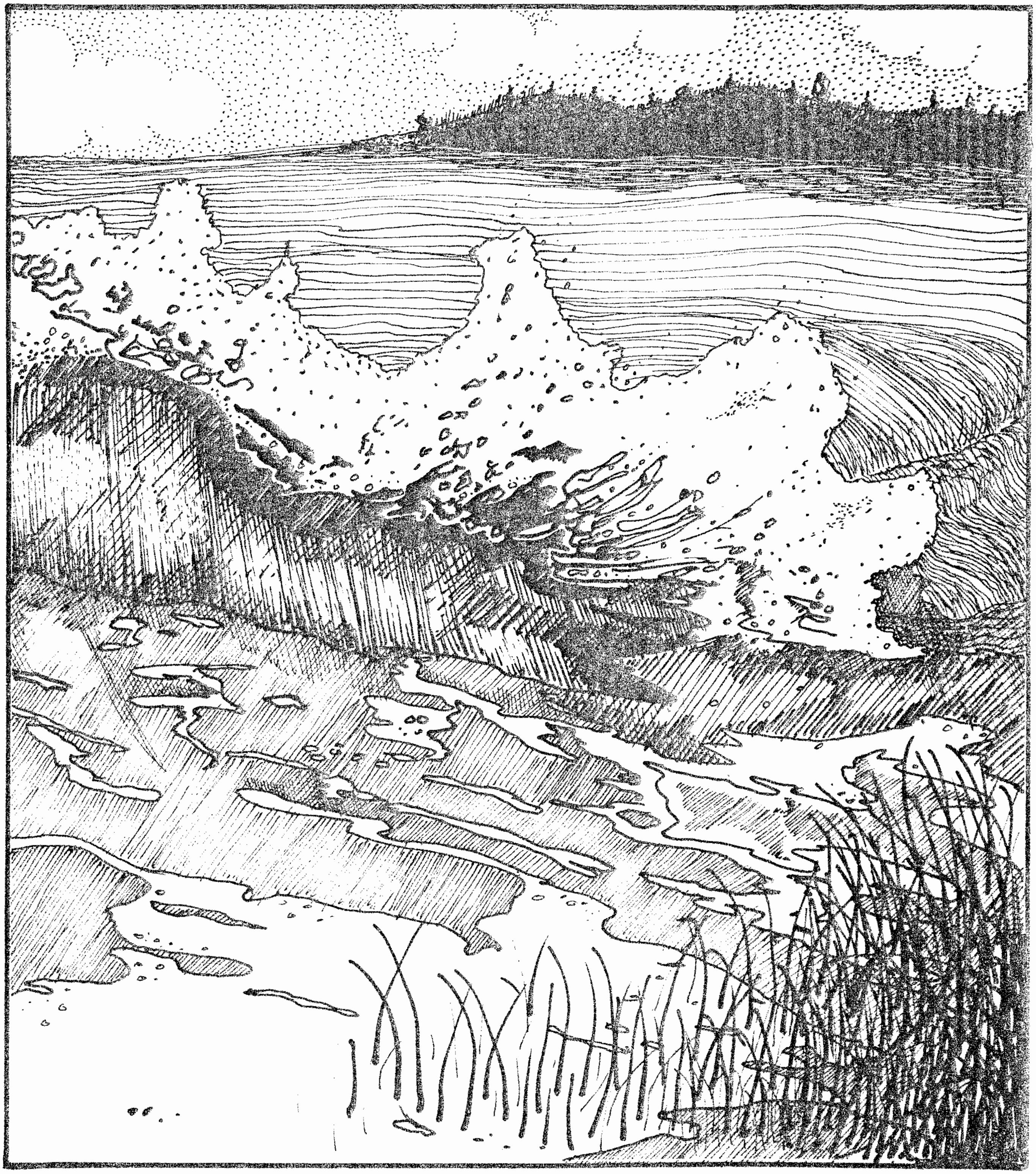
FINAL REPORT

THE ROLE OF BOAT WAKES IN SHORE EROSION In Anne Arundel County, Maryland



FINAL REPORT ON THE ROLE OF BOAT WAKES IN SHORE EROSION IN ANNE ARUNDEL COUNTY, MARYLAND

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EDITORS' NOTE

The environmental impacts caused by motorboats have been the subject of several recent studies. Much of the technical information which has been amassed so far deals with the effects of two-cycle outboard motorboat engines on water quality and the health of aquatic organisms (Jackivicz, et. al. 1973). A few studies have shown there are short-term changes in turbidity and other water parameters while boats are operating, but the effects are very temporary (Yousef, 1974, et. al., 1978; Anderson, 1976; Moss, 1977; Liou and Herbich, 1977). None of the studies have concluded that these short-lived environmental impacts are actually detrimental to the ecology of isolated lakes or small creeks and coves where boats operate.

