Delineation of Coastal Boundaries Using Tidal Data

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Key words: coastal boundaries, tidal datum planes, mean high water line

SUMMARY

The land/sea interface is one of the oldest boundaries used by mankind. Yet, due to its dynamic nature, together with the great demand for coastal land, the location of this boundary has often been a source of controversy. Therefore, it is important that objective methods be used for the delineation of this boundary, and the use of tidal data is arguably the best means of achieving the required objectivity and mathematical certainty. This paper describes methods for the use of tidal data for various types of boundaries relating to the land/sea interface including those defined under Anglo/American common law, those defined under the more expansive Roman civil law, and regulatory boundaries offset from the land/sea interface. Included is a discussion of tidal theory relative to datum determination, datum calculation methods, and datum line delineation techniques.

RESUMEN

La relación Tierra/Mar o línea de costa es uno de los linderos más antiguos usados por la humanidad. Sin embargo, debido a su naturaleza dinámica, junto con la gran demanda que existe de los terrenos costeros, el establecimiento de dichos linderos es fuente de controversias frecuentes. Por eso, es muy importante el usar métodos objetivos para delimitar esos linderos, y usando datos de mareógrafos es una manera de obtener la objetividad requerida y una certeza matemáticamente cuantificable. Este documento describe métodos para usar datos de mareógrafos para varias clases de linderos relacionados con la Tierra y el mar incluyendo aquellos definidos en las leyes angloamericana, los también definidos el derecho Romano y los linderos establecidos en las aguas costeras. Se incluye la discusión de la teoría de la marea relacionada con la determinación del datum de marea (Tidal Datum), métodos para calcular el datum, y técnicas para establecer sobre el terreno el límite del datum.

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1. INTRODUCTION

The edge of the sea is possibly the oldest boundary used by mankind. Yet, despite that long history of usage, coastal boundaries are, in today's society, one of the most frequently and bitterly contested of boundaries. The edge of water forms an excellent natural boundary in that it is easily defended and easily recognized. However, modern land use practices have created a growing demand for precisely located and legally defensible water boundaries, and when attempts are made to precisely locate a coastal boundary, complex technical and legal quagmires can result. This is primarily due to the fact that the land/water interface is dynamic. The surfaces of most water bodies are constantly changing due to tides and/or meteorological conditions. In addition, the shoreline in many areas is subject to erosion and accretion caused by waves and currents. Therefore, unlike most other boundaries which are two dimensional, one must consider a third dimension - height - and a fourth dimension - time - when dealing with coastal boundaries. Consequently, unique laws and techniques have developed for defining and locating water boundaries.

2. LEGAL HISTORY (Cole 1997)

2.1 Background

The concept of the sea as a global commons has roots as far back as the ancient Roman Civil Code of Emperor Justinian I, written about 500 A.D. Under that code, the sea as well as rivers were considered to be *res communes* or commonly owned by all mankind (Cole 1991). Yet, at the rise of the great maritime nations of the Middle Ages, some nations laid exclusive claim to entire seas or oceans, as opposed to that early Roman concept of the sea as a global resource. Gradually, such claims were found to be unrealistic and impossible to defend, and a new doctrine evolved with claims by various nations limited to a marginal sea of a width that could be defended. That doctrine, codified in the 20th century by the Law of the Sea Treaties, represents the current posture of most coastal nations. Those nations are considered to ”own” a marginal sea along the coastline that is reserved for the public use of those nations. The boundary, between those public trust submerged lands exclusive to each coastal nation, and the littoral uplands subject to private ownership, is the subject of this paper.

2.2 Anglo/American Law

The use of tidal data as the criteria for delineating coastal boundaraies is well-established in Anglo/American common law. Perhaps the earliest mention of this in English literature was in 1567 by Thomas Digges, an engineer, surveyor and lawyer, in a book entitled *Proofs of the Queen's Interest in Land Left by the Sea and the Salt Shores Thereof.* In the following century, the doctrine was generally accepted as evidenced by the writings of Lord Matthew Hale, a jurist who was to become the British Chief Justice. In his treatise *De Jure Maris,* written about 1666, Hale concluded that the foreshore, which is overflowed by "*ordinary tides or neap tides, which happen between the full and change of the moon*", belonged to the Crown, while the land above that level was subject to private ownership.

