An Analysis of Old Tide-Line Mapping for Coastal Zone Management

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ABSTRACT

Understanding and predicting climate change and associated sea level rise are crucial issues in coastal planning and management. Any data which increase the understanding of the long term behaviour of the natural environment are particularly important in enabling those concerned with coastal management to plan and predict future change. Tidal lines, as indicated on Ordnance Survey maps, have been used and have the potential for, the geomorphological analysis of change in beach width and associated erosion or accretion and may possibly be of value as an indicator of sea level rise. Tidal lines represent clearly resurveyed, temporally and spatially transient features which predate aerial photography as a potential source of evidence of coastal change. However, any use of these features requires an understanding of the reliability, repeatability and practicality of trying to map an ambiguous feature in the field. This research principally deals with tidal line definition, data capture and the practice of the mapping of tidal lines on the Ordnance Survey maps of England and Wales from 1868 until the 1960s.

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1. CARTOGRAPHY AND COASTAL GEOMORPHOLOGICAL RESEARCH

Maps have a well established history of use in research which has addressed the issue of longer-term coastal change (See for example, Baily et al 2002; Carr 1962; de Boer 1969; Thieler and Danforth 1994a and Van der Wal and Pye 2003). de Boer (1969) suggests that some of the earliest cartographic evidence by itself is rarely good enough to measure rates of change, but can be used as suggestive evidence of the existence of specific features. Later maps with tidal line data have the potential for determining changes in a landform such as the orientation of a coastal spit, or for the estimation of historical coastal change (see for example Hooke and Riley 1991, Baily 2001). Maps from a range of historical periods have been used for coastal investigations including the maps analysed from 1530 onwards by Carr (1969) in his study of Orford spit and from the Armada map onwards by Baily and Nowell (1996) in their temporal study of East Head spit, West Sussex. In both of these studies maps were used purely as an indicator of major change often across hundreds of metres. More precise analysis from historical maps is difficult partly due to the inherent inaccuracies in the cartographic form but also because of the transient nature of the forms being measured. A coastal cliff line may offer a clear, clean feature which can be surveyed and where change occurs more periodically. A beach in contrast may change regularly and often offers the surveyor no easily identifiable set of features which can be reliably remeasured in the future.

Inaccuracies both within mapping techniques and in data extraction from maps have been highlighted by a number of authors identifying potential errors in the source data (Anders and Byrnes 1991; Crowell et al 1991; Carr 1962; Harley 1968; Hooke and Kain 1982; Thieler and Danforth 1994b). A full review of sources of historical evidence for geomorphological change including cartographic materials is given by Hooke and Kain (1982), whilst Harley (1968, 1972, and 1975) and Oliver (1993) specifically review the details and development of the Ordnance Survey (OS) and their maps.

For those concerned with historical coastal geomorphological change, the selection of source evidence used in the research is dependent upon the scale of the features under examination and the degree of change which may have occurred. If the researcher is simply looking for the existence of a coastal form or feature, then maps several centuries old may be appropriate (see for example Carr 1969, Baily and Nowell, 1996). However, if the aim of the investigation is to measure more specific features, such as the estimation of retreat rates or the orientation of a landform, a more selective approach may be required. On pre-nineteenth century maps of coastal areas, tidal lines and coastal forms were often simply sketched on maps, as these boundaries were often not required for the land ownership or litigation issues for which many early maps were compiled. Since in effect, all cartographic sources are an endeavour by humans to represent reality using symbols, it is necessary to consider whether different classifications exist of coastal areas. One question of particular concern is the extent to which definitions of the coastline are the same or similar. This problem is discussed by Maling

(1989), who notes that two main types of discrepancy exist in mapping natural features. The first may be viewed as errors in presentation which relate to the way data is assembled and collected. The second discrepancy is an error in definition which arises from different, but not necessarily incorrect, definitions of features. Therefore, when using maps of different periods, it is necessary to ensure that the features referred to are indeed the same and also that the definitions at the time of data capture are the same. One example of this is the high and low water lines on Ordnance Survey maps across Great Britain. In most of Scotland, the tidal lines refer to the high water and low water levels during spring tides, whilst in England and Wales these refer to the medium tides. At other times Olivier (1993) notes that although some maps may state that the tide measured is a medium water mark, it is sometimes referring to spring rather than average tides.

