1-1-1972

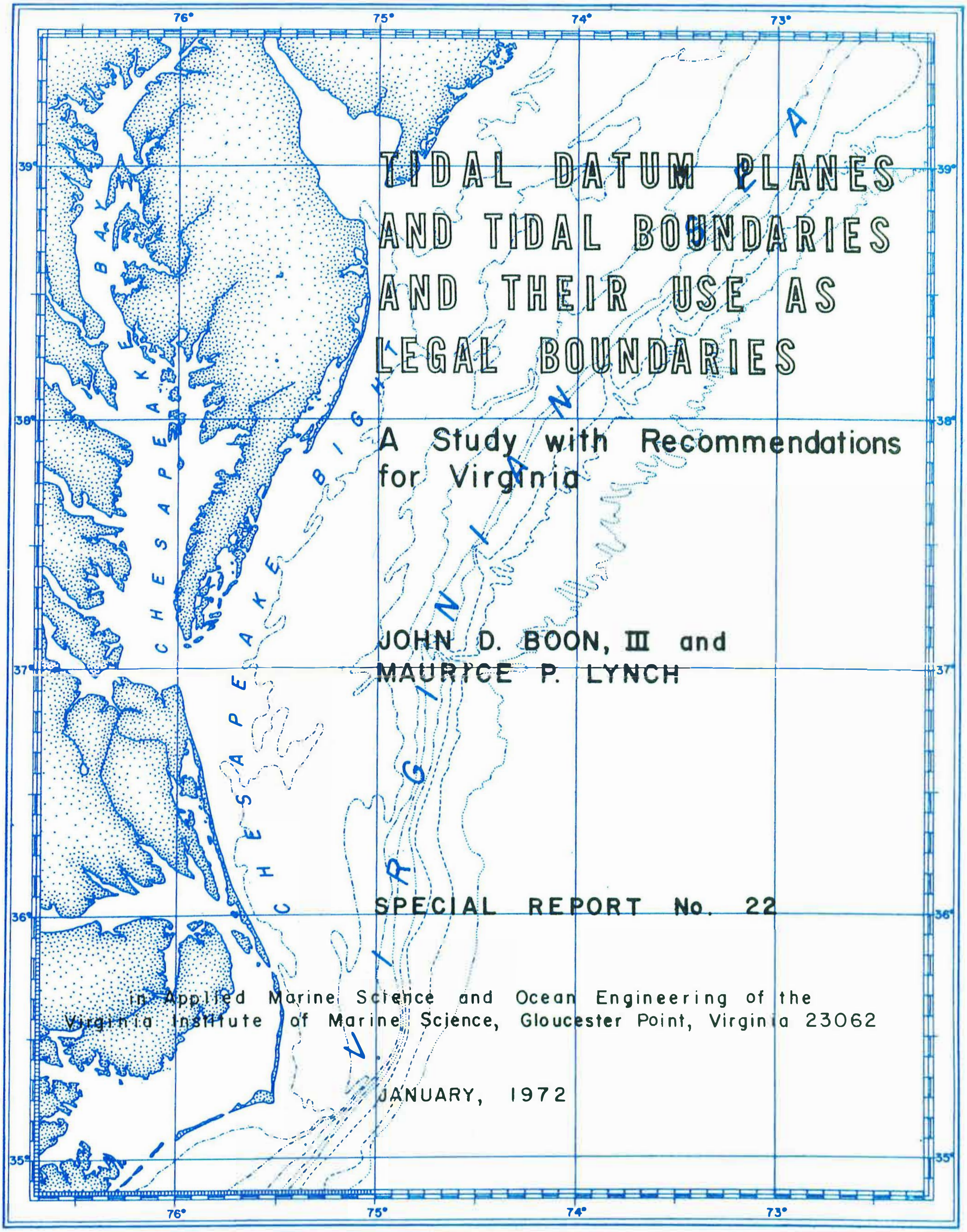
Tidal Datum Planes and Tidal Boundaries and Their Use as Legal Boundaries: A Study with Recommendations for Virginia

John D. Boon III
Virginia Institute of Marine Science

Maurice P. Lynch
Virginia Institute of Marine Science

Recommended Citation

Boon, J. D., & Lynch, M. P. (1972) Tidal Datum Planes and Tidal Boundaries and Their Use as Legal Boundaries: A Study with Recommendations for Virginia. Special Reports in Applied Marine Science and Ocean Engineering (SRAMSOE) No. 22. Virginia Institute of Marine Science, College of William and Mary. https://doi.org/10.21220/V5RJ13



TIDAL DATUM PLANES AND TIDAL BOUNDARIES AND THEIR USE AS LEGAL BOUNDARIES

A Study with Recommendations for Virginia

JOHN D. BOON, III and
MAURICE P. LYNCH

SPECIAL REPORT No. 22

in Applied Marine Science and Ocean Engineering of the
Virginia Institute of Marine Science, Gloucester Point, Virginia 23062

JANUARY, 1972

TIDAL DATUM PLANES AND TIDAL BOUNDARIES AND THEIR USE AS LEGAL BOUNDARIES:

A Study with Recommendations for Virginia

by

John D. Boon, III

and

Maurice P. Lynch

Special Report No. 22
in Applied Marine Science and Ocean Engineering
of the Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

William J. Hargis, Jr.
Director
January 1972

PREFACE

The almost 400,000 acres of wetlands located along the more than 5,000 miles of Virginia's coastline form a unique and irreplaceable natural resource of the Commonwealth. These areas serve a multitude of uses, including bathing beaches, nursery grounds for fish and crabs, access to major water transportation routes, sites for marinas, industry, and residential areas. As the population of the Commonwealth increases, conflicting and sometimes mutually exclusive demands for these resources generate both legal and social conflicts. A major concern of resource managers is the resolution of these conflicts. Essential to this task is the delineation of boundaries in the zone where land and sea meet. The solution of this problem requires definitions that will endure and are fair to all concerned.

Traditionally, the major boundary in coastal areas has been the water's edge. The water's edge, however, is not stationary but advances and retreats with the rise and fall of the tide. Customarily, some level of the tide has been chosen to fix the water's edge. Usually this has been a particular level such as high water or low water. These levels are part of the tide's never-ending cycle that occurs over and over again, the water's surface returning each time to some familiar mark on the shore or near this mark. In modern-day usage, a level or elevation established by the tide is called a tidal datum plane.

In point of fact, it is not as easy as one might think to locate a tidal datum. Many instances are known in which one or more persons have acted as experts in legal situations calling for a datum plane determination, only to cite from memory as to where that plane usually falls. It is not surprising that these "experts" often fail to agree, for the tide happens to be a very complicated phenomenon. Scientists and engineers, on the other hand, have precise definitions for all aspects of tidal datum planes and have been able to determine them in very objective ways for some time. There need be no problem at all in defining or locating a valid datum in any tidal waterway so long as the proper definitions and procedures are relied upon.

ACKNOWLEDGEMENT

This report was funded by the Research Applied to National Needs (RANN) Program of the National Science Foundation through the Chesapeake Research Consortium, Inc.

We wish to thank Drs. John M. Zeigler, Robert J. Byrne, and William J. Hargis, Jr., for their constructive review of this paper.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF FIGURES

TIDAL DATUM PLANES

Introduction

The periodic rise and fall of the tide is a familiar sight to a great many people. In spite of their regular appearance, however, tides represent a very complex natural phenomenon which has received careful study over many years, beginning before the time of Isaac Newton. The use of some characteristic level of the tide, such as high water[*] or low water[**] for the purpose of establishing a reference level, or datum plane, implies that the user has all the information he needs to accurately define such a level whenever and wherever necessary. Otherwise, tidal datum planes would differ as often as the person determining them.

To be fully reproducible, tidal datum planes require definitions that reflect a proper understanding of certain aspects of the tide and the tide-producing forces. Known variations in the level of the tide are then accounted for in a systematic and predictable way.

---

[*] The maximum height reached by a rising tide

[**] The minimum height reached by a falling tide

The Tide Producing Forces

Tides are caused by the gravitational attraction of the moon and sun. Because of the proximity of the moon to the earth, lunar gravity predominates, and as a consequence, much of the tide's behavior is related to the relative motion between the earth and the moon. The effect of the moon's gravitational attraction on the earth's ocean waters produces two tidal "bulges" on opposite sides of the earth and in line with the moon (Fig. 1).

As the earth rotates about its axis, an observer on earth notices the passage of a tidal bulge in the form of a high tide, followed by a low tide halfway to the next bulge. Thus, after one rotation with respect to the moon, the observer has witnessed two equal high waters and two equal low waters in a lunar day*. This type of tide is called a semidiurnal (twice daily) tide. It will be helpful at this point to think of the total tide-producing force as the sum of several parts or components, each one labelled by some characteristic length of time. Then the semidiurnal component becomes one such part.

The earth's equatorial plane has a tilt of about 23-1/2° with respect to the ecliptic, which is the plane of the earth's orbit around the sun. The moon's orbit around

---

*A lunar day is approximately 50 minutes longer than a solar day.

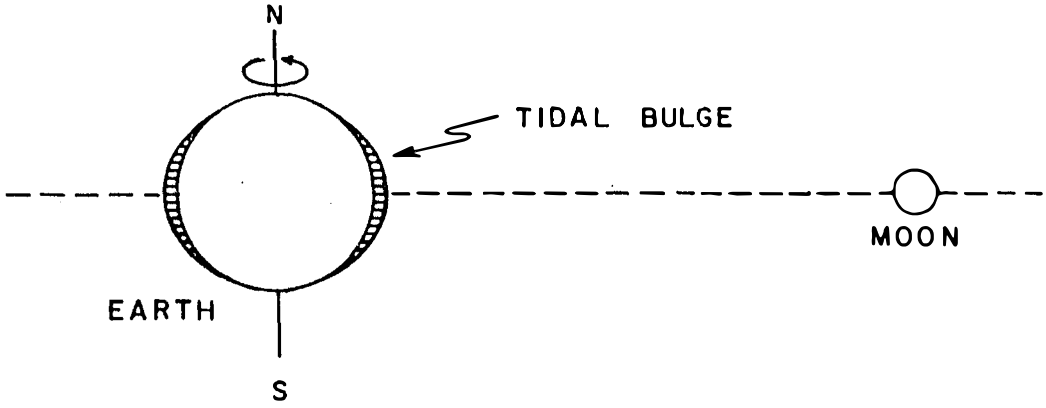


Figure 1. Schematic view of earth, moon, and tidal "bulges."

