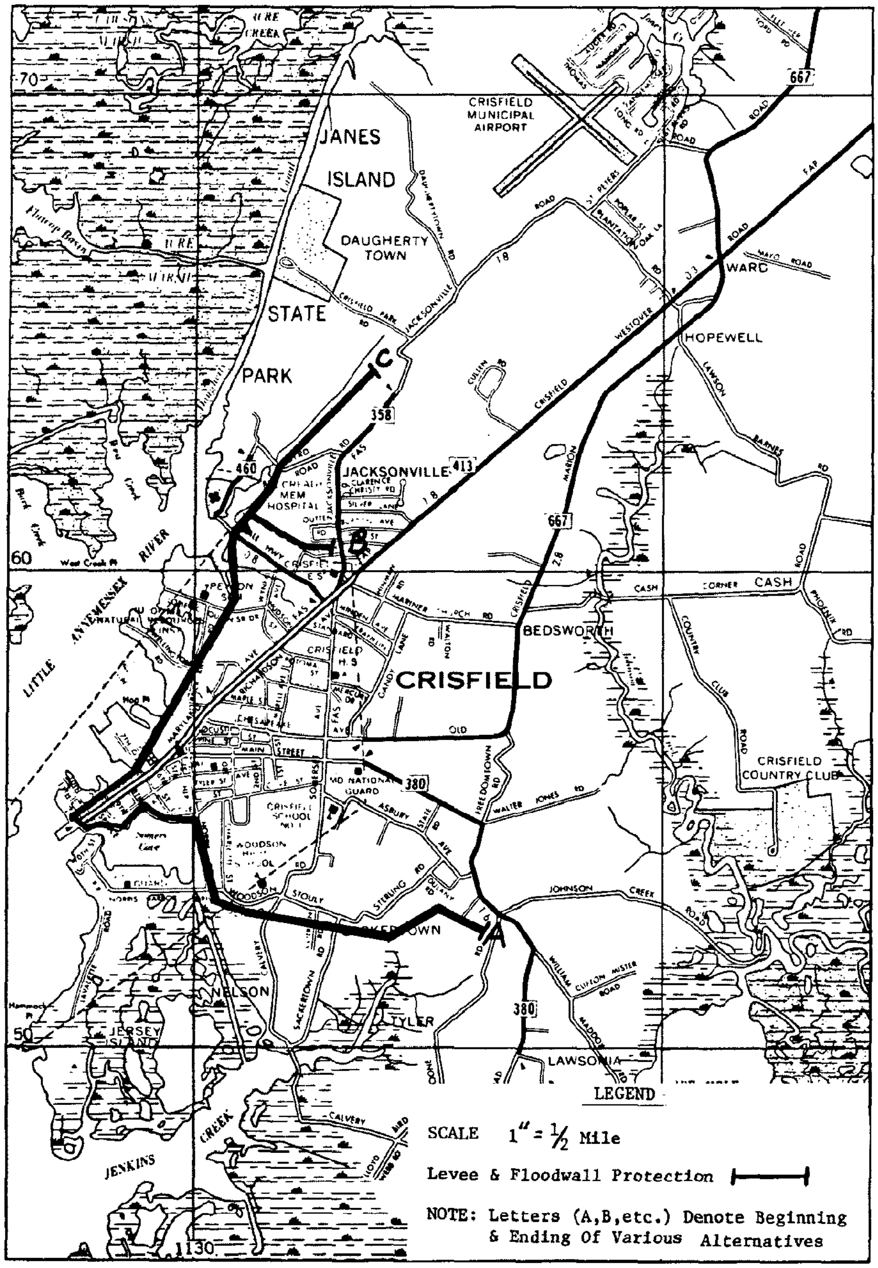


Figure 13 Crisfield Plans of Improvement

Pocomoke City, Maryland

A total of five plans of protection were considered for Pocomoke City. Two of the plans examined were structural and three were nonstructural in nature. The two structural plans consisted of approximately 10,000 feet of levee and floodwall which provide protection with freeboard against either a 70-year (eleva tion 6.0 NGVD) or 500-year (elevation 8.0 NGVD) flood. As shown in Figure 14 nearly all of the low lying portions of Pocomoke City would be protected.

The three nonstructural plans were designed to provide protection for the same general area as the structural plans against the 25-year (5.0 feet NGVD), 70-year (6.0 feet NGVD) and 220-year (7.0 feet NGVD) floods. The measures considered included providing utility additions, relocation, acquisition and demolition, raising and floodproofing.

Rock Hall, Maryland

Six structural and four nonstructural plans of protection were considered for Rock Hall. The structural plans were combinations of earth levees and floodwalls designed to provide protection with freeboard against either a stage of 9.0 feet NGVD (140-year flood) or 12.0 feet NGVD (approximate 500-year flood). As shown in Figure 15, several different alignments were investigated. Consideration was given to protecting the Gratitude area as well as Rock Hall. It should be noted that for the higher degree of protection, levee segment F-G is required in order to prevent flooding from Grays Inn Creek.

The four nonstructural plans examined consisted of utility additions, relocations, acquisition and demolition and floodproofing. The total number of structures affected would range between 30 and 170 all of which are located in both Rock Hall and Gratitude. Four levels of protection were considered including protection against the 15, 25, 50 and 80-year floods.

Snow Hill, Maryland

A total of seven plans of protection were considered for Snow Hill. Four of the plans were structural and three were nonstructural. The four structural plans consist of approximately 7,000 feet of levee and floodwall which would provide protection with freeboard against either a 70-year (elevation 6.0 feet NGVD) or an approximate 500-year (elevation 8.0 feet NGVD) flood. As shown in Figure 16 nearly the entire community of Snow Hill would be protected by the plans considered.

The three nonstructural plans would provide protection for the same general area as the structural plans and are designed against the 25-year (5.0 feet NGVD), 70-year (6.0 feet NGVD) and the 220-year (7.0 feet NGVD) floods. The measures employed would include relocation, acquisition and demolition, and floodproofing.

St. Michaels, Maryland

A total of four plans of protection (two structural and two nonstructural) were considered for St. Michaels. The structural plans consist of combinations of earth levees and floodwalls which would provide varying degrees of protection for the entire community of St. Michaels. The alignment of the plans considered is shown in Figure 17. Plan SM-1 would be constructed in two parts (Point A to

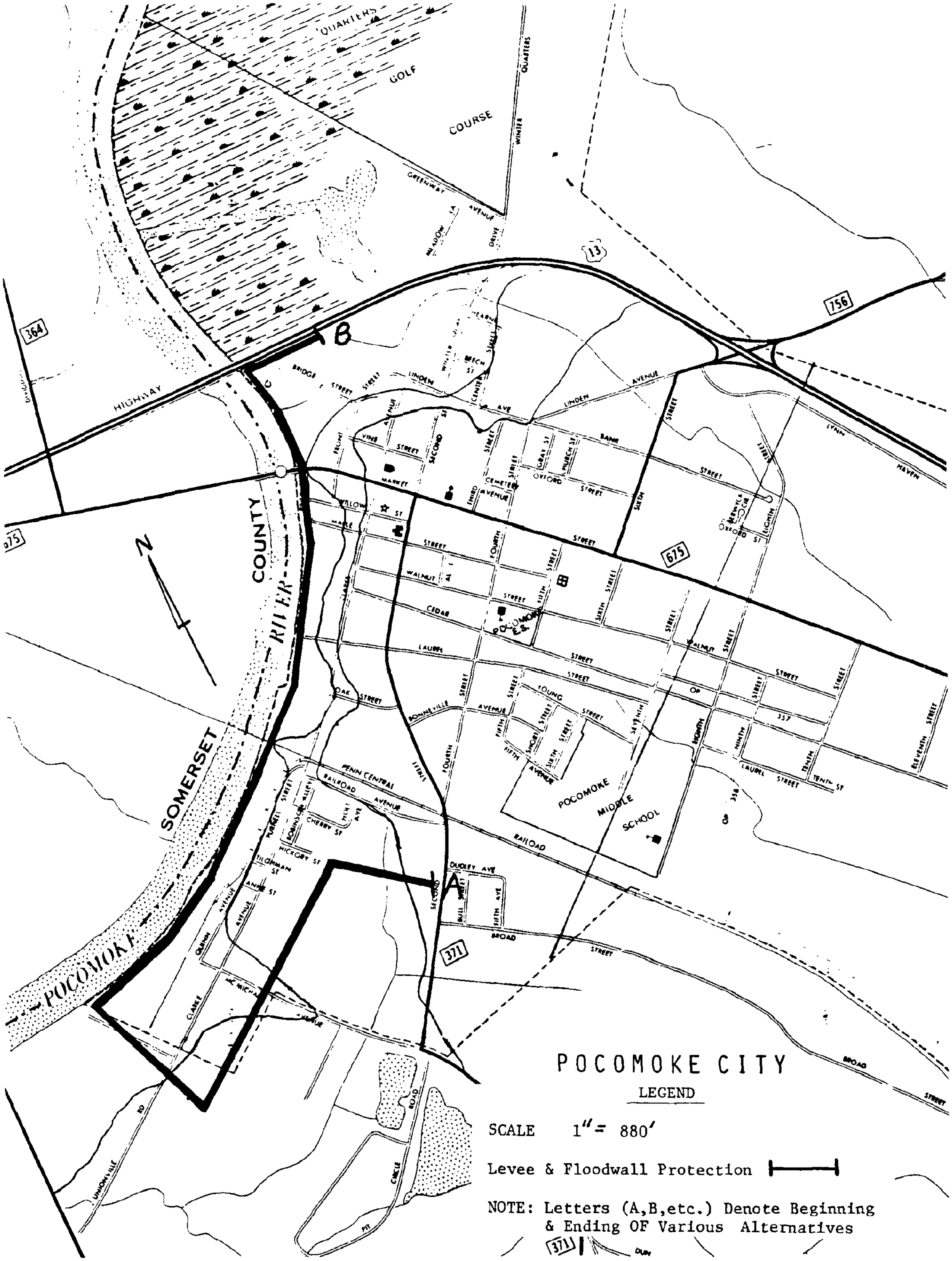


FIGURE 14 POCOMOKE CITY PLANS OF IMPROVEMENT

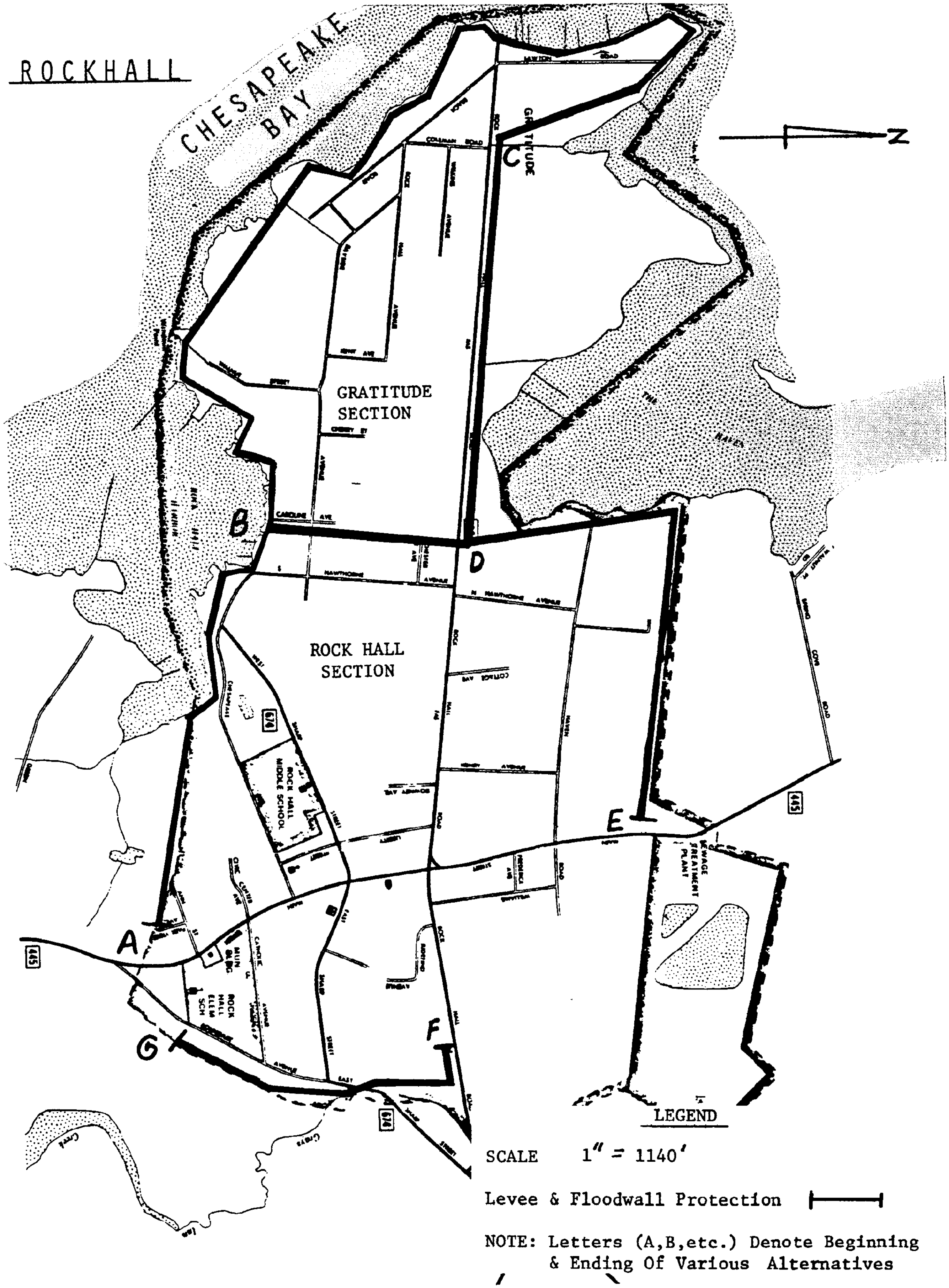


FIGURE 15 ROCK HALL PLANS OF IMPROVEMENT

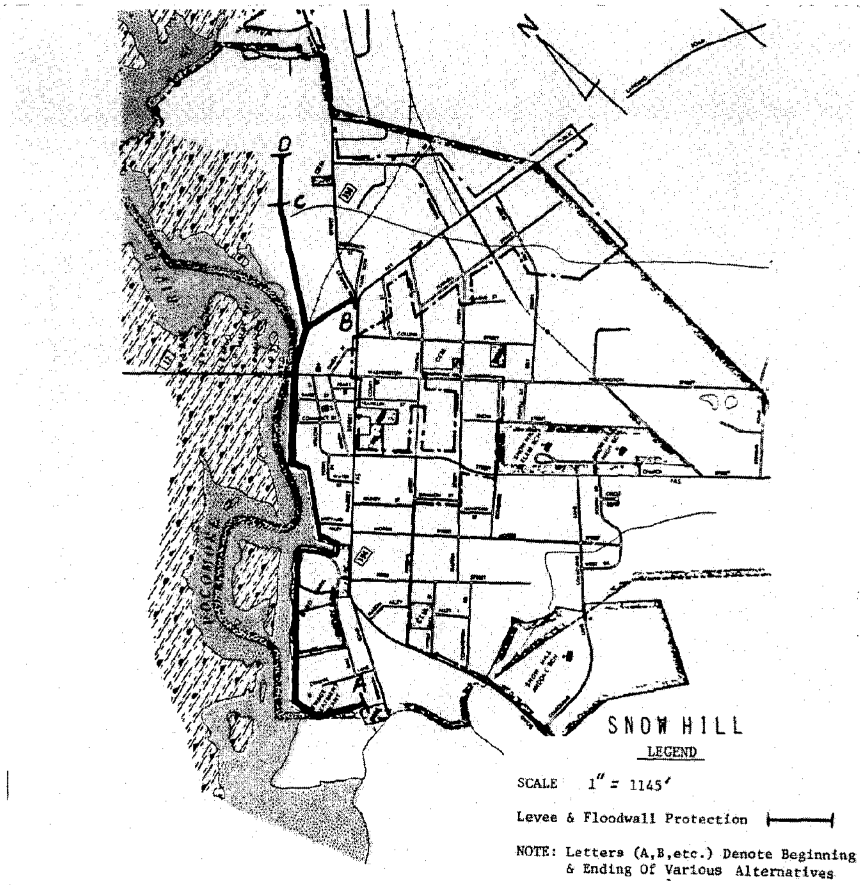


FIGURE 16 SNOW HILL PLANS OF IMPROVEMENT

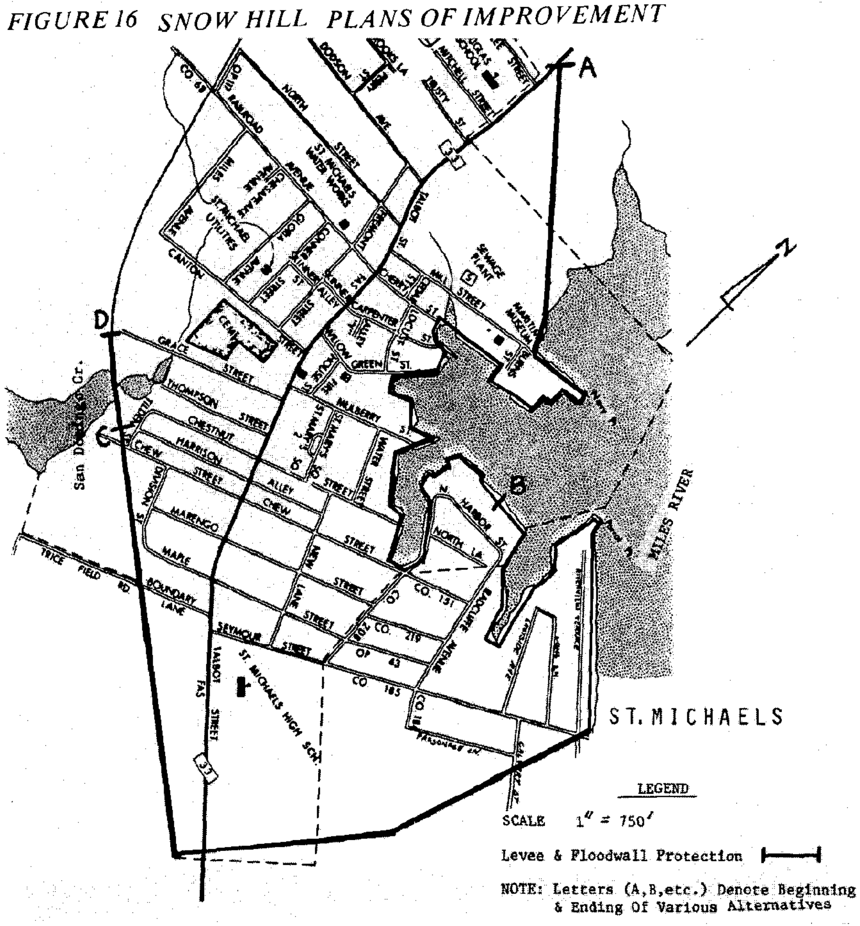


FIGURE 17 ST. MICHAELS PLANS OF IMPROVEMENT

Point B and Point C to Point D) and would provide protection against a flood with a recurrence interval of once in 100 years (elevation 7.0 feet NGVD). Plan SM-2 would be one continuous line of protection between Points A and D and would protect against the 450-year flood (elevation 9.0 feet NGVD).