With our knowledge of the tides today, it is obvious that Lord Hale was incorrect in equating "neap tides" with "ordinary tides". At the very least, his definition was ambiguous. In 1854, this definition was clarified in English common law by the case of *Attorney General v. Chambers*. That case, reflecting tidal theory developed after Hale's writings, ruled that the ordinary high water mark was to be found by "*the average of the medium tides in each quarter of a lunar evolution during the year (which line) gives the limit, in the absence of all usage, to the rights of the Crown on the seashore*".

In the United States, the ”ownership” of the public trust submerged lands was transferred from the Crown to the people of each state as confirmed by a series of U.S. Supreme Court cases beginning with *Martin v. Waddell* in 1842. According to the Court in that case:

When the revolution took place the people of each state became themselves sovereign and in that character hold the absolute right to all their navigable waters in the soils under them for their own common use ...

However, there was no generally accepted judicial clarification as to how the boundary should be established until 1935 with the U.S. Supreme Court's landmark decision in *Borax Consolidated v. City of Los Angeles*. In essence, that decision called for application of modern scientific techniques for precisely defining the boundary:

In view of the definition of the mean high tide, as given by the United States Coast and Geodetic Survey that "mean high water at any place is the average height of all the high waters at that place over a considerable period of time", and the further observation that "from theoretical considerations of an astronomic character" there should be "a periodic variation in the rise of water above sea level having a period of 18.6 years", the Court of Appeals directed that in order to ascertain the mean high tide line with requisite certainty in fixing the boundary of valuable tidelands, such as those here in question appear to be, "an average of 18.6 years should be determined as near as possible". We find no error in that instruction.

As the above quote demonstrates, the Borax decision applied modern technical knowledge and set forth a workable technique for precisely locating the boundary in question which still prevails in U.S. common law. This approach represents an attempt to define the upper reach of the daily tide as the boundary between publicly owned submerged lands and uplands subject to private ownership. Since the upper reach of the tide varies from day to day, the use of an average value, or mean high water, attempts to ”split the difference” for a compromise line. This results in a line which is exceeded by the high tide on approximately one half of the daily or twice daily tidal cycles.

Within the United States, case law in most of the coastal states has followed the English common law and its updated definition as put forth in the Borax decision. Sixteen states (Alabama, Alaska, California, Connecticut, Florida, Georgia, Maryland, Mississippi, New Jersey, New York, North Carolina, Oregon, Rhode Island, South Carolina, Texas, and Washington) have followed this course (*Maloney and Ausness 1974*, *Cole 1977*). Some states have codified their common law on this subject. For example, in Florida, the Coastal Mapping Act of 1974 (Chapter 177, Part II, Florida Statutes) declares that "*mean high water line along the shores of lands immediately bordering on navigable waters is recognized and declared to be the boundary between the foreshore owned by the State in its sovereign capacity and upland subject to private ownership*." The Statute also defines the mean high water line using the Borax definition.

There are exceptions within the United States to the general rule. For example, six Atlantic Coast states (Delaware, Maine, Massachusetts, New Hampshire, Pennsylvania, and Virginia) recognize the mean low water line as the sovereign/upland boundary. For many of these low water states, that boundary is based on an early Massachusetts colonial ordinance of 1641-1647 that provided as follows:

...in all creeks, coves and other places, about and upon salt water where the Sea ebs and flows, the Proprietor of the land adjoining shall have proprietie to the low water mark where the Sea doth not ebb above a hundred rods, and not more wheresoever it ebs farther.

