Delineation of Tidal Wetlands Boundaries in Lower Chesapeake Bay and Its Tributaries

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John D. Boon III
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Virginia Institute of Marine Science
Gloucester Point, Virginia 23062
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March  1977
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ABSTRACT

Ways of delineating the boundary between tidal marshes and adjacent uplands were investigated in both saline and freshwater systems found within lower Chesapeake Bay and its major tributaries. An engineering survey approach was utilized in which the elevational difference between the median point of the marsh-uplands vegetative transition zone and the local tidal datum of mean high water was determined at sixteen separate field locations selected near points where officially recognized datums were available. Thirteen of the chosen locations were at or near secondary control tide stations established by the National Ocean Survey. The latter meet datum accuracy standards requiring at least one year of tidal record for datum determination. The remaining three locations were chosen in areas of special interest where tertiary datums based on at least one month of record were available. The elevation at the median of the vegetative transition zone, taken as the upper limit of the marsh, was determined by botanists and related to the mean high water datum using specially developed limit recognition criteria in combination with leveling surveys and statistical sampling techniques.

Field survey results, after taking estimates of the expected vertical error into account, suggest a real difference in the limiting heights of the saline and freshwater marsh upper boundaries. The former averaged 0.95 feet and the latter 0.59 feet in height above mean high water at the secondary stations. The remaining tertiary stations were selected from saline marsh sites subject to apparently abnormal tidal characteristics imposed by exceptional hydrological and/or meteorological conditions. These stations indicated a somewhat higher limit to the saline marsh boundary on the order of 1.2 to 1.5 feet above mean high water.

A detailed examination of high water height distributions was made to determine annual immersion frequency levels at five primary tide stations possessing at least 19 years of tidal record in an attempt to define more clearly the fundamental relationship between the height of the marsh-uplands vegetative transition and the factor of tidal immersion. The results show that the high water heights recorded over a period of twenty years follow a statistical probability distribution that is remarkably similar at all five stations located in different parts of the Chesapeake Bay system. Further research and more extensive tidal data at critical locations is needed to ascertain whether or not a fixed rate of tidal immersion is the most universal factor establishing the vertical height position of the marsh-uplands boundary.
INTRODUCTION

This report presents the findings of a one year study of selected marsh sites in portions of lower Chesapeake Bay and its major tributaries in Virginia (The James, York, Rappahannock, and Potomac rivers). The study was undertaken at the request of the U.S. Environmental Protection Agency, the objective being to find improved means of defining and locating the upper limit of tidal wetlands for jurisdictional purposes.

In pursuing this rather specific study objective, the Virginia Institute of Marine Science (VIMS) has extended its overall research efforts in the area of marsh boundary definition and wetlands classification systems. Previous research results, in fact, have dictated our present approach to the EPA objective, particularly those portions dealing with the relationship between marsh boundaries and tidal datums. Certain aspects of this relationship have been clarified by the present study, others remain for future investigations.

The reader desiring background information on coastal zone wetlands in Virginia should consult Wass and Wright (1969). Information about specific wetlands types and their biological and physical properties may be found in Silberhorn, et al. (1974).
WETLANDS VEGETATIONAL DISTRIBUTIONS

As one approaches the problem of defining a vegetated wetlands and marking its limits, the key factor involved is the growth, or potential for growth, of one or more species of plants that are associated with the wetlands habitat; i.e., plants that can tolerate or are dependent in some way on partial or complete submergence by water. In tidal wetlands, submergence results primarily from quasi-periodic inundation by tides. While various types of wetlands have been recognized (Wass and Wright, 1969), this investigation has been limited to nonwooded wetlands or marshes, including salt, brackish, and freshwater varieties.

Research and wetlands inventory work by VIMS scientists indicate that 10 species of plants tend to dominate most marshes in Virginia, the term "dominant" being construed to mean at least 50% of the vegetated surface of a particular zone is covered by a single species (Silberhorn, et al., 1974). Exceptions include the freshwater and brackish marshes in which plant communities tend to be mixed and do not have clearly dominant species.

It happens, however, that among those plants which are usually dominant in a given marsh, few if any seem to be highly restricted in the upper limit of their growth levels to a specific elevational plane. The upper limit of the saltmarsh cordgrass, Spartina alterniflora, for example, is
ordinarily found near the level of mean high water, but extensions well above this elevation are frequently encountered for the short form of this plant (Lagna, 1975). On the other hand, the lower limits to the distributions of many saltmarsh plant species, including *Spartina alterniflora*, are strongly dependent upon their ability to tolerate a specific amount of tidal immersion (Johnson and York, 1915; Hinde, 1954; Chapman, 1960; Adams, 1963; Redfield, 1972). In general, frequency of tidal immersion sets a fairly precise lower limit to each particular species in a tidal marsh whereas competition with other species that are better adapted to the environment at higher levels causes a much more irregular upper limit for that species. The orderly sequencing of several such species proceeding from lower to higher elevations in a particular marsh community produces the familiar zonation pattern.

Other factors such as salinity, soil type, and drainage characteristics affect plant species distributions; but with few exceptions, all are secondary to the factor of tidal immersion in salt marshes (Chapman, 1960; Odum, 1961). Less is known, however, about the causes of species zonation in freshwater tidal marshes.

**MARSH-UPLANDS TRANSITION ZONE**

In the majority of cases, coastal marshes terminate on their landward side against an uplands. Entry into the latter is usually characterized by a noticeable increase in ground
elevation in the landward direction, accompanied by a change in vegetation from those grasses and shrubs that are usually dominant in marshes to grasses, shrubs, and trees that are dominant in areas rarely, if ever, subject to tidal inundation. The transition zone in which this vegetational change occurs is normally seen as a band of varying width (depending upon ground slope) running between the marsh and the uplands and tending to follow elevational contours. This is particularly evident where the marsh borders a forested uplands. However, in disturbed areas or in locations where cliffs and scarps have formed, a transition zone may not occur.

During our field studies in Virginia coastal areas, we noted that the transition zone is often quite striking to the eye due simply to the visual contrast of several morphologically distinctive species of plants in close proximity to one another. Upon closer inspection of the various vegetational sequences that occur, it became apparent that a recognizable species change takes place within a band roughly one to ten feet wide in most areas. A more precise determination of transition zone "limits" requires detailed measurement of species cover and abundance. Due to limitations in time and personnel, these measures could not be made at the large number of sites we were required to investigate in this study. In lieu of such measurements, we concentrated instead upon identification of the median point within the transition zone or the point in the vegetational sequence at which true
Uplands species first appear to have coverage and abundance approximately equal to that of marsh species. In most of the marshes visited, this point was not difficult to find due to the fact that the uplands vegetation usually ceases rather abruptly proceeding downslope toward the marsh, particularly in saline environments.

**UPPER LIMIT OF THE MARSH (ULM)**

The above observations and definitions suggest that the median point within the marsh-uplands transition zone effectively delineates the lower limit of uplands in that zone. We submit that the median point also provides an effective means of locating the upper limit of the marsh. While certain species of marsh plants are commonly found landward of the median point, their numbers appear to decrease erratically in that direction as a result of increasing competition with uplands species. Very often there is no abrupt terminus of the marsh vegetation landward except where uplands ground relief increases sharply. In areas of low uplands relief, marsh species penetrating farthest into uplands-dominated cover will normally consist of a few individual plants found only after an extended search. The uplands plants extending farthest into marsh-dominated cover can be found quickly, in most cases not far from the median point of the transition zone.

More detailed information concerning the median point and vegetational patterns used in locating the ULM in saline
and freshwater marshes is given in a later section of this report (ULM recognition criteria, p. 44).