This paper is principally concerned with the historical evolution of tidal line mapping on Ordnance Survey maps and investigates the practicalities of mapping tidal lines in the field. Unlike other work which has examined spatial inaccuracies in the cartographic medium, this research examines the rationale, policy and practice behind the mapping of tidal lines and whether this makes these features suitable for any reasonable geomorphological analysis of coastal change from tide line surveys. At a time when researchers are increasingly looking for evidence of coastal evolution, it is important to examine the 'fitness for purpose' of using tidal lines plotted on maps as an indicator of coastal geomorphological change. Several research questions arise with tidal line mapping including the definition of tidal lines, the conditions under which they were collected, the methodology used to collect the data and their reliability as a valid indicator of coastal geomorphological change (within a reasonable error limit). Tidal lines on maps offer one of the few recorded sources of evidence of coastal change during the last few hundred years. Whilst for many areas aerial photography exists from the 1940s onwards (and in some cases before this period), in most cases this photography was not collected with the principal aim of mapping tidal limits. As a result, tidal lines on maps offer one of the potentially best sources of evidence for analysis of change before the availability of suitable imagery.

2. THE EVOLUTION OF TIDE LINE MAPPING

Tide lines appear on various historical coastal maps and charts either as specific tidal lines, or sometimes, where the high water line is used to define the land/sea boundary. However, before the middle of the nineteenth century, these lines could refer to the position of ordinary tides or spring tides or simply the land/sea interface as defined by the surveyor. Many historical maps were not concerned with the coastline and in particular, variations in tidal position. Some historical maps provide a detailed outline of the coastal forms (Figure 1), whilst others were estimated or sketched, or alternatively copied from other maps. Following the formation of the Ordnance Survey of Great Britain in the eighteenth century, an evolving process of the formalisation of Ordnance Survey tidal line mapping policy began in the 1840s and was finally completed in 1868 (although this continued to be revised intermittently).

The Ordnance Survey Act 1841, paragraph 1 required Justices of the Peace to appoint meresmen to assist the Master General and Board of Ordnance in "examining, ascertaining and marking out the reputed boundaries of each County, City, Borough, Town, Parish" (House of Commons, 1841). Prior to the changes of 1868, the boundaries of a parish had been identified as the high water line of a tide. This meant that many extra parochial places including the foreshore were outside of their parish boundary and exempt from the Poor Laws. However, in 1868 the Poor Law Amendment Act was passed and all the remaining extra parochial places were included for civil parochial purposes in the next adjoining parish as the parish boundary was now extended to the low water line. Therefore, from 1868 onwards "very accretion from the sea whether natural or artificial and that part of the sea to the Low Water Mark and the bank of every river to the middle of the stream which on the 25th December next (1868) shall not be included within the boundaries of or annexed to or incorporated with any parish shall for the same purposes be annexed to and incorporated with the parish to which such accretion, part or bank adjoins in proportion to the extent of the common boundary" (House of Commons, 1868).