There have also been several recent studies on the impacts of boat wakes, but most of the attention has been directed to the wake characteristics of large commercial ships, barges, and tugboats. Information has been gathered to address some suspected environmental problems where boat wakes travel out of shipping lanes onto recreational beaches, and where wakes wash against levees in restricted channels and canals (Hay, 1968; Das, 1969; Johnson, 1969; Collins, et al, 1971). The technical studies show how different types of passes by these large-hulled craft can produce different wakes along the shoreline (Brebner, et. al., 1966; Johnson, 1957, 1968, 1969; Sorensen, 1967a, b, 1973; Das and Johnson, 1970).

This document describes a study of the role of wakes from smaller boats in causing erosion along the shoreline in areas which are relatively sheltered from natural wind-generated waves. The Severn and South Rivers are two tributaries to the Chesapeake Bay near Annapolis which are popular for recreational boating, along with the smaller creeks and coves adjacent to the main river channels. The information which was collected as part of this study was used to answer some important questions about the relationship between recreational motorboating and shoreline erosion in these areas:

1. What levels of wave energy are associated with boat wakes in particularly popular areas, and how do the wakes compare with the normal wind-generated waves as a source of energy for erosion and transport at the shoreline?

2. Can different types of boating patterns change the levels of wave energy in boat wakes which break along the shoreline?

3. How do rates of shore erosion during the boating season compare to other times of the year?

This study report describes measurements of boat wakes, wind waves, and shoreline surveys collected over a one-year period which included a single boating season and a single winter storm season. Thus, the length of time over which the data base extends is limited, and the results are strictly applicable only to the shorelines at the study sites. Nevertheless, the limited data set and associated analysis provide preliminary answers to the questions above which will be useful to scientists, managers, decision-makers, and other persons who participate with interest in public forums and related discussions where recreational motorboating is regarded as a significant management issue.

Chris Zabawa
Chris Ostrom
December 1, 1980

EXECUTIVE SUMMARY

In 1976, the Maryland General Assembly passed a resolution requesting that DNR design and undertake a study to determine whether recreational motorboat traffic is detrimental to the ecology of small creeks and coves in Anne Arundel County. The data which are described in this report were collected at five popular areas for motorboating to assess the effects of boat wakes on shore erosion. Over a one-year period, wave energy in boat wakes at each site was compared with the energy in wind waves to show the increased potential for shore erosion due to boats. Erosion rates during the boating season were also compared to other times of the year at each of the study sites. Finally, wakes were measured from controlled boat passes to determine the importance of different boat speeds and distances from the shore in producing different-sized wakes.

Except at one site, the most important contribution to shore erosion during the year of study was Tropical Storm David, which passed through Maryland in September, 1979, and was accompanied by the greatest changes in some of the shoreline profiles. Wind waves ranked behind the storm effects; and in all cases, boat wakes contributed less energy for erosion than wind waves.

Only one of the study sites showed evidence of erosion during the boating season. This site also had the highest levels of wave energy from boat wakes, even though some of the other sites had higher amounts of boat traffic. But the boats passed particularly close to the shoreline at the site where erosion occurred during the boating season; consequently, the wake energy did not dissipate before reaching the beach. Thus, the distance to which boats approach the shore is a very important factor for evaluating erosion due to boat wakes.

Two other important factors for evaluating erosion in small creeks and coves are the physical nature of the sediments, and the appearance of the shoreline profiles. The sites used in this study possessed physical characteristics which are representative of many other shoreline locations in Anne Arundel County, and the report discusses the particular characteristics at each site which were important to the erosion process.

Other factors were also studied because they affect the heights of waves, and thus the energy, in boat wakes. Besides distance from shore, the energy in boat wakes varied with different boat speeds, and with different depths of water. For the range of water depths in small creeks and coves of Anne Arundel County, the largest wakes can be expected from boats travelling slightly faster than the six-knot speed limit which is posted in many places. This increases the potential for erosion due to boat wakes in areas where boats reduce their speeds to conform to posted speed limits, as well as in areas where boats exceed the posted speed limit by only a small amount (1-2 knots).

Chapter VIII of this report contains a table of calculations for estimating those boat speeds which will generate maximum wakes in creeks and coves with different water depths. These ranges of boat speeds are suitable for use in a review of existing State policy to suggest changes in boating speed limits based on both safety and environmental reasons; but, this study shows that other environmental factors also need to be considered, especially the physical nature of the shoreline in any particular area, and the distance away from shore which motorboats pass.

I

INTRODUCTION

Chris Zabawa, Chris Ostrom,
Robert J. Byrne, John D. Boon III
Rhonda Waller, and Deborah Blades

A. Purpose of the Study

Since the close of World War II, the population in the counties fringing the Chesapeake Bay estuary in Maryland has increased dramatically, particularly on the western shore. Along with this population increase, recreational boating activity on the waterways has also increased substantially. For example, between 1968 and 1973, the number of pleasure boats registered in the State of Maryland grew at an annual rate of about 5% (from about 62,000 boats registered in 1968 to over 76,000 in 1973) (Roy Mann Associates, 1974). Approximately 40% of this increase in registered boats was concentrated in Anne Arundel, Baltimore, Harford, Cecil, Kent, Queen Annes, and Talbot counties.