The two nonstructural plans were appiled in the entire St. Michaels community and were designed to protect against the 45-and 100-year floods (elevations 6.0 and 7.0 NGVD, respectively). The measures considered included utility additions, raising, acquisition and demolition, and floodproofing.

Tilghman Island, Maryland

Four structural and three nonstructural plans of protection were considered for Tilghman. As shown in Figure 18, Knapps Narrows separates Tilghman Island from the mainland. Consideration was given to providing protection to the residential and commercial development north of the Narrows (northern section) and also the communities of Tilghman and Avalon which are located on the Island itself (southern section). Two levels of protection (90 and 500-year event) were investigated for both the northern and southern sections (six feet and eight feet NGVD, respectively).

Nonstructural plans were considered for both the northern section and the entire island. Measures considered included relocation, acquisition and demolition, raising and floodproofing. Three design levels to include protection against the 15, 40 and 90-year floods were evaluated (four feet, five feet, and six feet elevations, respectively).

Cape Charles, Virginia

In Cape Charles, the analysis of structural measures were limited to investigating several modifications that could be made to the existing bulkhead that is located adjacent to Bay Avenue (Figure 19). Providing flap gates and tying into high ground at each end of the existing bulkhead would in effect provide protection to the stillwater 100-year flood level. The measures could be considered for implementation by the Town of Cape Charles.

Consideration was given to four nonstructural plans that provide protection against the 35-year (elevation 7.0 feet

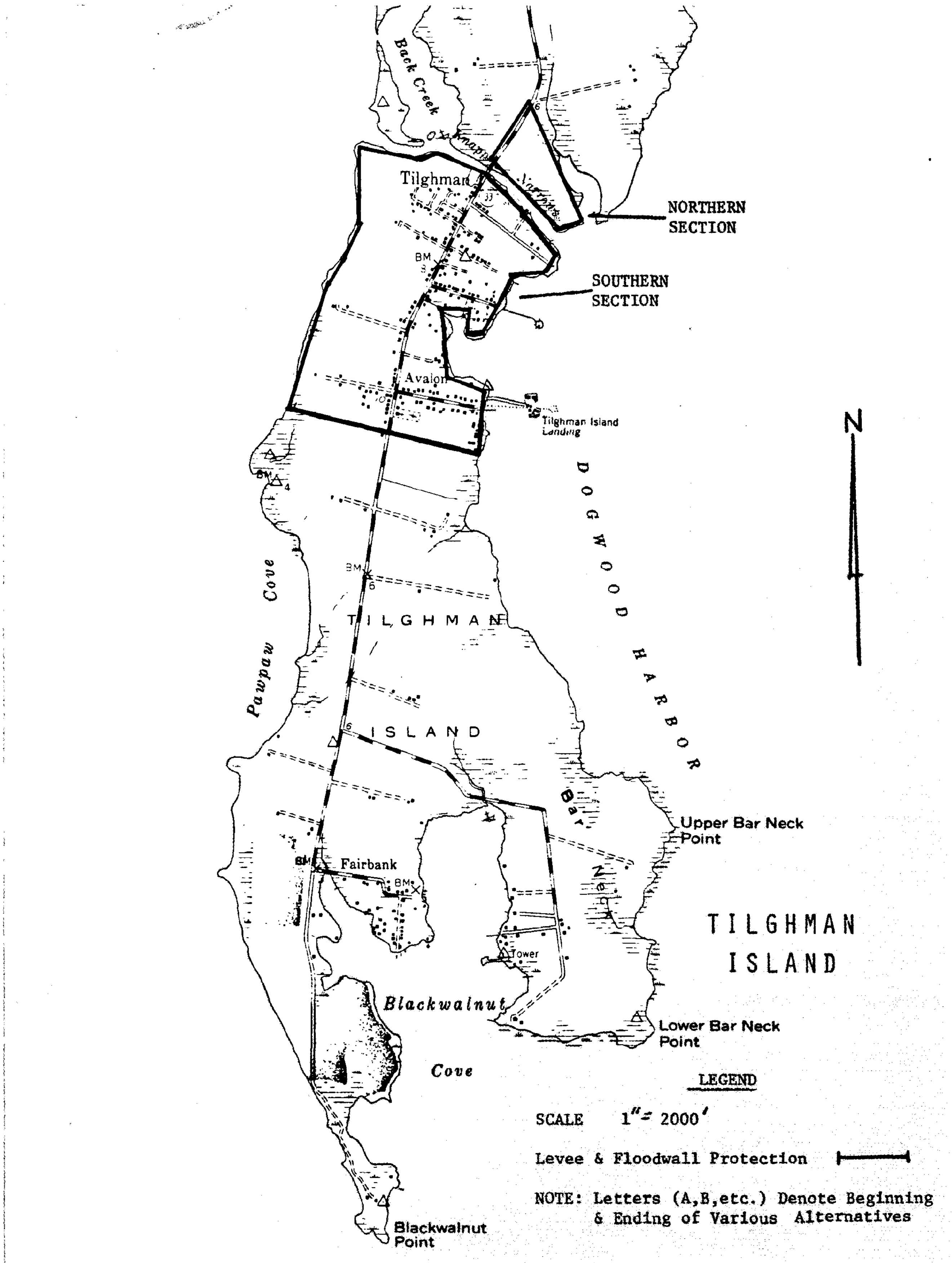


FIGURE 18 TILGHMAN ISLAND PLANS OF IMPROVEMENT

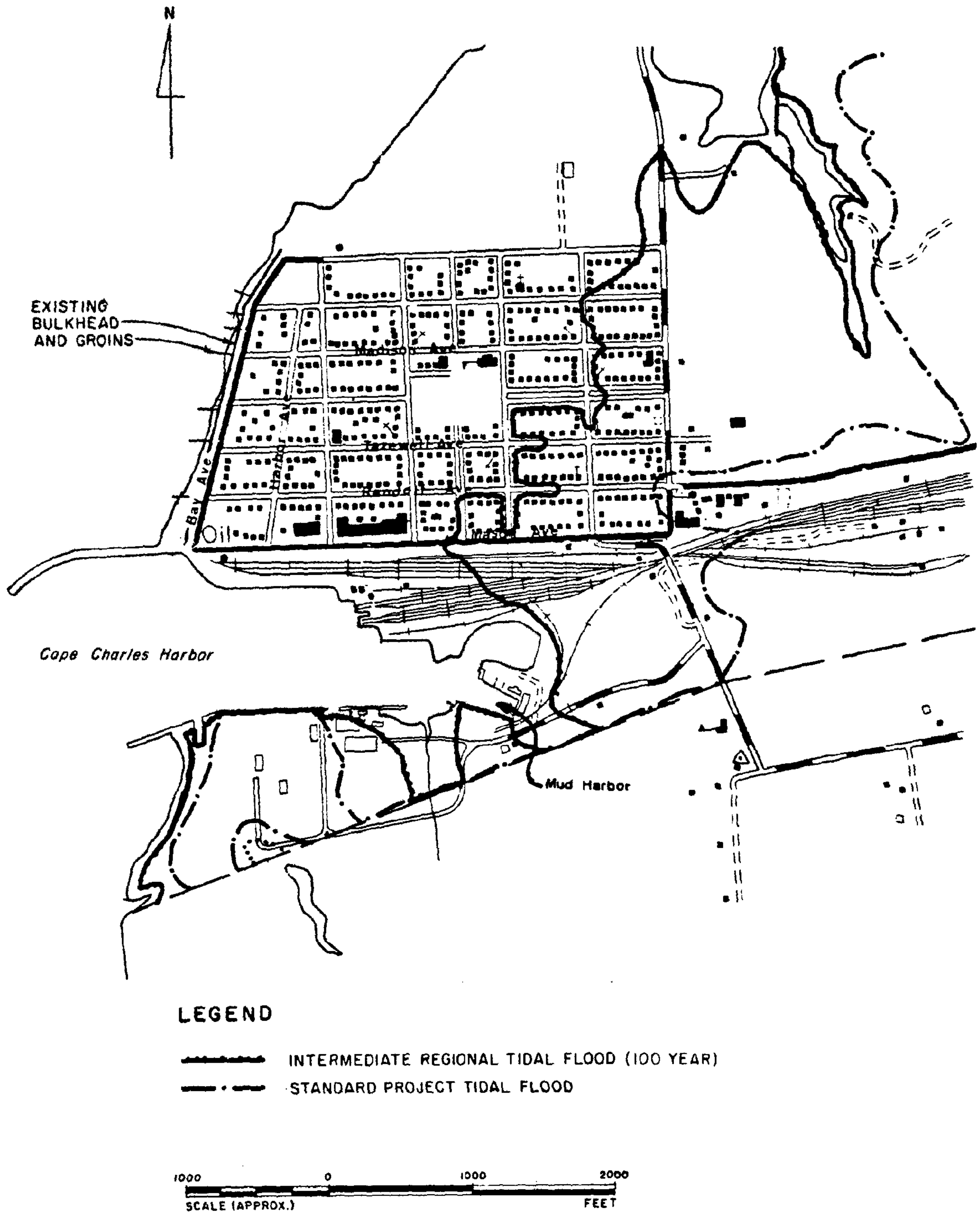


FIGURE 19 CAPE CHARLES AREA FLOOD MAP

NGVD) and the 100-year (elevation 8.0 feet NGVD) floods. Measures considered included raising houses and buildings, utility additions, and flood proofing. The area considered for these plans included the flood plain (35-or 100-year) for the entire community.

Hampton Roads, Virginia

For the purposes of this study, a complete investigation was not conducted on the feasibility of structural measures in the entire Hampton Roads area. Rather, several small typical areas within Norfolk and Hampton were investigated relative to the applicability of structural measures.

Four areas along the Lafayette River and Wayne Creek in Norfolk (Figure 20) were investigated to determine the feasibility of constructing tidal flood barriers at the four points where existing bridges crossed these small tidal streams. Based on field investigations, the above plans were not found to be practicable and no further analyses are included in this report. A fifth location investigated was the Fox Hill area of Hampton (Figure 21). The structural protection considered was a 6,200-foot floodwall that protected approximately 50 structures to the 100-year flood level.

As with the structural measures, no investigations were made of the entire Hampton Roads area relative to the feasibility of nonstructural plans. However, the Fox Hill area was chosen as a sample area for nonstructural plans. Based on a field survey of the 379 structures in Fox Hill, a sample area which includes 61 homes was selected for study. Two nonstructural plans which provided 25-and 100-year levels of protection for these 61 homes were developed. The nonstructural measures considered consisted solely of raising the existing structures.

Poquoson, Virginia

Based on field investigations and a review of the nature of the topography and the flood problem, it is concluded at this time that structural measures for the protection of Poquoson are not practicable. An exception would be the flood proofing of the Middle School or construction of a wall to enclose the structure, if necessary, to a level approaching the elevation of a rare flood. Consideration was given to nonstructural measures and four specific areas were investigated in detail (Figure 22).

(1) POQ-1 - primarily a commercial area.

(2) POQ-2 - a trailer court area.

(3) POQ-3 - a typical area with homes of above average value.

(4) POQ-4 - an area of moderate value homes in the central Poquoson area.

The types of nonstructural measures considered included relocation, raising, and acquisition and demolition. The plans were designed against floods having a recurrence interval of once in 10, 25, and 100 years. The plans under study affected as few as nine structures (Plan POQ-3, 25-year event) and as many as 383 structures (Plan POQ-4, 100-year).

Tangier Island, Virginia

Both structural and nonstructural plans were investigated for Tangier Island. One structural plan consisted of providing a floodwall around each of the three ridges (West Ridge, Main Ridge and Canton Ridge — see Figure 23) of high ground where all the development is located. Each of these walls would be built to the 100-year flood level plus three feet of freeboard. A second structural plans was to surround the community center or school with a floodwall designed to provide protection against