**MEAN ELEVATION OF THE ULM**

The case has been made that the horizontally depicted boundary between marsh and upland can be efficiently and accurately defined through the use of remote sensing techniques (Fornes and Reimold, 1973; Klemas, et al., 1974). This is certainly true insofar as aerial mapping and the determination of marsh acreages are concerned. However, it is in the vertical dimension that we measure tidal height distributions, the principal factor responsible for marsh-uplands differentiation. And to determine just how consistent this relationship may actually be, it is necessary to statistically sample the elevational distribution of the ULM through ground surveys, noting how the mean elevations and their associated variances compare from one type of marsh to the next when referred to a common datum.

We also feel that the use of a specific elevation to represent the ULM is consistent with the well-established use of elevational contours to delineate features and fix jurisdictional boundaries in coastal regions. This includes such traditional engineering practices as the positioning of shorelines (based on the tidal datum of mean high water) and flood plain determinations (based on storm tide levels having a specific interval of recurrence).
TIDAL DATUMS AND TIDAL BOUNDARIES

DEFINITIONS AND METHODS

The rise and fall of the tide, though a quite familiar natural phenomenon, is in reality a very complex one. Observed water level extremes that appear to recur on a daily or semi-daily basis are often referred to as the high water plane or low water plane without much concern as to whether these heights vary a little or a lot from one day, one month, or one year to the next. An examination of the individual high or low waters at any tide station would reveal that such variations exist and are periodic in nature, meaning that truly representative elevations must be obtained as the average of all tides during the time period covering all of the significant variational cycles (Marmer, 1951; Boon and Lynch, 1972).

The accepted definitions of mean high water (MHW) and mean low water (MLW), the principal tidal datums used on the U.S. East Coast, are given as the average heights of all high waters and all low waters, respectively, in a specific 19-year period. The specific 19-year period, called the National Tidal Datum Epoch, currently includes the years 1941-1959. Another commonly recognized tidal datum is that of mean tide level (MTL) defined as the plane halfway between MHW and MLW. The mean range of tide (Mn) is defined as the height interval between MHW and MLW (Marmer, 1951).

A federal agency within the U.S. Department of Commerce, the National Ocean Survey (formerly the U.S. Coast and Geodetic
Survey) of the National Oceanic and Atmospheric Administration (NOAA) has the responsibility of determining tidal datums and specifying which 19-year period or epoch is used in the United States and its territories. These epochs will be reviewed for consideration of possible updating with revised datums every 25 years. The next scheduled epoch for consideration will include the years 1966-1984. A primary datum determination obviously is not possible at a new location having a comparatively short tidal record. Fortunately there are reliable procedures in use for computing the equivalent of a 19-year datum. The procedure normally used by the National Ocean Survey (NOS) involves the comparison of corresponding tide gage records at two locations, one of which must be a primary control tide station having acceptable datums.

DATUM ACCURACY

In general, the accuracy of the simultaneous comparisons method for determining tidal datums locally increases with the length of the records used in the comparison. Marmer (1951) stated that a tidal datum derived through a one-month comparison would normally fall within 0.1 feet of the true (19-year) height. Swanson (1974) made a detailed analysis of errors for standard and alternate computational methods; he reports standard deviations on MHW and MLW determinations of between 0.12 and 0.13 feet for one-month comparisons, decreasing to about 0.08 feet for a six-month's comparison on the U.S. East Coast.
The horizontal surface passing through a local tidal datum is often referred to as a tidal datum "plane", but one cannot assume that such surfaces are level from one location to the next. The change in datum elevation over short distances in coastal areas is normally a function of local hydraulic conditions which can be influenced by river discharge, local restrictions to flow (e.g., narrow entrances to basins), channel resonance, shallow water and frictional effects. In practice, small spatial changes in datum elevations can scarcely be predicted even with the best numerical models. However, precise level networks around Chesapeake Bay and its tributaries show that a change of more than 0.05 foot per mile in any tidal datum would be uncommon for most open waterways in this region.

TIDAL BOUNDARIES

Within a local region where a MHW or MLW determination has been made, the resulting tidal datum may be used for certain practical purposes. These include locating the intersection of the datum elevation with the shoreline, forming a tidal boundary such as the mean high water line. While a tidal boundary can be accurately located on the ground by a qualified land surveyor, it is much more efficient to locate and map such lines by tidally-controlled aerial (photogrammetric) survey methods if large areas are to be covered.
The precision associated with the horizontal positioning of a tidal boundary is largely a function of ground slope and is much more subject to change, due to erosion and accretion, than the datum itself which the latter do not affect. If a datum elevation intersects a nearly flat surface (e.g., MHW in many so-called high marshes), it may be pointless to even attempt to locate the corresponding tidal boundary. This is certainly one of the reasons why the MHW line is not in itself a suitable boundary for most types of wetlands (Boon and Lynch, 1972).
FREQUENCY OF IMMERSION LEVELS IN CHESAPEAKE BAY

STATISTICAL ASPECTS

The use of tidal datums (MLW or MHW) as the primary reference on which to base wetlands boundaries via the ULM elevation has been advocated in a number of previous studies (Marcellus, 1972; Boon and Lynch, 1972; NOS, 1975). The difference ULM-MHW is found to be a positive though apparently variable quantity from one region of the country to the next. The variation may perhaps be explained at least in part if one starts with the hypothesis that the ULM coincides with a level representing a specific amount of tidal immersion. In researching this relationship, it is necessary to begin by examining certain statistical properties of the observed tide.

As pointed out by Dronkers (1964, p. 468), the astronomical or predicted tides have no statistical behavior whatever. That is, the heights of the astronomical tide including the extremes are, in theory, 100% predictable through deterministic formulae that include an infinite Fourier series for each one of a finite number of tidal constituents. But in any given record containing a sufficiently large number of observed tides such as the high water heights, we normally see clear evidence of a random element having been introduced by some set of statistically governed physical processes—weather dominated processes in most instances. It is therefore possible to consider the tidal datum as the static component of the observed tide which can be isolated and removed from the
record by the 19-year averaging, leaving a residual statistical component in the form of tidal immersion expressed as a frequency distribution of exceeding heights.

HIGH WATER CUMULATIVE FREQUENCY DISTRIBUTIONS

An effective technique for investigating tidal immersion as reflected in the distribution of high water heights over one or more years has been developed by members of the Rijkswaterstaat in Holland (Wemelsfelder, 1938, 1961; Dronkers, 1964), upon which the following methods are based.

High water cumulative frequency distributions are developed on an annual basis by enumerating the daily high water heights that equal or exceed a given elevation in a standard year containing 705 high tides. The exceeding number, n, is then cast as function of height, h, and is determined at discrete levels above some arbitrary datum. If a given year should contain for example, 707 high tides rather than 705, each value of n must be normalized through multiplication by the appropriate ratio (705/707, etc.). It then becomes possible to combine two or more years of record at a station by computing averages of the normalized n values from each year (one average for each discrete level).

For reasons to be given shortly, a logarithmic transformation of the exceeding number is made before plotting it against height. Figure 2 shows such a plot based on the observed high waters at Hampton Roads, Virginia (Figure 1) for the combined
years 1954-1974.\textsuperscript{1} The enumerations of \( n \) were made at intervals of 0.1 foot. Two characteristic features are illustrated in this figure: 1) for the lower elevations \( n \) gradually converges on the limit 705, 2) at the higher elevations that are of interest in this study, the plotted points enter a second region of convergence in which the relationship between \( n \) and \( h \) becomes linear. The linearity can be accounted for by statistical formulations based on a well-known probability distribution.