2.3 Civil Law

Under legal systems based on the Roman civil law, as opposed to Anglo/American common law, different defiinitions have evolved. This is generally in areas where the land title has its roots in a grant from a sovereign power under which the civil law, such as the Roman Institutes of Justinian, prevailed. Possibly because the Roman civil law code was developed in the Mediterrain Sea, with a minimal daily tidal range, that law does not define the coastal boundary in terms of daily tide, but rather in terms of seasonal water levels. As an example, a translation of a portion of the early Roman code reads as follows:

The sea-shore, that is, the shore as far as the waves go at furthest, was considered to belong to all men....... The sea shore extends as far as the greatest winter floods runs up (Sanders 1876)

This same concept is reflected in ancient Spanish law contained in *Las Siete Partidas*, written in the thirteenth century, where similar language also included both the sea shore and the sea within the public trust and defined the sea shore as follows (Partida 3, Title 28, Law 4):

… e todo aquel lugar es llamado ribera de la mar quanto se cubre el agua della, quanto mas crece en todo el ano, quier en tiempo del …

The difference between the common law and civil law boundary definitions was clearly made in the previously discussed Borax decision as follows:

By the civil law, the shore extends as far as the highest waves reach in winter. But by the common law, the shore "is confined to the flux and reflux of the sea at ordinary tides."

As an example of the use of the civil law definition within the United States, Louisiana has adopted the civil law boundary of the line of the highest winter tide. The State of Hawaii also appears to follow this tradition with a coastal boundary defined as "*the upper reach of the wash of the waves*" (*Maloney and Ausness 1974*). Another such example is the State of Texas which has recognized the civil law definition in areas of the state with origins of land title in Spanish or Mexican land grants. For such grants, it has been held that the limit of ownership is controlled by old Spanish law contained in *Las Sieta Partidas*, written in the thirteenth century, which closely tracts the Roman Institutes of Justinian.

In Puerto Rico, where the legal system is based on the Roman civil law as reflected in the Spanish codes, the upland limit of the public domain is the equixoxal spring tide occcuring at the maximum of the 19-year cycle, which is considered to be the reach of the greatest storm waves (Puerto Rico Departamento de Recursas Naturales y Ambientales 1999). This would appear to be very much in the traditions of the civil law. Interestingly, although defined in terms of tidal datums, the boundary is typically delineated using botanical and geological indicators.

Thus, a significant difference may be seen between the two legal systems. While the Anglo/American common law limits the public domain to the average daily reach of the tides, the civil law expands the public lands to the maximum reach of the waters.

3. TIDAL DATUM PLANES

The application of tidal data to boundaries requires an understanding of tidal mechanics. Therefore, the following overview is offered:

3.1 Tidal Constituents

The tide is the alternating rise and fall in sea level produced by the gravitational force of the moon and the sun. Other non-astronomical factors, such as meteorological forces, ocean floor topography and coast line configuration, also play an important role in shaping the tide. To understand the mechanics of the tide producing forces, visualize a moon orbiting around an earth covered only with a layer of water. Due to the attractive force of the moon, there would a bulge in the water on both sides of the earth beneath the moon wth low water zones in between. The high water on the side of the earth closest to the moon is caused by the moon's pull on the fluid water. On the side opposite the moon, the lesser gravitational force and the centrifugal force, as the earth spins, causes the high water. These bulges of water follow the moon in its revolution about the earth. Since the average interval between consecutive transits of the moon is 24.84 hours, the moving high waters take the form of a sine wave with a period of half that period or 12.42 hours. Similarly, there is a sine wave with a period of 12.00 hours following the apparent rotation of the sun.

The cycles associated with several other relationships between the sun, earth and moon may also be considered as sine waves of specific periods. For example, the elliptical orbit of the moon about the earth results in a constituent wave with a period of 27.55 days with highest water at the time of perigee (when the moon is closest to the earth) and lowest water when the moon is the greatest distance away. In addition to the constituents of different periods, another sinusoidal cycle, that associated with the regression of the moon's nodes[1] with a period of 18.6 years, affects the amplitudes of the various constituents. The resultant tide is the composite, or algebraic sum, of all the constituent cycles as modified by the 18.6 year nodal cycle.