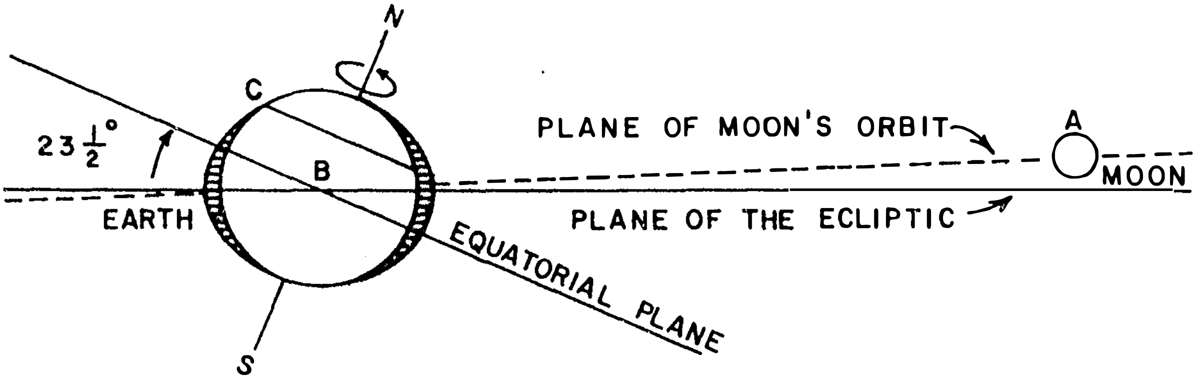


Figure 2. Schematic view of earth, moon, and their respective orbital planes in relation to the earth's axis and equatorial plane.

the earth nearly coincides with the ecliptic, meaning that an angle of roughly 23° exists between the plane of the earth's equator and the lunar orbit (Fig. 2).

Figure 2 shows the moon at position A in its orbit where it exhibits the maximum declination with respect to the earth's equator. Later it will reach position B where there is no declination. If an observer at position C were to note the tides with the moon at maximum declination, he would encounter unequal high and low waters, tending toward a situation in which only one high and one low water occur in a lunar day. The unequal heights of successive high and low waters is known as a diurnal inequality and the tendency toward a diurnal (daily) type of tide is the result of a diurnal component in the tide-producing force which is due to the moon's declination.

For the moon to complete one orbit with respect to the vernal equinox (point B in Figure 2) requires approximately 27-1/3 days; this period of time is called a tropical month. It can be seen (Fig. 2) that tropical tides (tides with maximum diurnal inequality) and equatorial tides (tides with no diurnal inequality) will each occur twice during a tropical month. This cycle represents a semimonthly component.

Two other semimonthly components are significant. One, based on the synodic or lunar month of 29-1/2 days, is associated with spring and neap tides. Spring tides occur near new and full moon when the earth, sun, and moon are approximately in line and their respective attractive forces combine to produce tides of greater range*. Thus, spring tides exhibit higher highs and lower lows than do other tides in the typical lunar month. Neap tides, on the other hand, occur when the moon is in quadrature (at right angles to the earth-sun line) and the moon-sun gravities tend to oppose one another. Neap tides exhibit a lesser range of tide with higher lows and lower highs compared to other tides in the typical lunar month.

The other semimonthly component is associated with apogean and perigean tides. These are a function of the moon's varying distance from the earth caused by a slightly elliptical lunar orbit. When the moon is closest to the earth (perigee), maximum gravitational attraction occurs; when farthest away from the earth (apogee), the least attraction occurs. Perigean tides show greater range in similar fashion to spring tides. Apogean tides have lesser range and thus correspond to neap tides in this way. Perigean and apogean tides occur twice in an anomalistic month of 27-1/2 days.

---

*The difference in height between consecutive high and low waters.

Combined Forces - The Astronomic Tide

Having considered the principal components of the tide-producing force, it is essential to recognize that all components act in combination to produce what is known as the astronomic tide. For example, one may recognize a spring tide, having witnessed an unusually high tide at the right time of the lunar month. But in fact, only a certain percentage of the total height reached during the high could be attributed to the spring component, the balance of that tide being the result of other components acting simultaneously. Therefore, if one chose to ignore this tide for some special reason (e.g., layman's determination of "ordinary" high water by process of elimination), all of the remaining components would be ignored as well without knowing the extent of their individual contributions--hardly a representative process.

The order of importance of the tidal components contributing to the tide varies with the locality. For example, the semidiurnal component is the principal one on the Atlantic coast of the United States where two high waters and two low waters are observed during most days. On the Gulf coast of the United States, the principal component is the diurnal one, tides there frequently containing only one high and low water in a day. The West coast is a mixed tide environment; i.e., large diurnal inequalities are usually present, the semidiurnal and diurnal components being about equal in importance. As it happens, there are factors in addition to astronomic forces that play a role in determining what type of tide will result at specific places.

Hydrographic Effects

The word hydrography, as used in this paper, refers to the delineation of depth contours in a body of water. What was referred to earlier as a tidal "bulge" (Fig. 2) will now be called a tidal "wave"* since, to the observer who moves with the earth, the bulge appears to travel as a wave.

The tidal wave moving around the earth must eventually encounter a land mass. This causes the tide to depart from the so-called "Equilibrium Theory" of tides which would require an earth completely covered by water, among other things. A stretch of open coastline causes a different response in the tide than does a bay or an estuary. The latter restricts the tide wave's progress where narrow entrances or shallow water areas exist. And, where the waterways end, wave reflection may occur and the effect of river discharge is often large. The net result is usually a change in the

---

*Not to be confused with a tsunami, a large wave caused principally by earthquakes.

mean tide level and/or mean range*. Figure 3 is an example of such change.

In Figure 3, the relationship between the mean tide level, mean range, and the sea level datum of 1929 is shown along the James River estuary. The sea level datum of 1929 is the standard leveling datum from which heights are reckoned across the U. S. (1). It is invariant with respect to local tide conditions. Thus, it can be seen that mean tide level increases more than a foot relative to the sea level datum of 1929 between Newport News and Richmond. The mean range undergoes an initial decrease from 2.6 feet at Newport News to 1.9 feet at the entrance of the Chickahominy River, before increasing again to 3.2 feet at Richmond (2).

Figure 4 shows the variation in mean range across the greater Chesapeake Bay system. The maximum mean range of 3.9 feet occurs at Walkerton, Virginia, on the Mattaponi, a tributary of the York River (3). This is almost a foot more than the mean range of 3.0 feet at the entrance to the Chesapeake Bay itself. Away from the confines of the tidal tributaries, however, the mean range shows a gradual decrease towards the upper Bay.

---

*Let it be understood presently that, using the term mean, an average over a considerable period of time is intended. Mean tide level is the level halfway between mean high water and mean low water whereas mean range is the vertical distance between mean high water and mean low water. The exact definitions will be given later.

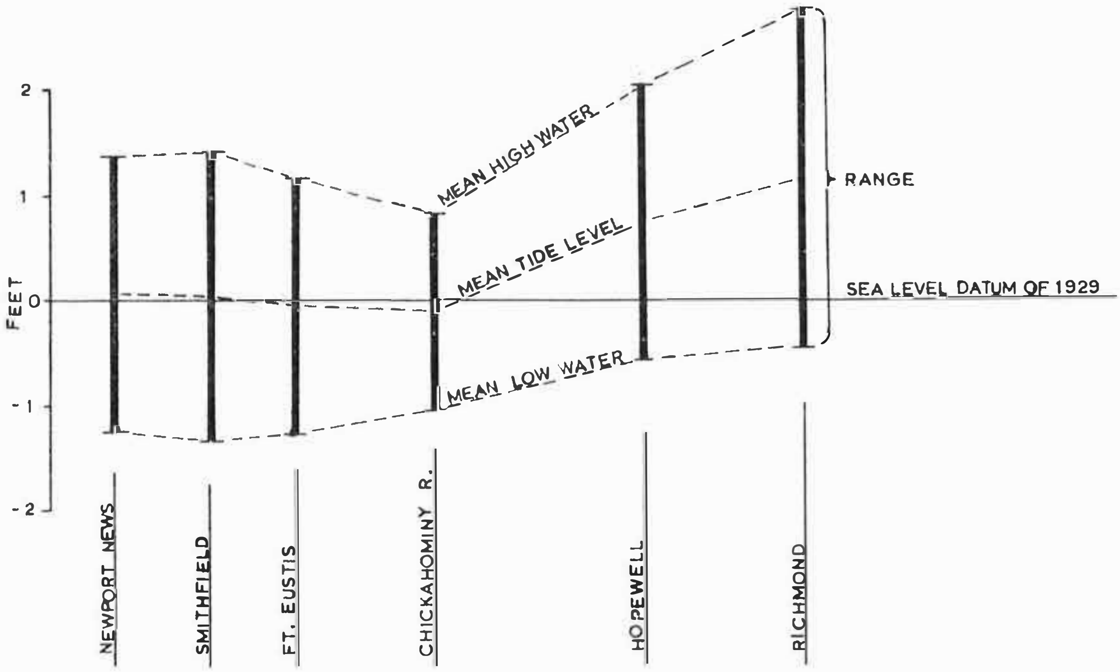


Figure 3. Relationship between mean tide level, mean high water, mean low water and the sea level datum of 1929 along the James River estuary in Virginia.