There has been increasing concern that the wakes generated in some of these areas due to the heavier boat traffic may be accelerating rates of shore erosion, particularly in the smaller creeks and coves. In 1976, the Maryland General Assembly passed a resolution requesting the Department of Natural Resources to undertake a study to evaluate whether recreational motorboat traffic is detrimental to the ecology of small creeks and coves in Anne Arundel County, Maryland (Appendix A).

Potential impacts from motorboats in small creeks and coves could include effects on the turbidity and mixing of the water, toxic effects of oil and gas emissions from boat engines, damage to aquatic vegetation, and increased shore erosion due to boat wakes. In response to the General Assembly resolution, DNR conducted a literature search of previous boating studies with the cooperation of Federal agencies, and assessed the implications of existing technical information for small creeks and coves in Anne Arundel County. There were few pertinent studies found, and none concluded that boating impacts were actually detrimental to the ecology. The Environmental Protection Agency is presently engaged in further studies of some potential boating impacts in the South River (Williams and Skove, 1980). Several years' worth of data are required in many of these studies to obtain an understanding of cause and effect, since the variability of environmental factors can be fairly large from year to year.

On the other hand, a one year study of boat-wake energy and shore erosion can provide an indication of the potential seriousness of the problem for sites similar to those selected in Anne Arundel County. Therefore, in response to the General Assembly Resolution, the Department of Natural Resources elected to conduct a study to evaluate the contribution of boat-wake energy to the erosion of the shoreline fringes of small creeks and coves.

B. Contents of this Report

This report describes the collection and analysis of data from five shoreline sites to test three hypotheses:

1. Boat-wake energy is a substantial contributor to the overall wave-energy budget at the study sites.

2. Erosion of the shoreline sites is higher during the boating season than at other times of the year.

3. Different boat designs and passage characteristics can change the levels of wave energy in boat wakes.

To test the first two hypotheses, measurements of boat wakes were collected during the summer of 1979, and measurements of wind waves were collected at all times of the year between October 1978 and October 1979. In addition, shoreline surveys at the study sites were collected on a monthly basis between October 1978 and October 1979. The study sites constituted a representative cross-section of shoreline types (including beach, marsh, and bluff) in Anne Arundel County. The principal sites and shoreline surveys are described in Chapter IV of this report. Some alternative sites were chosen to be used by the consultants in case the boating patterns at the original five selected sites were not as anticipated. Chapter V contains descriptions of these additional sites.

TABLE 1.1

Site	Location[1]	Average Boat-Passes Per Day[2] WD = Weekday WE = Weekend	Yearly Wave Energy Budgets[3]: Wave Energy (ft-lbs/ft^2) Wind Wave	Boat Wake	Yearly% Boat-Wake Energy	% of Wave Energy in Wakes in Boating Season
A	Vegetated sand spit on Lower South River at Harness Creek	170.5 (WD) 735.7 (WE)	5,450,816	118,100	2.2%	4.4%
B	Steep bank on Upper South River near Goose Island	91.9 (WD) 344.2 (WE)	4,133,173	70,680	1.7%	3.6%
C	Marshy promontory on Broad Creek	95.2 (WD) 326.2 (WE)	3,823,991	376,040	9.6%	20.4%
D	Bluff on lower Severn River at Severnside	155.8 (WD) 268.8 (WE)	6,969,310	247,660	3.6%	8.4%
E	Pocket marsh in Maynedier Creek	44.6 (WD) 69.8 (WE)	3,181,249	15,650	0.5%	0.9%

1. From Chapter IV.
2. From Chapter VI.
3. From Chapter VII and Appendix B.

Boating patterns at each of the five principal sites during the summer of 1979 are described in Chapter VI. The wind-wave measurements are contained in Appendix B, and the wind-wave energies are compared to boat wakes in Chapter VII.

To test the third hypothesis listed above, trial runs of boats with two different hull designs were conducted at one shoreline site, and the wakes from different boat passes were compared for boat passes at different speeds and distances from the shoreline. These data are described and analyzed in Chapter VIII.

C. The Results

Table 1.1 (opposite) summarizes the boating frequencies and wave-energy budgets which were collected for the study. At four of the study sites, there was no increase in shore erosion which could be attributed to boating during the summer. The most important contribution to shore erosion was Tropical Storm David, which passed through Maryland in early September 1979, and was accompanied by the largest erosion in some of the shoreline surveys. Wind waves rank behind the storm effects in causing the observed shoreline changes over the year of observations, and in all cases boat wakes represented lower levels of wave energy. It is important to note that these results are drawn from a one-year data base and do not incorporate any variability which might be detected over a longer period of data collection.

At one site (Site C) there was considerable erosion of the fastland during the summer of 1979. The boat-wake energy at Site C is an important factor responsible for the erosion, but the physical shoreline setting could also be important. Since Site C is located at a narrow point on a creek, the boats pass particularly close to shore relative to the other sites, and wake energy does not dissipate before reaching the beach. Thus this site experienced the highest boat-wake energy during the summer of 1979, even though some of the other sites had higher frequencies of boat passes.