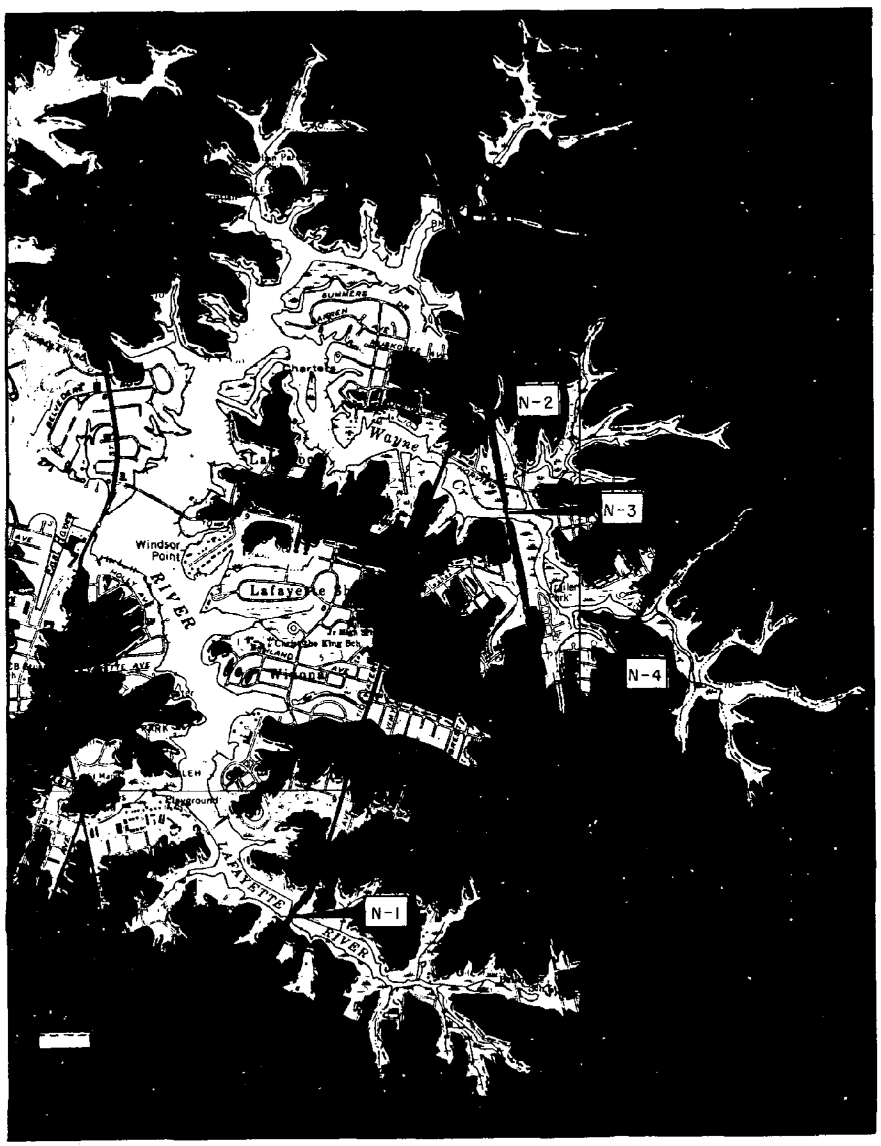


FIGURE 20 HAMPTON ROADS CITY COMPLEX STRUCTURAL SITES IN NORFOLK CONSIDERED-NOT RECOMMENDED

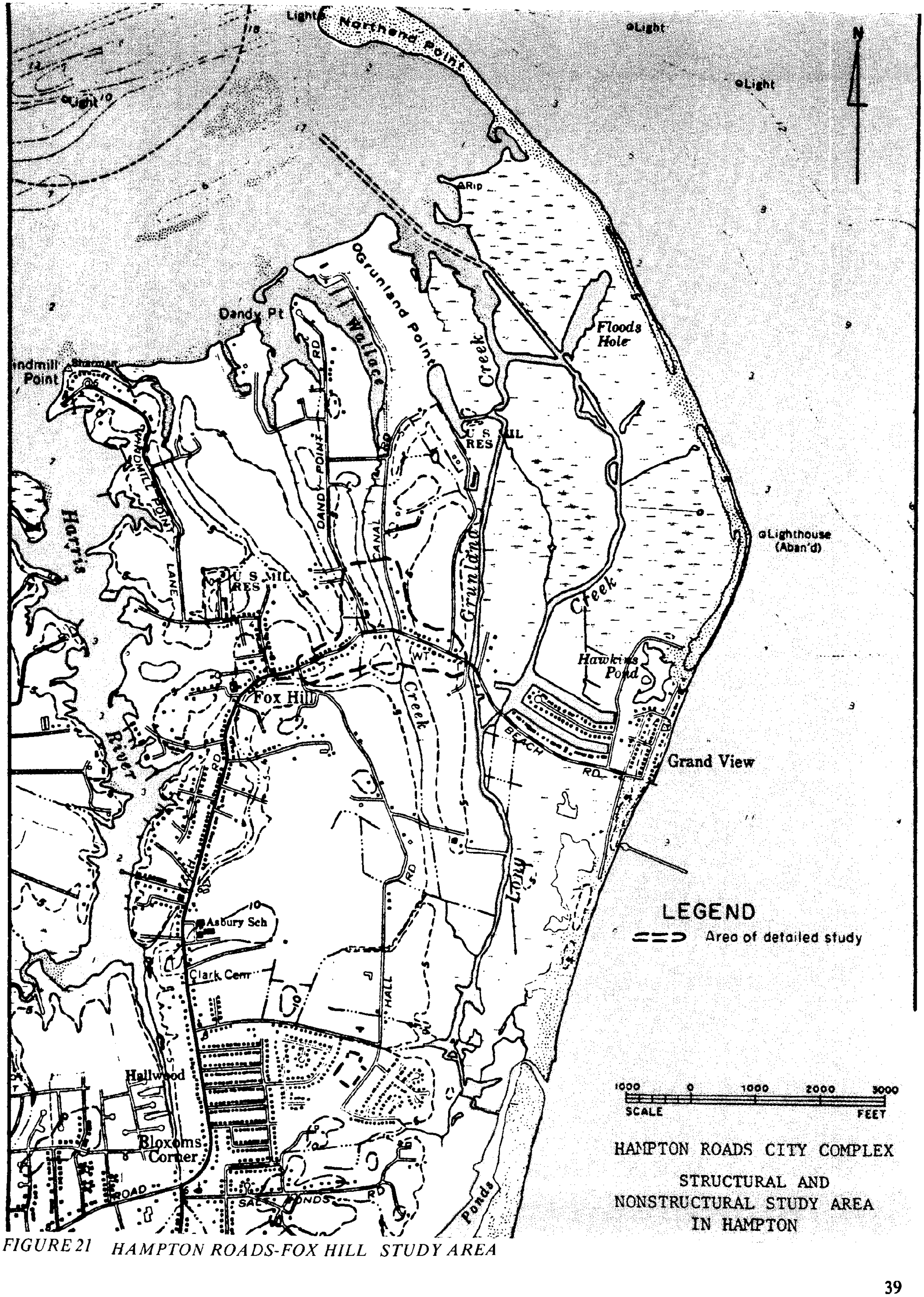


FIGURE 21 HAMPTON ROADS-FOX HILL STUDY AREA

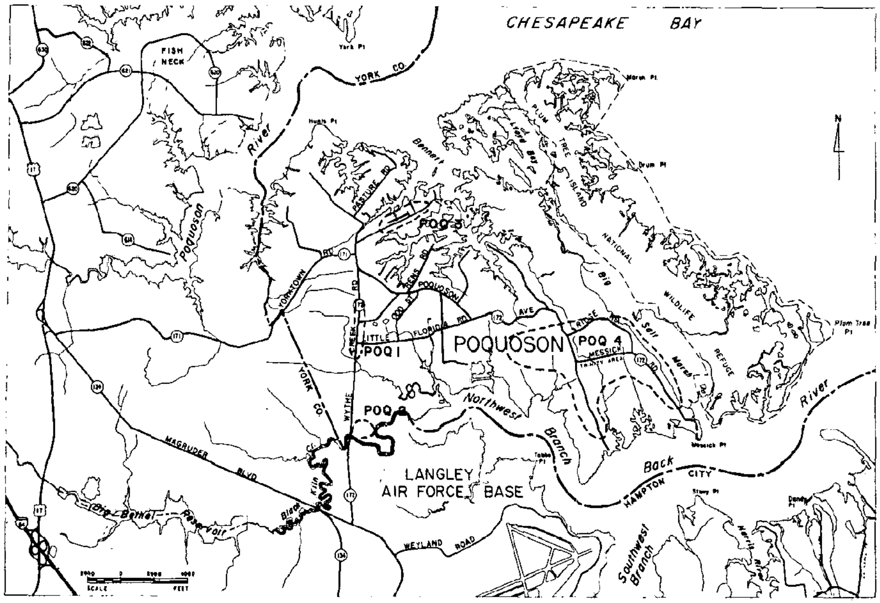


FIGURE 22 POQUOSON COASTAL FLOOD AREA

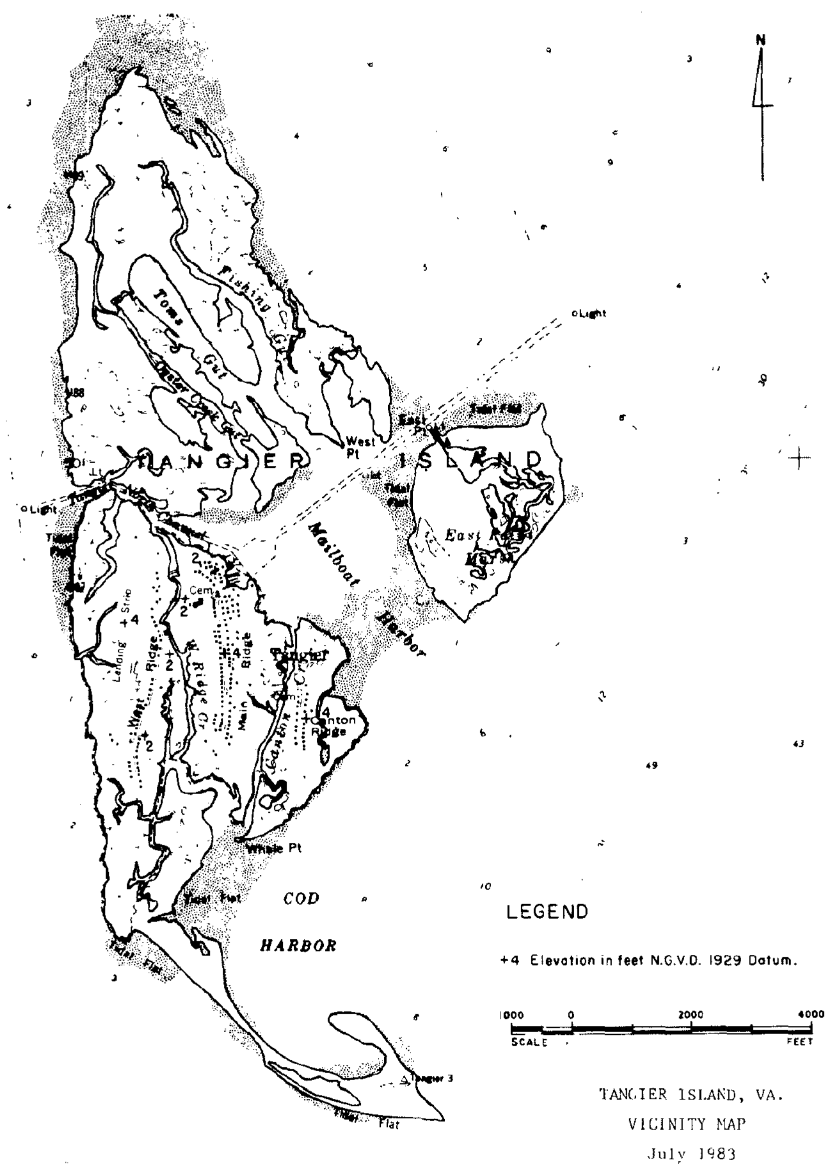


FIGURE 23 MAP OF TANGIER ISLAND

the standard project flood. The area protected would then serve as a sanctuary during rare flood events.

Two nonstructural plans were investigated. Each plan involved only the raising of structures. The two levels of protection considered were the 25-and 100-year flood levels. It should be noted that for purposes of the analyses, both a stage-frequency curve developed by the Corps and the stage-frequency relationship developed by the Virginia Institute of Marine Science (VIMS) for FEMA were considered.

West Point, Virginia

Structural protection in the form of a floodwall along First and Kirby Streets (see Figure 24) was given some initial consideration. However, further study indicated that structural measures were not practicable based on the elevation and density of the development. In the study area, which includes 15th Street and below, the nonstructural measures considered were limited to the raising of structures to prevent damages from the 25-and 100-year flood levels. The nonstructural plans were evaluated using both Corps and VIMS stage-frequency relationships. The plans considered involved the raising of as few as three structures (25-year plan) to as many as 43 structures (100-year plan).

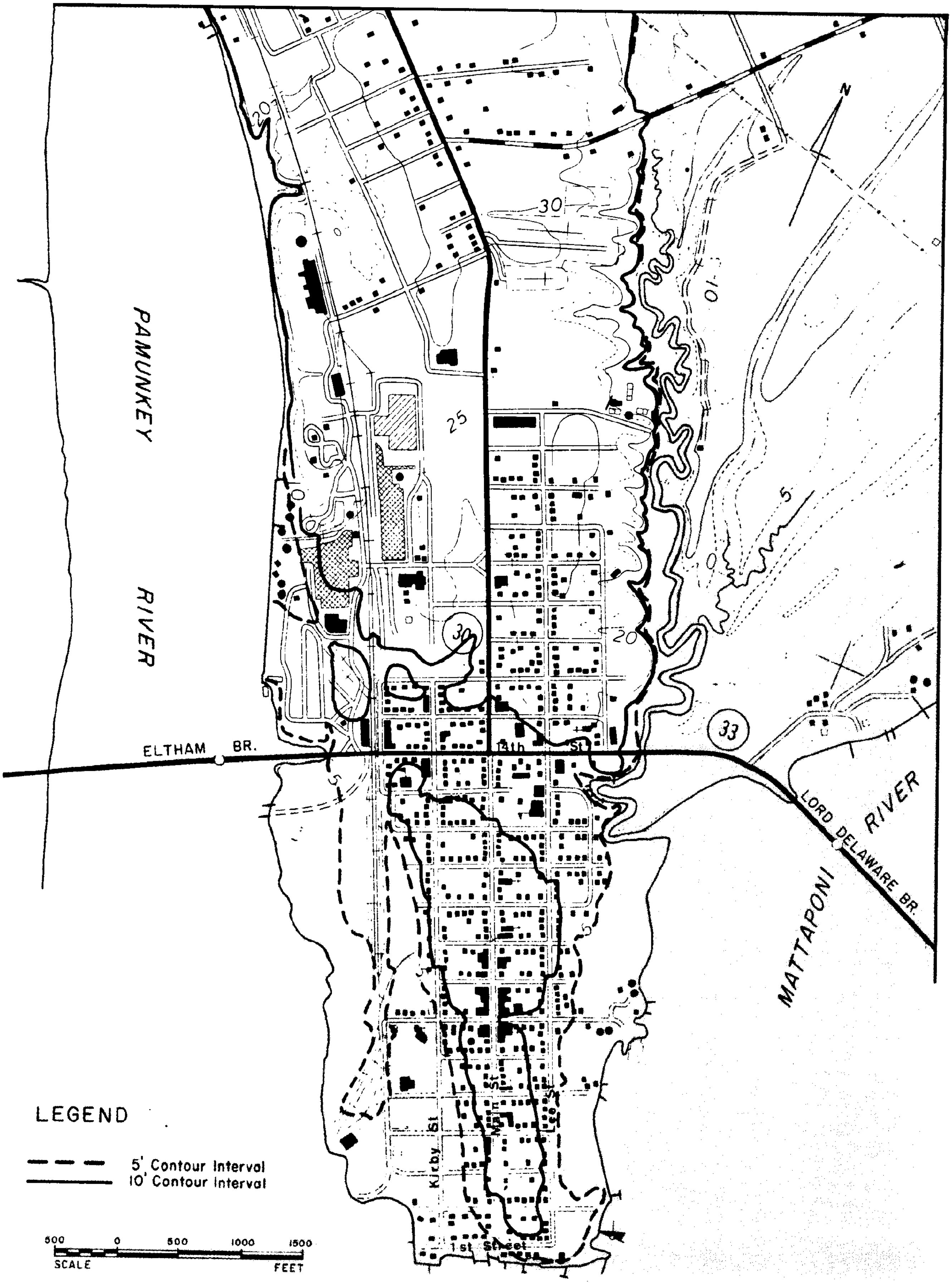


FIGURE 24 WEST POINT AREA FLOOD MAP

Assessment and Evaluation of Plans

Maryland Communities

Cambridge

Economic Analysis

A total of eight plans of protection were considered for the Cambridge area. The structural plans were the most costly with first costs ranging from $5.1 to $9.1 million as shown in Table 23. The structural plans were also the least cost effective with all plans having benefit-cost ratios of approximately 0.1. The non-structural plans were considerably less expensive ($357,000 and $749,000) than the structural plans; however, there is no economic justification for their implementation either. Table 23 also presents a detailed breakdown of the annual costs and benefits of each of the eight plans considered.

Assessment and Evaluation

The floodwall/levee plans would meet the study objective of providing flood protection for the low lying urban areas within the City of Cambridge. The two levels of protection considered would prevent flooding from the 120-year (approximate FOR) and the flood approximating the 500-year event.

As noted in the preceding paragraph, there is no economic justification for the structural plans of protection. In addition, if the structural plans were imple-

TABLE 23

SUMMARY ECONOMIC ANALYSIS OF ALTERNATIVE PLANS FOR CAMBRIDGE
(April 1980 Prices)
($1,000's)

	PLAN							
Item	*CA-1*	*CA-2*	*CA-3*	*CA-4*	*CA-5*	*CA-6*	*CA-7*	*CA-8*
Costs								
First	$7,588	$5,869	$5,156	$9,121	$7,028	$6,061	$357	$749
Annual								
I&A	541	419	368	651	501	432	26	55
O&M	47	36	32	56	44	38	0	0
Total	$ 588	$ 455	$ 400	$ 707	$ 545	$ 470	$ 26	$ 55
Benefits								
Intensification	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
Location	0	0	0	0	0	0	0	0
Employment	79	61	54	94	72	62	4	8
Inundation Reduction								
Existing	6	5	3	10	7	5	10	12
Future[1]	0	0	0	0	0	0	0	0
Total	$ 85	$ 66	$ 57	$ 104	$ 79	$ 67	$ 14	$ 20
Net Benefits	-$503	-$389	-$343	-$603	-$466	-$403	-$12	-$35
Benefit-Cost Ratio	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.4

[1]Consists of affluence factor for residential contents only.

TABLE 24

COMPARATIVE ASSESSMENT AND EVALUATION CAMBRIDGE, MARYLAND

Study Objective	*Plan*	*Description of Plan*	*Beneficial Effects*
Reduce flood damages in Cambridge.	Plan CA-1 Map Ref A-D	15,500 feet of Levee/wall which runs along a portion of the southern bank of the Choptank River from the city's western Limits (Pink's Pond) eastward; including Cambridge Creek and ending near the Port Commission Terminal *(6' NGVD design elev.).*	Will reduce flood hazard and provide degree of protection indicated for the portion of Cambridge within the city limits.
Reduce flood damages in Cambridge.	Plan CA-2 Map Ref B-D	11,400 feet of Levee/wall which begins near Mill St. and includes the municipal boat basin and Cambrdige Creek ending near the Port Commission Terminal *(6' NGVD design elev.)*	Will reduce flood hazard and provide degree of protection indicated for the area of Cambridge Creek and the municipal boat basin *only.*
Reduce flood damages in Cambridge.	*Plan CA-3 Map Ref C-D*	9,700 feet of Levee/wall which begins near High St., includes Cambridge Creek and ends near the Port Commission Terminal *(6'NGVD design elev.).*	Will reduce flood hazard and provide degree of protection indicated for the area of Cambridge Creek *only.*
Reduce flood damages in Cambridge.	Plan CA-4 Map Ref A—D	15,625 feet of Levee/wall which runs along a portion of the southern bank of the Choptank River from the city's western limits (Pink's Pond) eastward; including the municipal boat basin and Cambridge Creek areas and ending near the Port Commission Terminal *(8' NGVD design elev.).*	Will reduce flood hazard and provide degree of protection indicated for the portion of Cambridge within the city limits.
Reduce flood damages in Cambridge	Plan CA-5 Map Ref B-D	11,550 feet of Levee/wall which begins near Mill St. and includes the municipal boat basin and Cambridge Creek ending ending near the Port Commission Terminal *(8' NGVD design elev.).*	Will reduce flood hazard and provide degree of protection indicated for the area of Cambridge Creek and the municipal boat basin *only.*
Reduce flood damages in Cambridge.	Plan CA-6 Map Ref C-D	9,850 feet of Levee/wall which begins near High St., includes Cambridge Creek and ends near the Port Commission Terminal *(8' NGVD design elev.).*	Will reduce flood hazard and provide degree of protection indicated for the area of Cambridge Creek *only.*
Reduce flood damages in Cambridge.	Plan CA-7	Nonstructural protection to the *5' NGVD (40-year)* flood level; includes utility addition, standard floodproofing and floodproofing by floodwall.	Will reduce flood hazard and provide degree of protection iondicated for the entire community.
Reduce flood damages in Cambridge.	Plan CA-8	Nonstructural protection to the *6'NGVD (120-year)* flood levee; includes utility addition, acquisition and demolition, standard floodproofing and floodproofing by floodwall.	Will reduce flood hazard and provide degree of protection indicated for the entire community.

D.O.P. = Degree of Protection
F.C. = First Cost
A.A.C. = Average Annual Costs
A.A.B. = Average Annual Benefits
B.C.R. = Benefit-Cost Ratio

Adverse Effects	*Economics*
Destruction of fringe marsh areas scattered around the shores of Cambridge Creek (< 10 acres). Approximately six acres of wetland type #17 (irregularly flooded salt marsh) will be cut off by construction of flood wall/Levee resulting in eventual destruction. Less than five acres of marsh will be affected due to construction near Gray Marsh. Temporary destruction of benthic organisms due to construction. Recolonization may occur after completion of construction. Some permanent loss of habitat may also occur. Increased siltation and turbidity which may effect submerged aquatic vegetation and fish. Use of shoreline will be restricted and access to existing piers and wharves difficult. Adverse effects to the aesthetic conditions of the area.	D.O.P. = 120-year F.C. = $7,588,000 A.A.C. = $587,000 A.A.B. = $85,500 B.C.R. = 0.14
Same as above.	D.O.P. = 120-year F.C. = $5,869,200 A.A.C. = $454,000 A.A.B. = $65,900 B.C.R. = 0.14
Same as above.	D.O.P. = 120-year F.C. = $5,156,400 A.A.C. = $399,600 A.A.B. = $57,300 B.C.R. = 0.14
Same as above.	D.O.P. = stand. project flood F.C. = $9,120,600 A.A.C. = $706,700 A.A.B. = $103,800 B.C.R. = 0.15
Same as above.	D.O.P. = stand. project flood F.C. = $7,028,400 A.A.C. = $545,000 A.A.B. = $79,200 B.C.R. = 0.14
Same as above.	D.O.P. = stand. project flood F.C. = $6,061,200 A.A.C. = $469,900 A.A.B. = $67,200 B.C.R. = 0.14
Construction of small floodwalls may result in adverse environmental effects such as destruction of adjacent wetland areas, increased siltation and turbidity and destruction of benthic organisms. Use of shoreline will be restricted and access to existing piers and wharves difficult.	D.O.P. = 40-year F.C. = $356,300 A.A.C. = $26,200 A.A.B. = $13,500 B.C.R. = 0.52
Same as above.	D.O.P. = 120-year F.C. = $749,150 A.A.C. = $55,150 A.A.B. = $20,200 B.C.R. = 0.37

mented the use of the shoreline would be severely restricted and access would have to be provided to existing wharves and piers. Construction impacts associated with the structural plans would include noise pollution, destruction of benthic organisms due to turbidity and siltation, loss of some wetland areas and the creation of dust. Last, there would be adverse aesthetic impacts associated with constructing a floodwall/levee between the existing development and the scenic vista of the Choptank River.