PROBABILITY MODEL

Tidal immersion in marshes is occasionally expressed in terms of the number of hours each day that a particular part of the marsh is covered by water. Obviously the number of hours of immersion may vary considerably from one day to the next and from one marsh to the next. Applying a more rigorous definition, one can refer instead to the fraction of total time, \( T_h / T \), in which the tide falls within some height interval \( h \) to \( h + \Delta h \). By taking a very long tidal record and a very small height interval, this fraction will begin to converge to a limit defined mathematically by the probability density function

\[
p(h) = \lim_{\Delta h \to 0} \frac{1}{\Delta h} \left[ \lim_{T \to \infty} \frac{T_h}{T} \right]. \tag{1}
\]

\textsuperscript{1} These and other tidal data given in this report were furnished by the Tides and Water Levels Branch, National Ocean Survey, NOAA, Rockville, Maryland 20852.
The probability that some instantaneous value of the tidal height, \( h(t) \), is equal to or greater than a fixed height, \( h \), is then given by the probability distribution function defined as

\[
P(h) = \text{prob}\ [h(t) \geq h] = \int_{h}^{\infty} p(\xi) \, d\xi,
\]

(2)

the mean of the distribution being

\[
\mu_h = \int_{-\infty}^{\infty} h \, p(h) \, dh.
\]

(3)

The most common example of a probability distribution is the familiar Gaussian form which is the basis for much statistical sampling theory. However, in dealing with tides, one finds that increasingly higher levels are equalled or exceeded more in the fashion of rare events typically governed by a Poisson distribution.

Considering the daily high water heights at a station, let it be assumed that the number which fall within a selected height interval \( \Delta h = h - h_b \) follows a Poisson distribution with mean \( m\Delta h \) where \( m \) is a proportional constant. The Poisson probability distribution function

\[
P(r, \Delta h) = e^{-m\Delta h} \frac{(m\Delta h)^r}{r!}
\]

(4)

expresses the probability that exactly \( r \) high waters will fall within the interval \( h_b \) to \( h \). The probability that all will exceed \( h \) if \( h_b \) is assumed to be the minimum height possible within the distribution is

\[
P(0, \Delta h) = e^{-m(h-h_b)}
\]

(5)
Hence the number expected to exceed \( h \) in a sample of size \( N \) is

\[
n = N P(0, \Delta h) = N e^{-m(h-h_b)}
\]

noting that when \( h = h_b \) in this equation the exceeding number equals the sample size \( (n = N) \).

A model based on equation (6) can be applied at once to the data shown in Figure 2 using the log form

\[
\ln n = -m (h - h_b) + \ln N.
\]

(6a)

Choosing data points \((n, h)\) that fall within the linear region, equation (6a) can be fitted to them by ordinary least squares methods to obtain the slope factor \( m \) assuming \( h_b = 0 \) initially. Thereafter \( h_b \) is found by substituting \( m \) and the values \( n = 705, h = 0 \) in the fitted equation. For any given data set, some of the points at the extreme upper heights should be excluded from the least squares fit since they approach the limit of resolution imposed by the sample size (record length). In theory, the longer the record length, the higher the level included in the region of linear definition.\(^2\)

Using equation (6), one can determine the annual immersion frequency for any given height expressed as the number of high waters per standard year equal to or higher than that height.

\(^2\) In practice there may be additional complications if several extreme tides happen to be caused by one severe storm or a flood. Such tides cannot be considered independent events, a fact which biases the upper portion of the distribution toward higher frequencies. However, the most extreme levels do not concern us here as they far exceed ULM elevations.
It is also possible to find the height corresponding to a particular annual immersion frequency.

**OBSERVED DISTRIBUTIONS IN CHESAPEAKE BAY**

The distribution set forth by equation (6) is an entirely statistical one containing no periodic elements or trends in itself. Variations in \( h_b \) and \( m \) at a station during successive computational periods may, however, reflect changes or shifts in the distribution with time and there may also be differences in contemporaneous values of \( h_b, m \) from one location to the next. To explore the nature and extent of such variations, five 20-year records from selected tide stations within Chesapeake Bay were analyzed, including Hampton Roads and Kiptopeke Beach in Virginia, Annapolis and Solomons Island in Maryland, and Washington, D.C. Their locations are shown in Figure 1.

The high water frequency data for Hampton Roads were plotted in combinations consisting of one, two, four, and ten-year groups are shown in Figures 3-6, respectively. The heights in each case are elevations above staff zero as taken directly from NOS tabulation sheets. The one-year plots in Figure 3 show, as expected, the greatest amount of scatter. In general, there are no clear indications of significant slope differences among curves, rather the primary variation seems to be in the form of shifts along the height scale. Of particular interest are anomalous height displacements of the 1965 and 1972 plots relative to other years.
Plots of the same ten-year groups are shown for the other stations in Figures 7-10 for visual comparison. Although yearly plots are not shown, each of these stations contained a similar anomaly in 1972. Hence further analysis was indicated.

We computed a least squares fit based on equation (6) for each year at each of the five primary stations. The elevations of specific frequency levels were then determined from the resulting formulas. For example, $h_{60}$ denotes the staff height that corresponds to an annual immersion frequency of 50 tides per standard year for the period and place in question.

Figures 11 and 12 show the yearly values for $h_{25}$, $h_{60}$, $h_{100}$ plotted along with yearly high water averages at two nearby stations, Hampton Roads and Kiptopeke Beach. The yearly high waters for this 20-year segment contain almost identical variations and the same upward trend reflecting relative sea level rise as that reported by Hicks (1973) for yearly mean sea level at Hampton Roads. The figures illustrate how variations in each of the annual immersion frequency levels ($h_{100}$ in particular) are closely related to variations in yearly high water. Moreover, as shown in the bottom three graphs of each figure, the deviations from yearly high water exhibit a similar pattern at each station but have no apparent long-term trend; mean deviations over the 20 years are essentially the same for a given frequency level from one station to the next. Viewing this evidence, it becomes clear that immersion frequency levels that occur in an unusual year such as 1972 or 1965 may
appear to be anomalous unless the change in yearly high water is taken into account.

**RELATION TO MEAN HIGH WATER**

If an investigator wishes to express the upper limit of a marsh (the ULM) in terms of an elevation above a tidal datum (MHW) and if he assumes that the marsh limit corresponds to a specific immersion frequency level, it is a matter of some importance to know whether the difference between the tidal datum and the specified frequency level remains constant from one region to the next. Table 1 contains differences between MHW and four separate frequency levels ($h_{10}, h_{25}, h_{50}, h_{100}$), each based on 20 years of data at the five stations selected in Chesapeake Bay and its tributaries. From these data we see that the lowest level, $h_{100}$, is the most consistent, ranging from 0.77 to 0.86 foot above MHW at the five stations. As might be expected, slightly greater variations are reflected at each higher level reached less frequently in the standard year. A very significant result is the apparent lack of any correlation between the height of the frequency levels above MHW and the range of tide ($M_n$). The latter varies from 0.89 foot at Annapolis to 2.90 feet at Washington.

**DISCUSSION**

Based on the information at hand, we would conclude that annual immersion frequency is a parameter that is independent
### TABLE 1. TIDAL DATUMS AND 20-YEAR ANNUAL IMMERSION FREQUENCY LEVELS AT FIVE PRIMARY TIDE STATIONS IN CHESAPEAKE BAY