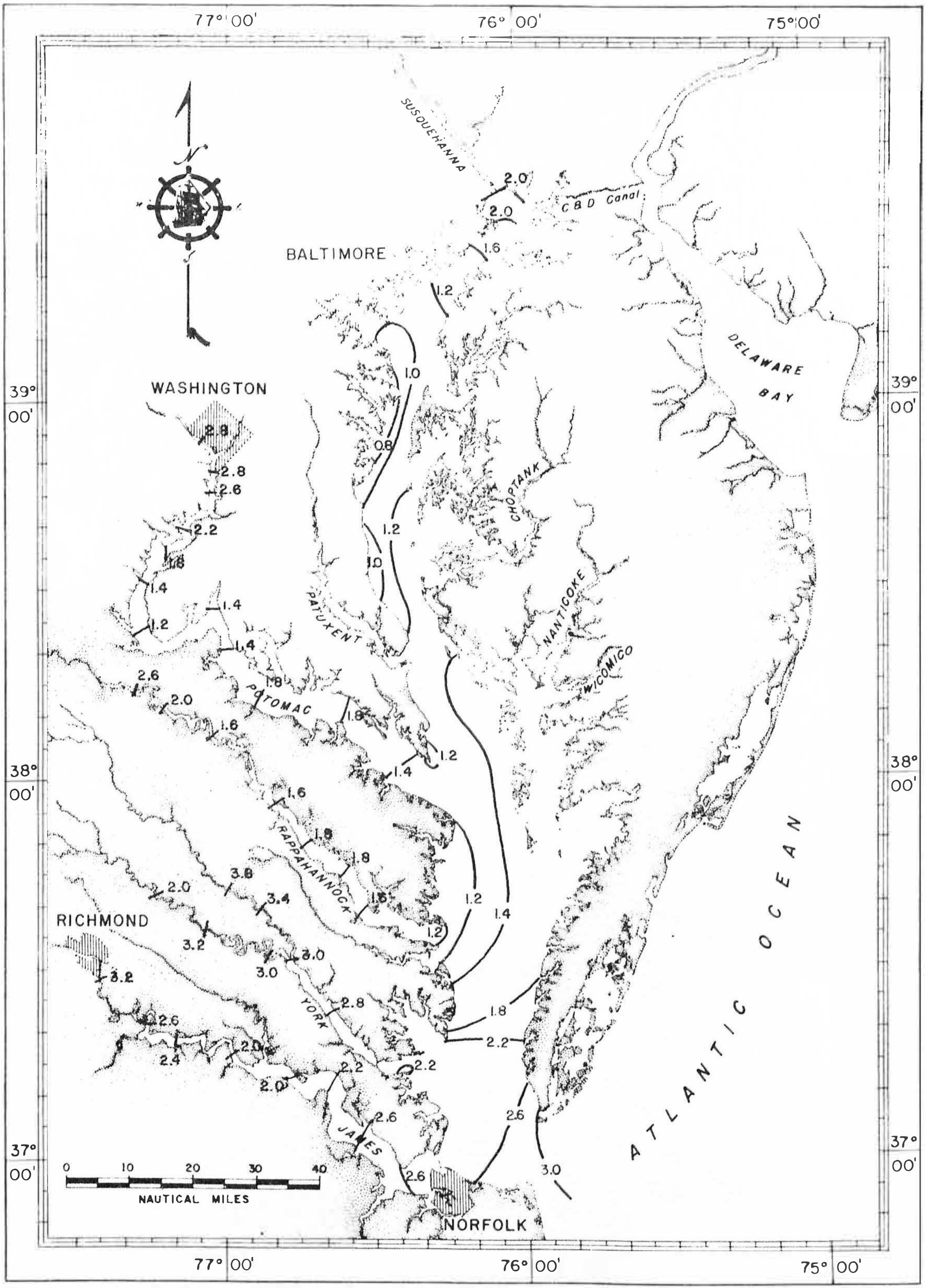


Figure 4. Mean Range in feet, Chesapeake Bay (after Hicks, 1965).

Weather Effects

Weather conditions may cause variations in the level of the tide through two principal effects: one related to winds and one related to barometric pressure.

Strong, steady winds blowing either onshore or offshore may produce a considerable change in tide levels. During intense storms, the astronomic tides may be completely obliterated by the "weather" tide. In Chesapeake Bay, strong winds from the northwest quadrant result in depressed tide levels whereas easterly winds commonly produce an elevated tide level. In specific reaches of many tidal tributaries, weather tides often modify or even dominate the astronomic tide.

To a lesser degree, barometric pressure also affects the tide. According to Marmer (4) "... as a first approximation, any arm of the sea may be regarded as constituting a huge inverted water barometer. When the barometric pressure over this arm of the sea rises, the level of the water will be lowered, while with a decrease in barometric pressure the level of the water will rise."

Except for seasonal trends, weather effects produce changes in the tide in a more or less random way. One may expect roughly as many unusually high tides as unusually low tides caused by weather in a given year. In the long run, weather tides do not affect tidal datum planes.

Table 1 is a simple summary of the principal tidal variations and their respective causes.

Variations in Observed Tide Levels

Tides are observed continuously through the use of the recording tide gage. Records from tide stations established by the U. S. Coast and Geodetic Survey in the Chesapeake Bay area date back to the year 1844 (5). Many records of considerable length are available today, permitting one to look at variations in the real tide over various periods of time at various locations.

Figure 5 illustrates a semidiurnal type of tide with a slight diurnal inequality that is more pronounced for the high waters than for the low waters. This is a typical example of daily variations in the tide on the Atlantic coast of the United States (6). Simple day-to-day comparisons will not be very useful, however, in examining tidal variations that take place over much longer periods than a day. A value is needed that is representative of many days. In order to arrive at values that are typical of all the high water and low water heights that occur during a given period, an average or mean* value is used.

---

*The sum of all high or low water heights observed during a specific period, divided by the total number of observations.

Table 1. Principal tidal variations - cause and effect

Cause	Effect
Earth's rotation	Movement of tidal bulges around the earth; produces two equal high waters and two equal low waters per lunar day (24 hrs. 50 min.). These are the basic semidiurnal (twice daily) tides.
Moon's declination with respect to earth's equator	Unequal high and low waters (diurnal inequality) tending toward diurnal (daily) tides.
Moon's cycle between maximum (tropical) and minimum (equatorial) declination	Two tropical tides (maximum inequality) and two equatorial tides (minimum inequality) per tropical month (27-1/3 days)
Moon and sun in line with earth	Spring tides (maximum tidal range); high waters are higher, low waters are lower than usual.
Moon and sun at right angles to earth	Neap tides (minimum tidal range); high waters are lower, low waters are higher than usual.
Cycle of moon's orbit around earth with respect to the sun	Two spring tides and two neap tides per lunar month (29-1/2 days).
Moon closest to earth	Perigean tides (greater tidal range).
Moon farthest from earth	Apogean tides (lesser tidal range).
Elliptical shape of moon's orbit around earth	Two perigean tides and two apogean tides per anomalistic month (27-1/2 days).
Long-term relationship between positions of earth, moon, and sun	Systematic variation in tidal range over 18.6-year cycle.
Land masses, bottom topography	Variations in mean tide level and mean range with location.
Wind and barometric pressure changes	Variations in local tide levels, often of considerable magnitude but usually having a short duration.
Worldwide increase in level of the sea in combination with slow sinking of coast lands	Progressive rise in sea level of approximately 0.011 feet per year on the Atlantic coast.
Combinations of above	Observed tide.

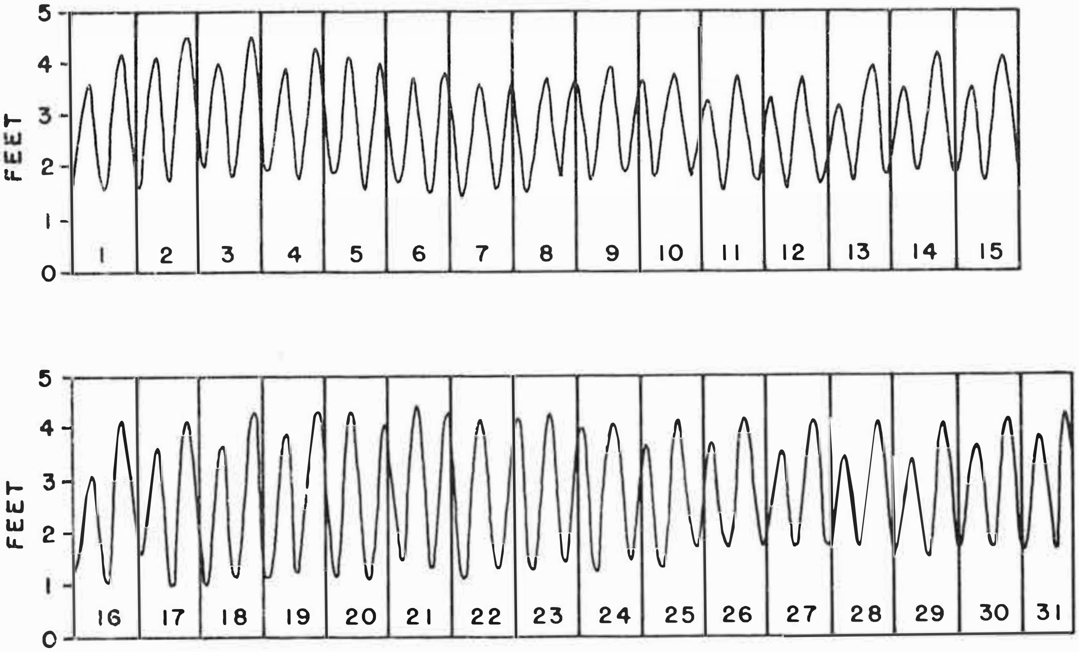


Figure 5. Tide curve, Gloucester Point, Virginia, July, 1970.

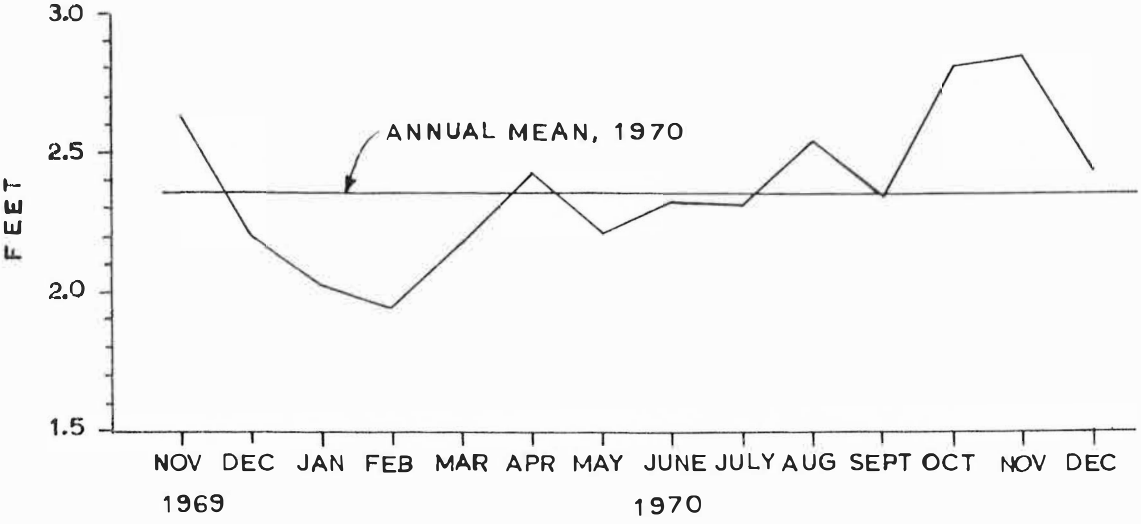


Figure 6. Monthly mean low water, Wachapreague, Virginia, November 1969 - December 1970.

Figure 6 is an example of monthly means of low water at Wachapreague, Virginia, plotted over several months. It is clear from this example that low water is not properly represented by only one month of observations; two months selected at random might differ by as much as 0.9 foot. Note that the 1970 annual mean of low water at Wachapreague is more representative in that it does not differ more than 0.5 foot from any of the monthly means. One would naturally have more confidence in the annual mean over the monthly mean of low water in determining a tidal datum plane. But means over still longer periods continue to show variations and must be examined.