The results of the experiment with controlled boat passes show different types of boats, and different modes of operation of the same boat, can produce measurable changes in the wave energy contained in boat wakes. For the types of boats tested, maximum boat-wake energy occurred when the boat speed was about 8 knots; a high-speed passage (20 knots) produced lower wake energy. The water depth in this case was approximately 12 feet. For different water depths, maximum wake energy can occur at different speeds since the wave energy varies with both the speed of the boat and the water depth. In water depths of 6 feet or less, maximum or near-maximum wake energies can occur at boat speeds closer to 6 knots.

D. <u>The Conclusions</u>

One conclusion about boat wakes is the largest contribution to the total wave energy (and thus to the total potential for shore erosion) from wakes can be anticipated where there is a high frequency of boat passes close to a particular shoreline site. The actual level of fastland retreat in response to recreational boating patterns at any particular site will also depend upon the nearshore change in slope on the shoreline profile, upon the composition of the fastland, and upon the supply of sediment carried onto the shoreline site from alongshore.

The type of shoreline most susceptible to erosion would have a combination of:

- o exposed point of land in a narrow creek or cove;
- o fastland consisting of easily-erodable material such as sand or gravel;
- o steep nearshore gradient on the shoreline profile;
- o location adjacent to a high rate of boating, with boat passes relatively close to the shoreline.

The site which experienced the most fastland erosion during the boating season (Site C) had all four of the above characteristics.

Three more conclusions about wakes can be drawn from this one-year study for the range of basin depths frequently encountered in narrow creeks and coves in Anne Arundel County:

1. As boats reduce their speeds to conform to posted speed limits, they pass through a speed range in which the hull generates a maximum wake.

2. If the approach to a posted speed-control area is within a narrow creek, then the shores adjacent to the speed-reduction zone will be exposed to the high wake energies.

3. Boat operators can unknowingly generate a near-maximum wake while they are transiting a waterway if they misestimate their speed by only a few knots while their boat is in a posted speed-control zone.

E. Thoughts for Managers

1. The data collected for this study show that depth conditions are suitable at some shoreline sites in Anne Arundel County for maximum boat-wake energies to be generated from boats passing a posted 6-knot (or 6.9 mph) speed-limit zone. One of the products of this study is Table 8.3 in Chapter VIII which can be used to estimate the speeds at which maximum wakes would be generated in different areas which have different water depths. In some cases, posting a lower speed limit would decrease the wave heights in wakes which break on the shoreline.

2. Since boats which are slowing to approach a posted speed-control zone will pass through the range of

speeds which generate maximum wake, speed-limit signs should be posted, when possible, in portions of creeks which are so wide that wake energies will substantially dissipate before reaching the shoreline.

3. The data collected for this study indicate that the greatest potential for boating to increase erosion rates above natural levels can be expected when high frequencies of boat passes occur within a few hundred feet from the shore.

F. Suggested Future Studies

Further studies at other sites in Anne Arundel County are not likely to show boat wakes contribute more wave energy than wind waves for shore erosion. In the one-year period of observations, narrow waterways where boats passed closed to the shore held the greatest potential for increased erosion due to boat wakes. Further studies over a period of 4 to 5 years might show this potential is highly variable depending on boat traffic and boating patterns.

At Site C, about 80% of the boat traffic occurred at distances of 200 feet or less from the shore; in contrast, Site B had about 75% of the boat passes at distances greater than 500 feet. As a result, the wave energy due to boats at Site B was only about 20% of that experienced at the Broad Creek site. So boat passes between 200-500 feet from shore can appreciably reduce the level of wave energy in wakes which break along the shoreline. Further observations of controlled boat passes over a wider range of distances at selected shoreline sites would permit a more accurate determination to be made of the critical creek width which is needed to produce negligible wake energy along the shoreline. The controlled boat passes which were conducted for the study described in this report covered the range of distances from 50 to 200 feet offshore at a single shoreline site. This range of controlled boat passes should be extended to at least 500 feet from the shore. In addition, other areas with different beach and nearshore profiles could be selected for measuring wakes from controlled boat passes, and boats with different hull designs could be tested.

II
THE EROSION PROCESS

Robert J. Byrne, John D. Boon III
Rhonda Waller, and Deborah Blades

Shoreline erosion is defined here as the loss of subaerial fastland to the aqueous environment; it is <u>not</u> necessarily reflected in short-term changes in the beach which can be measured by surveying the shoreline over periods of a few weeks or months.

As an example, consider a shoreline segment where the "fastland" is a bluff (Figure 2.1). In the geologic setting of Anne Arundel County, there is generally a narrow sand beach at the base of the bluff shorelines. Excavation of this sand beach would disclose that the sand layer was relatively thin, and that within a few feet below the beach surface the consolidated bluff sediments would again be encountered. Observations of shoreline profiles at such a site throughout the course of a year would quite possibly show that the width and depth of the sand lens on this beach varied, while the portion of the shoreline profile on the bluff face remained unchanged.