<table>
<thead>
<tr>
<th>Station</th>
<th>Mn</th>
<th>MHW</th>
<th>$h_{10}$</th>
<th>$h_{26}$</th>
<th>$h_{50}$</th>
<th>$h_{100}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. HRVA</td>
<td>2.47</td>
<td>6.40</td>
<td>8.18</td>
<td>7.81</td>
<td>7.53</td>
<td>7.25</td>
</tr>
<tr>
<td>2. KBCB</td>
<td>2.72</td>
<td>5.90</td>
<td>7.62</td>
<td>7.28</td>
<td>7.02</td>
<td>6.76</td>
</tr>
<tr>
<td>3. SOLI</td>
<td>1.20</td>
<td>4.63</td>
<td>6.09</td>
<td>5.81</td>
<td>5.60</td>
<td>5.39</td>
</tr>
<tr>
<td>4. ANNA</td>
<td>0.89</td>
<td>5.25</td>
<td>6.82</td>
<td>6.54</td>
<td>6.32</td>
<td>6.10</td>
</tr>
<tr>
<td>5. WADC</td>
<td>2.90</td>
<td>7.16</td>
<td>8.78</td>
<td>8.44</td>
<td>8.18</td>
<td>7.93</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Station</th>
<th>$h_{10}$-MHW</th>
<th>$h_{26}$-MHW</th>
<th>$h_{50}$-MHW</th>
<th>$h_{100}$-MHW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. HRVA</td>
<td>1.78</td>
<td>1.41</td>
<td>1.13</td>
<td>0.85</td>
</tr>
<tr>
<td>2. KBCB</td>
<td>1.72</td>
<td>1.38</td>
<td>1.12</td>
<td>0.86</td>
</tr>
<tr>
<td>3. SOLI</td>
<td>1.46</td>
<td>1.18</td>
<td>0.97</td>
<td>0.76</td>
</tr>
<tr>
<td>4. ANNA</td>
<td>1.57</td>
<td>1.29</td>
<td>1.07</td>
<td>0.85</td>
</tr>
<tr>
<td>5. WADC</td>
<td>1.62</td>
<td>1.28</td>
<td>1.02</td>
<td>0.77</td>
</tr>
</tbody>
</table>

19.
of the astronomical tide and is mostly governed by local meteorological and hydrological effects as well as the secular rise in sea level. The question arises as to the usefulness of this information in light of possible spatial variations. Although the consistency in the data of Table 1 encourages the use of MHW as a reference on which to base marsh ULM elevations at widely separated points within the Chesapeake Bay system, we are concerned that some areas may remain that do not conform to the usual pattern. In shallow embayments and along certain lee shores, intermittent storm surges can receive significant local amplification affecting high water frequency distributions but having little effect on the tidal datum of MHW. Unfortunately, only a few tidal records of any length exist in areas where this type of phenomenon is suspected. We will discuss one such location in our presentation of field survey results later on.

Another important factor has to do with variations in the difference ULM-MHW through time. Lagna (1975, p. 12) advanced the idea that elevations of marsh vegetation may be attuned to short-term averages of recent high water height observations rather than the local MHW datum. This concept appears extremely unlikely for high water averages covering a period of one year or less; Figures 11 and 12 illustrate that a vertical change of nearly 0.3 foot up or down might be required in some years for vegetation keeping pace with yearly high water—a considerable response on the part of any marsh.
More conventional concepts would simply have the ULM keep pace with the long-term trend in relative sea level rise, about 0.011 feet per year on the U.S. Atlantic Coast (Hicks and Schofnos, 1965). At this rate, the MHW reference datum would change by approximately 0.3 foot after a scheduled 25-year update and the difference ULM-MHW should vary by no more than this amount for any two ULM determinations made during the 25 years between updates. By considering the temporal position of ULM determinations relative to the tidal epoch in use, it should be possible to adjust the difference ULM-MHW to a standard value which will be consistent from one epoch to the next.

Finally, a compelling argument in favor of adopting MHW as the basic level of reference in marsh boundary or immersion frequency investigations is the accessibility of this datum through the existing network of NOS tidal bench marks in coastal areas throughout the country. The network is continually expanding in response to coastal boundary mapping efforts now in progress in many states.
LIST OF NOS TIDE STATIONS AT SITES SELECTED FOR STUDY

**PRIMARY STATIONS (20-year records available)**

<table>
<thead>
<tr>
<th>Station Code</th>
<th>Station Name</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRVA</td>
<td>Hampton Roads, Va.</td>
<td></td>
</tr>
<tr>
<td>KBCB</td>
<td>Kiptopeke, Va.</td>
<td></td>
</tr>
<tr>
<td>SOLI</td>
<td>Solomons Island, Md.</td>
<td></td>
</tr>
<tr>
<td>ANNA</td>
<td>Annapolis, Md.</td>
<td></td>
</tr>
<tr>
<td>WADC</td>
<td>Washington, D.C.</td>
<td></td>
</tr>
</tbody>
</table>

**SECONDARY STATIONS (1 - 4 year records available)**

<table>
<thead>
<tr>
<th>Station Code</th>
<th>Station Name</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRPT</td>
<td>Ferry Point, Va.</td>
<td></td>
</tr>
<tr>
<td>CHAX</td>
<td>Cheatham Annex, Va.</td>
<td></td>
</tr>
<tr>
<td>WSPT</td>
<td>West Point, Va.</td>
<td></td>
</tr>
<tr>
<td>BELL</td>
<td>Bellville Creek, Va.</td>
<td></td>
</tr>
<tr>
<td>MILL</td>
<td>Mill Creek, Va.</td>
<td></td>
</tr>
<tr>
<td>BAPR</td>
<td>Bayport, Va.</td>
<td></td>
</tr>
<tr>
<td>TAPP</td>
<td>Tappahannock, Va.</td>
<td></td>
</tr>
<tr>
<td>SNMF</td>
<td>Saunders Wharf, Va.</td>
<td></td>
</tr>
<tr>
<td>FLPT</td>
<td>Fleet Point, Va.</td>
<td></td>
</tr>
<tr>
<td>LEWS</td>
<td>Lewisetta, Va.</td>
<td></td>
</tr>
<tr>
<td>COLE</td>
<td>Coles Point, Va.</td>
<td></td>
</tr>
<tr>
<td>DAHL</td>
<td>Dahlgren, Va.</td>
<td></td>
</tr>
<tr>
<td>AQUI</td>
<td>Aquia Creek, Va.</td>
<td></td>
</tr>
</tbody>
</table>

**TERTIARY STATIONS (1 - 6 month records available)**

<table>
<thead>
<tr>
<th>Station Code</th>
<th>Station Name</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOSQ</td>
<td>Mosquito Creek, Va.</td>
<td></td>
</tr>
<tr>
<td>GARD</td>
<td>Guard Shores, Va.</td>
<td></td>
</tr>
<tr>
<td>HARB</td>
<td>Harborton, Va.</td>
<td></td>
</tr>
</tbody>
</table>

\[ n = N \exp(-m(h-h_b)) \]

\[ m = 2.30 \]

\[ h_b = 6.38 \]
FIGURE 11. ANNUAL IMMERSION FREQUENCY LEVELS AND YEARLY HIGH WATER AT HAMPTON ROADS, 1954-1974
FIGURE 12. ANNUAL IMMERSION FREQUENCY LEVELS AND YEARLY HIGH WATER AT KIPTOPEKE BEACH, 1954-1973
FIELD SURVEYS OF THE MARSH BOUNDARY

PREVIOUS STUDY IN VIRGINIA

The distribution of tidal marsh communities in relation to factors such as salinity and elevation was addressed by Marsh (1969) in the first comprehensive report on Virginia's Coastal Wetlands by Wass and Wright (1969). Marcellus (1972) later presented field study results establishing a quantitative relationship between the uppermost reaches of Virginia salt marshes, which he identified by means of the so-called salt bush line (SBL), and the tidal datum of mean low water. Marcellus conducted field surveys at 24 different marsh sites, leveling from nearby NOS tidal bench marks to the lower limits of the salt bushes *Iva frutescens* and *Baccharis halimifolia* where he established the SBL elevation in most cases from the average of several spot readings. He noted (p. 6) that the SBL fell within and slightly below the true upper limit of the marsh.