When the high water of several constituents are in phase, tides higher than normal occur. Such is the case twice a month when the moon's and the sun's principal constituents are in phase. This occurs near the time of the new and full moon when the earth, moon, and sun are in a line and produce the so-called spring tides. Neap tides are those which occur at the time of the quarter or three quarter moon when the sun and moon are at 90 degrees to each other as measured from the earth. Their respective following waves are then out of phase and result in lower high waters. Occasionally, the spring tides take place at the time of the moon's perigee (when the moon is closest to the earth). When this happens, the highest water of the cycle resulting from the moon's proximity to earth is in phase with (and therefore added to) the highest points of the waves resulting from the moon's and sun's apparent rotation around the earth. This produces abnormally high tides which have been associated with historic coastal flooding (*Wood 1976*).

The above discussion regarding spring and neap tides applies in most areas of the world where semi-diurnal or twice daily tidal oscillations predominate. In some areas, only one high water and one low water per tidal day are experienced for most of the month. In such diurnal tide areas, tides are more affected by the declination of the moon and sun than by the moon's phases. Declination, in this context, is the apparent angle of an astronomic body above or below the plane of the earth's equator. In such diurnal tide areas, tides with greater range, called tropic tides, occur every two weeks when the moon is at its maximum northing or southing or maximum declination. When the moon is over the equator, tides of lesser range called equatorial tides, occur. In addition, two high and two low waters generally occur in diurnal areas during such times when the moon is over the equator. The sun's declination has a similar effect on the tides with a maximum near the time of the winter and summer solstice when the sun is at maximum declination (equinoxial tides) and at a minimum during early spring and fall when the sun is over the equator.

3.2 Tidal Datum Planes

A tidal datum is a plane of reference for elevations which is based upon average tidal height. Considering the above discussion, it is obvious that to be statistically significant, a tidal datum should include all of the periodic variations in tidal height. Therefore, a tidal datum is usually considered to be the average of all occurrences of a certain tidal extreme for a period of 19 years

[1] Regression of the moon's nodes refer to the movement of the intersection of the moon's orbital plane and the plane of the Earth's equator which occurs over a cycle of 18.6 years.

(18.6 years, rounded to the nearest whole year to include a multiple of the annual cycle associated with the declination of the sun.) Such a period is called a tidal epoch.

As examples of tidal datum planes (Figure 1), mean high water (MHW) is defined as the average height of all the high waters occurring over a period of 19 years. Likewise, mean low water (MLW) is defined as the average of all of the low tides over a 19-year tidal epoch. Mean tide level (MTL) or half tide level is the plane halfway between mean high and mean low water which is used for datum computation purposes. This should not be confused with mean sea level (MSL) which is defined as the average level of the sea as measured from hourly heights over a tidal epoch. The relationship between mean sea level and mean tide level varies from location to location, depending upon the phase and amplitude relations of the various tidal constituents at each location.