This beach is a natural feature which is formed and reshaped by the action of breaking waves throughout the nearshore and particularly in the swash zone, where the undulatory wave motion is transformed into turbulent uprush and backwash on the beach slope. Once beaches are formed by wave erosion of the fastland sediments, the beach sediments

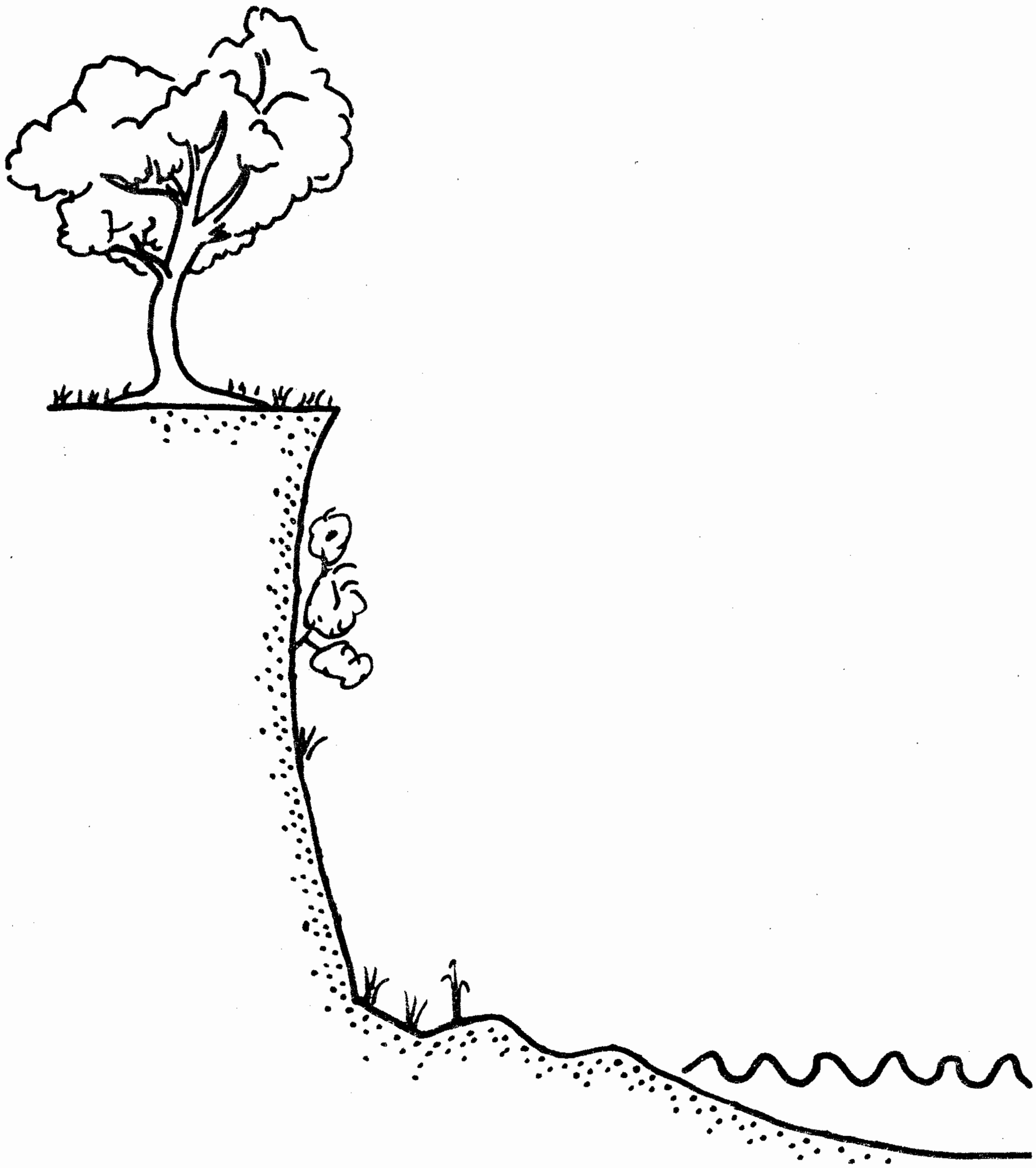

Figure 2.1

are in turn the most effective natural absorber of wave energy along the shoreline. The volume of sand on the beach at any given time depends upon wave conditions and water elevations over the previous several days. Since the beach profile is so affected by short-term wave events, the condition of a single beach profile is itself not a reliable indicator of erosion. However the retreat of the fastland, which can also be measured on shoreline profiles through time, is an unambiguous indicator.

The chief agents of fastland erosion are wave action against the shoreline and the elevation of the water surface both during the normal tidal cycle and during severe storms. Tidal currents in certain circumstances may also exert a significant control on shoreline stability. Finally, surface rain runoff and groundwater seepage may play a particularly important role in eroding steep bluffs and banks (Palmer, 1973). During periods of active rainfall or snow melt, surface runoff may trickle down the steep slopes of bluffs or banks, and incise small channels in the exposed sediments. A more serious impact on erosion is probably due to the percolation of rainwater into the sediments which form the bluffs or steep embankments. This seepage can subsequently discharge from the face of an embankment and cause instability and slumping.