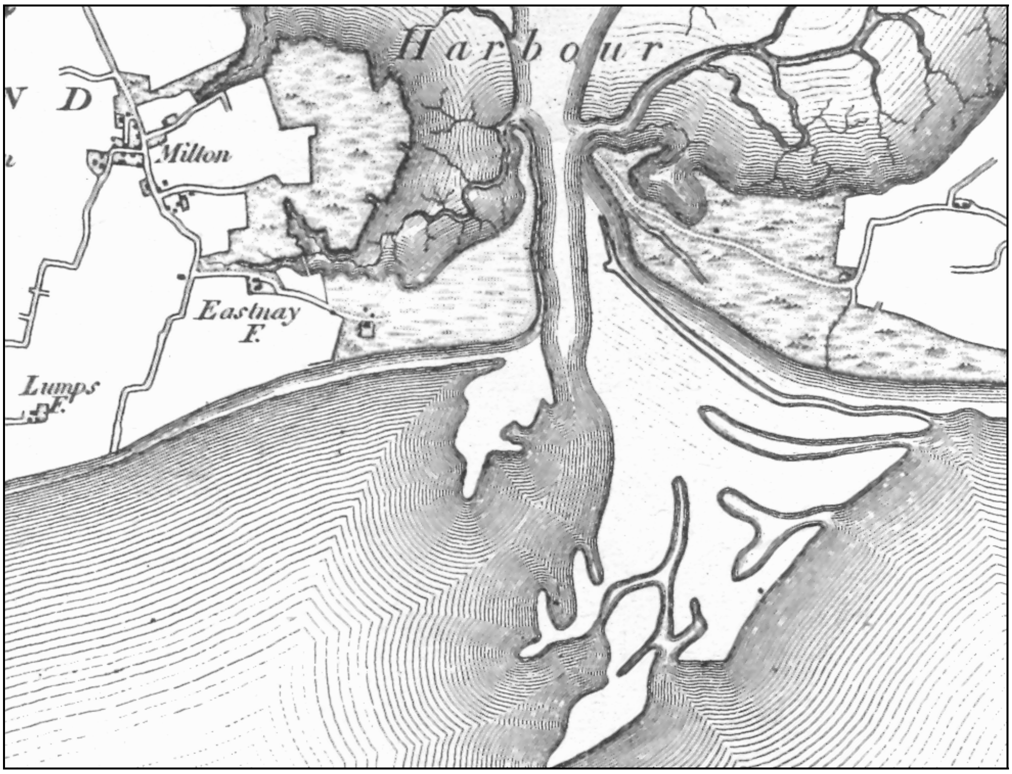

Figure 1. An example of an early map covering a costal area where the detail of the coast is clearly shown (1810 map of the Hampshire coast).

The Poor Law Amendment altered the approach of the Ordnance Survey mapping of the inter-tidal area, as it now became necessary for the Ordnance Survey to include areas of the foreshore within the rating area. As a consequence, the survey of 1878 carried parish boundaries to the Low Water Mark of Ordinary Tides, as this line now represented the seaward extent of the city, parish and town etc. Unlike many previous surveys, these data recorded the position of the ordinary tide (later changed to medium tides in August 1935). The changes in legal boundaries can be traced back to a judgement by the Lord Chancellor

(Lord Cranworth) in 1854, who legally recognised the high and low water mark of an ordinary or average tide as the boundary of the foreshore. It should be noted that in Scotland where there was no legal definition, mapping followed the historic practice of measuring the mean spring tide position except where Udal Law operates (For a detailed discussion of the legal definitions of the foreshore see McGlashan *et al,* 2004 and 2005).

The development of tidal line mapping practice is important to understand as it demonstrates that after 1868 and the subsequent resurveys, there was at least a clear understanding and definition of what should be mapped and defined as a tidal line. However, whilst this legislation obliged the Ordnance Survey to map the tidal lines, there occurred periodically a debate concerning the need to actually publish this data. As late as 1946/7 this debate continued with the Director General of the Ordnance Survey accepted "an interpretation of the Act making the publishing of tide lines a legal obligation" (PRO OS 11/46).

3. DEFINING AND MAPPING A TIDAL LINE

The representation of tidal lines on maps varies depending on the tidal characteristic surveyed and the datum used. As a result, a variety of nomenclature is found on different maps from various agencies (Table 1). On Admiralty Charts the tide lines shown are the mean high and low water marks of spring tides related to the Admiralty chart datum. On Ordnance Survey maps of England and Wales before 1868, the tidal lines depicted were often the High and Low Water Marks of Ordinary Spring Tides (this still applies to all maps of Scotland). This changed in England and Wales (but not Scotland) in 1868 to the Low Water Mark of Medium Tides. Oliver (1993) notes that tidal lines of spring tides marked on maps before 1868 may be marked as mean tide lines and that since *circa* 1950 the date of survey of the tidal lines and their revision date have been consistently shown on the 1:2500 and 1:1250 maps. Table 1 exemplifies the nomenclature used in various maps and charts whilst Table 2 and Figure 2 show the nomenclature used on Ordnance Survey maps.

Abbreviations for tidal lines	**Nomenclature for various tidal mapping**
M.H.W.S.	Mean high water springs
M.L.W.S.	Mean low water springs
M.H.W.N.	Mean high water neaps
M.L.W.N.	Mean low water neaps
M.H.W.	Mean high water
M.L.W.	Mean low water
H.W.M.O.T.	High water mark of ordinary tides
L.W.M.O.T	Low water mark of ordinary tides
H.W.M.M.T.	High water mark of medium tides
L.W.M.M.T.	Low water mark of medium tides
H.A.T.	Highest astronomical tide
L.W.O.S.T.	Low water mark of ordinary spring tides
H.W.O.S.T.	High water mark of ordinary spring tides

Table 1. Nomenclature of tidal levels used on various coastal and marine charts.