The Marcellus study is particularly noteworthy because the results constituted the basis for the wetlands definition used in the Virginia Wetlands Act of 1972 (Virginia Code, Title 62.1, Section 62.1-13.2f). The act defines wetlands as "all that land lying between and contiguous to mean low water and to an elevation above mean low water equal to the factor 1.5 times the mean tide range at the site...in question;" a list of marsh plants including some 35 species completes the definition. The incorporation of mean low water (MLW) and the
tidal range (Mn) is a distinctive feature in comparison to other state wetlands definitions and results primarily from the fact that riparian rights of ownership have traditionally extended to the low-water mark in Virginia (Virginia Code, Title 62.1, Section 62.1-2). Using the low-water mark, i.e. MLW, as a reference Marcellus' data show that the height of the SBL is strongly range dependent (Figure 13a) and the factor 1.5 emerges as the average ratio of elevation to range. However, referring these same SBL elevations to other datums such as MTL or MHW selectively removes the range dependency (Figures 13b, 13c) and reveals that the difference SBL-MHW is in fact rather uniformly distributed in the range domain except for a slight (and very questionable) trend amid unexplained residual scatter in the data. Figure 13c also illustrates that the present wetlands definition, while adequately covering most marsh situations, may fail in those areas having a very small tidal range while remaining exposed to weather tides. The latter situation appears to exist for Chincoteague Bay marshlands in Maryland and Virginia.

SELECTION OF PRESENT SURVEY SITES

The present study, as mentioned previously, places the upper limit of the marsh (ULM) at the median of the marsh-uplands vegetational transition zone. While this point is not far removed from the saltbush line in most salt marshes in Virginia, the obvious advantage of the vegetational median
FIGURE 13. ELEVATION OF SALT BUSH LINE VERSUS TIDAL RANGE
(Data from Marcellus, 1972).
is its wider applicability with respect to other types of marshes including freshwater marshes where the salt bushes are not found. In addition, the median point within a naturally-occurring transition zone may be sampled with greater precision in most instances since the botanist's criteria for locating this point is not limited to one or two species.

To obtain maximum precision in our survey results, we selected undisturbed marshes insofar as possible from among those situated near tidal datums established by NOS. We had the considerable advantage of selecting the majority of our sites near tide stations with record lengths of between one and four years; these have recently become available within each of the major Chesapeake estuaries and at points along the western Bay shore. The accuracy of the MHW datums at stations 6-18 (Figure 1) is estimated to be ±0.05 feet or better (Swanson, 1974). Stations 19-21 having datums of lesser precision were selected for marsh sites of special interest, including one at the south end of Chincoteague Bay (Mosquito Creek) and two along the eastern Bay shore (Guard Shores and Harborton).

SURVEY METHODS AND PROCEDURES

Double-run leveling between NOS tidal bench marks and the marsh boundary was conducted using a Nikon auto-level and a Metagrad Philadelphia rod by Kueffel and Esser. A forward and backward run was made between the NOS marks and a temporary mark placed just inside the fastland at each marsh transition.
zone to be surveyed. Level closure after the backward run was ±0.015 feet or less at all sites for single-run distances varying between 1,000 feet and one mile. Balanced backsight and foresight distances of 150 feet or less were used between all turning points in either run.

A series of short foresights were subsequently made from instrument set-ups near the temporary mark to the median point of the marsh-uplands vegetational transition zone. The botanist was instructed to place the level rod on the soil surface for a reading at each selected median point using criteria to be discussed shortly. The readings were repeated at 15 points spaced approximately 10-20 feet apart along the length of the transition zone, excluding however any modified portions of the zone such as erosional scarps or filled areas. The 15 sample elevations obtained were then averaged to obtain an estimate of the true ULM elevation referred to the nearest NOS bench mark. Each set of sample elevations was followed by closure with the temporary mark.

ESTIMATION OF ERRORS

The quantity sought in this study is the elevational difference ULM-MHW, a difference resulting from two entirely independent sets of measurements. The MHW elevation contains the error inherent in the tidal datum computations by NOS and refers to a height measured below a fixed bench mark. Our ULM elevation refers to the same bench mark but its primary source of
error consists of the variance about the mean of the 15 sample elevations.

In order to obtain an estimate of the probable error associated with the mean difference ULM-MHW, it was first necessary to have an estimate of the variance associated with MHW as determined at each of the selected tide stations. Swanson (1974, p. 22) gives $S_1 = 0.119$ as the standard deviation representative of monthly MHW determined in any one month at primary tide stations on the U.S. East Coast. Using this value, the average MHW value at a station with several months of record will have variance $S_{11}^2/n_1$ where $n_1 =$ number of months. The variance associated with the mean difference $\Delta Y = ULM - MHW$ is therefore

$$S_{\Delta Y}^2 = S_{11}^2/n_1 + S_{22}^2/n_2$$

where $S_2$ = standard deviation of ULM sample with $n_2 = 15$ (Young, 1962; Snedecor and Cochran, 1967). Based on the above, confidence limits were computed at the 95% level as $\pm S_{\Delta Y} t_{.05}$ where $t_{.05}$ is student's $t$ with $(n_1 + 13)$ degrees of freedom. The results of the ULM sampling and error analysis are presented in Table 2.

MARSH-UPLANDS PROFILES AND VEGETATION MAPS

In addition to the ULM sampling at each marsh site, we obtained three to four transects or profiles running across
<table>
<thead>
<tr>
<th>Station</th>
<th>ULM</th>
<th>MHW</th>
<th>ΔY = ULM - MHW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$S_2^2$</td>
<td>$n_2$</td>
<td>$S_1^2$</td>
</tr>
<tr>
<td>A.) TAPP</td>
<td>0.07076</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td>MILL</td>
<td>0.00858</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td>BELL</td>
<td>0.00724</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td>LEWS</td>
<td>0.00858</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td>BAPR</td>
<td>0.01131</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td>FLPT</td>
<td>0.03222</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td>CHAX₁</td>
<td>0.08334</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td>CHAX₂</td>
<td>0.10586</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td></td>
<td>AV. 0.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.) FRPT</td>
<td>0.05406</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td>COLE</td>
<td>0.00802</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td>AQUI</td>
<td>0100996</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td>SNWF</td>
<td>0.01279</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td>WSPT</td>
<td>0.07254</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td>DAHL₁</td>
<td>0.02260</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td>DAHL₂</td>
<td>0.02433</td>
<td>15</td>
<td>0.01416</td>
</tr>
<tr>
<td></td>
<td>AV. 0.59</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 ULM sample by VIMS botanist.
2 ULM sample by U.S. Fish and Wildlife botanist.
the marsh and into the uplands. Each transect consisted of level measurements taken along the transect line at 10-ft. intervals or less at points of significant change in ground slope and/or vegetation. We measured these transects in order to sample the overall elevational distribution of marsh plants and in particular to determine the effectiveness of the ULM elevational plane in covering all parts of the marsh.

Vegetation maps were made using low-altitude aerial photographs of each site taken immediately after the ground survey work. Both color transparencies and black and white negative film in 70 mm format were exposed using a Hasselblad camera with wide-angle lens mounted near the vertical in a modified rental aircraft. Ground truth and scale were established in each photograph from field notes and a network of ground targets placed along the survey transects and positioned by distance and azimuth measurements using a one-minute transit. The transfer of vegetation patterns from each color transparency to a map drawn at a 1:600 scale was accomplished with a Bausch and Lomb Model 2T4-H Zoom Transfer Scope.

Marsh transects and vegetation maps for stations 6-18 are presented in the Appendix.

**SUPPLEMENTARY SURVEY SITES**

In addition to the marsh sites selected at NOS secondary tide stations (Stations 6-18), three other marshes were surveyed
near tertiary stations of special interest in terms of the ULM-MHW difference. These included Guard Shores (4 months data) located on the Eastern Bay shore and two VIMS-NOS cooperative stations with preliminary datums (1 month of data) at Harborton on the Eastern Bay shore and Mosquito Creek at the lower end of Chincoteague Bay. The locations of all three stations are shown in Figure 1.

The above supplementary stations were selected in areas that are believed to be subject to a pronounced weather tide influence. Unfortunately, the data now available are not of sufficient length at this time to establish any relationships between MHW and various high water frequency levels similar to those in Table 1. The accumulation of tidal data is being continued, however, at Harborton and Mosquito Creek for future reference once these stations have been upgraded to secondary status.