In comparing annual means, one finds that, aside from random variations due to weather, a progressive rise in sea level has been going on for a number of years. Figure 7 illustrates that this fact is true from one end of the U. S. Atlantic coast to the other. This steady rise in sea level averages about 0.011 foot per year (7) and is related to subsidence of the coast lands as well as a general rise in the level of the oceans everywhere. Coincident with this progressive rise of sea level, there remains one more periodic variation which has to do with the tidal range. This variation is illustrated in Figure 8 which shows the difference between yearly low water and yearly sea level for the period 1924-1948 at Boston, Massachusetts. A similar diagram for yearly high water (8) reveals that in years

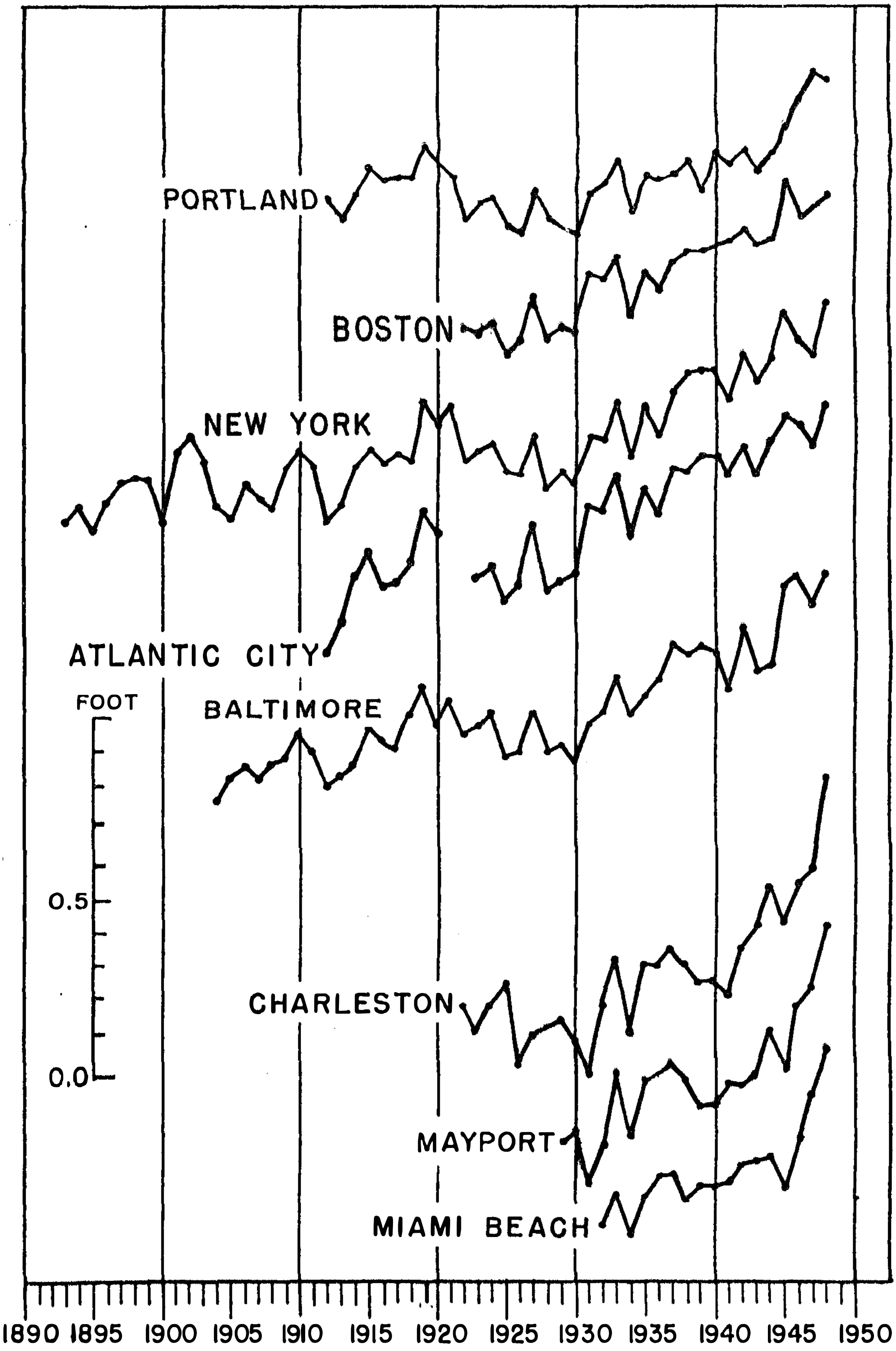


Figure 7. Yearly sea level, Atlantic coast (after Marmer, 1951).

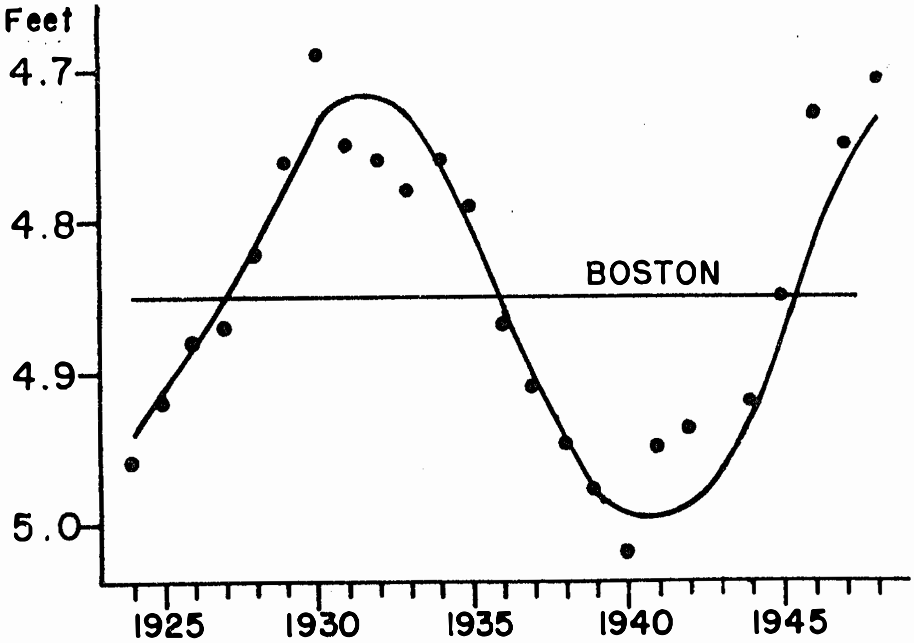


Figure 8. Difference between yearly low water and yearly sea level plotted against time in years (after Marmer, 1951).

when the high waters are highest, the low waters are lowest and vice-versa, indicating a range variation cycle which requires about 19 years to complete. During this period, the range may differ by as much as 0.3 foot from the 19-year average at Boston. Similar results have been found throughout the United States, though the magnitude of the variations may change with the location.

The behavior of the tide that is revealed by both theory as well as observation points to one clear result: periodic variations occur in each of the tide levels that could be used for a reference level or datum. These variations are, for all practical purposes, eliminated if averages are used that cover a 19-year period.

Definitions of the Principal Tidal Datum Planes

Having discussed the tide-producing forces, modifying effects, and the nature of the observed tide, it is time to give the precise definitions of the principal tidal datum planes as accepted by numerous scientific and engineering organizations for many years (9, 10, 11):

Mean High Water (MHW) - The average height of the high water over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value.

Mean Low Water (MLW) - The average height of the low waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value.

Mean Range of Tide (Mn) - The difference in height between mean high water and mean low water.

Mean Tide Level (MTL) - A plane midway between mean high water and mean low water.

Mean Sea Level (MSL) - The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings.

Recalling that sea level is progressively rising, it is necessary to specify which 19-year series, or Epoch, is being used in each of the above definitions. Currently, the National Ocean Survey (formerly the U. S. Coast and Geodetic Survey), a division of the National Oceanic and Atmospheric Administration, uses the series 1941-1959.

METHODS OF DETERMINING TIDAL DATUM PLANES

For most users, direct determination of tidal datum planes is impossible. Therefore, use of an alternative method which corrects a shorter series result to an equivalent 19-year value is essential. This may be done in one of two ways, either by utilizing tabular values based on both theory and observations, or by the method of simultaneous comparisons. The latter method is the preferred one (12).

In effect, the simultaneous comparisons method is not unlike a leveling procedure which utilizes the intervening water surface between two tide stations as a level plane by which tidal information may be transferred. One of the stations serves as a reference and must have 19-year tidal values or the equivalent. Of course the sea's surface will not always conform to a level surface, but if a number of comparisons are made during the same phase of the tide (i.e., high water or low water), a uniform difference will usually emerge between the two stations. Consider the illustration of Figure 9.

Here there are two measuring staffs which observers may read, say, at low water. Suppose that the reference staff reads 1 foot and that mean low water intersects the staff at 0 feet. Then the difference between the new station

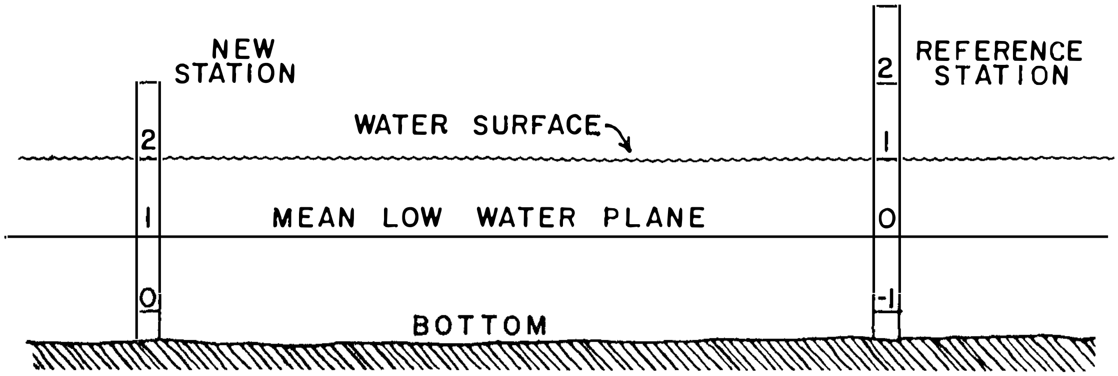


Figure 9. Simultaneous comparison at low water.

reading and the reference station is 2 - 1 = 1 foot and the new station will have mean low water at 0 + 1 = 1 foot on its staff. Another comparison might show a difference of 0.9 foot and so on, but as long as the stations are subject to the same tidal influences, the differences will tend to be uniform except for minor variations. The average difference will primarily be due to the actual difference in elevation of the tide staffs as they happened to be placed, and the actual difference in elevation of the tidal datum which can indeed vary from point to point (Fig. 3). However, since the tidal datum is the chosen level of reference, the latter fact is of no consequence.