Nomenclature (England and Wales)	Dates
High and Low Water Marks of Ordinary Tides (H./L.W.M.O.T)	December 1868 – August 1935
High and Low Water Marks of Medium Tides (H./L.W.M.M.T)	August 1935 – March 1965
Mean High or Mean Low Water (M.H.W/M.L.W)	March 1965 - present

Table 2. Nomenclature of tidal lines on OS maps from 1868 – present

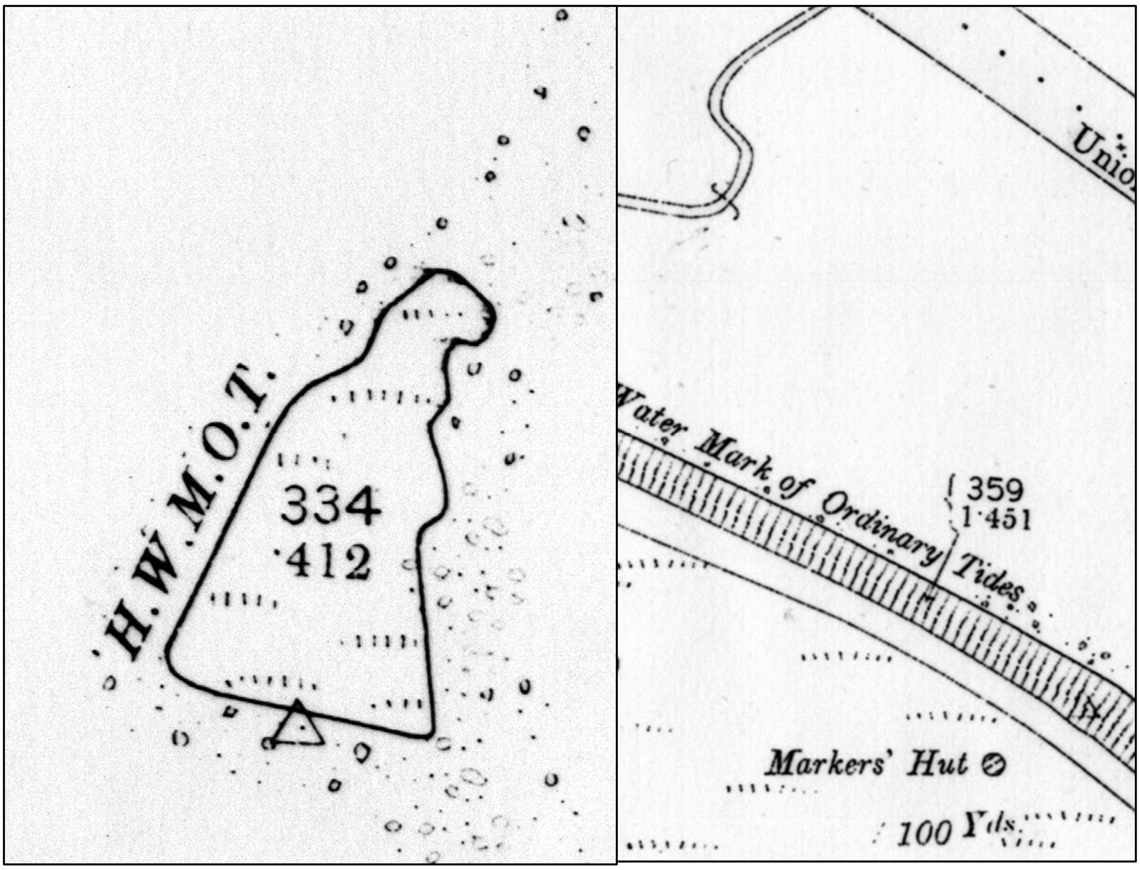

Figure 2. Tidal line representation on an Ordnance Survey map of Langstone Harbour 1897 (Hampshire Sheet LXXVI 13, surveyed 1868 revised 1895).