Transects measured at the supplementary sites are included in Figure 16.
ULM RECOGNITION CRITERIA

Tidal wetlands areas, particularly saline marshes, characteristically exhibit a banded or zoned appearance as to the distribution of vegetation. Numerous authors have observed this zonation and have attempted to relate it to environmental factors, especially tidal immersion and salinity. The dominant factor, tidal immersion, has two effects: 1) it permits growth of certain halophytic and/or hydrophytic genera such as Spartina or Typha, 2) it inhibits the growth of halophobic and/or hydrophobic genera such as Pinus or Quercus. Hinde (1954) provides an extensive review of the subject; Adams (1963) and Chapman (1974) bring this review up to date.

As used in this study, the upper limit of the marsh (ULM) is defined as the median point of the marsh-uplands vegetational transition zone, or the point in the transition sequence at which coverage of true uplands plants is about equal to that of wetlands plants. Therefore, although we have investigated distributions among all plant species strictly belonging to the marsh community at our study sites, special attention has been given to the region of transitional vegetation that separates the marsh from wooded or grassy uplands as well as some modified uplands (cultivated fields and clearings). This region is the most common natural terminus landward of tidal wetlands in Virginia with the possible exception of low-lying barrier beach systems that often prograde into marshes through overwash deposition. For the purpose of identifying characteristic
species transitions between marsh and upland, the tidal wetlands surveyed in this study were divided into two general categories, saline and freshwater marshes. Brackish marshes are considered a transitional type exhibiting characteristics of both categories in varying proportions and hence were grouped with one or the other of the above on an individual basis.

The reader is referred to Silberhorn (1976) for pictorial descriptions and identifying characteristics of most of the wetlands plants mentioned in the following sections.

**SALINE MARSH TRANSITION ZONE**

The salt marshes along most of the U.S. Middle Atlantic coastline can generally be divided into two zones, lower and upper marsh. The lower, intertidal marsh usually consists of a monotypic community of *Spartina alterniflora* in tall form bordering creek banks with shorter forms occurring farther landward. The upper marsh above the intertidal zone usually has a greater diversity of species, *Spartina patens* (Saltmeadow Hay), *Distichlis spicata* (Salt Grass), and *Juncus roemerianus* (Black Needlerush) being common. *Juncus roemerianus* occurs in dense, often monospecific stands whereas *Spartina patens*, and *Distichlis spicata* usually occur in a mixed community of dense stands often referred to as a "saltmeadow". Various combinations of species such as *Borrichia frutescens* (Sea Oxeye), *Limonium carolinianum* (Sea Lavender), *Aster tenuifolius*, and *Fimbristylis spadicea* may also be components of the
Figure 14. Marsh to Uplands Transition in a Typical Saltwater Marsh

- Poison Ivy
- Pine
- Honeysuckle
- Greenbrier
- Red Cedar
- Wax Myrtle
- Saltmarsh Bulrush
- Along Freshwater Streamlets
- Panne
- Saltmarsh Elders
- Sea Oxe-eye
- Saltmeadow Hay
- Salt Grass
- Black Needlerush
- Spartina Alterniflora
  - Short form
  - Tall form
- Transition Zone
saltmeadow flora. This portion of the marsh is often extremely flat with no appreciable grade until the transition with the uplands is reached, or it may be punctuated with shallow, poorly-drained depressions or "pannes" sparsely vegetated with *Salicornia* spp. (*Saltwort*), *Limonium carolinianum*, and *Distichlis spicata*.

As or shortly before the transition zone is reached proceeding landward, *Iva frutescens* (*Marsh Elder*) often appears either in clusters at local relief points or as a dense band. When present in the transition zone, *Iva* is almost always found in close proximity to another very similar shrub, *Baccharis halimifolia* (*Groundsel Tree*). Careful examination of their distributions has shown that the lower or marsh side of the transition zone is almost entirely *Iva* while the upper or fastland side is usually dominated by *Baccharis*. The latter plant sometimes extends in sporadic fashion well into the uplands but its lower limit is normally seen as a fairly precise line featuring a concentration of plants. The upper limit of *Iva* and/or the lower limit of *Baccharis* are ordinarily found slightly below the median point of the transition zone when these plants are present in significant numbers.

Uplands groundcover consisting of herbaceous annuals and perennials, woody vines and shrubs that abruptly appear among the *S. patens- Distichlis* community (proceeding landward) may provide an indication that the upper limit of the marsh has been reached. A list of the species commonly found include
Elymus virginicus (Virginia Rye Grass), Apocynum cannabinum (Indian Hemp), Panicum virgatum (Switch Grass), Rhus radicans (Poison Ivy), Parthenocissus quinquefolia (Virginia Creeper), Campsis radicans (Trumpet Creeper), Lonicera japonica (Japanese Honeysuckle), Smilax spp. (Green Briar), Setaria geniculata (Foxtail Grass), and Ipomoea purpurea (Common Morning Glory).

An uplands shrub useful as an indicator of the uplands boundary is Myrica cerifera (Wax Myrtle) which has a sharply defined lower limit that occurs slightly landward of the Iva Baccharis transition. Myrica thickets very commonly appear as a dark green belt surrounding the uplands side of the transition zone and are often a considerable obstacle to anyone walking from marsh to uplands. Behind such thickets one immediately encounters the uplands proper where Pinus, Prunus, and Juniperus woodlands begin. Other trees in the woodlands may include Sassafras albidum, Quercus spp., Nyssa sylvatica or Liquidambar styraciflua.

In some areas the woodlands overstory may have considerable development which obfuscates the transition zone through shading. Myrica thus frequently responds to heavy uplands overstory by extending its foliage several feet towards the marsh although its root system remains at the uplands border. In such cases the marsh-uplands boundary is not discernable from aerial photographs.
In practice we used a combination of the above indicator species to locate the median of the marsh-uplands transition zone, most of the plants lying within 1-10 feet of one another at the sites visited. An example of a typical transect through the salt marsh transition zone is shown in Figure 14.

**FRESHWATER MARSH TRANSITION ZONE**

Little research has been done on the vegetation distribution in tidal freshwater marshes. Marsh (1969) noted the increased species diversity in fresh marshes but made no mention of zonation. Jervis (1963) observed different communities in deep and shallow water marshes but commented only on the effects of seasonal fluctuations of water level and not tidal fluctuations. A recent study by Doumlele (1976) described plant community structure in Virginia's tidal freshwater marshes.

A freshwater marsh may also be divided into zones although these are usually not as distinct or readily identifiable as those in the salt marsh. In Virginia, the lowest zone is often dominated by the yellow pond lily (*Nuphar luteum*). The next higher zone may be dominated by *Pontederia cordata* (Pickerelweed) and *Peltandra virginica* (Arrow Arum). Above this a highly diverse freshwater community may be found, with *Polygonum* spp. (Smartweeds), *Acorus calamus* (Sweet Flag), *Scirpus* spp. (Bulrushes), *Typha* spp. (Cattails), *Rumex verticillatus* (Water Dock), *Hibiscus moscheutos* (Marsh Hibiscus) and numerous other species generally intermixed (Silberhorn, et al., 1974).
As mentioned earlier, brackish marshes are a transition between saline and freshwater marshes and as such contain species representative of both. One species, *Spartina cynosuroides* (Big Cordgrass), is more common in brackish marshes than elsewhere.

Locating the transition zone in freshwater marshes can be a difficult if not impossible task in areas of minimum relief; an extreme example can be found in certain tidal marshlands which merge almost imperceptibly with extensive cypress swamps and lowlands along the Chickahominny River in Virginia. Except for these areas, tidal freshwater marshes occur either as extensive border or point marshes in the winding upper reaches of the major estuaries or as narrow re-entrant marshes within the smaller freshwater tributaries. As it happens, most of the above areas have moderate relief in the form of numerous Pleistocene terraces and drainage channels, the latter having been drowned by post-glacial sea level rise.