The two nonstructural plans considered would provide protection against either a 40-year flood (elevation five feet NGVD) or a 120-year flood (elevation six feet NGVD). Both plans were found lacking from the standpoint of economic feasibility. The nonstructural plans would not be expected to have a significant environmental impact. There would be only minor temporary impacts during the relocation or demolition of the structures affected. There would also be some adverse social impacts associated with those individuals required to relocate. A full array of the beneficial and adverse effects of each of the plans is included in Table 24.

Crisfield

Economic Analysis

A total of six plans of protection were considered for Crisfield. As shown in Table 25, the total first cost of the plans ranged from $7.3 to $0.7 million with the least costly plan being the nonstructural plan that would provide protection to elevation 4.0. This plan was also found to be the most cost effective with a benefit-cost ratio of 0.6. The benefits accruing to the plans are categorized as employment and inundation reduction (existing and future). Table 26 presents a detailed breakdown of the annual benefits and costs for all the plans considered.

Assessment and Evaluation

The floodwall/levee plans investigated would nearly encircle the Town of Crisfield and protect against floods with return intervals of approximately 80 to 400 years. As noted in the preceding paragraph, there is no economic justification for any of the plans considered.

The construction impacts associated with building levees and floodwalls in Cris-

TABLE 25

SUMMARY ECONOMIC ANALYSIS OF ALTERNATIVE PLANS FOR CRISFIELD
(April 1980 Prices)
($1,000's)

ITEM	CR-1	CR-2	CR-3	CR-4	CR-5	CR-6
Costs						
First	$ 7,019	$ 7,333	$ 5,807	$ 7,215	$ 676	$ 6,294
Annual						
I&A	501	523	414	515	50	463
O&M	42	44	35	43	0	0
Total	$ 543	$ 567	$ 449	$ 558	$ 50	$ 463
Benefits						
Intensification	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
Location	0	0	0	0	0	0
Employment	72	76	60	75	7	65
Inundation Reduction						
Existing	71	92	66	85	24	89
Future[1]	2	3	2	3	1	3
Total	$ 145	$ 171	$ 128	$ 163	$ 32	$ 157
Net Benefits	-$398	-$396	-$321	-$395	-$18	-$306
Benefit-Cost Ratio	0.3	0.3	0.3	0.3	0.6	0.3

[1]Consists of affluence factor for residential contents only.

field would be essentially the same as those previously discussed for Cambridge; however, a more substantial acreage of wetlands and fringe marshes would be destroyed. Also, adverse social impacts would be expected to be major due to the extensive nature of the plan and the limiting of access to the water of a predominately water-oriented community.

The nonstructural plans would not be expected to have significant long-term environmental or social impacts of an adverse nature. Plan CR-5 has the most favorable economic evaluation (B-C Ratio + 0.6); however, it is unlikely that a more rigorous examination of the costs and benefits associated with this plan would result in a favorable project. A full array of the beneficial and adverse effects of each of the plans is included in Table 26.

Pocomoke City

Economic Analysis

Five plans of protection were considered for Pocomoke City. The structural plans were the most costly with first costs of $3.5 and $4.3 million for plans PC-1 and PC-2, respectively. From an economic standpoint, both structural plans were very ineffective as they had benefit-cost ratios of 0.1 or less. The nonstructural plans while less costly ($1.3 to $0.3 million) were also not economically justified. Table 27 presents a detailed breakdown of all annual costs and benefits for each of the plans considered.

Assessment and Evaluation

The plans of protection investigated would have satisfied to varying degrees the study objective of providing flood protection for the flood-prone area in Pocomoke City. As noted previously none of the plans investigated were found to be economically feasible. The best plan from an economic standpoint was PC-3 which was a nonstructural plan having a benefit-cost ratio of 0.5.

The environmental and social impacts associated with the alternatives considered would be similar to those previously discussed for Cambridge and Crisfield. An area of concern would be the adverse environmental/aesthetic impacts of a structural plan in the Cypress Park area. The beneficial and adverse impacts of all the plans considered are shown in Table 28.

Rock Hall

Economic Analysis

A total of 10 plans of protection were considered for Rock Hall. Included in Table 29 is a summary of the findings of the economic analysis conducted for each plan. The table includes first costs, annual costs, annual benefits and benefit-cost ratios for each plan.

The benefits accruing to the plans considered are categorized as employment and inundation reduction (existing and future). With benefit-cost ratios of either 0.2 or 0.3, it is obvious there is no economic justification for any of the plans of improvement.

Assessment and Evaluation

The floodwall/levee plans investigated would protect Rock Hall and Gratitude against floods with return inverbals of approximately 140 and 500 years. While meeting the study objective of providing flood protection for the community, the structural plans would have some adverse environmental and social impacts as noted in Table 30. The nonstructural plans RH-7 thru RH-10, while not providing the degree of protection offered by the structural plans, would not be expected to have significant environmental or social impacts. The one exception would be Plan RH-10 which requires such a large number of relocations and acquisitions and demolitions that adverse social impacts would likely be severe. As noted in the preceding paragraph, all plans considered lacked economic justification and it is unlikely that a more detailed examination would materially effect the results of the studies to date.

Snow Hill

Economic Analysis

A total of seven plans of protection were considered for Snow Hill. The structural plans were the most costly with the first costs ranging from $2.8 to $3.7 million. From an economic standpoint none of the structural plans, while less costly $1.2 to $0.3 million), were also not economically justified. Table 31 presents a detailed breakdown of the annual costs and benefits for each of the plans considered.

Assessment and Evaluation

The plans of protection investigated would have satisfied to varying degrees the study objective of providing flood protection for the flood-prone area in Snow Hill. As noted previously, none of the plans investigated were found to be economically feasible.

The environmental and social impacts associated with the alternatives considered would be similar to those previously discussed for Cambridge and Crisfield. An area of concern would be the adverse environmental/aesthetic impacts of a structural plan in the Byrd Park area. Included as Table 32 is a comparative assessment of the beneficial and adverse impacts of all the plans considered.

St. Michaels

Economic Analysis

The four plans investigated had first costs ranging from nearly $12.0 to $0.7 million. As shown in Table 33, a comparison of annual benefits and costs yields B-C ratios of 0.2 and lower for the alternatives considered.

Assessment and Evaluation

Based on review of the findings of the economic analyses it may be concluded that further investigation of St. Michaels is not warranted. Consideration of some of the adverse social and environmental impacts associated with the structural plans would also strongly support the above conclusion. Of particular concern would be the adverse social/aesthetic impacts associated with levee and floodwall construction in the harbor area in the vicinity of the Chesapeake Maritime Museum. A full listing of all impacts associated with the plans is included in Table 34.

Tilghman Island

Economic Analysis

Seven plans of protection were considered for Tilghman Island. As shown in Table 35 the total first costs of the alternatives had a wide range ($8.9 to $0.1 million). As further indicated in the Table all plans were found to lack economic justification by a wide margin. The structural plans all had benefit-cost ratios less than 0.1 while the most cost effective nonstructural plan (TI-5) had a benefit-cost ratio of only 0.3.

Assessment and Evaluation

Based on the results of the economic analyses it appears that further consideration of flood protection measures for Tilghman Island is not warranted. The adverse environmental and social impacts associated with the structural plans in particular would also support this conclusion. Table 36 provides a comparison of all beneficial and adverse impacts of the plans investigated.

Virginia Communities

Cape Charles

Economic Analysis

An analysis was not conducted of the costs and benefits associated with the modifications previously discussed. Such accomplishment by the Corps would require the raising of the existing wooden bulkhead to at least the level of the 100-year storm plus wave action and freeboard, construction of dikes on the north and south sides of the town to the same level, reconstruction of some of the storm outlets and the installation therein of tide gates, and the construction of a pumping station. Such a project would not be justified on the basis of the benefits to be derived. Included as Table 37 is a summary of the benefits and costs associated with the four nonstructural plans. It should be noted that all plans considered had benefit-cost ratios of 0.13 or less.

Assessment and Evaluation

As shown in Table 38 the plans studied would have little impact on the community except during construction operations. The addition of earth levees on the north and south sides of the town to the same level as the top of the existing bulkhead could be so sloped as to create no adverse effect. A closure may be required on the south side where the commercial area is located.

Raising the few residential buildings and stores, constructing small adjoining buildings to house existing utilities that are now located in the basements of these structures and providing temporary closures for windows in basements would have practically no effect on adjacent property or on the community. No significant environmental and/or biological impacts appear to be associated with the above plans.

Hampton Roads

Economic Analysis

The first cost of the three plans considered in Fox Hill ranged from almost $3.2 million for the structural plan to $0.9 million for the 25-year nonstructural plans. Table 39 includes a summary of the annual benefits and costs associated with the plans considered.

Assessment and Evaluation

A substantial portion of the Hampton Roads city complex is susceptible to tidal flood damage. There are tidal flood protection projects for the downtown commercial areas of Norfolk and Portsmouth. Also the Corps has recently recommended the construction of a protective sand berm along the entire 7.3-mile Chesapeake Bay shoreline of the

TABLE 26

COMPARATIVE ASSESSMENT AND EVALUATION CRISFIELD, MARYLAND

Study Objective	*Plan*	*Description of Plan*	*Beneficial Effects*
Reduce flood damages in Crisfield.	Plan CR-1 Map Ref A-C	22,600 feet of levee/wall beginning at high ground near Jacksonville Road and running along the shoreline to exclude Somer's Cove and tie-out at high ground near Johnson Creek Road (*5' NGVD design elev.*).	Will reduce flood hazard and provide degree of protection indicated for most of Crisfield and the surrounding area.
Reduce flood damages in Crisfield.	Plan CR-2 Map Ref A-C	23,300 feet of levee/wall with identical alignment as Plan CR-1. Degree of protection increases to 400-year recurrence level. Additional levee sections are needed to tie into higher ground (*6' NGVD design elev.*).	Will reduce flood hazard and provide degree of protection indicated for most of Crisfield and the surrounding area.
Reduce flood damages in Crisfield.	Plan CR-3 Map Ref A-B	20,900 feet of levee/wall beginning at high ground near Outten Road and running along the shoreline to exclude Somer's Cove and tie out at high ground near the intersection of Johnson Creek Rd. and Rt. 380 (*5' NGVD design elev.*).	Will reduce flood hazard and provide degree of protection indicated for most of Crisfield and the surrounding area.
Reduce flood damages in Crisfield.	Plan CR-4 Map Ref A-B	21,650 feet of levee/wall with identical alignment as Plan CR-3. Degree of protection increases to 400-year recurrence level. Additional levee sections are needed to tie into higher ground. (*6' NGVD design elev.*).	Will reduce flood hazard and provide degree of protection indicated for most of Crisfield and the surrounding area.
Reduce flood damages in Crisfield.	Plan CR-5	Nonstructural protection to the *4' NGVD (12-year)* flood level; includes utility addition, acquisition and demolition, trailer relocation, structure raising, standard floodproofing, and floodproofing by floodwalls.	Will reduce flood hazard and provide degree of protection indicated for entire community.
Reduce flood damages in Crisfield.	Plan CR-6	Nonstructural protection to the *5' NGVD (80-year)* flood level; includes utility addition, acquisition and demolition, trailer relocation, structure raising, standard floodproofing, and floodproofing by floodwalls.	Will reduce flood hazard and provide degree of protection indicated for entire community.

Adverse Effects	*Economics*
Destruction of fringe marsh areas near Woodson High School (< 5 acres), near Collins Street west of Main Street, (< 10 acres) and west of Wynnfall Ave (< 20 acres). Destruction of marsh area west of Jacksonville Road to the site of construction (< 25 acres). Temporary destruction of benthic organisms due to construction. Recolonization may occur after completion of construction. Some permanent loss of habitat may also occur. Increased siltation and turbidity due to construction which may effect submerged aquatic vegetation and fish. Use of shoreline will be severely restricted. Adverse effects to the aesthetic conditions of the area.	D.O.P. = 80-year F.C. = $7,018,000 A.A.C. = $543,100 A.A.B. = $145,700 B.C.R. = 0.27
Same as above.	D.O.P. = 400-year F.C. = $7,333,200 A.A.C. = $567,200 A.A.B. = $172,000 B.C.R. = 0.30
Same as above except excluding destruction of marsh area near Jacksonville Road.	D.O.P. = 80-year F.C. = $5,807,400 A.A.C. = $449,100 A.A.B. = $128,300 B.C.R. = 0.29
Same as plan CR-3.	D.O.P. = 400-year F.C. = $7,215,000 A.A.C. = $558,200 A.A.B. = $164,200 B.C.R. = 0.29
Loss of unique social life style for those that are relocated. Construction of floodwall may result in adverse environmental effects such as destruction of adjacent wetland areas, increased siltation and turbidity, and destruction of benthic organisms. Use of shoreline will be restricted. Adverse effects to the aesthetic conditions of the area. Temporary noise pollution.	D.O.P. = 12-year F.C. = $676,300 A.A.C. = $49,800 A.A.B. = $33,000 B.C.R. = 0.66
Same as above.	D.O.P. = 80-year F.C. = $6,294,300 A.A.C. = $463,300 A.A.B. = $158,600 B.C.R. = 0.34

City of Norfolk. Although the studies in this and previous reports offer some insight to the feasibility of both structural and nonstructural alternatives, they are not sufficient to present conclusive evidence of the economic feasibility of tidal flood protection based on today's level of residential, commercial, and industrial development. Further comprehensive consideration of both structural and nonstructural measures for the protection of portions of the Hampton Roads city complex — Norfolk, Portsmouth, Chesapeake, and Hampton — from tidal flooding is warranted. Table 40 provides an assessment and evaluation of the plans considered.

TABLE 27

SUMMARY ECONOMIC ANALYSIS OF ALTERNATIVE PLANS FOR POCOMOKE CITY
(April 1980 Prices)
($1,000's)

	PLAN				
Item	*PC-1*	*PC-2*	*PC-3*	*PC-4*	*PC-5*
Costs					
First	$ 3,543	$ 4,323	$ 260	$ 729	$ 1,357
Annual					
I&A	253	308	19	54	100
O&M	22	27	0	0	0
Total	$ 275	$ 335	$ 19	$ 54	$ 100
Benefits					
Intensification	$ 0	$ 0	$ 0	$ 0	$ 0
Location	0	0	0	0	0
Employment	0	0	0	0	0
Inundation Reduction					
Existing	11	17	10	14	18
Future[a]					
Total	$ 11	$ 17	$ 10	$ 14	$ 18
Net Benefits	-$264	-$318	-$9	-$40	-$82
Benefit-Cost Ratio	0.0	0.1	0.5	0.3	0.2

[1] Consists of affluence factor for residential contents only.

TABLE 28

COMPARATIVE ASSESSMENT AND EVALUATION POCOMOKE CITY, MARYLAND

Study Objective	*Plan*	*Description of Plan*	*Beneficial Effects*
Reduce flood damages in Pocomoke City	Plan PC-1 Map Ref A-B	10,190 feet of levee/wall which runs along the eastern banks of the Pocomoke River south of the Rt. 13 Bridge (*6′ NGVD design elev.*).	Will reduce flood hazard and provide degree of protection indicated for the portion of Pocomoke City south of the Rt. 13 Bridge.
Reduce flood damages in Pocomoke City	Plan PC-2 Map Ref A-B	10,500 feet of levee/wall which runs along the eastern banks of the Pocomoke River south of the Rt. 13 Bridge (*8′ NGVD design elev.*).	Will reduce flood hazard and provide degree of protection indicated for the portion of Pocomoke City south of the Rt. 13 Bridge.
Reduce flood damages in Pocomoke City	Plan PC-3	Nonstructural protection to the *5′ NGVD (25-year)* flood level; includes utility relocation, acquisition and demolition, and floodproofing by floodwall.	Will reduce flood hazard and provide degree of protection indicated for entire community.
Reduce flood damages in Pocomoke City	Plan PC-4	Nonstructural protection to the *6′ NGVD (70-year)* flood level; includes utility relocation, structure raising, acquisition and demolition, trailer relocation, standard floodproofing, and floodproofing by floodwall.	Will reduce flood hazard and provide degree of protection indicated for entire community.
Reduce flood damages in Pocomoke City	Plan PC-5	Nonstructural protection to the *7′ NGVD (220-year)* flood level; includes utility relocation, acquisition and demolition, trailer relocation, structure raising, standard floodproofing, and floodproofing by floodwall.	Will reduce flood hazard and provide degree of protection indicated for entire communtiy.

TABLE 29

SUMMARY ECONOMIC ANALYSIS OF ALTERNATIVE PLANS FOR ROCK HALL
(April 1980 Prices)
($1,000's)

PLAN

Item	*RH-1*	*RH-2*	*RH-3*	*RH-4*	*RH-5*	*RH-6*	*RH-7*	*RH-8*	*RH-9*	*RH-10*
Costs										
First	$ 9,455	$ 13,514	$ 7,996	$ 10,308	$ 3,292	$ 4,797	$ 1,093	$ 2,504	$ 4,832	$ 7,081
Annual										
I&A	674	964	570	735	235	342	81	184	356	521
O&M	58	82	49	63	20	29	0	0	0	0
Total	$ 732	$ 1,046	$ 619	$ 798	$ 255	$ 81	$ 184	$ 356	$ 521	
Benefits										
Intensification	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
Location	0	0	0	0	0	0	0	0	0	0
Employment	97	139	82	106	34	49	11	26	50	73
Inundation Reduction										
Existing	39	53	23	32	15	21	12	24	40	50
Future[1]	1	2	1	1	1	1	0	1	2	2
Total	$ 137	$ 194	$ 106	$ 139	$ 50	$ 71	$ 23	$ 51	$ 92	$ 125
Net Benefits	-$595	-$852	-$513	-$659	-$205	-$300	-$58	-$133	-$264	-$396
Benefit-Cost Ratio	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.2

[1] Consists of affluence factor for residential contents only.