Standard procedures were initially developed by the U. S. Coast and Geodetic Survey for computing tidal datums from simultaneous observations (13). A procedure will now be described which is useful for comparisons involving one month of data or less. In general, the method will give results correct to within 0.1 foot when a full month of data is used.

Let the new station be designated Station A, the reference station as Station B. At both stations the high and low waters are read from the records which indicate elevations marked on tide staffs fixed in place. Differences between corresponding high waters and between corresponding low waters are then tabulated and the mean high water and mean low water differences computed. Next the mean tide level (MTL) difference is computed as

MTL difference = 1/2 (MHW difference + MLW difference)

and the range (Mn) difference as

Mn difference = MHW difference - MLW difference.

The Mn ratio becomes

Mn ratio = (Mn at *A*) ÷ (Mn at A - Mn difference)

where Mn at *A* is the uncorrected range at A found by subtracting uncorrected MLW at *A* from uncorrected MHW at *A*.

To the accepted MTL value given for station *B*, add the MTL difference to obtain the corrected MTL value for station *A*. Multiply the accepted Mn value for station *B* by the Mn ratio to get the corrected Mn value at *A*. Finally

Corrected MHW at *A* = MTL + 1/2 Mn at A
Corrected MLW at *A* = MTL - 1/2 Mn at A

The above method works well provided the two stations being compared are not too widely separated, and provided they are not in adjacent bodies of water with completely dissimilar tides. The key to the quality of the comparison lies in the consistency of the *height differences* between corresponding tides. If these differences show a great deal of "scatter" or variation, then the final result becomes much less precise and comparisons over a greater period of time are indicated.

Tabulations of high and low water heights are available from NOAA (National Oceanic and Atmospheric Administration, Rockville, Maryland) for a number of reference stations on the Atlantic coast. The accepted values of MTL and Mn for these stations are also available upon request.

As regards the location of the new station, a site must be selected which affords sufficient depth of water so that unusual lows will not be missed. Some means of support must be found for the tide gage itself, such as a pier or dock, and a tide staff graduated in feet and tenths must be rigidly mounted near the gage. When operating the gage, frequent checks should be made of the time and of comparative readings between staff and gage to insure against errors due to malfunctions; i.e., the staff is considered to be the permanent reference against which all heights are measured. To be sure of such permanence, the top of the staff or else one of the whole foot marks is in turn connected by leveling to one or more permanent markers on shore (a disc set in concrete usually) both before and after the period of observation. The respective level readings should agree closely (0.001 foot or less).

After a sufficient length of record has been obtained at the new station, the times and heights of the high and low waters for each day are then tabulated.

To facilitate the reduction of tidal data and permit rapid calculation of tidal datum planes using the simultaneous comparisons method, two computer programs written in FORTRAN IV for the IBM 1130 are presented in the Appendix. A sample comparison using actual field data taken from the Elizabeth River in Norfolk, Virginia is included.

TIDAL BOUNDARIES

General Tidal Boundaries

Tidal boundaries such as the high water mark and the low water mark are formed by the intersection of a tidal datum plane with the shore (Fig. 10). They do not constitute permanent boundaries since they move horizontally as the shore erodes or accretes. Nevertheless, when set by properly determined tidal datum planes, they are the ideal boundaries of the zone between land and sea.

Once the establishment of a tidal datum plane such as mean low water has been carried out, it is usually the practice to transfer the elevation of that plane from the tide staff on which it was determined to a permanent marker on the shore. This is done by a surveyor using standard leveling techniques. The datum will then be given as X number of feet below the surface of the marker (usually called a tidal bench mark). From this point on, it is a matter of transferring elevations by leveling to various other points which can be made to coincide with the actual datum being used. Then the horizontal line or contour that intersects these points becomes the tidal boundary in question, usually called the high-water line or low-water line, or, at one particular place, the high-water mark or

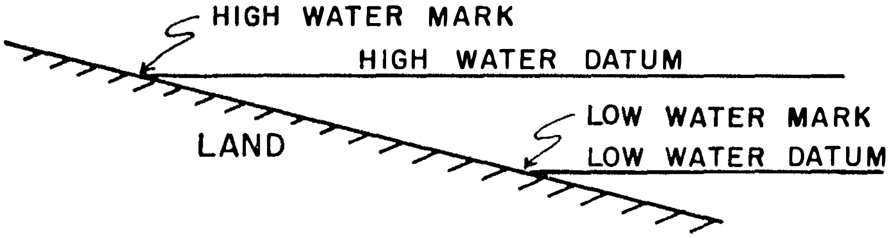


Figure 10. Tidal datum planes intersecting shore.

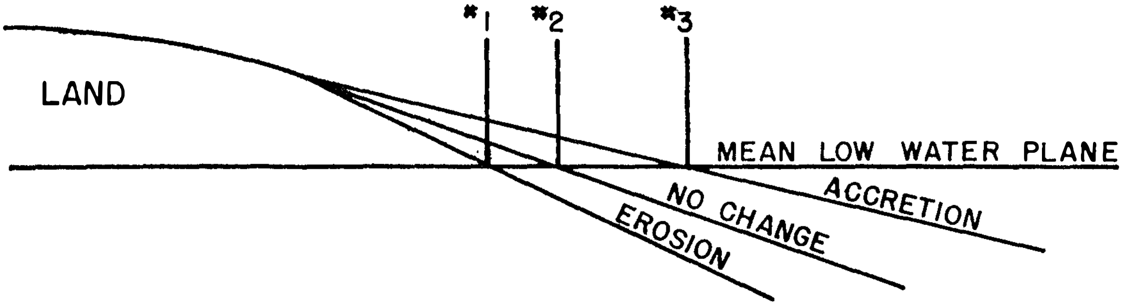


Figure 11. Diagram showing three possible low-water marks, given mean low water, by erosion (#1), no change (#2), or accretion (#3).

low water mark. Thus a tidal boundary constitutes a lateral or horizontally-measured entity whereas the tidal datum plane is vertically measured.

Tidal boundaries in general are not as stable as tidal datum planes, owing to frequent changes in the shoreline due to erosion or accretion (Fig. 11).

Tidal datum planes, on the other hand, may be affected in the short run only by relatively large scale changes, such as major dredging in the tidal section of a river estuary (which consequently affects the tidal boundary also). Under normal circumstances, the tidal datum plane is considered a permanent reference, whereas the tidal boundary must often be resurveyed to keep it up to date, particularly in areas with sandy shores having gentle slopes.

In special areas, such as marshland, the high water line may show great lateral sinuosity because of the very small slopes found on the upper surfaces of most marshes and the fact that mean high water nearly coincides with these surfaces. Not only does a sinuous boundary call for more measured points to define its position, but the softness of the marsh surface causes logistical difficulties as well. Thus, aerial photographs made near the mean high water stage are often the only reliable means of obtaining the high water line in marsh areas, even though one still faces the problem of locating this line on the ground and and marking it for future recovery.

Proposed Tidal Boundary for Wetlands

Practically speaking, the high water line is not in itself a particularly desirable boundary for civic or legislative purposes in many instances regarding wetlands. A number of fauna and flora properly belonging to the marine community or transitional with respect to marine and terrestrial communities are divided by this line. Moreover, as in the case of marshlands, tidal flats, and swamps, the physical delineation of the high water line is not at all straightforward. For these reasons, it has been proposed (14) that a more useful and accessible boundary be adopted for Virginia wetlands, one that is based on a recognized tidal datum plane which is to be augmented by an additional elevation in direct proportion to the local tidal range. Field studies in Virginia (15) indicate that the new boundary should be set to correspond with the mean low water elevation increased by an amount equal to the mean tidal range multiplied by the constant factor of 1.5. The factor of 1.5 was determined empirically in field studies which matched the proposed boundary to characteristic wetland floral zones in key areas.

The advantages of the proposed wetlands boundary given above are threefold:

1. The proposed boundary is a true tidal boundary and thus enjoys a precise definition in the engineering sense;

2. The increased elevation and shoreward shift of the proposed boundary relative to the mean high water line will permit better accessibility and should produce a more regular, more reproducible line in most cases since the new elevation will intersect upland areas having steeper surface slopes as compared to those of marshes, for example, which have very little slope (Fig. 12); and
3. The effect of the local tidal range which directly affects the horizontal extent of the wetland fauna and flora beyond the mean high water line is taken into account.

Figure 12. Aerial photograph of a marsh creek showing areas below mean high water and proposed wetlands boundary


▨ AREAS BELOW MHW
PROPOSED WETLANDS BOUNDARY

TIDAL BOUNDARIES AS LEGAL BOUNDARIES

In the previous section, various tidal datum planes and tidal boundaries have been specifically and technically defined. Problems have arisen in interpreting various statutes referring to tidal boundaries in that the particular boundaries are usually stated as the "low (or high) water mark" or "ordinary low (or high) water mark". The term "ordinary" lacks a technical definition while the use of the words low or high without an appropriate and technically acceptable modifying term leaves room for argument as to whether means or extremes or some other high (or low) water mark is meant.

"Ordinary" High or Low Water Marks in Common Law

Shalowitz (16) in his treatise on shore and sea boundaries describes in detail the development of the interpretation of "ordinary" to be equivalent to "mean" when referring to the high or low water mark. Briefly, the term "ordinary" when applied to tidal boundaries can be traced back to Lord Chief Justice Hale's De Jure Maris (17) in which he described three types of "shores", based upon extent of tidal coverage. Two of the "shores" are those covered only at high spring or regular spring tides. These two "shores" are through most of the year dry and manoriable and therefore subject to private ownership. The third "shore" is that covered by "ordinary" or neap tides which happen between the full and change of the moon, which since it is covered as much by water as it is uncovered is not subject to cultivation. This is the true "shore" which marks the boundary between private property and the King's property.

One of the leading cases in English judicial history in the area of tidal boundaries is Attorney-General v. Chambers (18). In this case, the rule laid down by Lord Hale that the King's right is limited to that land which is not dry or manoriable for most of the time, was taken to mean "that the limit indicating such land is the line of medium high tide between the springs and the neaps". The technique suggested for determining this tidal boundary was "the average of these medium tides in each quarter of a lunar revolution during the year gives the limit, in the absence of all usage, to the rights of the Crown on the seashore".