Where hilly relief is present at the edge of the marsh, the transition from the freshwater mixed communities to uplands vegetation is often very abrupt and easily recognized. Otherwise, the overlapping marsh-uplands groundcover and the lower limit of characteristic uplands shrubs are useful guides as shown in Figure 15. Points at which uplands runoff and seepage zones enter the marsh must be excluded from the ULM sampling since soil saturation here is quite independent of tidal immersion.
FIGURE 15. MARSH TO UPLANDS TRANSITION IN A TYPICAL FRESHWATER MARSH
ANALYSIS OF RESULTS

The results of the field surveys conducted at Stations 6-18 point to a more consistent elevational relationship between a tidal datum (MHW) and the upper limit of tidal marshes than has been hitherto observed to our knowledge. As the data in Table 2 indicate, the difference ULM-MHW which quantifies this relationship varies between approximately 0.8 and 1.2 feet (average 0.95 feet) in the saline marsh group, decreasing to between 0.5 and 0.8 feet (average 0.59 feet) in the freshwater marsh group. Confidence limits computed at the 95% level of confidence for the differences listed in Table 2 show that the probable range for each individual difference either includes or comes very close to the respective group average. On the other hand, these limits evidence little or no overlap between marsh groups. Therefore, based on the sites examined in this study, we would not reject the hypothesis that a single ULM-MHW difference exists within but not between saline and freshwater marshes in our area. If the hypothesis is correct, then the observed differences within either group are entirely due to measurement error or random chance in sampling. As previously stated, our confidence interval estimates take into account the expected error in both the MHW and ULM determinations.

We are aware that evidence of a significantly greater vertical separation between MHW and the upper limits of marsh-lands exists in other regions. In Georgia, for example, it
appears that this separation may amount to as much as 2.5 feet in high salinity marshes with tidal ranges of six feet or more (F.C. Marland, Georgia Department of Natural Resources, personal communication). An NOS pilot study conducted in 1975 at seven locations around the country reported ULM-MHW differences ranging between 1.2 and 3.2 feet. In view of this evidence, we have attempted to identify possible controlling factors in the distribution of marsh upper limits.

CONSISTENCY IN ULM DETERMINATIONS

What constitutes the marsh upper limit and how representative of it any one set of numbers may be has often been disputed. As a test of the limit recognition criteria advanced in this study and the precision of our ULM determination method, we repeated the surveys at Cheatham Annex and Dahlgren, Virginia, with the assistance of a botanist from the U.S. Fish and Wildlife Service. The botanist was briefed on our method prior to conducting these samplings of the ULM elevation. The replications (Table 2) came within 0.2 foot in one instance and 0.1 foot in the other of repeating our original determinations of the ULM-MHW elevational difference for the stations. We note that the probable errors associated with each pair of values are sufficient to account for most, if not all, of the difference.

As used in the NOS study, the ULM was defined as the extreme upper limit of the marsh-uplands transition zone or "the highest elevation contiguous to the coastal marsh supporting
coastal marsh vegetation" (NOS, 1975, p. 4). We question the ability of this definition to produce an appropriate and consistent ULM elevation since it is known that a few high marsh plant species are often present but not thriving at points actually within the uplands—the limiting factor for these plants is competition with upland species, not lack of tidal immersion. This is very likely the reason that the ULM-MHW difference of 2.6 feet reported by NOS for the Virginian Biogeographic Region (based on surveys at Sandy Hook, N.J.) is considerably higher than any of those we report in Table 2.

**FREQUENCY OF TIDAL IMMERSION**

If one accepts that the high water frequency levels in Table 1 (stations 1-5) are representative of conditions at stations 6-18 as well, then it is apparent that the ULM elevations at the saline marsh stations correspond to heights that are exceeded by between 50 and 100 high tides per standard year of 705 high tides—roughly 10% of the highs occurring in an average year. For the freshwater marshes, the immersion rate at the ULM elevation is estimated to be between 100 and 200 high tides per standard year or about 20% of those in an average year. Although we base these figures on 20 years of record, Figures 6-10 suggest that the utilization of 10 year records would produce much the same results; however, in Figure 3 it is apparent that a single year of data picked at random could be quite misleading as in the year 1972.

54.
The most probable reason for a higher frequency of tidal immersion at the ULM elevation in freshwater as opposed to saline marshes is that uplands halophobic species adjacent to the former type are able to withstand more frequent immersion in the absence of the salt tolerance restriction, causing the ULM elevation to be shifted downwards. In this instance salinity may be considered an intermediate variable which modulates the dominant factor of tidal immersion. More than likely, other intermediate variables affecting the vertical limits of species distributions are operative in other biogeographic regions.

AREAS WITH UNUSUAL TIDAL CHARACTERISTICS

Considering that frequency of tidal immersion is a factor of prime importance among those governing ULM elevations in any region, we expected to find unusually high ULM elevations at the supplementary marsh sites selected in areas where weather appears to affect the tide to a greater than usual extent. The first area that came to our attention in this regard was Chincoteague Bay at the northern end of Virginia's Eastern Shore peninsula. This embayment has a considerable surface area but is quite shallow and has an astronomic tide range of less than one foot in its interior (Harleman and Lee, 1969). Occasional northeast winds can raise water levels far above MHW, particularly at the southern end where extensive S. alterniflora marshes are found. Our survey site near Mosquito Creek lies within these marshes. Two other sites were selected on the west side of the
peninsula (Harborton and Guard Shores) where strong northwest winds and a large fetch contribute to a piling up of water against the eastern Bay shoreline during typical storm events. A very high annual rate of shoreline erosion in the latter area has been attributed to the combination of wind waves and raised water levels during such storms (R.J. Byrne, VIMS Geological Oceanography, personal communication).

Although the tidal datums now available at the above three stations are based on short-term comparisons and thus should be used with caution, the differences presented in Table 3 reflect the unusual position of the ULM at the supplementary marsh sites, all of which are saline. Typical marsh profiles from each site are shown in Figure 16.

TABLE 3. Results of ULM Surveys at Supplementary Marsh Sites (all saline)

<table>
<thead>
<tr>
<th>Station</th>
<th>$S_2^2$</th>
<th>$n_2$</th>
<th>$S_1^2$</th>
<th>$n_1$</th>
<th>$S_{\Delta Y}^2$</th>
<th>d.f.</th>
<th>$\Delta Y$</th>
<th>$S_{\Delta Y \cdot 05}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOSQ</td>
<td>0.00613</td>
<td>15</td>
<td>0.01416</td>
<td>1</td>
<td>0.01457</td>
<td>14</td>
<td>1.43</td>
<td>$\pm 0.26$</td>
</tr>
<tr>
<td>GARD</td>
<td>0.01024</td>
<td>15</td>
<td>0.01416</td>
<td>4</td>
<td>0.00422</td>
<td>17</td>
<td>1.45</td>
<td>$\pm 0.14$</td>
</tr>
<tr>
<td>HARB</td>
<td>0.05942</td>
<td>15</td>
<td>0.01416</td>
<td>1</td>
<td>0.01812</td>
<td>14</td>
<td>1.30</td>
<td>$\pm 0.29$</td>
</tr>
</tbody>
</table>

At this time we can only speculate as to the reason for increased ULM-MHW differences at the supplementary sites which are on the order of 0.5 foot greater than the group average for saline marshes at stations 6-18 (Table 2). There appears to
FIGURE 16. MARSH PROFILES AT SUPPLEMENTARY SURVEY SITES.
be no connection between the increase and local factors such as salinity or tidal range. The factor which appears most obvious is that of wind tides augmenting the height of each level corresponding to a specific frequency of tidal immersion.