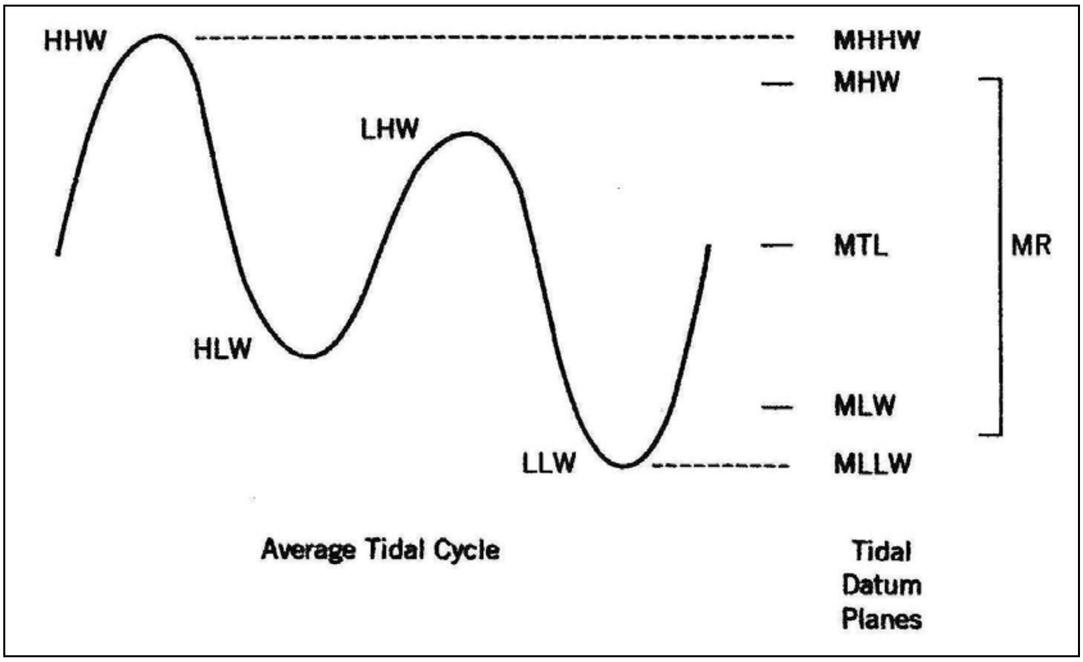

Figure 1
Common Tidal Datum Planes

In addition to the above, there are two other commonly used datum planes. Mean higher high water (MHHW) is the average of the higher of the high tides occurring each day. Mean lower low water (MLLW) is the average of the lower of the low tides occurring each day. Both of these averages are calculated over a tidal epoch. The difference between mean higher high water and mean high water is called diurnal high water inequality or DHQ. The difference between mean lower low water and mean low water is called diurnal low water inequality or DLQ.

From the foregoing, it may be seen that the primary determination of a tidal datum involves the relatively straightforward determination of the arithmetic mean, or average, of all the occurrences of a certain tidal extreme over a 19-year tidal epoch. In practice, this is usually accomplished by computing mean values of the various tidal extremes for each calendar month, and then annual mean values by averaging the 12 monthly means for each calendar year. Finally, the mean values for the tidal epoch used are determined by averaging the annual mean values for the 19 years comprising the epoch.

Although the previously described astronomical relationships generate tidal cycles, various local topographic forces shape the tidal cycles. In large water bodies, such as the oceans, there is direct response to the tide producing forces in the form of oscillations. The pattern and magnitude of such oscillation is governed by the volume of water available as well as the natural oscillation period of the ocean basin. A natural oscillation period similar to the period of the gravitational force results in reinforcement of the tidal oscillation. The topography of the basin also has an effect on the stilled water level which in turn affects the average tidal heights in some regions. As an example of this phenomenon, the sea surface has been noted to be significantly depressed over ocean trenches and may bulge significantly over seamounts (*Duxbury 1989*). Futhermore, the shoaling of the continental shelf, together with friction, resonance, and the Coriolis effect within estuaries, all tend to modify the tidal range. Thus, there may be significant differences in the elevation of a tidal datum from point to point in even the same general vicinity (*Cole 1977*). Therefore, a tidal datum should be determined in the immediate area of its intended use.

Another important consideration regarding tidal datum planes is long term sea level trends. As mentioned in the previous section, a tidal datum is defined as an average over a 19-year period known as a tidal epoch. A specific 19-year period should be used since variation in mean sea level is noted from one 19-year period to another. It is not known if these trends are truly non-periodic or a part of some long term oscillation, but based on studies (Millima and Emery 1968) using carbon dating of coastal indicators, there has been considerable variation of sea level over the last 36,000 years (Figure 2). Furthermore, such studies indicate that there has been a more or less continuous rise in sea level over the last 14,000 years which, at times, has been at significantly higher rates than the current. At any rate, it is important that when using tidal datums, you should be aware of the epoch over which the datum was calculated. In the United States, tide data is calculated over a standard epoch which currently is 1983 - 2001.