Adverse Effects	*Economics*
Impact on the wooded wetland areas on the shore at the end of Laurel Street and northwest of Quinn Avenue (total area < 10 acres). Temporary destruction of benthic organisms due to construction. Recolonization may occur after completion of construction. Some permanent loss of habitat may also occur.	D.O.P. = 70-year F.C. = $3,542,600 A.A.C. = $274,800 A.A.B. = $11,000 B.C.R. = 0.04
Same as above.	D.O.P. = stand. project flood F.C. = $4,322,700 A.A.C. = $335,300 A.A.B. = $16,600 B.C.R. = 0.05
Construction of floodwall may result in adverse environmental effects such as destruction of adjacent wetland areas, increased siltation and turbidity, and destruction of benthic organisms. Use of shoreline will be restricted. Adverse effects to the aesthetic conditions of the area. Temporary noise pollution.	D.O.P. = 25-year F.C. = $259,700 A.A.C. = $19,100 A.A.B. = $10,100 B.C.R. = 0.53
Same as above with the addition of loss of unique social lifestyle for those that are relocated.	D.O.P. = 70-year F.C. = $728,500 A.A.C. = $53,600 A.A.B. = $13,000 B.C.R. = 0.24
Same as above.	D.O.P. = 220-year F.C. = $1,357,200 A.A.C. = $99,900 A.A.B. = $18,000 B.C.R. = 0.18

TABLE 30

COMPARATIVE ASSESSMENT AND EVALUATION
ROCK HALL, MARYLAND

Study Objective	*Plan*	*Description of Plan*	*Beneficial Effects*
Reduce flood damages in Rock Hall	Plan RH-1 Map Ref A-E	22,400 feet of levee/wall "ringing" the Rock Hall—Gratitude areas (*9' NGVD design elev.*).	Will reduce flood hazard and provide degree of protection indicated for both Rock Hall and Gratitude.
Reduce flood damages in Rock Hall	Plan RH-2 Map Ref A-G	25,500 feet of levee/wall "ringing" the Rock Hall-Gratitude areas. Includes protection from flooding on Gray's Inn Creek. (*12' NGVD design elev.*).	Will reduce flood hazard and provide degree of protection indicated for both Rock Hall and Gratitude.
Reduce flood damages in Rock Hall	Plan RH-3 Map Ref B,C,D	16,000 feet of levee/wall encircling the Gratitude area *only (9' NGVD design elev.*).	Will reduce flood hazard and provide degree of protection indicated for the Gratitude area *only*.
Reduce flood damages in Rock Hall	Plan RH-4 Map Ref B,C, D	16,000 feet of levee/wall encircling the Gratitude area *only (12' NGVD design elev.*).	Will reduce flood hazard and provide degree of protection indicated for the Rock Hall area *only*.
Reduce flood damages in Rock Hall	Plan RH-5 Map Ref A-B, D-E	9,900 feet of levee/wall encircling the Rock Hall area *only (9' NGVD design elev.*).	Will reduce flood hazard and provide degree of protection indicated for the Rock Hall area *only*.
Reduce flood damages in Rock Hall	Plan RH-6 Map Ref A-B-D-E-F-G	11,650 feet of levee/wall encircling the Rock Hall area *only*. Includes protection from flooding on Gray's Inn Creek (*12' NGVD design elev.*).	Will reduce flood hazard and provide degree of protection indicated for the Rock Hall area *only*.

Adverse Effects	*Economics*
Destruction of marsh areas along the shoreline in Rock Hall Harbor (< 2 acres) northwest of Windmill Point (< 20 acres) and east of Rock Hall Harbor (< 10 acres). A portion of the marsh areas in Gratitude near the Havens will be destroyed due to construction (< 20 acres). Use of shoreline will be severely restricted and access to existing piers and wharves difficult. Temporary destruction of benthic organisms due to construction. Recolonization may occur after completion of construction. Some permanent loss of habitat may also occur. Increased siltation and turbidity due to construction which may effect submerged aquatic vegetation and fish. Adverse effects to the aesthetic conditions of the area.	D.O.P. = 140-year F.C. = $9,454,800 A.A.C. = $731,900 A.A.B. = $137,100 B.C.R. = 0.19
Same as above with additional marsh destruction near Gray's Inn Creek. (< 10 acres).	D.O.P. = stand. project flood F.C. = $13,513,800 A.A.C. = $1,046,300 A.A.B. = $194,500 B.C.R. = 0.19
Destruction of marsh area along the shoreline in Rock Hall Harbor (< 2 acres), northwest of Windmill Point (< 20 acres), two areas near the Havens (< 20 acres) and a fringe area north of Caroline Avenue (< 1 acre). Temporary destruction of benthic organisms due to construction. Recolonization may occur after completion of construction. Some permanent loss of habitat may also occur. Increased siltation and turbidity due to construction which may effect submerged vegetation and fish. Adverse effects to the aesthetic conditions of the area. Use of shoreline will be restricted.	D.O.P. = 140-year F.C. = $7,995,600 A.A.C. = $619,200 A.A.B. = $106,700 B.C.R. = 0.17
Same as above.	D.O.P. = stand. project flood F.C. = $10,308,200 A.A.C. = $798,500 A.A.B. = $139,000 B.C.R. = 0.17
Partial destruction of marsh areas east of Rock Hall Harbor (< 20 acres) and on the eastern shore of the Havens (< 15 acres). Use of shoreline restricted. Adverse effects to the aesthetic conditions of the area. Temporary destruction of benthic organisms due to construction. Recolonization may occur after completion of construction. Some permanent loss of habitat may also occur. Increased siltation and turbidity due to construction which may effect submerged aquatic vegetation and fish.	D.O.P. = 140-year F.C. = $3,291,600 A.A.C. = $254,600 A.A.B. = $50,400 B.C.R. = 0.20
Same as above with the addition of marsh destruction along Gray's Inn Creek (< 10 acres).	D.O.P. = stand. project flood F.C. = $4,797,000 A.A.C. = $370,900 A.A.B. = $71,500 B.C.R. = 0.19

TABLE 31

SUMMARY ECONOMIC ANALYSIS OF ALTERNATIVE PLANS FOR SNOW HILL (April 1980 Prices) ($1,000's)

	PLAN						
ITEM	*SH-1*	*SH-2*	*SH-3*	*SH-4*	*SH-5*	*SH-6*	*SH-7*
Costs							
First	$3,011	$2,845	$3,742	$3,596	$304	$421	$1,210
Annual							
I&A	215	203	267	256	22	38	89
O&M	19	18	23	23	0	0	0
Total	$ 234	$ 221	$ 290	$ 279	$ 22	$ 38	$ 89
Benefits							
Intensification	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
Location	0	0	0	0	0	0	0
Employment	0	0	0	0	0	0	
Inundation Reduction							
Existing	5	5	9	8	3	6	8
Future[1]	0	0	0	0	0	0	0
Total	$ 5	$ 5	$ 9	$ 8	$ 3	$ 6	$ 8
Net Benefits	-$229	-$216	-$281	-$271	-$19	-$32	-$81
Benefit-Cost Ratio	0.02	0.02	0.03	0.03	0.1	0.2	0.09

[1]Consists of affluence factor for residential contents only.

TABLE 30 (Cont'd)

Study Objective	*Plan*
Reduce flood damages in Rock Hall	Plan RH-7
Reduce flood damages in Rock Hall	Plan RH-8
Reduce flood damages in Rock Hall	Plan RH-9
Reduce flood damages in Rock Hall	Plan RH-10

TABLE 32

COMPARATIVE ASSESSMENT AND EVALUATION SNOW HILL, MARYLAND

Study Objective	*Plan*	*Description of Plan*	*Beneficial Effects*
Reduce flood damages in Snow Hill	Plan SH-1 Map Ref A-C	7,190 feet of levee/wall which runs along the southern banks of the Pocomoke River from north of the Rt. 12 Bridge to the city's southern limits *(6' NGVD design elev.)*.	Will reduce flood hazard and provide degree of protection indicated for the entire community.
Reduce flood damages in Snow Hill	Plan SH-2 Map Ref A-B	5,080 feet of levee/wall which runs along the southern banks of the Pocomoke River from just north of the Rt. 12 Bridge to the city's southern limits *(6' NGVD design elev.)*.	Will reduce flood hazard and provide degree of protection indicated for the entire community.
Reduce flood damages in Snow Hill	Plan SH-3 Map Ref A-D	7,920 feet of levee/wall which runs along the southern banks of the Pocomoke River from near the northern city limits to the city's southern limits *(8' NGVD design elev.)*.	Will reduce flood hazard and provide degree of protection indicated for the entire community.
Reduce flood damages in Snow Hill	Plan SH-4 Map Ref A-B	6,460 feet of levee/wall which runs along the southern banks of the Pocomoke River from north of the Rt. 12 Bridge to the city's southern limits. *(8' NGVD design elev.)*.	Will reduce flood hazard and provide degree of protection indicated for entire community.

COMPARATIVE ASSESSMENT AND EVALUATION
ROCK HALL, MARYLAND

Description of Plan	*Beneficial Effects*	*Adverse Effects*	*Economics*
Nonstructural protection to the *5′ NGVD (15-year)* flood level; includes utility addition, acquisition and demolition, trailer relocation, standard floodproofing, and floodproofing by floodwalls.	Will reduce flood hazard and provide degree of protection indicated for entire community.	Loss of unique social life style for those relocated. Construction of floodwall may result in adverse environmental effects such as destruction of adjacent wetland areas, increased siltation and turbidity, and destruction of benthic organisms. Use of shoreline will be restricted. Adverse effects to the aesthetic conditions of the area. Temporary noise pollution.	D.O.P. = 15-year F.C. = $1,093,000 A.A.C. = $80,450 A.A.B. = $22,500 B.C.R. = 0.28
Nonstructural protection to the *6′ NGVD (25-year)* flood level; includes utility additions, house raising, trailer relocation, acquisition and demolition, standard floodproofing, and floodproofing by floodwalls.	Will reduce flood hazard and provide degree of protection indicated for entire community.	Same as above.	D.O.P. = 25-year F.C. = $2,504,450 A.A.C. = $184,350 A.A.B. = $50,900 B.C.R. = 0.26
Nonstructural protection to the *7′ NGVD (50-year)* flood level; includes utility additions, house raising, trailer and house relocation, acquisition and demolition, standard floodproofing, and floodproofing by floodwalls.	Will reduce flood hazard and provide degree of protection indicated for entire community.	Same as above.	D.O.P. = 50-year F.C. = $4,831,500 A.A.C. = $355,650 A.A.B. = $91,500 B.C.R. = 0.26
Nonstructural protection to the *8′ NGVD (80-year)* flood level; includes utility additions, house raising, house and trailer relocation, acquisition and demolition, standard floodproofing, and floodproofing by floodwalls.	Will reduce flood hazard and provide degree of protection indicated for entire community.	Same as above.	D.O.P. = 80-year F.C. = $7,080,700 A.A.C. = $521,200 A.A.B. = $125,100 B.C.R. = 0.24

Adverse Effects	*Economics*
Construction will impact on the wooded areas along the river just north of Green Street (< 2 acres). A fringe marsh area along the shore near Commerce Street will be destroyed (< 2 acres). Adverse effects to the aesthetic conditions of the areas especially at Byrd Park. Cypress trees in the park along the shoreline will be impacted due to construction. Temporary destruction of benthic organisms due to construction. Recolonization may occur after completion of construction. Increased siltation and turbidity due to construction which may effect submerged aquatic vegetation and fish. Use of the shoreline will be severely restricted.	D.O.P. = 70-year F.C. = $3,010,800 A.A.C. = $233,500 A.A.B. = $5,500 B.C.R. = 0.02
Same as above.	D.O.P. = 70-year F.C. = $2,844,600 A.A.C. = $220,700 A.A.B. = $5,300 B.C.R. = 0.02
Same as above with the addition of extension of impacts on the wooded area near the cemetery (< 10 acres).	D.O.P. = stand. project flood F.C. = $3,741,600 A.A.C. = $290,300 A.A.B. = $9,100 B.C.R. = 0.03
Same as SH-1.	D.O.P. = approximate 500-year F.C. = $3,595,600 A.A.C. = $278,900 A.A.B. = $8,800 B.C.R. = 0.03

TABLE 32 (Cont'd)

COMPARATIVE ASSESSMENT AND EVALUATION
SNOW HILL, MARYLAND

Study Objective	*Plan*	*Description of Plan*	*Beneficial Effects*
Reduce flood damages in Snow Hill	Plan SH-5	Nonstructural protection to the *5' NGVD (25-year)* flood level; includes structure raising, acquisition and demolition, standard floodproofing, and floodproofing by floodwalls.	Will reduce flood hazard and provide degree of protection indicated for entire community.
Reduce flood damages in Snow Hill	Plan SH-6	Nonstructural protection to the *6' NGVD (70-year)* flood level; includes structure raising, acquisition and demolition, standard floodproofing, and floodproofing by floodwalls.	Will reduce flood hazard and provide degree of protection indicated for entire community.
Reduce flood damages in Snow Hill	Plan SH-7	Nonstructural protection to the *7' NGVD (220-year)* flood level; includes structure raising, acquisition and demolition, standard floodproofing, and floodproofing by floodwalls.	Will reduce flood hazard and provide degree of protection indicated for entire community.

TABLE 33

SUMMARY ECONOMIC ANALYSIS OF
ALTERNATIVE PLANS FOR ST. MICHAELS
(April 1980 Prices)
($1,000's)

PLAN

Item	*SM-1*	*SM-2*	*SM-3*	*SM-4*
Costs				
First	$7,224	$11,971	$730	$916
Annual				
I&A	515	854	54	67
O&M	44	73	0	0
Total	$ 559	$ 927	$ 54	$ 67
Benefits				
Intensification	$ 0	$ 0	$ 0	$ 0
Location	0	0	0	0
Employment	0	0	0	0
Inundation Reduction				
Existing	10	17	8	11
Future[1]	0	0	0	0
Total	$ 10	$ 17	$ 8	$ 11
Net Benefits	-$549	-$910	-$46	-$56
Benefit-Cost Ratio	0.02	0.02	0.1	0.2

[1]Consists of affluence factor for residential contents only.

TABLE 34

Study Objective	*Plan*
Reduce flood damages in St. Michaels	Plan SM-1 Map Ref A-B, D-C
Reduce flood damages in St. Michaels	Plan SM-2 Map Ref A-D
Reduce flood damages in St. Michaels	Plan SM-3
Reduce flood damages in St. Michaels	Plan SM-4

Adverse Effects	*Economics*
Construction of floodwall may result in adverse environmental effects such as destruction of adjacent wetland areas increased siltation and turbidity, and destruction of benthic organisms. Use of the shoreline will be restricted. Adverse effects to the aesthetic conditions of the area. Temporary noise pollution.	D.O.P. = 25-year F.C. = $303,500 A.A.C. = $22,300 A.A.B. = $3,400 B.C.R. = 0.15
Same as above.	D.O.P. = 70-year F.C. = $521,200 A.A.C. = $38,400 A.A.B. = $6,200 B.C.R. = 0.16
Same as above.	D.O.P. = 220-year F.C. = $1,210,200 A.A.C. = $89,100 A.A.B. = $8,100 B.C.R. = 0.09

COMPARATIVE ASSESSMENT AND EVALUATION ST. MICHAELS, MARYLAND

Description of Plan	*Beneficial Effects*	*Adverse Effects*	*Economics*
14,000 feet of levee/wall which begins near Rt. 33 at the town's northern limits, runs around St. Michaels Harbor, and ties into high ground near the southern town limits at Radcliffe Ave. *(7' NGVD design elev.)*.	Will reduce flood hazard and provide degree of protection indicated for area within town's old city limits.	Use of the shoreline will be severely restricted and access to existing piers and wharves difficult. Destruction of fringe marsh areas near Parrot Point and northwest of Navy Point (total area < 5 acres). Temporary destruction of benthic organisms due to construction. Recolonization may occur after completion of construction. Some permanent loss of habitat may also occur. Increased siltation and turbidity due to construction which may effect submerged aquatic vegetation and fish. Adverse effects to the aesthetic conditions of the town.	D.O.P. = 100-year F.C. = $7,224,000 A.A.C. = $559,300 A.A.B. = $10,200 B.C.R. = 0.02
23,890 feet on levee/wall which begins near Rt. 33 at the town's northern limits, runs around St. Michaels Harbor to Seymour St., and ties into the levee section near San Domingo Creek at Rt. 33 and the town's southern limits *(9' NGVD design elev.)*.	Will reduce flood hazard and provide degree of protection indicated for area within town's old city limits as well as a portion of the new development near Rio Vista.	Same as above except for the addition of the destruction of a small marsh area at the end of San Domingo Creek (end of Thompson Street). (Total area less than 5 acres.)	D.O.P. = 450-year F.C. = $11,970,800 A.A.C. = $926,600 A.A.B. = $16,000 B.C.R. = 0.02
Nonstructural protection to the *6' NGVD (45-year)* flood level; includes utility addition, acquisition and demolition, standard floodproofing, and floodproofing by floodwalls.	duce flood hazard and provide degree of protection indicated for entire community.	Temporary, minor noise pollution and aesthetic disturbances. Construction of floodwall may result in adverse environmental effects such as destruction of adjacent wetland areas, increased siltation and turbidity, and destruction of benthic organisms. Use of shoreline will be restricted. Adverse effects to the aesthetic conditions of the area.	D.O.P. = 45-year F.C. = $730,000 A.A.C. = $53,700 A.A.B. = $8,200 B.C.R. = 0.15
Nonstructural protection to the *7' NGVD (100-year)* flood level; includes utility addition, structure raising, acquisition and demolition, standard floodproofing, and floodproofing by floodwalls.	Will reduce flood hazard and provide degree of protection indicated for entire community.	Same as above.	D.O.P. = 100-year F.C. = $916,300 A.A.C. = $67,400 A.A.B. = $10,800 B.C.R. = 0.16

TABLE 35

SUMMARY ECONOMIC ANALYSIS OF ALTERNATIVE PLANS FOR TILGHMAN ISLAND (April 1980 Prices) ($1,000's)

	PLAN						
Item	*TI-1*	*TI-2*	*TI-3*	*TI-4*	*TI-5*	*TI-6*	*TI-7*
Costs							
First	$7,370	$2,342	$8,896	$2,878	$121	$1,038	$2,772
Annual							
I&A	526	167	635	205	9	76	204
O&M	45	15	55	18	0	0	0
Total	$ 571	$ 182	$ 690	$ 223	$ 9	$ 76	$ 204
Benfits							
Intensification	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
Location	0	0	0	0	0	0	0
Employment	0	0	0	0	0	0	0
Inundation Reduction							
Existing	3	0	6	1	3	14	21
Future[1]	0	0	0	0	0	0	1
Total	$ 3	$ 0	$ 6	$ 1	$ 3	$ 14	$ 22
Net Benefits	-$568	-$182	-$684	-$222	-$6	-$62	-$182
Benefit-Cost Ratio	0.0	0.0	0.0	0.0	0.3	0.2	0.1

[1]Consists of affluence factor for residential contents only.