Surveying tidal lines in the field required accurate information about the period when the transient feature, the tide, would be in the correct position for mapping. The timing of the survey was obviously crucial to the potential accuracy of any mapping. The Admiralty tide tables were used to predict when an ordinary or medium tide would occur. The tidal level was predicted from an estimate calculated from the 18.6 year metonic cycle. A form of tide table was available for London from as early as 1683 onwards and Liverpool from 1770. The Hydrographic Department of the Admiralty published its first tide table in 1833 which concerned the predicted times of high water for the four main ports of the British Isles. The development of tide tables for other areas increased piecemeal, until by 1941 twenty nine locations had tide tables available. After this it was possible to predict tide times at various locations. A contemporary reference, Doodson and Warburg (1941), state that 94% and 85% of low water predictions were correct within ten minutes. It is also suggested that 90% of high water predictions and 91% of low water predictions were correct within one foot. However, the authors did note that accuracy could vary from month to month and unexpected surges could occur.

Whilst the tide tables are accurate for the specified purpose, relatively small differences between the predicted and actual tides could have serious impacts on tidal lines. Correspondence from a civil engineering company to the OS Director General in 1951, pointed out that a one foot error in tide level would make a planimetric difference of 50 feet on a beach with a 1 in 50 slope. (PRO OS 11/46). As the number and accuracy of the tide gauges increased around the country, the surveying superintendent would in theory, be able to use these to check the level the tide reached at a predicted time. In 1932, the OS instructions to be used for revision in the field state that if "the tide was not ordinary another tide must be taken" (OS 1932, p.26). However, Morton and Speed (1998) note tide gauges and their recorded levels will vary from the tides experienced on the beach because they are designed not to be influenced by short period waves. As a result it is argued that the records recorded by tide gauges are "biased towards lower water levels than are actually observed on adjacent beaches" (Morton and Speed, 1998 p.1373). The implication of this is that another potential error or spatial difference may be introduced into the data collected by the surveyors. Small tidal variations would have a serious effect on the position of the recorded line on wider flatter beaches. Whilst this difference may have been acceptable for the purpose of the survey it does have potentially critical implications for the use of tidal lines as indicators of coastal change.

An appendix to the Ordnance Survey Field Bulletin 31 (PRO OS 1/561), states that the high water mark generally presents fewer problems for ground survey as a clear mark is usually left by the tides. However, the document also suggests that the low water mark is much more difficult to establish and that as much as possible is surveyed in a short period as is feasible "the normal field method of surveying the Low Water Mark was to select a time from the Admiralty Tide Tables when the actual Low Water Mark was predicted to be close to the computed Low Water Mark of Medium Tides. All other work could then be put aside and a greatest effort made to survey as much of the water line as possible in the short time the actual water level could be regarded as being identical with L.W.M.M.T" (PRO OS 11/46). However, whilst the low water line was recorded as the instructions dictated, short term differences in morphology, the unpredictability of tides and the difficulty in the physical definition of this feature may make this an unreliable indicator of coastal change when used on its own. Furthermore, on beaches with a wide flat foreshore, the element of doubt increased significantly as small changes in the offshore slope could lead to large morphological variations and hence positional changes.

From the late 1870s onwards, the High and Low Water Marks of Ordinary Tides were recorded by teams of surveyors in the field. A Field Superintendent would oversee the operations of a number of surveyors and labourers, both military and non-military personnel. The rates at which these teams should work was clearly laid out in the instructions for surveyors from circa 1882 onwards (PRO OS 45/8) which state that an average surveyor under ordinary conditions should survey 35 to 40 acres a day at the one to two thousand five hundred scale and three to four acres at the one to five hundred scale. Particular stress is laid upon the need for accuracy with repeated reminders to check the work performed. The guidance and flexibility given to field surveyors is crucial in determining the reliability of tidal lines shown on the maps. In particular, it is necessary to establish whether the instructions and definitions changed enough to affect the relevance of the comparisons of maps of different ages. The Ordnance Survey instructions to surveyors state that particular care has to be exercised in the surveys of high and low water lines that they are made at specified tides and “superintendents must arrange to make the most of the time available” (PRO OS 45/8, p.4). The difficulty of mapping these features is recognised and the guidelines to surveyors crucially state that “The high-tide line will in all cases be surveyed, but the low-tide line may often be left with advantage to the examiner to insert at the discretion of the division officer” (PRO OS 45/8 p.5). Presumably, this allowed examiners to sketch the low water line where survey proved impractical, something which cannot be verified.