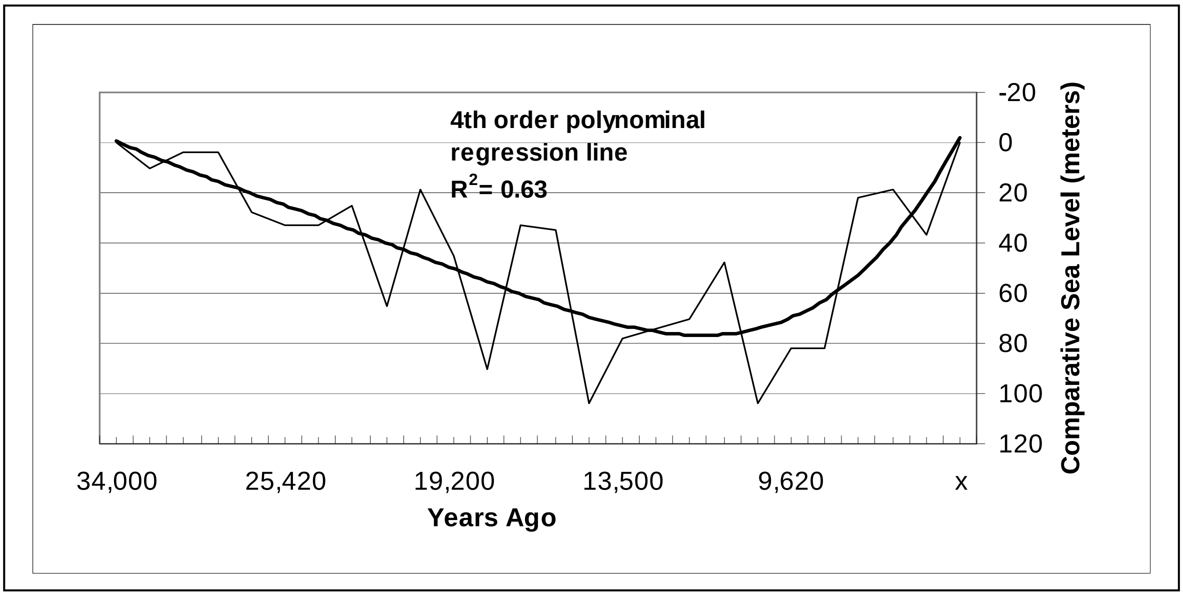

Figure 2
Sea Level Trends over the Last 36,000 Years
Based on Data from Milliman and Emery (1968)

3.3 Tidal Datum Calculations

As previously discussed, the primary determination of a tidal datum involves the calculation of the arithmetic mean, or average, of all the occurrences of a tidal extreme over a 19-year tidal epoch. Yet, most tidal datum elevations are determined from observations of less than 19 years. Methods have been developed for correcting such short term observations by comparison with simultaneous observations at a control station at which 19-year mean values are known. That correlation process determines a value equivalent to a 19-year mean using a ratio of tide ranges observed at the two stations.

The standard method (*Marmer 1951*) for accomplishing this process, also known as the range ratio method, may be expressed by three equations using the following notation:

MHW	=	19-year mean high water
MTL	=	19-year mean tide level
MLW	=	19-year mean low water
MR	=	19-year mean range
TL	=	mean tide level for observation period
R	=	mean range for observation period
s	=	subscript used to denote subordinate station
c	=	subscript used to denote control station

The first step in the process estimates the equivalent 19-year mean range at the subordinate station:

$$\frac{MR_S}{R_S} = \frac{MR_C}{R_C} \quad or \quad MR_S = \frac{MR_C\, RS}{R_C} \tag{1}$$

The second step estimates the equivalent 19-year mean tide level at the subordinate station:

$$MTL_S - TL_S = MTL_C - TL_C \quad or \quad MTL_S = MTL_C - TL_C + TL_S \tag{2}$$

The 19-year mean high and mean low water may then be determined by applying half of the mean range to the mean tide level:

$$MHW_S = MTL_S + \frac{MR_S}{2}$$
$$MLW_S = MTL_S - \frac{MR_S}{2} \tag{3}$$

Other tidal datum elevations may be calculated using similiar processes.