TABLE 36

COMPARATIVE ASSESSMENT AND EVALUATION TILGHMAN ISLAND, MARYLAND

Study Objective	*Plan*	*Description of Plan*	*Beneficial Effects*
Reduce flood damages on Tilghman Island	Plan TI-1 Map Ref. Southern Section	17,560 feet of levee/wall encircling the large area south of Knapp's Narrows *(6' NGVD design elev.)*.	Will reduce flood hazard and provide degree of protection indicated for area south of Knapp's Narrows.
Reduce flood damages on Tilghman Island	Plan TI-2 Map Ref. Northern Section	5,350 feet of levee/wall encircling the small area north of Knapp's Narrows *(6' NGVD design elev.)*.	Will reduce flood hazard and provide degree of protection indicated for area north of Knapp's Narrows
Reduce flood damages on Tilghman Island	Plan TI-3 Map Ref. Southern Section	17,560 feet of levee/wall encircling the large area south of Knapp's Narrows *(8' NGVD design elev.)*.	Will reduce flood hazard and provide degree of protection indicated for area south of Knapp's Narrows.

Adverse Effects

Destruction of fringe marsh areas in scattered patches along the eastern and western shores of Tilgham Island. (Total area < 10 acres). Use of the shoreline will be severely restricted and access to public landings at Knapp's Narrows and Dogwood Harbor will be difficult. Temporary destruction of benthic organisms due to construction. Recolonization may occur after completion of construction. Some permanent loss of habitat may also occur. Increased siltation and turbidity due to construction which may effect submerged aquatic vegetation and fish. Adverse effects to the aesthetic conditions of the town.

Economics

D.O.P. = 90-year
F.C. = $7,369,800
A.A.C. = $570,900
A.A.B. = $3,300
B.C.R. = 0.00

Destruction of marsh area along the cove just north of Knapp's Narrows. (Total area less than 20 acres). Access to shoreline at Knapp's Narrows severely restricted.

D.O.P. = 90-year
F.C. = $2,342,400
A.A.C. = $181,600
A.A.B. = $400
B.C.R. = 0.00

Same as TI-1.

D.O.P. = stand. project flood
F.C. = $8,896,360
A.A.C. = $689,300
A.A.B. = $6,400
B.C.R. = 0.01

TABLE 36 (Cont'd)

COMPARATIVE ASSESSMENT AND EVALUATION
TILGHMAN ISLAND, MARYLAND

Study Objective	*Plan*	*Description of Plan*	*Beneficial Effects*
Reduce flood damages on Tilghman Island	Plan TI-4 Map Ref. Northern Section	5,350 feet of levee/wall encircling the small area north of Knapp's Narrows *(8' NGVD design elev.)*.	Will reduce flood hazard and provide degree of protection indicated for area north of Knapp's Narrows.
Reduce flood damages on Tilghman Island	Plan TI-5	Nonstructural protection to *4' NGVD (15-year)* flood level; includes trailer relocation, housing aquisition and demolition, and floodproofing by floodwall.	Will reduce flood hazard and provide degree of protection indicated for entire community.
Reduce flood damages on Tilghman Island	Plan TI-6	Nonstructural protection to *5' NGVD (40-year)* flood level; includes structure raising, home and trailer relocation, acquisition and demolition, standard floodproofing, and floodproofing by floodwall.	Will reduce flood hazard and provide degree of protection indicated for entire community.
Reduce flood damages on Tilghman Island	Plan TI-7	Nonstructural protection to *6' NGVD (90-year)* flood level; includes structure raising, home and trailer relocation, acquisition and demolition, standard floodproofing, and floodproofing by floodwall.	Will reduce flood hazard and provide degree of protection indicated for entire community.

TABLE 38

Plan	*Description*	*Beneficial Effects*
Structural	Recommend that town consider construction of low dikes, installation of flapgates or storm drains.	Ensure that entire town is protected to same tidal elevation as top of existing bulkhead.
Nonstructural		
Plan A	Raise buildings, construct utility additions and temporary closure.	Provide tidal flood protection.
Plan B	Raise buildings and construct utility additions.	"
Plan C	Construct utility additions and temporary closures.	"
Plan D	Construct utility additions.	"

[1] Elevation 8. No wave action, runup, or freeboard considered.
[2] Elevation 7.

TABLE 37

CAPE CHARLES SUMMARY ECONOMIC ANALYSIS (Based on January 1983 Price Levels)

Plan	*Average Annual Cost*	*Annual Benefits*	*Net Benefits*	*Benefit/ Cost Ratio*
A	$45,400	$5,000	-$40,400	0.11
B	41,500	5,200	-36,300	0.13
C	11,500	200	-11,300	0.02
D	$ 9,300	$ 300	-$ 9,000	0.03

Adverse Effects	*Economics*
Same as TI-2.	D.O.P. = stand. project flood F.C. = $2,878,200 A.A.C. = $223,200 A.A.B. = $1,100 B.C.R. = 0.00
Loss of unique social life style for those relocated. Temporary, minor noise pollution and aesthetic disturbances. Construction of floodwall may result in adverse environment effects such as destruction of adjacent wetland areas, increased siltation and turbidity and destruction of benthic organisms. Use of the shoreline will be restricted. Adverse effects to the aesthetic conditions of the area.	D.O.P. = 15-year F.C. = $120,500 A.A.C. = $8,900 A.A.B. = $2,500 B.C.R. = 0.28
Same as above.	D.O.P. = 40-year F.C. = $1,038,150 A.A.C. = $76,400 A.A.B. = $12,500 B.C.R. = 0.16
Same as above.	D.O.P. = 90-year F.C. = $2,772,100 A.A.C. = $204,100 A.A.B. = $21,000 B.C.R. = 0.10

CAPE CHARLES COMPARATIVE ASSESSMENT AND EVALUATION
(Based on January 1983 Price Levels)

	Economics				
			Average Annual		
Adverse Effects	*Degree Protection*	*First Cost*	*Costs*	*Benefits*	*B/C Ratio*
Minor impact during construction activity.	100-year flood[1]	Cost and benefits of dikes and flapgates not estimated			—
"	100-year flood	$502,000	$45,400	$5,000	0.11
"	100-year flood	$458,000	$41,500	$5,200	0.13
"	35-year flood[2]	$127,000	$11,500	$ 200	0.02
"	35-year flood	$103,000	$ 9,300	$ 300	0.03

TABLE 39

ANNUAL BENEFITS, COSTS AND B/C RATIOS FOR HAMPTON
(Based on January 1983 Price Levels)

Plan	Average Annual Damages (Dollars)		Average Annual Benefits (Dollars)			Average Annual Costs (Dollars)	Net Benefits (Dollars)	Benefit/Cost Ratio
	Without Project	With Project	Inundation Reduction	Affluence Factor	Total			
Structural Plan for Protection to 100-year flood level	$100,100	$13,600	$86,500	$20,400	$106,900	$352,000	-$245,100	0.30
Nonstructural Plan for Protection to 100-year flood level	$100,100	$12,300	$87,800	$20,800	$108,600	$187,000	-$ 78,400	0.58
Nonstructural Plan for Protection to 25-year flood level	$100,100	$50,000	$50,100	$11,900	$ 62,000	$ 81,800	-$ 19,800	0.76

TABLE 40

COMPARATIVE ASSESSMENT AND EVALUATION
FOX HILL AREA OF HAMPTON, VIRGINIA
(Based on January 1983 Price Levels)

Plan	Description of Plan	Beneficial Effects	Adverse Effects	Economics
Structural 100-year	6,200 feet of floodwall to protect 50 structures	Provide tidal flood protection.	Environmental impact during construction activity.	D.O.P. = 100-year F.C. = $3,184,000 A.A.C. = $352,000 A.A.B. = $106,900 B.C.R. = 0.30
Nonstructural 100-year	Raise 59 structures.	Provide tidal flood protection.	Minor environmental impact during construction activity. Major social effects during construction activity.	D.O.P. = 100-year F.C. = $2,065,000 A.A.C. = $187,000 A.A.B. = $108,600 B.C.R. = 0.58
Nonstructural 25-year	Raise 34 structures.	Provide tidal flood protection.	Minor environmental impact during construction activity. Major social effects during construction activity.	D.O.P. = 25-year F.C. = $904,000 A.A.C. = $81,800 A.A.B. = $62,000 B.C.R. = 0.76

Poquoson

Economic Analysis

A total of seven plans of protection were considered for Poquoson. As shown in Table 41, the 25-year plan for area POQ-3 was found to be economically feasible. Due to the low level of the terrain and the potential danger of loss of life, it would appear that additional study is warranted.

No attempt was made to estimate the cost of protecting the Poquoson Middle School wherein people and families can and do congregate during high water. The school should be protected up to the level of a rare flood. Unfortunately, the roads leading to the school are at a relatively low level making it necessary for the City of Poquoson to promptly warn its citizens of an impending major tidal flood, soon after a severe storm warning is issued.

TABLE 41

POQUOSON ANNUAL COSTS, BENEFITS, AND B/C RATIOS (Based on January 1983 Price Levels)

Area Considered	*Plan Considered*	*Average Annual*		*Net Benefits*	*Benefit/Cost Ratio*
		Costs	*Benefits*		
POQ-2	Complete relocation	$ 71,700	$ 15,000	*-$56,700*	0.21
POQ-3	100-year flood level	91,300	39,200	*-52,100*	0.43
POQ-3	25-year flood level	18,100	21,300	*3,200*	1.18
POQ-4	100-year flood level	792,800	362,000	*-430,800*	0.46
POQ-4	25-year flood level	353,400	223,800	*-129,600*	0.63
POQ-4[1]	25-year flood level	381,200	253,200	*-128,000*	0.66
POQ-4[2]	10-year flood level	$ 52,800	$ 27,800	*-$25,000*	0.53

[1]Purchase and demolish structures. Raise others.
[2]Purchase and demolish structures.

Assessment and Evaluation

Eighty-five percent of the entire City of Poquoson is below the level of the 25-year tidal flood as established by the Corps. Construction of a wall which would encircle a large portion of the city would separate it from adjacent areas. Because this is not deemed to be in the city's best interest, this measure was not considered. Data were approximated for protection of the areas investigated to 10-, 25-, and 100-year tidal flood levels. The studies indicate that such projects are generally not economically feasible.

As shown in Table 41, only Plan POQ-3 exceeds the requirements for economic feasibility. However, only a segment of Poquoson has been sampled to determine the desirability of further investigations relative to the justification of nonstructural measures by the Corps. While it is believed that one or more of the seriously affected areas has been investigated, further detailed studies of this and other areas will have to be made to obtain a comprehensive understanding of the entire tidal flood situation at Poquoson, particularly in view of the low-lying terrain and the potential for loss of life.

Tangier Island

Economic Analysis

Four plans of protection were considered for Tangier Island. Included in Table 43 is a summary of the findings of the economic analysis of the plans considered. The Corps 100-year structural plan is the least feasible with a B-C ratio of only 0.17. Both the Corps 100-year and 25-year nonstructural plans approach economic feasibility with B-C ratios of 0.76 and 0.78, respectively.

Assessment and Evaluation

The entire community of Tangier is below the level of a major tidal flood. An estimate was made of the cost of protecting the Tangier School to the level of the Corps Standard Project Flood so that people could congregate there during high water. The school or another building should be protected up to the level of a rare flood. No benefit-cost ratio is presented for the construction of a wall around the school building since this is considered a must to insure a safe refuge for the people in the community. Unfortunately, the roads leading to the school are at a relatively low level making it necessary for the officials of Tangier to promptly warn its citizens of an impending tidal flood.

Table 44 is the estimated cost of providing tidal flood protection via walls and/or raising buildings. A comparison of the annual costs and benefits indicates that economic justification is lacking except for the few structures encompassed within VIMS 100-year stage. Table 44 also presents an assessment and evaluation of the effects of the plans investigated. It does not take into account the safety and/or lives of the population in the event that the waters of a major tidal storm overtop the island to a considerable depth. Escape to the mainland by boat, helicopter, or plane would not be practical.

Any additional structures on Tangier, such as concrete walls, would further reduce the small amount of land available to the islanders. The raising of practically all the houses on Tangier would have a major social and possibly an environmental effect on the community. Undoubtedly, construction activities could create side effects on some of the adjacent marshland through litter, the placement of material thereon, and the movement of vehicles. Noise during construction activities would also con-

TABLE 42

POQUOSON COMPARATIVE ASSESSMENT AND EVALUATION
(Based on January 1983 Price Levels)

Nonstructural Plan	*Description*	*Beneficial Effects*	*Adverse Effects*
POQ-1	Commercial area on Wythe Creek Road near Hudgins Road	Since the average annual damages in this area are less than $1,240 at the 100-year tidal flood stage, further study of this area is not warranted	
POQ-2	Relocate 96 structures in a trailer court	Provide tidal flood protection	Minor impact during construction activity. Major social effects.
POQ-3	Raise 45 buildings	"	"
POQ-3	Raise 9 buildings	"	"
POQ-4	Raise 383 buildings	"	"
POQ-4	Raise 182 buildings	"	"
POQ-4	Purchase and demolish 58 structures. Raise 124 structures	"	"
POQ-4	Purchase and demolish 25 structures.	"	"

TABLE 43

TANGIER ISLAND ECONOMIC ANALYSIS OF PLANS
(Based on January 1983 Price Levels)

Plan	*Annual Costs*	*Average Annual Benefits*	*Net Annual Benefits*	Benefit/ Cost Ratio
Structural				
100-yr (Corps)	$2,503,300	$419,000	-$2,084,300	0.17[1]
Standard Project Flood (Corps)	170,600	—[2]	—[2]	—[2]
Nonstructural				
100-yr (Corps)	$704,800	$534,100	-170,700	0.76[3]
25-yr (Corps)	473,400	370,500	-102,900	0.78[3]
100-yr (VIMS)	16,300	23,800	7,500	1.46[4]

[1]Affluence factor benefit not projected since b/c ratio is very small.
[2]Not determined.
[3]Indicates effect of including affluence factor benefits.
[4]Affluence factor benefit not projected since b/c ratio is greater than 1.

tribute to the temporary impacts associated with projects.

West Point

Economic Analysis

Two plans of protection were considered for the Town of West Point. Included as Table 45 is a summary of the results of the economic analysis of the nonstructural plans based on Corps and VIMS frequencies. As shown, the 25-year plan of protection was found to approach economic feasibility in the Corps plan and was economically feasible in the VIMS plan.

Assessment and Evaluation

Although West Point is exposed on

		Economics		
		Average Annual		
Degree Protection	*First Cost*	*Costs*	*Benefits*	*B/C Ratio*
Complete	$ 792,000	$ 71,700	$ 15,000	0.21
100-year flood	1,008,000	91,300	39,200	0.43
25-year flood	199,000	18,100	21,300	1.18
100-year flood	8,754,000	792,800	362,000	0.46
25-year flood	3,902,000	353,400	223,800	0.63
25-year flood	5,127,000	381,200	253,200	0.66
10-year flood	$ 978,000	$ 52,800	$ 27,800	0.53

three sides to water, the flood problem there (exclusive of the Chesapeake Corporation plant) is confined mostly to the areas around 1st Street, at the southernmost edge of the town, and 14th Street, where State Route 33 crosses the peninsula on which the town is located. Structural measures to alleviate the problem in the lower reaches of the town, including the construction of a wall and the removal or demolition of some houses were found to be not feasible at this time and were not considered further. A wall along the waterfront would require the removal of many of the houses along First Street and would be socially objectionable. The raising of residences would have little effect on the environment. However, it could inconvenience the residents during construction. No environmental and/or biological factors appear to be involved in connection with raising the houses. Nonstructural measures involving the raising of a maximum of 43 structures were evaluated at the 25-and 100-year flood levels and were found to be not economically justified although the B-C ratio of the 25-year plan approached unity. Table 46 presents a summary of the effects of the plans investigated.

Separate consideration was given to Chesapeake Corporation's paper manufacturing plant north of 14th Street along the Pamunkey River. The plant is susceptible to tidal flooding; however, the company has a program in effect to raise its equipment and machinery to elevation 8.0. Therefore, it was decided that no further study of possible protective measures for the plant was necessary.

TABLE 44

TANGIER ISLAND COMPARATIVE ASSESSMENT AND EVALUATION (Based on January 1983 Price Levels)

Plan	*Description*	*Beneficial Effects*	*Adverse Effects*
Structural	Construct concrete wall around ridges.	Provide tidal flood protection	Impact on marshland and adjacent areas during and following construction. Also social impacts.
Structural	Construct concrete walls around buildings.	Provide tidal flood protection	Impact on marshland and adjacent areas during and following construction. Also social impacts.
Nonstructural	Raise buildings.	Provide tidal flood protection	Impact on marshland and adjacent areas during and following construction. Also social impacts.
Nonstructural	Raise buildings.	Provide tidal flood protection	Impact on marshland and adjacent areas during and following construction. Also social impacts.

[1] Affluence factor benefit not projected since b/c ratio is very small.
[2] Not determined. Required for safety of public during severe tidal floods.
[3] Indicates effects of including affluence factor benefit.
[4] Affluence factor benefit not projected since b/c ratio is greater that 1.0.