In those bluffs containing impermeable layers, the groundwater discharge can be more concentrated where the

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opposite: Figure 2.1 Schematic drawing of a beach at the base of a bluff.

upper surface of the impermeable layer is exposed. This surface then becomes a slide plane offering little support to the sediments above the layer. Over the long-term, the slumping of these sediments will form a talus deposit at the base of the bluff, and the overall gradient of the exposed bluff face will decrease. Vegetation may also grow on the bluff face and stabilize the eroding sediments. However, with the presence of significant wave action, the talus material at the toe of the bluff is transported away from the site, leaving the embankment in an oversteepened configuration once again.

In regions of the Chesapeake Bay basin where wave energy for shore erosion is generated by local winds, the levels of wave energy are dependent upon the open water distance over which the wind blows (fetch), the duration of the wind, and most importantly on the wind speed. However, the changes which are produced in the shoreline profile at any site due to wave energy are dependent upon the level of the water surface on the profile.

Several factors control this level of the water surface, and thus control the zone of application of breaking waves on shorelines. Besides the "normal" semi-diurnal tidal excursion of about 1 foot in the small creeks and coves of Anne Arundel County, the long-term fluctuation in sea level is an additional factor which influences the level of the water on shoreline profiles. Due to the melting of the polar ice caps over recent geologic time, mean sea level has risen to its present location over the past few thousand years. Within the Chesapeake Bay region the relative sea-level rise is presently about 1 foot per century. At Annapolis, the sea level has risen at least 4 inches since 1929, when tide gauge records first began to be collected (Hicks, 1972) (Figure 2.2). While this rate of sea-level rise is slow, it is sufficient to drown low-lying lands and to maintain a continual landward encroachment of the zone of application of wave energy by natural forces on any shoreline profile.

Short-term sea-level variations due to large-scale atmospheric events also play a strong role in determining where waves will erode sediments on shoreline profiles. With the onset and duration of a regional northeast storm, variations in regional atmospheric pressure cause additional water to be forced into some portions of the Chesapeake Bay basin. This results in a super-elevation of the mean tide level, or storm surge, which may overtop a beach in some areas and allow the waves to expend their energy directly against the fastland. Storm surge elevations of two to three feet above expected tide level are not uncommon during northeasters in Chesapeake Bay. As a storm center passes through the Bay region, the easterly winds shift to the north and northwest and frequently become stronger and of longer duration. This may increase the wind-generated wave heights but it also relaxes the storm tidal surge in the vicinity of Anne Arundel County as the water level in the rivers fringing the western side of the Bay is then depressed below normal. Under these circumstances, the wave energy is dissipated along the lower portions of the shoreline profiles on the foreshore of the beach or in the nearshore zone, and the fastland is relatively immune to direct wave attack.

Even in the absence of major northeasters, several other factors combine to produce a measurable variation in mean tide level throughout the year. These include an annual variation in oceanic water temperature, and normal seasonal differences in regional atmospheric pressure.

At Annapolis, the monthly variation in sea level due to all factors is such that between April and October the mean tidal level is higher than between November and March (Figure 2.3). The range in the annual elevation of mean tide level is about equal to the tide range. The importance of this phenomenon is that the zone of application of wave energy is generally at higher elevations on the shoreline profile during the recreational boating season, with the maximum elevations being attained in August and September.

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opposite: Figure 2.2 (top) Changes in values for yearly mean sea level at Annapolis, Md. (after Hicks, 1972).

Figure 2.3 (bottom) Monthly variation in mean sea level at Annapolis (after Boon, 1978).