4. APPLICATION OF TIDAL DATA TO ANGLO/AMERICAN COMMON LAW

As discussed, under the Anglo/American common law, coastal boundaries are based on the average reach of daily tides. Thus, the mean high water tidal datum, which is the average of all high tides over a tidal epoch, is used for those boundaries. The location of those boundaries involves the straight-forward process of using the elevation of mean high water from a near-by tide station and mapping where that elevation meets the rising shoreline.

In areas where a densified network of tide stations exist, a suitable tidal datum can usable be found and used directly. If this is not the case, it is necessary to establish a new tide station in the area of interest using short-term tidal observations from the new station corrected by simultaneous observations with an established station, as previously described, to develop an equivalent 19-year mean value.

In either eventuality, the result is a precise, defensible result that has mathematical certainty. Even though these boundaries are ambulatory and may change with time due to erosion or accretion, they can be found as needed once the elevation of the tidal datum is known. Where coastal management involves regulatory lines that are offset from tidal datum lines, those lines also can be determined with objectivity and certainty. The certainty of either type of boundary provides stability to both private ownership and governmental management of the coastal zone and thus contributes to its orderly management.

5. APPLICATION OF TIDAL DATA TO ROMAN CIVIL LAW

As discussed, for jurisdictions with legal systems based on the civil law, both the sea and the shore are typically considered to be within the public domain. Thus, rather than the average reach of the daily tides, coastal boundaries in these jurisdictions are usually considered to be the maximum reach of the waters. There has been considerable debate in the courts as to the best translation of this definition. Does it define the shore as that area regularly covered and uncovered by "tide" in the astronomical sense or does it refer to the highest level typically reached by storms? The general consensus has been that the definition implies an average value that the waters typically reach. With such a modified definition, that level could be associated with either perigean spring tides or equinoxial spring tides, especially those occuring at the maximum of the 18.6 year nodal cycle in the area.

Obviously, since the ocurrances of such a tide is infrequent and could be affected by meterorological conditions, determination of that type of tidal datum could not practically be determined by direct observation. Rather, it could be best determined by harmonic analysis of the constituents based on a period of observed tides. Once the phase and amplitude of the tidal constituents are determined for an area, precise predictions may be made. Based on those predictions, the predicted maximum tide for a tidal epoch can be determined. While the elevation may possibly be exceeded during a severe storm, that elevation would be the expected maximum tide that occurs on a regular basis, once each 19 years.

Interestingly, this is essentially how the coastal boundary is defined in Puerto Rico, although, in practice, the boundary is typically not located in accordance with that definition. Nevertheless, this definition does result in a boundary that can be readily located if tide stations exist along a coastline. Furthermore, it results in a boundary that appears to be in keeping with the legal definition of the maximum level that occurs with some regularity. Therefore, this is an approach that should be considered in areas where the boundary is defined under the civil law.

6. CONCLUSIONS

The predominate method used for the delineation of coastal boundaries in jurisdictions with legal systems based on the Anglo/American common law is to use the elevation of the average highest reach of the daily tides or mean high water. That boundary represents the line between public domain waters and upland subject to private ownership and may be located with mathematical precision by appropriate use of tidal data.

In jurisdictions where land title is based on the civil law, the public domain is usually considered to include not only the seas, but also the shores. In such areas, the coastal boundary is usually considered to be the maximum reach of the waters. It is suggested that tidal data may also be used for that boundary. Rather than use of direct observation of the tides, that elevation would best be determined by harmonic analysis of the tidal constituents based on a period of observed tides. Once the phase and amplitude of the tidal constituents are determined for an area, precise predictions may be made. Based on those predictions, the predicted maximum tide for a tidal epoch could be determined. That elevation would be the expected maximum tide that occurs on a regular basis, once each 19 years and would appear to meet the civil law definition. Thus, the boundary under the civil law may also be determined with the mathematic precision associated with tidal data.

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