TABLE 45

WEST POINT ECONOMIC ANALYSIS (Based on January 1983 Price Levels)

Stage frequency data	*Level of Protection*	*Annual Costs*	*Average Annual Benefits*	*Net Benefits*	*Benefit-Cost Ratio*
Corps	*100-yr.*	*$94,900*	*$40,200*	*-$54,700*	*0.42*
Corps	*25-yr.*	*42,100*	*38,300*	*-3,800*	*0.91*
VIMS	*100-yr.*	*30,800*	*11,200*	*-19,600*	*0.36*
VIMS	*25-yr.*	*$ 8,200*	*$ 9,400*	*$1,200*	*1.15*

		Economics		
		Average Annual		
Degree Protection	*First Cost*	*Costs*	*Benefits*	*B/C Ratio*
Corps 100-year.	$24,891,000	$2,503,300	$419,000	0.17[1]
Corps Stand. Proj. Flood	$ 1,697,000	$ 170,600	—[2]	—[2]
Corps 100-yr. VIMS 100-yr.	$7,781,000 $ 180,000	$704,800 $ 16,300	$534,100 $ 23,800	0.76[3] 1.46[4]
Corps 25-yr.	$5,227,000	$473,400	$370,500	0.78[3]

TABLE 46

WEST POINT COMPARATIVE ASSESSMENT AND EVALUATION
(Based on January 1983 Price Levels)

Stage Frequency Data	*Plan Description*	*Beneficial Effects*	*Adverse Effects*
Corps	Raise 43 structures	Provide tidal flood protection	Minor environmental and social impact during construction
Corps	Raise 17 structures	Provide tidal flood protection	Minor environmental and social impact during construction
VIMS	Raise 15 structures	Provide tidal flood protection	Minor environmental and social impact during construction
VIMS	Raise 3 structures	Provide tidal flood protection	Minor environmental and social impact during construction

Degree of Protection	Economics: First Cost	Average Annual: Costs	Average Annual: Benefits	B/C Ratio
100-yr.	$1,048,000	$94,900	$40,200	0.42
25-yr.	$ 465,000	$42,100	$38,300	0.91
100-yr.	$ 340,000	$30,800	$11,200	0.36
25-yr.	$ 90,000	$ 8,200	$ 9,400	1.15

CHAPTER V

Summary and Conclusions

Summary

As part of its comprehensive Chesapeake Bay Study, the Corps of Engineers conducted an analysis of tidal flooding and its impact on shoreline communities. This analysis addressed the Maryland and Virginia communities that were determined, through a series of screenings, to be critically flood-prone.

The communities selected for detailed study were done so as part of an iterative process which successively screened communities from further consideration. The initial step in this analysis identified all Bay communities with a population of

TABLE 47

TIDAL FLOODING
CRITICAL PROBLEM AREAS

Flood-prone Communities[1]	*Communities With Critical Existing Problems*[2]	*Communities Facing Additional Critical Problems in Future*[3]	*Communities Designated For Detailed Study*
MARYLAND			
Anne Arundel County			
Arundel on the Bay	X	X	
Avalon Shores	X		
Broadwater			
Columbia Beach			
Deale	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

[1]Communities having at least 50 acres of existing development in the Standard Project Tidal Flood Plain.
[2]Communities having at least 25 acres of existing development in the 100-year tidal flood plain.
[3]Communities having at least 25 acres of additional proposed development in the 100-year tidal flood plain

at least 1,000 that were located within the Standard Project Tidal Flood Plain. The Standard Project Tidal Flood (SPTF) was defined as the flood event, resulting from the combination of tidal surge and wave action, which would inundate areas up to an elevation of 20 feet above NGVD. These areas were identified as existing tidal flood areas.

The next step in the tidal flooding analysis was to determine the "flood-prone" communities. To designate an area as "flood-prone" at least 50 acres of intensively developed land had to be inundated by the SPTF. Sixty communities were identified as being "flood-prone" and these are listed in the first column of Table 47.

A further examination of the flood prone communities was conducted to determine whether the tidal flooding problem was of a "critical" nature. The Intermediate Regional Tidal Flood (IRTF) was selected as the determining factor. The IRTF is defined as that tidal flood which has a one percent chance of occurrence in any one year. This is generally referred to as the 100-year flood. The tidal flood problem was considered to be critical if the IRTF inundated 25 or more acres of intensively developed land and caused significant physical damage. As a result of this iteration, 32 Bay communities were determined to be "critically flood-prone." The communities so designated are indicated in the second column of Table 47.

A further iteration eliminated from consideration those "critical" communities where it was evident that flood protection would not be desirable. This determination was based on the fact that many residential communities are located along the Chesapeake Bay shoreline solely for aesthetic and recreational reasons. Structural solutions would impact upon the use of the shoreline for recreation and would cause visual disruption of the shoreline's environment. Nonstructural solutions in these areas would also be inappropriate because many structures are old and not suitable for flood proofing modifications. Several more communities were eliminated from further analysis as detailed studies of these same communities were already being conducted by the Corps under separate authorizations.

Based on this iterative process, 12 critically flood-prone communities were retained for detailed examination. These communities are identified in column four of Table 47. Detailed flood damage analyses were conducted in 1979 to establish relationships between flood stages and damages in the critically flood-prone communities. Field surveys were also undertaken to determine the number of structures subject to tidal flooding. In 1983 these communities were revisited to determine if the findings of the earlier analyses were still valid.

Once the severity and frequency of the tidal flooding problem in each community had been defined, alternative plans for reducing the magnitude of the problem were formulated. Potential structural and nonstructural measures were first examined in general terms along with important factors to be considered in developing detailed plans. The structural measures considered included projects such as earth levees, concrete floodwalls, dikes. The nonstructural measures included programs such as flood proofing, utility room additions, acquisition and demolition of certain structures, relocation, and raising of buildings.

Several plans were developed for each of the communities studied. All of the plans included some or all of the measures previously identified. The plan designs themselves varied in size, degree of protection, and physical configuration based on the areal extent of damages, the frequency of flooding, and the economic severity of flooding. They emphasized both the structural and

TABLE 47 (Cont'd)

TIDAL FLOODING CRITICAL PROBLEM AREAS

Flood-prone Communities[1]	*Communities With Critical Existing Problems*[2]	*Communities Facing Additional Critical Problems in Future*[3]	*Communities Designated For Detailed Study*
Harford County			
Harve de Grace			
Kent County			
Rock Hall	X	X	X
Queen Anne's County			
Dominion			
Grasonville	X	X	
Stevensville		X	
St. Mary's County			
Colton			
Piney Point	X		
St. Clement Shores			
St. George Island			
Somerset County			
Crisfield	X		X
Smith Island	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

[1]Communities having at least 50 acres of existing development in the Standard Project Tidal Flood Plain.
[2]Communities having at least 25 acres of existing development in the 100-year tidal flood plain.
[3]Communities having at least 25 acres of additional proposed development in the 100-year tidal flood plain.

TABLE 47 (Cont'd)

TIDAL FLOODING CRITICAL PROBLEM AREAS

Flood-prone Communities[1]	*Communities With Critical Existing Problems*[2]	*Communities Facing Additional Critical Problems in Future*[3]	*Communities Designated For Detailed Study*
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		

[1]Communities having at least 50 acres of existing development in the Standard Project Tidal Flood Plain.
[2]Communities having at least 25 acres of existing development in the 100-year tidal flood plain.
[3]Communities having at least 25 acres of additional proposed development in the 100-year tidal flood plain

nonstructural protective measures. Costs for each alternative plan were also developed and then annualized for comparison to the benefits.

Maryland Communities

For the most part, the Maryland communities were found to be older village centers with relatively stable populations. The economy in most of the critical Maryland communities is tied to the seafood industry and other Bay-related trades. Little growth is projected for the coming years. Table 48 contains a list of the Maryland communities and a summary of the structural and nonstructural measures which were considered. Some plans contained only structural elements, some plans contained only nonstructural measures, and some plans contained both structural and nonstructural measures. Alternative plans for a given community sometimes differed only in the level of protection provided. In other communities, different levee and/or floodwall alginments were examined to furnish protection to different sections in the town.

Adverse environmental effects were found to range from minimal for most of the nonstructural measures to significant for the structural components such as levees and floodwalls. 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 48. 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 which would be necessary for economic justification. Indeed, the highest benefit-cost ratio was 0.66 for Crisfield. An examination of these communities in the summer of 1983 indicated that minor growth had occurred in nearly all the communities, but not to the degree necessary to substantially alter any of the earlier findings.

Virginia Communities

Generally, the Virginia communities were found to be somewhat larger and of a broader economic base than those in Maryland. Significant growth is expected in future years in some of these communities. These communities are also close to the Atlantic Ocean and exposed to potentially great damages as storms move along the coastline.

Similar to the plan development process which was undertaken for the flood-prone Maryland communities, alternative plans were formulated for each of the Virginia communities facing critical tidal flooding problems. These plans again included both structural and nonstructural measures in various combinations as indicated in Table 49. It should be noted that the intense level of development in the Hampton/Norfolk/Chesapeake/Portsmouth region preclude 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 including 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 update of the economic analysis are shown in the last several columns of Table 49. Confirming the earlier work, certain combinations of tidal flood reduction measures appear to be economically justified for Poquoson, Tangier Island, and West Point.

TABLE 48

PLANS FOR TIDAL FLOOD REDUCTION MARYLAND COMMUNITIES

	Structural Measures		*Nonstructural Measures*				
Community	*Earth Levee*	*Concrete Floodwall*	*Flood Proofing*	*Utility Room Addition*	*Acquisition Demolition*	*Relocation*	*Raising*
Cambridge (8 Plans)	x	x	x	x	x		
Crisfield (6 Plans)	x	x	x	x	x	x	x
Pocomoke City (5 Plans)	x	x	x	x	x	x	x
Rock Hall (10 Plans)	x	x	x	x	x	x	x
Snow Hill (7 Plans)	x	x	x		x		x
St. Michaels (4 Plans)	x	x	x	x	x		x
Tilghman Island (7 Plans)	x	x	x		x	x	x

[1] Economic information is based on July 1979 price levels and the fiscal year 1980 interest rate of $7\frac{1}{8}$ percent.
[2] Figures for annual costs include operation and maintenance as well as interest and amortization.

TABLE 49

PLANS FOR TIDAL FLOOD REDUCTION VIRGINIA COMMUNITIES

	Structural Measures			*Nonstructural Measures*				
Community	*Earth Levee*	*Concrete Flood Wall*	*Dikes, Flapgates*	*Flood Proofing*	*Utility Room Addition*	*Acquisition & Demolition*	*Relocation*	*Raising*
Cape Charles (5 Plans)			x		x			x
Hampton/Norfolk/Chesapeake/Portsmouth [3] (3 Plans)		x						x
Poquoson (8 Plans)						x	x	x
Tangier Island (4 Plans)		x						x
West Point (4 Plans)								x

[1] Economic information based on January 1983 price levels and fiscal year 1983 interest rate of $7\frac{7}{8}$ percent.
[2] Figures for annual costs include operation and maintenance as well as interest and amortization.
[3] Figures are for the Fox Hill sample area only.

Average Annual Damages	Economic Information [1] First Cost of Plans	Annual Cost of Plans [2]	Annual Benefits of Plans	Benefit to Cost Ratios
$ 18,400	$ 356,300 to $ 9,120,600	$ 55,150 to $ 706,700	$ 13,500 to $103,800	0.14 to 0.5
$142,500	$ 676,300 to $ 7,333,200	$ 49,800 to $ 567,200	$ 33,000 to $172,000	0.3 to 0.7
$ 23,900	$ 259,700 to $ 4,322,700	$ 19,100 to $ 335,300	$ 10,100 to $ 18,000	0 to 0.5
$ 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
$ 11,400	$ 303,500 to $ 3,741,600	$ 22,300 to $ 290,000	$ 3,400 to $ 9,100	0 to 0.2
$ 26,300	$ 730,000 to $11,970,800	$ 53,700 to $ 926,600	$ 8,200 to $ 16,000	0 to 0.2
$ 34,700	$ 120,500 to $ 8,896,360	$ 8,900 to $689,300	$ 400 to $ 21,000	0 to 0.3

Average Annual Damages	Economic Information [1] First Cost of Plans	Annual Cost of Plans [2]	Annual Benefits of Plans	Benefit To Cost Ratios
$ 37,400	$ 103,000 tc $ 502,000	$ 9,300 to $ 45,400	$ 200 to $ 5,200	0.02 to 0.13
$100,100	$ 904,000 to $ 3,184,000	$ 81,800 to $ 352,000	$ 62,000 to $108,600	0.3 to 0.8
$501,400	$ 199,000 to $ 8,754,000	$ 18,100 to $ 792,800	$ 15,000 to $362,000	0.2 to 1.2
$481,700	$ 180,000 to $24,891,000	$ 16,300 to $2,503,300	$ 23,800 to $534,100	0.2 to 1.5
$ 62,500	$ 90,000 to $1,048,000	$ 8,200 to $ 94,900	$ 9,400 to $ 40,200	0.4 to 1.2

Findings and Conclusions

As a result of the tidal flooding analysis conducted during the Chesapeake Bay Study, several observations and findings are noteworthy. Tidal flooding is a problem that periodically affects all of Chesapeake Bay's shorelines at one time or another. Based on the screening criteria, 60 day communities were identified as having existing or potentially serious tidal flooding problems. Less obvious perhaps, is that significant monetary loss resulting from tidal flooding is incurred by only a few of these 60 communities which, because of topography and land use pattern, are especially susceptible to damage in developed sections.

Both structural and nonstructural measures were considered for preventing or reducing the adverse effects of tidal flooding in the 12 communities examined in detail. Structural measures usually impact adversely on the environment and are expensive.

Furthermore, residents dislike structural measures for aesthetic reasons and because direct and easy access to the Bay shoreline may be hindered. Nonstructural measures, on the other hand, are less damaging to the environment and are, usually, less expensive. However, to make a nonstructural tidal flood protection program effective on a community-wide basis, voluntary participation by nearly all residents and businesses is required. Furthermore, these solutions usually require direct monetary outlays by the residents.

Economic information developed during the Tidal Flooding Study indicated that protection programs were economically justified in only a few communities. Of the 12 communities investigated only some the plans formulated for Poquoson, Tangier Island, and West Point were found to have benefit-cost ratios greater than 1.0. The value and intensity of development in most flood-prone areas was not great enough to warrant a full-scale tidal flooding program. An additional observation is that many residents of flood-prone communities view tidal flooding as a temporary inconvenience which is a tolerable trade-off for the convenience of living and working close to the waters of Chesapeake Bay.

Although flood protection plans for the Town of Cape Charles and the Hampton Roads city complex are not justified, several findings did result from the analysis of these areas. The ground level on the north and south sides of Cape Charles should be raised to the level of the existing bulkhead with flapgates installed in the storm drains.

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. Therefore, further studies of the Hampton Roads city complex should be made to ascertain the economic feasibility of structural and/or nonstructural measures. This should take into account the effect of wave action and runup, particularly in the exposed areas adjoining Chesapeake Bay. Emphasis should be placed on all factors-economic, environmental, social, and technological. Furthermore, city officials throughout the Hampton Roads city complex should insure that the first floor level of the numerous evacuation shelters are sufficiently reinforced and at an elevation so as to protect occupants from a major catastrophic flood including the effect of wave action. The Corps of Engineers should assist in this matter if so requested by local officials.

The analysis of Poquoson indicated that one plan for tidal flooding protection has a benefit-cost ratio greater than 1.0. Because of the extent and seriousness of its tidal flood problem, the Corps of Engineers should prepare a detailed feasibility investigation of the entire city to establish the seriousness and extent of the tidal flood problem, the need and justification for the evacuation of individual houses from the flood plain particularly those that are in serious jeopardy, the justification for low levees or walls for individual and/or small groups of houses, the raising of escape roads during high water, and the desirability of an urban renewal program in the extremely low-lying areas which FIA indicates are subject to major wave action. Consideration should also be given to flood proofing the Middle School or another building wherein the public could congregate in the event of a major flood. The building should be flood proofed or protected by a wall to a high level of protection.

The analysis of Tangier Island indicated that a definitive stage-frequency relationship does not exist. A stage-frequency analysis of Chesapeake Bay should be conducted based on a numerical tidal surge model developed by the U.S. Waterways Experiment Station at Vicksburg, Mississippi. This should be coordinated with the Federal Insurance Administration and the Virginia Institute of Marine Science so that the stage-frequency analysis for Tangier can be resolved. Further studies should then be made of structural and/or nonstructural protection measures based on the results of the frequency analysis referred to above. This would be particularly desirable due to the isolation of the population from the mainland. Consideration should also be given to flood proofing the Tangier School or another public building wherein the public could take shelter in the event of a major flood. The building should be flood proofed to a high level of protection.

Another finding that is common to all of the Virginia communities is that the State, with the assistance of the Corps and local officials, should insure that concrete or metal markers be placed to indicate to the public the height of future floods. The same program would also have merit in Maryland.

Given the lack of historical tidal flood-stage and frequency information, a coordinated program should be instituted to collect and record stage-frequency data. This program should include appropriate state agencies as well as Federal agencies such as the Corps of Engineers, the Coastal Zone Agency of the National Oceanographic and Atmospheric Administration, the Federal Emergency Management Agency, the National Weather Service, and other appropriate agencies. This program should not limit its scope to the communities examined in this study but should be Bay-wide in nature. Thus an effective Bay-wide data base can be established which will be of great benefit in the future evaluation of tidal flooding.

As much still is to be learned about the intricacies of natural events which result in tidal flooding, the completion of a storm-surge model would be beneficial. A model of this type would permit more accurate forecasts of tidal flooding stages. A storm-surge model would also be useful in developing better stage-frequency relationships on which to base the economic evaluation of flood protection plans. A model of this nature, if developed to represent surges Bay-wide, could be of much benefit to all of the tidal communities.