State Judicial Interpretation

The problem of tidal boundaries in American State courts is confused by the differences in types of tide between the East and West Coast of North America. On the West Coast, a marked diurnal inequality is predominant, i.e., two highs and two lows occur each tidal day, with marked differences between the two tides. This leads to the possibility of having mean higher highs, mean lower lows, etc. In fact, the tidal datum plane used in hydrographic charts is mean lower low water. On the Atlantic and Gulf Coast of the United States, the two tides during a tidal day are essentially equal. In addition, many of the early decisions indicated a lack of awareness of the technical aspects of the tides discussed in the previous section. In one early California case, for example, the "ordinary high water mark" is defined as "... the limit reached by the <u>neap tides;</u> that is, those tides which happen between the full and change of the moon, twice in every 24 hours" (19).

The majority of state cases, however, have interpreted "ordinary" as equivalent to mean. East Boston v. Commonwealth (20) refers to the report of a special master in which 17 cases were cited as using the term ordinary as synonymous with average. The court in this case stated:

> " 'Ordinary' in the grant, in 1640, of tide flats around the island to the 'ordinary low water mark' means 'mean'..."

Some other state decision read:

> " The expressions 'mean low water mark' and 'ordinary low water mark' are synonymous. "
> Esso Standard Oil Co. v. Jones (21)

> " The 'mean high tide' or 'ordinary high tide' is a mean of all the high tides, and the average to be used should be, if possible, the average of all the high tides over a period of 186 years."
> Oneill v. State Highway Department (22)

> " The terms 'ordinary high tide' and 'mean high tide' as used in cases and statutes refer to an average over a long period."
> People v. William Kent Estate Co. (23)

> " 'Ordinary high tide' within constitutional provision relating to ownership of tidal lands,...is the average of all high tides during the tidal cycle."
> Hughes v. State (24)

> " The 'ordinary high tide' is the average of all high tides, but for the purpose of fixing a boundary line of valuable tidelands, and based on scientific and astronomical reasons, the average should be computed on records of at least 18.6 years."
> Banks v. Wilmington Terminal Co. Del. Super. (25)

A few state decisions (26) refer to the inaccurate definition of neap tides as given in Teschewacher and Thompson (19).

Federal Judicial Interpretation

The principal decision in Federal courts on tidal boundary problems is Borax Consolidated, Ltd. v. Los Angeles (27). The court in this case held ordinary high water mark to be synonymous with mean high water and that this mean should be determined from an average of 18.6 years of tidal data if possible. In setting this definition of ordinary high water, the Supreme Court specifically rejected the concept of using only neap tides to determine "ordinary" high water.

The problem of "ordinary" low water came before the court in the first California tidelands case (28). A Special Master recommended that "ordinary low water" be defined as the mean of all the low waters. Subsequent to the report of the Special Master, the United States became party to the Four 1958 Geneva Law of the Sea Conventions. The Convention on the Territorial Sea and the Contiguous Zone stipulates that "the normal baseline for measuring the breadth of the territorial sea is the low water line along the coast as marked on large scale charts officially recognized by the coastal State" (29).

In the 1965 California Case (30) the Supreme Court held that the "line of ordinary low water" as used in the Submerged Lands Act was synonymous with the baseline described in the Geneva Law of the Sea Conventions.

In the United States, therefore, the ordinary low water line or mark is <u>mean</u> <u>low</u> water on the Atlantic and Gulf Coasts and mean <u>lower</u> low water on the Pacific Coasts.

Virginia Cases

The problem of judicial interpretation of tidal boundaries in Virginia is primarily one of determining the meaning of the term "low water mark". The Code of Virginia states that:

> " Subject to the provisions of the preceding section, the limits or bounds of the several tracts of land lying on such bays, rivers, creeks, and shores, and the rights and privileges of the owners of such lands, shall extend to low-water mark, but no farther, unless where a creek or river, or some part thereof, is comprised within the limits of a lawful survey." (31)

Judicial interpretation of the term "low-water mark" is that the "ordinary" low water mark is meant. In Scott v. Doughty (32), the term "low water mark" is defined as follows:

> " The term 'low water mark' used in the statute means 'ordinary low water', not spring tide or neap tide, but normal, natural, usual, customary or ordinary low water, uninfluenced by special seasons, winds or other circumstances."

Unfortunately, no method for determining "ordinary low water" or no precise definition of the term "ordinary" in technical terms compatible with those in the first section of this paper exists either in statute law or in the Virginia Judicial Reports. In a recent case heard in a Circuit Court, however, the judge stated that:

> " In my opinion, the term 'low water mark', as used in Section 62.1-2 of the Code, is synonymous with the 'mean low water mark' for any given area." (33)

Although the preponderance of recent decisions and the traditional concept of Common Law equate "ordinary" as applied to tidal boundaries with "mean", the lack of specific statements as to what is meant by the term "low water mark" or how it is to be determined in the Code of Virginia or in Virginia Judicial Reports, provides the opportunity for various interpretations of the meaning and method of location of the "low water mark" in specific areas.

RECOMMENDATIONS

1.) It is recommended that, to eliminate the possibility of various interpretations in terminology, a specific definition indicating the terms "ordinary low water" and "low-water mark" to be synonymous with the terms "mean low water" and "mean low-water mark" respectively, be added to the Code of Virginia.

2.) It is further recommended that the term "mean low water" be defined as the average of all the low waters measured over a period of 19 years, or for a lesser period, the average of the low waters corrected to the equivalent of a 19-year average using the method of simultaneous comparisons as given on pages 20 - 25 of this paper.

3.) In any consideration of proposed definitions for wetlands boundaries, either as presented on pages 29 - 30 of this paper or elsewhere, the utilization of a tidal datum plane be mandatory.

REFERENCES CITED

(1) Schureman, P., 1949. "Tide and current glossary". Spec. Pub. No. 228, Revised ed., U. S. Dept. of Commerce, Coast and Geodetic Survey, Washington, D. C., 40 p.

(2) U. S. Dept. of Commerce, Coast and Geodetic Survey, 1971. *Tide tables, high and low water predictions,* 290 p.

(3) Hicks, S. B., 1964. "Tidal wave characteristics of Chesapeake Bay". *Chesapeake Science,* Vol. 5, No. 3, pp. 103-113.

(4) Marmer, H. A., 1951. "Tidal datum planes". Spec. Pub. No. 135, Revised ed., U. S. Dept. of Commerce, Coast and Geodetic Survey, Washington, D. C., 142 p.

(5) Haight, F. J., 1930. "Tides and currents in Chesapeake Bay and tributaries". Spec. Pub. No. 162, U. S. Dept. of Commerce, Coast and Geodetic Survey, Washington, D. C., 143 p.

(6) Marmer, *op.cit.,* p. 97.

(7) Hicks, S. D. and Shofnos, W., 1965. "Yearly sea level variations for the United States". *Jour. Hydraulics Div.,* ASCE, Vol. 96, HY7, July, pp. 1567-1586.

(8) Marmer, *op.cit.,* p. 85.

(9) Schureman, *op.cit.*

(10) Marmer, *op.cit.*

(11) Wiegel, R. L., 1953. "Waves, tides, currents and beaches: Glossary of terms and list of standard symbols". Council on Wave Research, Engineering Foundation, 113 p.

(12) Marmer, *op.cit.,* p. 7.

(13) Ibid.

(14) Zeigler, J. M., Virginia Institute of Marine Science, Personal communication.

(15) Wass, M. and Marcellus, K., 1971. "Proposed Wetlands Definitions". Proposal submitted by the Virginia Institute of Marine Science to the Virginia State Legislature.

(16) Shalowitz, A. L., 1962. *Shore and sea boundaries,* Vol. I, U. S. Government Printing Office, Washington, D. C., 420 p.

Shalowitz, A. L., 1964. *Shore and sea boundaries,* Vol. II., U. S. Government Printing Office, Washington, D. C., 749 p.

(17) Hale, *De Jure Maris;* Hargroves Tracts 25(1787).

(18) 4 De G. M. & G., 206(1854), reproduced in full in 2 Shalowitz 640.

(19) Teschemacher v. Thompson, 18 Cal. 11(1861).

(20) 89 N.E. 236 (1909).

(21) 98 So 2d 236.

(22) 235 A 2d 1.

(23) 50 Cal Reptr 215.

(24) 410 P2d 584.

(25) 24 A 2d 592.

(26) Miller v. Bay to Gulf, 193 So. 425.
Narrows Realty Co. v. State 329 P2d 836.

(27) 296 U. S. 10(1935), reproduced in full in 2 Shalowitz 646.

(28) U. S. v. California 332 U. S. 19(1947).

(29) For Text see 1 Shalowitz 371.

(30) 381 U. S. 139(1965).

(31) Virginia Code, Title 62.1, Section 62.1-2.

(32) French v. Bankhead 52 Va. 136(1854).
Scott v. Doughty 97 S.E. 802(1919).

(33) Comm. Va. *ex rel* Marine Resources Commission v. Forbes-Peabody Construction Corp. *et al.* 32nd Judicial Circuit of Va., Circuit Court of the City of Norfolk, 19 Nov. 1971. Thomas M. Johnston, Judge, presiding.

APPENDIX

The following computer programs are designed for use on an IBM 1130 computer system featuring:

IBM 1131 Processor
IBM 1403 Printer
IBM 1442 Card Read Punch

Section A

PROGRAM TISECON

(Time Series Conversion for Tidal Data)

INSTRUCTIONS FOR USING PROGRAM TISECON

I. Description

Program TISECON (Time Series Conversion for Tidal Data) is used to convert tidal data tabulated on a daily basis to a time series in which times are given as elapsed times in hours and tenths since midnight (00.0 hours) at the beginning of the first day of the month. This procedure allows corresponding tides to be compared directly in the computer and eliminates the confusion that results whenever such tides occur on different days.

The limit of program TISECON is 31 consecutive days (interpolative values must be added for days missing within the series). If the series spans portions of two months, it is necessary to assign consecutive day numbers to the second month (e.g., March 30, March 31, April 32, April 33,....).

The output of Program TISECON is given in both printout and card form. Cards for various stations to be compared are in the proper format and sequence for use in Program COSIOB (Comparison of Simultaneous Observations) to be described in Section B of the Appendix.

In the instructions which follow, THW is time of high water, TLW is time of low water, HW is height of high water, and LW is height of low water. All times are in hours and tenths (00.0 through 23.9); all heights are in feet and tenths (-9.9 to 9.9). Two data cards are punched for each day, one for the morning high and low, one for the afternoon high and low. NOTE: Frequently, there will be no afternoon high or else no afternoon low, a consequence of the tide's coming approximately 50 minutes later each day and eventually "slipping" past midnight (00.0); when this happens, enter 99.9 for the missing time and 9.9 for the missing height on the afternoon card in question.