**GROUND SLOPE AT THE ULM BOUNDARY**

The major objective of this study has been to establish an elevational relationship between some suitable reference such as a tidal datum and the point of transition from marsh to uplands in naturally occurring vegetative communities. This is a relationship which is independent of ground slope per se but its application to the wetlands boundary problem requires some assessment of the change in surface elevation within the marsh-uplands transition zone. Without this information, it is impossible to specify how far the ULM boundary might be displaced horizontally given some vertical error associated with the ULM elevation.

We obtained estimates of ground slope using the profile measurements taken at each marsh site. The slopes measured at the ULM position varied between approximately 0.02 (2%) and 0.10 (10%). Table 4 shows the expected range of ULM boundary displacements for these slopes and various estimates of vertical error in the difference ULM-MHW (Tables 2 and 3). Unlike the ULM elevations, we did not find an average value of the ground slope at the ULM, and hence an average set of limits for the
ULM boundary, which could be said to represent a particular marsh type or geographic region. Therefore, it appears that ULM boundary limits must be ascertained from the conditions at the actual site in question. However, the range of displacements shown in Table 4 do not seem unduly large unless a poorly determined ULM elevation is to be applied in an area with minimum ground slope. Once the elevational difference ULM-MHW has been set at a fixed value for the area and type of marsh it represents, the vertical error will reflect only the accuracy in locally determined MHW which one can improve at any time through acquisition of additional tidal data.

TABLE 4. Horizontal Displacements of the ULM Boundary in Feet for Typical Combinations of Vertical Error and Ground Slope.

<table>
<thead>
<tr>
<th>Vertical Error (ft.)</th>
<th>2%</th>
<th>4%</th>
<th>6%</th>
<th>8%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 0.05</td>
<td>± 2.5</td>
<td>± 1.2</td>
<td>± 0.8</td>
<td>± 0.6</td>
<td>± 0.5</td>
</tr>
<tr>
<td>± 0.10</td>
<td>± 5.0</td>
<td>± 2.5</td>
<td>± 1.7</td>
<td>± 1.2</td>
<td>± 1.0</td>
</tr>
<tr>
<td>± 0.15</td>
<td>± 7.5</td>
<td>± 3.8</td>
<td>± 2.5</td>
<td>± 1.9</td>
<td>± 1.5</td>
</tr>
<tr>
<td>± 0.20</td>
<td>±10.0</td>
<td>± 5.0</td>
<td>± 3.3</td>
<td>± 2.5</td>
<td>± 2.0</td>
</tr>
<tr>
<td>± 0.25</td>
<td>±12.5</td>
<td>± 6.2</td>
<td>± 4.2</td>
<td>± 3.1</td>
<td>± 2.5</td>
</tr>
</tbody>
</table>
SUMMARY AND CONCLUSIONS

Based on the evidence obtained in this study, we now report the following results and conclusions:

1.) Consistent elevational differences between the upper limit of tidal marshes (ULM) and the tidal datum of mean high water (MHW) have been determined at 13 survey sites representing a large portion of lower Chesapeake Bay and its major estuaries. The tidal datums at these sites were part of a precise datum network recently established by the National Ocean Survey.

2.) The ULM-MHW differences fell into two groups differentiating saline and freshwater tidal marshes. For the saline marshes, the group average of the ULM elevation at seven sites was 0.95 feet above MHW; for the freshwater marshes, the average ULM elevation at six sites was 0.59 feet above MHW. The distinction made between the two marsh types is supported by statistical confidence limits on the ULM-MHW difference.

3.) Analyses of 20-year tidal records at five locations in Chesapeake Bay and its tributaries show that the ULM elevation designated for saline marshes will be exceeded by approximately 10% of the high tides occurring in an average year. The freshwater ULM elevation will be exceeded by approximately 20% of the high tides occurring in an average year.
4.) Three supplementary survey sites having MHW datums of lesser precision were selected in saline marsh areas where weather effects appear to have a greater than usual influence on the observed tide. This situation occurs in broad, shallow embayments and coastal sounds having restricted tidal communication with the sea and consequently a very small astronomical tide range in their interior regions. Local wind and pressure effects acting more or less at random do not alter the tidal datums (MHW and MLW) but do cause a large variance in observed water levels above and below their mean elevations. Such variance may well be enhanced by the configuration of the restricted water body. Thus, the ULM elevation at the supplementary sites stood between 0.3 and 0.5 feet higher in relation to MHW than the average ULM elevation determined for saline marshes in this study. Our hypothesis is that the increase in ULM elevation occurs in response to tidal immersion that reaches greater than usual heights at the supplementary sites. Tidal data are not yet available in sufficient quantity in these areas to verify this hypothesis nor do we know if the existing frequency of tidal immersion at the ULM elevation is the same frequency that was found at the other saline marsh sites. These questions must be resolved through further research.

5.) Further research is also needed to extend the above findings to other areas and to determine whether or not an engineering definition based on a tidal datum can provide a
suitable means for delineation of wetlands boundaries in various regions. Eventually, it may be possible to specify the ULM elevation in terms of a fixed height above the local MHW datum for distinctive marsh types and regions. The results of this study tend to suggest that the size of the region over which the ULM-MHW difference is comparatively uniform may be larger than expected. It will be necessary, however, to employ consistent survey methods and procedures, particularly in the botanical criteria for recognition of the ULM, in order to make valid comparisons on any scale.
REFERENCES CITED


LEGEND FOR VEGETATION MAPS

The legend for the vegetation maps identifies the dominant plant communities whose distributions were mapped from aerial photographs and verified by field inspection. On some maps the *Spartina alterniflora* community is labeled Sal or Sah delineating low or high vigor forms where these are distinguishable. Also, the high marsh *Spartina patens* - *Distichlis spicata* community is labeled S-D or D-S, the order indicating the dominant member of the community. Where a community label is followed by w/ and another letter, a non-dominant but contributing species is indicated.

The freshwater mixed community (F) is a highly diverse combination of many freshwater species whose numbers may vary considerably. A partial list of the species normally included is given in the main text.
LEGEND

- TARGET LOCATION
- WATER AND MUDFLAT

UPLAND

UPLAND

Spartina patens, Fimbristylis spadicea, Setaria geniculata

DUNE

Ammophila breviligulata (Ab), Spartina patens (Sp)

BEACH

SALT MARSH

Spartina alterniflora

S-D

Spartina patens, Distichlis spicata

Spartina cynosuroides

Juncus roemerianus

Iva frutescens, Baccharis halimifolia

Myrica spp.

Scirpus spp.

FRESH MARSH

FRESH WATER MIXED

Pontedaria cordata, Peltandra virginica

Typha spp.

Nuphar advena

Alnus serrulata

68.
FERRY POINT (FRPT)
CHEATHAM ANNEX (CHAX)
KINGS CREEK
CHEATHAM ANNEX

CHEATHAM ANNEX
WEST POINT (WSPT)
BELLEVILLE CREEK (BELL)
MILL CREEK (MILL)
BAYPORT (BAPR)
RAPPAHANNOCK RIVER

BAYPORT
TAPPAHANNOCK (TAPP)
TAPP

A

beach dune

A'

- ULM
- MHW

B

- ULM
- MHW

C

- ULM
- MHW

D

- ULM
- MHW

DISTANCE IN FEET

0 50 100 150 200

FEET ABOVE MLW

0 2 4 6 8

DISTANCE IN FEET

0 50 100 150 200

FEET ABOVE MLW

0 2 4 6 8

DISTANCE IN FEET

0 50 100 150 200

FEET ABOVE MLW

0 2 4 6 8

DISTANCE IN FEET

0 50 100 150 200

FEET ABOVE MLW

0 2 4 6 8
RAPPAHANNOCK RIVER

TAPPAHANNOCK

100.
SAUNDERS WHARF (SNWF)
LEWISETTA (LEWS)
COLES POINT (COLE)
DAHLGREN (DAHL)
AQUIA CREEK (AQUI)
AQUI

DISTANCE IN FEET

FEET ABOVE M.L.W.

126.