Despsite the fact that few of the plans for tidal flood protection are justified, steps can be taken to reduce inconvenience and damage in any community. Perhaps one of the most promising measures is the coordinated development of an accurate tidal flood forecasting and warning system. A measure of this type could be developed through the efforts of the National Weather Service and state and local civil defense and disaster preparedness departments. Included in a flood forecasting and warning system could be items such as: (1) advance weather and tidal stage forecasts, (2) communication networks to inform communities and residents of potential flooding, (3) permanent markers placed in critical areas to indicate tidal flood heights, (4) identification of low-lying areas and planned evacuation routes from these same areas, and (5) designation of municipal buildings out of the flood-prone areas for temporary shelter during flood events. While these actions will not reduce the incidence or magnitude of tidal flooding, inconvenience, physical damage, and personal injury may be reduced.

It is recognized that many residents of flood-prone communities view tidal flooding as a temporary inconvenience which is a traded off against the aesthetics and benefits of living and working near the Chesapeake Bay. It is also recognized that development in some of these areas may be faster than in others attracting residents who may view tidal flooding as a problem rather than as an inconvenience. Through the use of comprehensive planning documents, land use designations, and zoning ordinances prudent use should be made of flood-prone areas in such a way as to minimize the loss that may result from future tidal flooding events.

CHAPTER VI

Recommendations

Based on the information gathered during the Tidal Flooding Study, and the findings and conclusions resulting from the tidal flooding analyses, the following recommendations are made:

(1) The ground level on the north and south sides of Cape Charles should be raised to the level of the existing bulkhead with flapgates installed in the storm drains.

(2) Additional studies of the Hampton Roads city complex should be conducted to ascertain the economic feasibility of structural and/or nonstructural measures to include the effect of wave action and runup.

(3) Due to the extent and seriousness of the tidal flooding problem, the Corps of Engineers should conduct a detailed feasibility investigation of the entire City of Poquoson to fully determine the feasibility of constructing tidal flood protection measures.

(4) Based on the positive results of the preliminary analysis of Tangier Island's tidal flooding problem, further detailed investigations should be made by the Corps of Engineers to determine the feasibility of implementing protective measures.

(5) Given the lack of historical tidal floodstage and frequency information, a coordinated program should be instituted to collect and record stage-frequency data on a Bay-wide basis and should include appropriate state agencies as well as the Corps of Engineers, the Coastal Zone Agency, FEMA, and the National Weather Service.

(6) Development of a storm-surge model should be completed for use in establishing reliable stage-frequency relationships on which to base economic evaluations of flood protection plans.

(7) Investigations should be conducted to determine the feasibility of implementing a coordinated tidal flood forecasting and warning system within the Bay Region communities.

LIST OF ABBREVIATIONS

AAB	- Average Annual Benefits
AAC	- Average Annual Costs
AC	- Acre
BCI	- Building Construction Index
BPT	- Best Practicable Treatment
BCR	- Benefit-Cost Ratio
CATV	- Cable Antenna Television
CPCB	- Citizens Program for the Chesapeake Bay
C.Y.	- Cubic Yard
D.O.P.	- Degree of Protection
D.O.T.	- Department of Transportation
ENR	- Engineering-News Record
FAA	- Federal Aviation Administration
F.C.	- First Costs
FEMA	- Federal Emergency Management Agency
FIA	- Flood Insurance Administration
FOR	- Flood of Record
FWS	- U.S. Fish and Wildlife Service
FY	- Fiscal Year
I&A	- Interest and Amortization
I.W.R.	- Institute for Water Resources U.S. Army Corps of Engineers
JTU	- Jackson Turbidity Units
Lb	- pound
MGD	- million gallons per day
MPN	- most probable number
NASA	- National Aeronautic and Space Administration
NGVD	- National Geodetic Vertical Datum
NMFS	- National Marine Fisheries Service
NOAA	- National Oceanic and Atmospheric Administration
NPDES	- National Pollutant Discharge Elimination System
NWS	- U.S. National Weather Service
OBERS	- Acronym referring to the agencies responsible for demographic projections used in water resources planning — the Bureau of Economic Analysis (formerly the *Office of Business Economics*) and the *Economic Research Service*.
O&M	- Operations and Maintenance
PPT	- Parts Per Thousand
SMSA	- Standard Metropolitan Statistical Area
SPTF	- Standard Project Tidal Flood
SY	- Square Yard
VIMS	- Virginia Institute of Marine Science
WES	- U.S. Army Corps of Engineers Waterways Experiment Station

GLOSSARY

Accretion — May be either natural or artificial; Natural accretion is build-up of land, solely by the action of the forces of nature, on a beach, by deposition of waterborne or airborne material. Artificial accretion is a similar build-up of land by reason of an act of man, such as the accretion formed by a groin, breakwater, or beach fill deposited by mechanical means. Opposite of erosion.

Amortization — The process of setting money aside at intervals for gradual payment of a debt, etc. either at or before maturity; the economic process of repaying or liquidating a debt or recovering the wealth invested in a project over a given period of time.

Armoring — The use of riprap material to protect the water side of levees.

Astronomical Tide — The alternate rise and fall of the oceans, seas, and the bays, rivers, etc. connected with them; caused by the attraction of the moon and sun; it occurs twice in each period of 24 hours and 50 minutes.

Atlantic Flyway — Flying route along the Atlantic seaboard taken regularly by migratory birds going to and from their breeding grounds.

Average Annual Equivalent Benefits — Term referring to the annual benefits estimated to be associated with plan/project implementation over the period of analysis.

Average Annual Equivalent Charges — Term referring to the annual payment associated with project costs which include amortization of the investment costs, the annual operation and maintenance costs, and the annual equivalent of major replacement costs.

Bay — A recess in the shore or an inlet of a sea between two capes or headlands, not as large as a gulf but larger than a cove.

Beach — The zone of unconsolidated material that extends landward from the mean low water line — unless otherwise specified — to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation.

Beach Erosion — The carrying away of beach materials by wave action, tidal currents, or littoral currents, or by wind.

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.

Benefits — Increases or gains, net of associated or induced costs, in the value of goods and services which result from conditions with the project as compared with conditions without the project. National economic benefits include direct output increases, use of unemployment or underemployed resources, and increases in output resulting from external economies.

Berm — Portion of a beach or backshore that is formed by deposition of material by wave action; marks the limit of ordinary high tide.

Biota — The plant and animal life of a region.

Breakwater — A structure for breaking the force of waves to protect craft anchored in a harbor or to protect a beach from erosion. An offshore barrier may be either an artificial structure or a natural formation. Sometimes it is connected at one, or both ends, with the shore.

Building Construction Index (BCI) — Index published monthly by the *Engineering - News Record* magazine which applies to general construction costs and how much it costs to purchase a hypothetical package of goods and services compared to a base year. The BCI includes skilled labor for bricklayers, carpenters and structural ironworkers.

Bulkhead — A low wall of stones, concrete or piling built to protect a shore, or fills, from wave erosion. A bulkhead may be built to protect navigable waters, and serve as a line, limiting filling, or beyond which filling of submerged lands is not permitted. A secondary purpose is to protect the upland against damage from wave action.

Coriolis Force — The inertial force caused by the earth's rotation that deflects a moving body to the right in the Northern Hemisphere and to the left in the Southern Hemisphere; this deflection (Coriolis Effect) is produced by the acceleration of any body moving at a constant speed above the earth with respect to the surface of the rotating earth.

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.

Dike — Artificial embankment (technically neither dams or levees) constructed to hold bodies of water, mostly on relatively flat land. A body of water so retained may be in the nature of a reservoir, lake, pond, or flooding. Also dikes may be constructed on the shores or borders of a lake either to prevent flooding, from overflow of the lake, or adjacent land, or to prevent inflow into a lake of undesirable water. Dike also has the meaning of a ditch which holds water, but such usage is rare.

Diurnal — Occurring once a day; i.e., with a variation period of one day; having a period or cycle of approximately one Tidal Day.

Drainage Area — The region which drains all the rain water that falls on it, apart from that removed by evaporation, into a river or stream, which then carries the water to the sea or to a lake; its boundary is defined by the ridge beyond which water flows in the opposite direction — away from the basin.

Dune — A mound or ridge of sand formed, either in a desert or along the sea coast, through transportation by wind. Sand particles are carried by wind and piled in a heap. Dunes often form around an obstacle. They change constantly in size, shape and location.

Ecology — The science which treats organisms in relation to their environment; frequently subdivided into human ecology, plant ecology, and bioecology. The latter deals with the interrelationships between animal life and plant life.

Ecosystem — A community and its (living and none-living) environment considered collectively; the fundamental unit of ecology; the interacting system of things with their physical and chemical environment.

Embayment — A bay or a formation resembling a bay which offers protection and shelter.

Estuary — That portion of a stream or river influenced by the tide of the body of water into which it flows; 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.

Euphotic Zone — The uppermost portion of a body of water, into which light enters to a degree sufficient for photosynthesis and the consequent growth of plants.

Evapotranspiration — The total water loss from the soil, including that by direct evaporation and that by transpiration from the surfaces of plants.

Extratropical Storm — See Northeaster.

Fall Line — The geographical line indicating the beginning of a plateau, usually marked by many waterfalls and rapids; the line east of the Appalachian Mountains marking the end of the coastal plains and the beginning of the Piedmont Plateau.

Fetch — The area in which seas are generated by a wind having a rather constant direction and speed; sometimes used synonymously with Fetch Length.

Fetch Length — The horizontal distance (in the direction of the wind) over which a wind generates seas or creates wind setup.

First Costs — The total project construction cost including costs of lands, relocations, engineering, design, administration, and supervision.

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, 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.

Flood Stage — The stage or elevation at which overflow of natural banks of a stream or body of water begins in the reach or area in which the elevation is measured.

Floodwall — A structure built along a water course to prevent flooding in the adjacent land area. Primarily used where levees are not feasible, either due to space limitations or considerable wave action. See Seawall.

Fluvial — That which is produced by a river.

Freeboard — The vertical distance between a design maximum water level and the top of a structure.

Frequency (Statistics) — The number of observations or measures in one of the class intervals of a frequency distribution. Also called frequency, class size, and variate frequency. The number of observations or measures in one of the cells of a double entry table. Also called cell frequency.

Groin — A low wall built out into the sea, more or less perpendicular to the coastline, to resist the travel of sand and shingle along a beach, or minimize erosion by the sea.

Harbor of Refuge — A name given to havens along shorelines located between commercial and recreational harbors; designed primarily to be a place of refuge for small craft during storm periods.

Head of Navigation — The farthest point up a river to be reached by vessels for the purposes of trade.

Hurricane — An intense tropical cyclone in which winds tend to spiral inward toward a core of low pressure, with maximum surface wind velocities that equal or exceed 75 mph (65 knots) for several minutes or longer at some points. Tropical Storm is the term applied if maximum winds are less than 75 mph.

Hydraulic Model — A flow system so operated that the characteristics of another similar system may be predicted. A model is generally a small-scale reproduction of the prototype, but may be larger and/or geometrically distorted. The Chesapeake Bay Model is a hydraulic model.

Hydrodynamics — The study of the motion of and the forces acting on water.

Hydrograph — A graph showing stage, flow velocity or other properties of water with respect to time.

Hydrology — The scientific study of the waters of the earth, especially with relation to the effects of precipitation and evaporation upon the occurrence and character of water in streams, lakes, and on or below the land surface.

Hydrostatic Forces — Pressures due to the weight of a water column above a given point.

Impervious — Incapable of being passed through or penetrated; usually said of material that is not penetrated by water.

Intermediate Regional Tidal Flood — A tidal flood having an average frequency of occurrence on the order of once in 100 years although the tidal flood may occur in any year. It is based on statistical analyses of tide records available for the "general region of the study area." Another way to refer to a 100-year flood is to say that it is a flood that has a one-percent chance of occurring during any year.

Intertidal Zone — Of or pertaining to a shore zone (line) bounded by the levels of high and low tide.

Jetty — On open seacoasts, a structure extending into a bay of water, and designed to prevent shoaling of a channel by littoral materials, and to direct and confine the stream or tidal flow. Jetties are built at the mouth of a river or tidal inlet to help deepen and stabilize a channel.

Knot — A unit of speed of one nautical mile (6,076.10 feet) an hour; same as nautical mile.

Levee — A dike or embankment to protect land from inundation.

Littoral — Of or pertaining to a shore, especially of the sea.

Littoral Current — Any current in the littoral zone caused primarily by wave action, e.g., longshore current.

Littoral Drift — The sedimentary *material* moved in the littoral zone under the influence of waves and currents.

Littoral Transport — The movement of littoral drift in the littoral zone by waves and currents; includes movement parallel (longshore transport) and perpendicular (on-shore transport) to the shore.

Littoral Zone — In beach terminology, an indefinite zone extending seaward from the shoreline to just beyond the Breaker Zone.

Lunar Day — 24.84 hours; within the Chesapeake Bay Area, a period encompassing two tidal cycles; see Tidal Day.

Macrophytes — large plants (visible to the naked eye).

Mean Low Water (mlw) — The average height of the low waters over a long period of time.

Mean Tidal Range — Average difference between mean low water and mean high water.

Mean Tide — Mid-point between mean high and mean low water.

National Geodetic Vertical Datum of 1929 (NGVD) — is a geodetic datum derived from a general adjustment of the first order level nets of both the United States and Canada. It was formerly called "Sea Level Datum of 1929" or "mean sea level." Although the datum was derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts, it does not necessarily represent local mean seal level at any particular place.

Northeaster — A cyclonic type storm which developes 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.

Phytoplankton — Plankton consisting of plants; i.e. some forms of algae and diatoms.

Port — A place where vessels may discharge or receive cargo; this may be the entire harbor including its approaches, or it may be the commercial part of a harbor where the wharves and facilities for transfer of cargo, docks, and repair shops are situated.

Probable Maximum Tidal Flood — The tidal flood that can be expected from the most severe combination of meteorological and hydrologic conditions reasonably possible in the region.

Reaches — A straight section of restricted waterway of some extent; a straight section of a stream or river.

Recurrence — The act or instance of occurring again; often used interchangeably with frequency to indicate the statistical probability of the occurrence of a particular hydrologic event; such as the 100-year flood event, or a recurrence interval of 100 years.

Revetments — A facing of stone, concrete, etc., built to protect a scrap, embankment, or shore structure against erosion by wave action or currents.

Riprap — A layer, facing, or protective mound of stones randomly placed to prevent erosion, scour, or sloughing of a structure or embankment; also the stone so used.

Runup — The rush of water up a structure or beach on the breaking of a wave. The amount of runup is the vertical height above stillwater level that the rush of water reaches.

Scour — Removal of underwater material by waves and currents, especially at the base or toe of a shore structure.

Seawall — A structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action. See Also Bulkhead and Floodwall.

Semidiurnal — Of, lasting, or performed in half a day; coming twice a day, or about every 12 hours, as do the tides.

Sheet Piling — A group of piles with a generally slender flat cross section to be driven into the ground or seabed and meshed or interlocked with like members to form a diaphragm, wall, or bulkhead.

Shoal — A shallow place in a river, sea, etc.; a sandbar or piece of rising ground forming a shallow place that is a danger to navigation.

Shore — The narrow strip of land in immediate contact with the sea, including the zone between high and low water lines. A shore of unconsolidated material is usually called a beach.

Shoreline — The intersection of a specified plane of water with the shore or beach (e.g., the highwater shoreline would be the intersection of the plane of a mean high water with the shore or beach). The line delineating the shoreline on U.S. Coast and Geodetic Survey nautical charts and surveys approximates the mean high water line.

Spillway — In broad terms, a "spillway" may be defined as any passageway, channel, or structure designed expressly or primarily to discharge "excess" water from a reservoir. A "controlled" spillway is equipped with crest gates, stoplogs, or other movable structures to permit various degrees of variation in outflow rates.

Stage — In hydrology, the height of the water surface above or below an arbitrary datum; a gage height. As a physiographic term as in the "stage of development of a shoreline," stage refers to a period or phase in the cycle of erosion; for example, the youthful stage or mature stage. The final period in the life history of a lake may be called a stage of extinction. Also former levels of a lake marking periods in its geological history are called stages and often given the geographic name of the ancient predecessor lake, as for example, the Algonquin Stage of Lake Michigan.

Standard Project Tidal Flood — The flood in coastal areas caused by a storm surge that may be expected from the most severe combinations of meteorological and hydrological conditions that are considered reasonably characteristic of the geographical area in which the drainage basin is located, excluding extremely rare combinations. Such floods, as used by the Corps of Engineers, are intended as practicable expressions of the degree of protection that should be sought in the design of flood control works, the failure of which might be disastrous.

Storm Surge — A rise above normal water level on the open coast due to the action of wind stress on the water surface. Storm surge resulting from a hurricane also includes that rise in level due to atmospheric pressure reduction as well as that due to wind stress. See Wind Setup

Stratification — The state of a fluid that consists of two or more horizontal layers arranged according to their density, the lightest layer being on top and the heaviest at the bottom.

Tidal Day — The time of the rotation of the earth with respect to the moon, or approximately 24.84 solar hours (24 hours and 50 minutes) or 1.035 times the mean solar day. Also called lunar day.

Tidal Station (gage) — A place at which tide observations are being taken. It is called a primary tide station when continuous observations are to be taken over a number of years to obtain basic tidal data for the locality. A secondary tide station is one operated over a short period of time to obtain data for a specific purpose.

Tide — The periodic rising and falling of the water that results from gravitational attraction of the moon and sun and other astronomical bodies acting upon the rotating earth.

Topography — The configuration of a surface, including its relief, the position of its streams, roads, building, etc.

Tributary — A stream or other body of water that contributes its water to another and larger stream or body of water.

Tropical Cyclone — See Hurricane.

Tropical Disturbance — A cyclonic wind storm of tropical origin with winds from 39 to 74 mph.

Turbidity — A condition of a liquid due to fine visible material in suspension. The particles may not be of sufficient size to be seen by the naked eye, but do prevent the passage of light through the liquid. A measure of fine suspended material (usually colloidal) in liquids.

Wind Setup — (1) The vertical rise in the stillwater level on the leeward side of a body of water caused by wind stresses on the surface of the water. (2) The difference in stillwater levels on the windward and the leeward sides of a body of water caused by wind stresses on the surface of the water. (3) Synonymous with storm surge. Storm surge is usually reserved for use in referring to the ocean and large bodies of water. Wind setup is usually reserved for use in referring to reservoirs and smaller bodies of water.

Wind Waves — Waves being formed and built up by the wind. Loosely, any wave generated by wind.

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