II. Data Deck

A. Sequence

1. Execute Card (//XEQ)

2. Control Card

Col.	Data	Format
1	Blank	
2-3	Month number	(I2)
4-5	No. days in series	(I2)
6-13	Station code	(2A4)

3. Data Cards

Col.	Data	<u>Format</u>
1	Blank	
2-3	Month number	(I2)
4-5	Day number	(I2)
6	Blank	
7-9	THW	(F3.1)
10	Blank	
11-12	HW	(F2.1)
13	Blank	
14-16	TLW	(F3.1)
17	Blank	
18-20	LW	(F2.1)
21-72	Blank	---
73-80	Station code	(2A4)

NOTE: Data cards must be in proper time sequence; i.e., morning cards before afternoon cards, day numbers following consecutively.

III. <u>Computer Instructions</u>

A. Program TISECON with data deck must be followed by at least as many blank cards as are present in the data deck for loading into the <u>IBM 1442 Card Read Punch.</u>

B. Upon printing and punching the output of the first data deck, computer will pause. After clearing card hopper, a second data deck with blank cards may be loaded and run by pressing <u>START</u> button.

C. Punched card output of program TISECON should be interpreted on an <u>IBM 029 Card Punch</u> to facilitate reading and identification.

```
C TIME SERIES CONVERSION PROGRAM FOR TIDAL DATA
C OUTPUT SERIES IN CUMULATIVE HOURS AND TENTHS
C JD BOON,VIMS,1970
      DIMENSION ND(62),THW(62),HW(62),TLW(62),XLW(62)
     1,CTHW(62),CHW(62),CTLW(62),CLW(62)
C*************************************
C READ CONTROL CARD
C*************************************
    4 READ(2,1) MO,N,XIDEN,STA
    1 FORMAT(1X,2I2,2A4)
    3 M=2*N
      DO 60 J=1,M
      CTHW(J)=0.0
      CHW(J)=0.0
      CTLW(J)=0.0
      CLW(J)=0.0
   60 CONTINUE
C*************************************
C READ DATA CARDS
C*************************************
      READ(2,2) (ND(I),THW(I),HW(I),TLW(I),XLW(I),I=1,M)
    2 FORMAT(3X,I2,1X,F3.1,F3.1,1X,F3.1,F3.1)
C*************************************
C CONVERT DATA TO TIME SERIES
C*************************************
      J=0
      DO 20 I=1,M
      IF(THW(I)-99.9)10,20,10
   10 CONTINUE
      J=J+1
      CTHW(J)=THW(I)+24*(ND(I)-1)
      CHW(J)=HW(I)
      N1=J
   20 CONTINUE
      J=0
      DO 40 I=1,M
      IF(TLW(I)-99.9)30,40,30
   30 CONTINUE
      J=J+1
      CTLW(J)=TLW(I)+24*(ND(I)-1)
      CLW(J)=XLW(I)
      N2=J
   40 CONTINUE
      IF(N1-N2)41,41,42
   41 M=N1
      GO TO 43
   42 M=N2
C*************************************
C READ BLANK CARD
C*************************************
   43 READ(2,46) BLANK
   46 FORMAT(A4)
C*************************************
C PRINT OUTPUT
C*************************************
```

```
      WRITE(5,45) M,XIDEN,STA,MO
      WRITE(5,44) (CTHW(J),CHW(J),CTLW(J),CLW(J),J=1,M)
C*************************************
C PUNCH OUTPUT
C*************************************
      WRITE(2,45) M,XIDEN,STA,MO
      WRITE(2,44) (CTHW(J),CHW(J),CTLW(J),CLW(J),J=1,M)
   44 FORMAT(F8.1,F6.1,F8.1,F6.1)
   45 FORMAT(1X,I2,2A4,I2)
      PAUSE
      GO TO 4
      END
```

Section B

PROGRAM COSIOB

(Comparison of Simultaneous Observations)

INSTRUCTIONS FOR USING PROGRAM COSIOB

I. Description

Program COSIOB (Comparison of Simultaneous Observations) is used to compare high and low water times and heights for two tidal stations on the Atlantic coast. One station (B) is used as a reference; the mean tidal level (MTL) and mean range (MN) for this station must be known. The other station (A) is usually a new station for which MTL, MN, MLW (Mean Low Water) values are desired. The essential feature of the comparison is the computation of a MTL difference and MN ratio so that a 19-year average (of MTL, MN) for the reference station is translated into a 19-year average(of MTL, MN, MLW) for the subordinate station. The program requires the output of program TISECON (Times Series Conversion for Tidal Data).

II. Data Deck

A. Sequence

1. Execute Card (//XEQ)
2. Control Card, Station A
   Provided by TISECON
3. Data Cards, Station A
   Provided by TISECON
4. Control Card, ~~Station~~ B
   Provided by TISECON
5. Data Cards, Station B
   Provided by TISECON
6. MTL, MN Card, ~~Station~~ B

Col.	Data	Format
1	Blank	---
2-4	MTL	(F4.2)
5	Blank	---
6-7	MN	(F3.1)

III. Computer Instructions

A. After cards have been read, computer will pause if phasing is required (leading high or low waters for

Stations A & B do not match). Console printer will write:

A Station - Subordinate station code name
THW - Time of first high water, A Station
TLW - Time of first low water, A Station
B Station - Reference station code name
THW - Time of first high water, B Station
TLW - Time of first low water, B Station

Computer will then pause. Do the following:

(1) If the THW difference is more than 6 hours, and if high water at A is earlier than at B, turn Sense Switch 1 on.

(2) If the THW difference is more than 6 hours, and if high water at B is earlier than at A, turn Sense Switch 2 on.

(3) If the TLW difference is more than 6 hours, and if low water at A is earlier than at B, turn Sense Switch 3 on.

(4) If the TLW difference is more than 6 hours, and if low water at B is earlier than at A, turn Sense Switch 4 on.

B. Press START button; output will be printed on 1403 printer.

```
C PROGRAM COSIOB-COMPARISON OF SIMULTANEOUS OBSERVATIONS FOR SUBORDINATE TIDE
C STATION(A) AND CONTROL STATION(B), ATLANTIC COAST ONLY
C BASED ON C+GS FORM 248-TIDES,COMPARISON OF SIMULTANEOUS OBSERVATIONS
C BY J.D.BOON,VIMS,1969
      DIMENSION ATHW(62),AHW(62),ATLW(62),ALW(62),BTHW(62),BHW(62),
     1BTLW(62),BLW(62),DTHW(62),DTLW(62),DHW(62),DLW(62)
C***********************************************
C READ TIME SERIES DATA FOR STATION A, STATION B
C***********************************************
   88 READ(2,1) M,AIDEN,STA,MO
      READ(2,2) (ATHW(I),AHW(I),ATLW(I),ALW(I),I=1,M)
      READ(2,1) N,BIDEN,STB,MO
      READ(2,2) (BTHW(I),BHW(I),BTLW(I),BLW(I),I=1,N)
C******************************************
C READ ACCEPTED MTL,MN VALUES FOR STATION B
C******************************************
      READ(2,3) BMTL,BMN
    1 FORMAT(1X,I2,2A4,I2)
    2 FORMAT(F8.1,F6.1,F8.1,F6.1)
    3 FORMAT(F4.2,F3.1)
C****************************************************
C TEST PHASE RELATIONSHIP BETWEEN STATION A, STATION B
C****************************************************
      I=1
      C=ABS(ATHW(I)-BTHW(I))
      D=ABS(ATLW(I)-BTLW(I))
      IF(C-6.0)14,15,15
   14 IF(D-6.0)23,15,15
C***********************************
C ADJUST PHASE IF REQUIRED
C***********************************
   15 WRITE(1,75) MO
   75 FORMAT(///1X,'MONTH-',1X,I2,2X,'PHASING REQUIRED')
      WRITE(1,6) AIDEN,STA,ATHW(I),ATLW(I),BIDEN,STB,BTHW(I),BTLW(I)
    6 FORMAT(//1X,'A STATION-',2A4,2X,'THW-',F6.1,2X,'TLW-',F6.1,/1X
     1,'B STATION-',2A4,2X,'THW-',F6.1,2X,'TLW-',F6.1)
      PAUSE 1
      CALL DATSW(1,J)
      GO TO (7,8),J
    8 CALL DATSW(2,J)
      GO TO (9,10),J
   10 CALL DATSW(3,J)
      GO TO (11,12),J
   12 CALL DATSW(4,J)
      GO TO (13,23),J
    7 K=M-1
      DO 30 I=1,K
      J=I+1
      ATHW(I)=ATHW(J)
      AHW(I)=AHW(J)
   30 CONTINUE
      M=M-1
      GO TO 23
    9 K=N-1
```

```
      DO 31 I=1,K
      J=I+1
      BTHW(I)=BTHW(J)
      BHW(I)=BHW(J)
   31 CONTINUE
      N=N-1
      GO TO 23
   11 K=M-1
      DO 32 I=1,K
      J=I+1
      ATLW(I)=ATLW(J)
      ALW(I)=ALW(J)
   32 CONTINUE
      M=M-1
      GO TO 23
   13 K=N-1
      DO 33 I=1,K
      J=I+1
      BTLW(I)=BTLW(J)
      BLW(I)=BLW(J)
   33 CONTINUE
      N=N-1
C********************************************
C COMPUTE UNCORRECTED MHW,MLW AT STATION A
C********************************************
   23 CONTINUE
      IF(M-N)43,43,44
   43 K=M
      GO TO 20
   44 K=N
   20 SHWA=0.0
      SLWA=0.0
      SDTHW=0.0
      SDTLW=0.0
      SDHW=0.0
      SDLW=0.0
      SSDTH=0.0
      SSDTL=0.0
      TN=FLOAT(K)
   21 DO 22 I=1,K
      SHWA=AHW(I)+SHWA
      SLWA=ALW(I)+SLWA
   22 CONTINUE
      AMHW=SHWA/TN
      AMLW=SLWA/TN
C********************************************
C COMPUTE UNCORRECTED MN,MTL AT STATION A
C********************************************
      AMN=AMHW-AMLW
      AMTL=0.5*(AMHW+AMLW)
C******************************************
C COMPUTE MEAN THW,TLW,HW,LW DIFFERENCES
C******************************************
      DO 24 I=1,K
```

```
      DTHW(I)=ATHW(I)-BTHW(I)
      DTLW(I)=ATLW(I)-BTLW(I)
      DHW(I)=AHW(I)-BHW(I)
      DLW(I)=ALW(I)-BLW(I)
      SDTHW=DTHW(I)+SDTHW
      SDTLW=DTLW(I)+SDTLW
      SDHW=DHW(I)+SDHW
      SDLW=DLW(I)+SDLW
      SSDTH=DTHW(I)**2.0+SSDTH
      SSDTL=DTLW(I)**2.0+SSDTL
   24 CONTINUE
      THWMD=SDTHW/TN
      TLWMD=SDTLW/TN
      HWMD=SDHW/TN
      XLWMD=SDLW/TN
      RMSH=((SSDTH-SDTHW**2.0/K)/(K-1.0))**0.5
      RMSL=((SSDTL-SDTLW**2.0/K)/(K-1.0))**0.5
C***********************************
C COMPUTE MTL DIFFERENCE, MN RATIO
C***********************************
      DMN=HWMD-XLWMD
      DMTL=0.5*(HWMD+XLWMD)
      RMN=AMN/(AMN-DMN)
C*********************************************
C COMPUTE CORRECTED MTL,MN,MLW FOR STATION A
C*********************************************
      AMTL=BMTL+DMTL
      AMN=BMN*RMN
      AMLW=AMTL-0.5*AMN
C*****************************************************
C PRINT LIST OF TIME DIFFERENCES, HEIGHT DIFFERENCES
C*****************************************************
      WRITE(5,26) AIDEN,STA,BIDEN,STB,MO
   26 FORMAT('1 STATION A-',1X,2A4,2X,'STATION B-',1X,2A4,2X
     1,'MONTH-',1X,I2)
      WRITE(5,27)
   27 FORMAT(//1X,'TIME DIFF-HW',3X,'TIME DIFF-LW',3X,'HEIGHT DIFF-HW'
     1,3X,'HEIGHT DIFF-LW',5X,'ATHW',3X,'BTHW',3X,'ATLW',3X,'BTLW',4X,'A
     2HW',3X,'BHW',3X,'ALW',3X,'BLW')
      WRITE(5,28) (DTHW(I),DTLW(I),DHW(I),DLW(I),ATHW(I),BTHW(I)
     1,ATLW(I),BTLW(I),AHW(I),BHW(I),ALW(I),BLW(I),I=1,K)
   28 FORMAT(/5X,F5.2,10X,F5.2,10X,F5.2,12X,F5.2,9X,F6.2,1X,F6.2
     1,1X,F6.2,1X,F6.2,1X,F5.1,1X,F5.1,1X,F5.1,1X,F5.1)
C****************
C PRINT RESULTS
C****************
      WRITE(5,26) AIDEN,STA,BIDEN,STB,MO
      WRITE(5,29) THWMD,TLWMD,RMSH,RMSL,DMN,RMN
   29 FORMAT(//1X,'MEAN TIME DIFFERENCE',6X,'RMS TIME DIFFERENCE',/1X
     1,'HW=',1X,F5.2,3X,'LW=',1X,F5.2,5X,'HW=',1X,F5.2,3X,'LW=',1X
     2,F5.2,//1X,'RANGE DIFF=',1X,F5.2,3X,'RANGE RATIO=',1X,F5.3)
      WRITE(5,39) AMTL,AMN,AMLW,K
   39 FORMAT(//1X,'MTL ON STAFF AT A=',2X,F4.2,/1X,'MEAN RANGE AT A='
     1,1X,F4.2,/1X,'MLW ON STAFF AT A=',1X,F4.2,//1X,
```

```
2'NO. TIDES COMPARED-',I2)
 PAUSE
 GO TO 88
 END
```