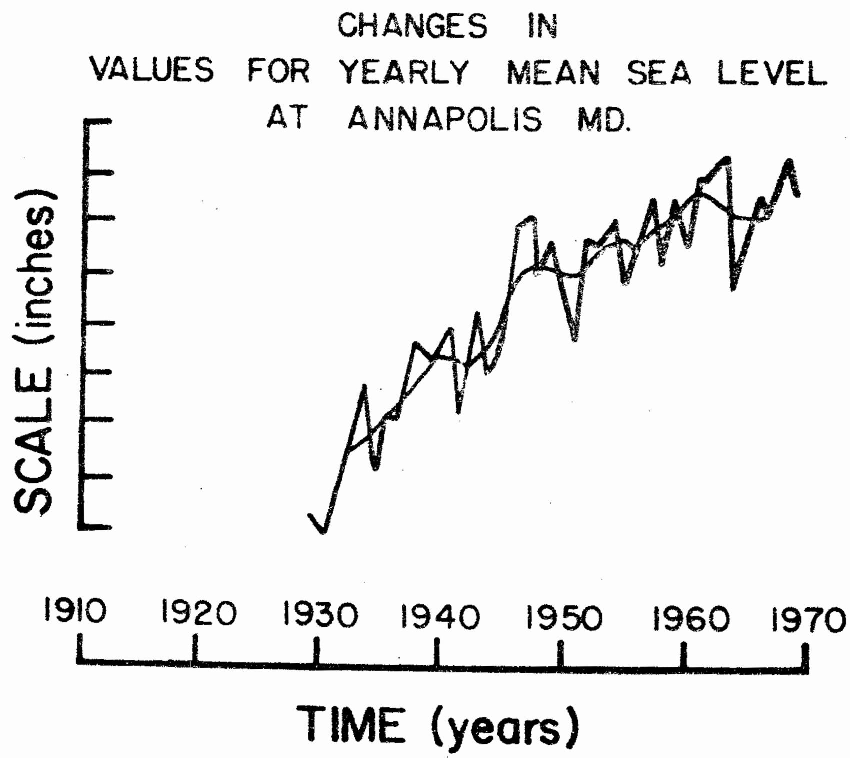

Figure 2.2

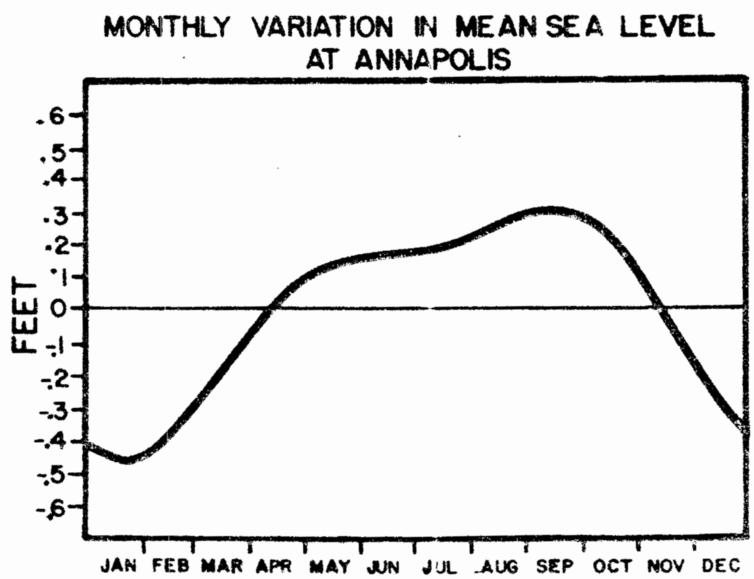

Figure 2.3

III
SAMPLING STRATEGY AND SITE SELECTION

Chris Zabawa, Chris Ostrom, and Mark Alderson

A. Sampling Strategy

To study the effects of boat wakes on the erosion process which was discussed in the previous chapter, measurements of shoreline changes were collected over a year at some selected sites in Anne Arundel County. Changes in the beach and fastland in the time between surveys can be discussed in terms of the wind-generated waves which dissipated their energy on the shoreline all year, and in terms of the boat wakes which are concentrated during the summer months. The sites were selected principally because they were in popular areas for boating and water skiing, but they also are respresentative types of shorelines which occur in Anne Arundel County, including beach, marsh, and bluff. Some effort was made to obtain sites which received wind waves from different directions and fetches.

B. Site Selection

The site selection process involved the following steps:

1) Areas of intense boating activity were identified by several groups, including:

   a. Magothy, Severn, and South River Associations;
   b. Anne Arundel County Boating Advisory Committee;
   c. Anne Arundel County Planning and Zoning Office;
   d. Maryland DNR Marine Police.

2) Once areas of intense boating activity were identified, potential shoreline sites were identified from aerial photographs which accompany the county tax assessment maps;

3) Letters were sent to approximately 120 landowners explaining the purpose of the study and requesting permission to make a site visit;

4) Visits were made by a DNR team to approximately 84 sites whose owners had no objection to participating in the study. Sites were disqualified if the owner indicated that he had applied for a permit for erosion control structures, or was planning to install shoreline structures within the forthcoming year. Owners were also asked whether they felt their land was located adjacent to an area of high boating activity. During the site visit, other observations were made, including:

   a. shoreline and beach morphology:
   b. shoreline sediment type;
   c. evidence of erosion;
   d. proximity of shoreline structures;
   e. orientation into the wind and approximate fetch;

5) 15 candidate sites were identified from the site visits. From these, five sites were selected for study by geologists from Coastal Resources Division of DNR and Maryland Geological Survey, together with the consultants.

The locations of these five sites are shown in Figure 3.1. The sites which were selected include:

Site A. A vegetated sand spit on the lower South River, at the entrance to Harness Creek.

Site B. A steep bank on the upper South River, near Goose Island.

Site C. A broad, marshy promontory on Broad Creek off the upper South River.

Site D. A bluff on the lower Severn River at Severnside.

Site E. A pocket marsh near the entrance of Mayneider Creek, off the upper Severn River.

The sites were chosen as being representative of varying physiographic conditions with respect to bank elevation, sediment composition, nearshore bottom gradient, and exposure to wind-wave activity.

Chapter IV contains a description of the shoreline profiles which were collected at these sites by the consultants on a monthly basis from October 1978 through October 1979. Chapters VI and VII describe the boating frequencies which were measured at these sites during the summer of 1979, and the boat-wake energy levels. Appendix B describes the wind-generated waves which were measured at these sites during the year of study.

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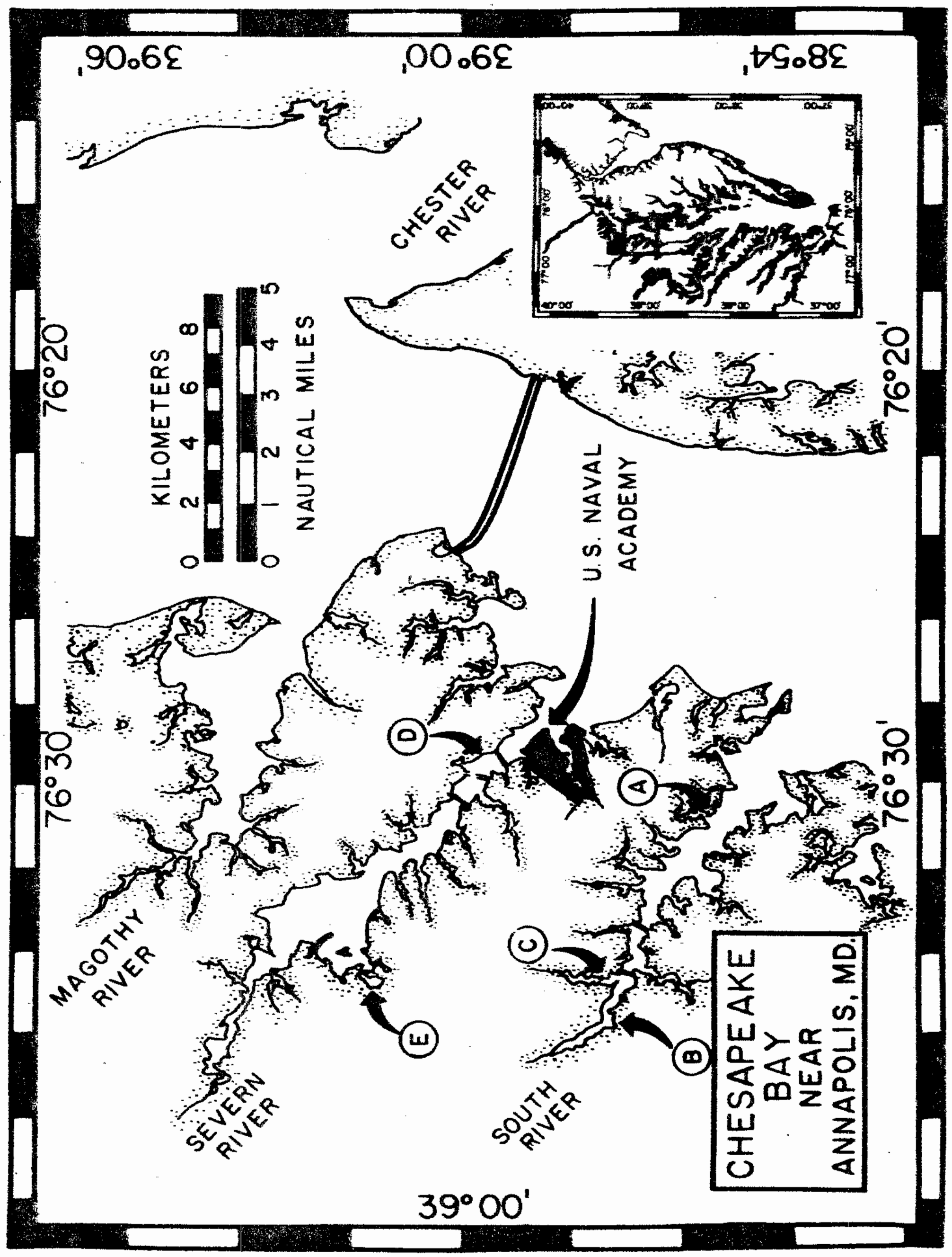
opposite: Figure 3.1 Location map of the consultants' study sites in Anne Arundel County.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NAUTICAL MILES
0 1 2 3 4 5
CHESTER RIVER
MAGOTHY RIVER
SEVERN RIVER
SOUTH RIVER
U.S. NAVAL ACADEMY
A
B
C
D
E

Figure 3.1

At the beginning of the study period, two additional sites were selected by students participating in a DNR co-operative work-study program at the Anne Arundel Community College. One site (AA) was located along a bluff and adjacent pocket marsh inside Harness Creek, in the vicinity of the consultants' site A. Another site (FF) was located along a beach and sandy marsh at Beard's Point on the upper South River. These sites were regarded as "back-up" sites to be used by the consultants in the case that boating patterns at one of the initial sites A-E were less intense than expected. The AA Community College students also monitored shoreline changes directly adjacent to two of the consultants' sites in areas where a different type of shoreline (marsh and bank) was immediately adjacent to the principal study area. The description of these additional sites prepared by the students is contained in Chapter V.