Section C

SAMPLE OUTPUT - PROGRAM COSIOB

Part 1

LIST OF TIME AND HEIGHT DIFFERENCES

NOTE: Base times for Stations A and B are elapsed hours since beginning of month.

STATION A- SMCO7571 STATION B- SEWL7571 MONTH- 8

TIME DIFF-HW	TIME DIFF-LW	HEIGHT DIFF-HW	HEIGHT DIFF-LW	ATHW	BTHW	ATLW	BTLW	AHW	BHW	ALW	BLW
0.30	0.00	3.20	3.00	116.20	115.90	110.60	110.60	6.8	3.6	3.6	0.6
0.50	0.00	3.30	3.00	128.70	128.20	122.70	122.70	6.1	2.8	3.3	0.3
0.39	0.39	3.30	2.90	140.80	140.40	134.90	134.50	6.5	3.2	3.0	0.1
0.19	0.30	3.30	3.00	153.20	153.00	147.50	147.20	6.1	2.8	2.8	-0.2
0.39	0.39	3.30	3.00	165.80	165.40	159.70	159.30	6.4	3.1	2.9	-0.1
0.19	0.09	3.29	3.00	178.20	178.00	172.10	172.00	6.3	3.0	2.8	-0.2
0.39	0.40	3.20	3.00	190.60	190.20	184.50	184.10	6.4	3.2	2.8	-0.2
0.40	0.39	3.30	2.90	203.00	202.60	197.10	196.70	6.4	3.1	2.8	-0.1
0.39	0.40	3.20	3.00	215.30	214.90	209.50	209.10	6.1	2.9	2.8	-0.2
0.60	0.39	3.29	3.00	227.80	227.20	221.80	221.40	6.3	3.0	2.5	-0.5
0.60	0.20	3.30	2.90	240.20	239.60	234.30	234.10	5.6	2.3	2.6	-0.3
0.30	0.39	3.29	2.90	252.90	252.60	246.60	246.20	5.8	2.5	2.1	-0.8
0.39	-0.10	3.40	2.80	264.90	264.50	258.70	258.80	5.8	2.4	2.5	-0.3
0.50	0.29	3.20	3.00	277.60	277.10	271.20	270.90	6.8	3.6	2.7	-0.3
0.29	0.09	3.30	3.00	290.20	289.90	284.10	284.00	6.2	2.9	3.6	0.6
0.20	0.29	3.29	3.00	302.30	302.10	296.20	295.90	6.8	3.5	3.6	0.6
0.39	-0.09	3.20	3.00	314.90	314.50	309.00	309.10	6.2	3.0	4.1	1.1
0.29	0.10	3.29	3.00	327.30	327.00	321.00	320.90	6.8	3.5	4.0	1.0
0.39	0.40	3.20	2.90	340.20	339.80	334.50	334.10	5.9	2.7	4.0	1.1
0.50	0.50	3.20	3.00	352.60	352.10	346.50	346.00	6.4	3.2	3.6	0.6
0.29	0.30	3.20	3.00	365.30	365.00	359.50	359.20	5.7	2.5	3.6	0.6
0.20	0.50	3.20	3.00	377.80	377.60	371.50	371.00	6.5	3.3	3.6	0.6
0.40	0.29	3.20	3.00	390.30	389.90	384.40	384.10	6.0	2.8	3.8	0.8
0.50	0.50	3.29	3.00	402.80	402.30	396.60	396.10	6.3	3.0	3.5	0.5
0.10	0.39	3.30	3.00	415.00	414.90	409.40	409.00	5.7	2.4	3.4	0.4
0.59	0.29	3.20	2.90	427.60	427.00	421.30	421.00	6.2	3.0	3.1	0.2
0.29	0.29	3.20	3.00	440.10	439.80	434.30	434.00	5.7	2.5	3.3	0.3
0.50	0.29	3.20	3.00	452.50	452.00	446.30	446.00	6.2	3.0	3.0	0.0

0.59	0.60	3.20	3.00	465.10	464.50	459.00	458.40	5.9	2.7	3.2	0.2
0.29	0.50	3.20	3.00	477.10	476.80	471.30	470.80	6.1	2.9	3.2	0.2
0.40	0.59	3.30	3.00	489.50	489.10	483.60	483.00	6.0	2.7	3.0	0.0
0.70	0.50	3.20	2.90	501.90	501.20	495.70	495.20	6.1	2.9	3.0	0.1
0.29	0.40	3.30	3.00	513.90	513.60	508.00	507.60	6.1	2.8	3.1	0.1
0.60	0.29	3.20	3.00	526.00	525.40	520.30	520.00	6.1	2.9	3.3	0.3
0.59	0.50	3.20	2.90	538.80	538.20	532.60	532.10	6.2	3.0	3.0	0.1
0.40	0.50	3.30	3.00	551.10	550.70	544.80	544.30	6.5	3.2	3.5	0.5
0.59	0.50	3.30	2.90	563.10	562.50	557.00	556.50	6.6	3.3	3.5	0.6
0.40	0.40	3.30	2.90	575.50	575.10	569.60	569.20	5.9	2.6	3.6	0.7
0.40	0.29	3.30	2.90	587.70	587.30	581.40	581.10	6.0	2.7	3.2	0.3
0.30	0.40	3.20	3.00	600.00	599.70	594.30	593.90	5.4	2.2	3.3	0.3
0.40	-0.29	3.20	2.90	612.60	612.20	605.50	605.80	6.0	2.8	3.2	0.3
0.59	0.59	3.30	3.00	624.70	624.10	618.80	618.20	5.6	2.3	3.6	0.6
-0.30	0.40	3.29	3.00	636.70	637.00	630.60	630.20	6.3	3.0	3.7	0.7
0.50	0.00	3.30	3.00	645.60	645.10	642.10	642.10	7.9	4.6	4.9	1.9
0.69	0.40	3.20	3.00	662.70	662.00	657.50	657.10	5.6	2.4	3.8	0.8
0.39	0.29	3.20	3.00	674.40	674.00	668.90	668.60	5.0	1.8	3.3	0.3
0.40	0.59	3.30	3.00	686.60	686.20	680.60	680.00	5.7	2.4	3.6	0.6
0.39	0.50	3.20	3.00	699.40	699.00	693.80	693.30	4.9	1.7	3.4	0.4
0.30	0.29	3.10	2.90	712.00	711.70	705.40	705.10	5.4	2.3	3.3	0.4
0.40	0.59	3.10	3.00	724.60	724.20	718.80	718.20	5.0	1.9	3.2	0.2
0.10	0.09	3.20	3.00	737.50	737.40	730.20	730.10	5.9	2.7	3.3	0.3
0.40	0.39	3.20	3.00	749.60	749.20	743.90	743.50	5.8	2.6	4.0	1.0

Part 2

RESULTS - PROGRAM COSIOB

```
 STATION A- SMCO7571  STATION B- SEWL7571  MONTH-  8

MEAN TIME DIFFERENCE       RMS TIME DIFFERENCE
HW = 0.39   LW = 0.33      HW = 0.17   LW = 0.19

RANGE DIFF = 0.27   RANGE RATIO =1.109


MTL ON STAFF AT A = 4.30
MEAN RANGE AT A = 2.77
MLW ON STAFF AT A = 2.92

NO. TIDES COMPARED=52
```