One question which arises is how the timing of the survey period was calculated and executed. In England and Wales, the 1882 instructions state that the tidal lines measured are the tide lines half-way between neaps and springs. The instructions state that in order to do this, the Divisional Officer should calculate where Admiralty tide tables allow for it, an ordinary tide level for both high and low water and diagrams should be supplied to show this. The instructions also state that where it is not possible to survey on the mean tidal period, the survey should be done at the fourth tide before new and full moon. However, as the Ordnance Survey (1948) note these tide levels may be vary a good deal at times from the true mean (OS 1948, p. 46). In Scotland, this survey should be carried out three to four tides after the new or full moon, although this should not include the tides near the equinoxes. Close (1912), states that local tide gauges should be used “as far as possible for fixing the datum, and the mean tide should be worked out from their record for the past two or three years if the gauges are in any way reliable” (Close 1912, p22).

Having established the method for the timing of the survey, it is necessary to review the conditions applied to this survey and the methods used in the field to record the geomorphological features. One crucial factor which would have affected these surveys would be the effects of the weather. In particular, pressure readings would affect tidal height and the wind would obviously affect wave run up the beach. The instructions for surveyors state, “that the level of any particular tide may be very considerably affected by wind and weather, and selected tides should only be utilised under normal conditions” (PRO OS 45/8 p.4), although this is obviously open to subjective interpretation. If doubts arise from the conditions noted in the field, there are clear instructions for field superintendents as to the action to be taken. It is stated that the superintendent should check the local tide gauge to ascertain how much the realised tide varied from the predicted tide and whether this difference is enough to make the survey invalid. If errors have occurred the instructions state that an area should be resurveyed or adjusted accordingly. The tolerance in variation of the actual and predicted tide was eventually set at 0.3m for ground survey data collection. Whilst this permissible variation may make little difference on a steeply sloping beach, for many low water areas this difference would represent a significant variation in the tidal line position.

It was recognised that surveying of tidal lines causes particular problems for survey and that surveyors should ensure that tide surveys are the priority within a survey area. When the actual survey was to be carried out “every available surveyor should be told off to such a portion of the tide line as he can complete without fail within the time at his disposal”. (PRO OS 45/8 p.4). In 1959, the Ordnance Survey state that the HWM is easier to mark either by using the jetsam line or by staking out the highest tide line reached. However, the Ordnance Survey (PRO OS 1/561) also notes that experience has shown that the mapping of the HWM has three potentially serious problems including:

a. The tide level may be wrong and different from that predicted.
b. Local configurations along the coast may alter the tide locally.
c. The line being surveyed is on a surface which is liable to alteration and varies according to recent conditions.

The justifiable concerns expressed by the Ordnance Survey as to the mobility of the high water line are exemplified in studies which have mapped the variability of this feature. Morton and Speed (1998) mapped the spatial and temporal variations of a range of features used in coastal cadastral mapping. The research suggests that the mean high water line moved across a 20 metre envelope over a twelve month period. Furthermore, no two surveys of the mean high water mark were in the same position.

The low water mark was not always as easy to survey accurately as the high water mark, especially in areas where this was difficult for example on mudflats. Indeed, Ordnance Survey records and correspondence suggest that Admiralty data was often used in inaccessible areas. The instructions recommend that the surveyors should be in position ready to survey this line an hour before the predicted low tide level in order to take the fullest advantage of the period of slack water for the survey, for the half hour or so before and after the low tide (PRO OS 45/8 p.5). There is indeed some evidence to support the view that surveyors did survey this line, even in hazardous areas, as a mud and water allowance was often paid to surveyors who became wet or dirty whilst surveying the low water line. In regard to the high water line, this is defined as “generally marked by seaweed which can be pegged out and surveyed at leisure” (PRO OS 45/8 p.5). This definition is obviously ambiguous as not all areas have seaweed and if they do this often represents either the storm surge line or at least the line of highest wave action which may be different from the ordinary mean tide height. The instructions for surveyors also go on to explain that the degree of trouble which a surveyor should take is dependant upon the coastal type. These seem to accept that the unpredictability of the tide potential effect on the surveyed line. In rocky coasts it is argued, tidal levels varying a foot or more in the actual and predicted tidal levels “ may make no practical alteration in the position of the line surveyed, but on sand flats, two or three inches difference may alter the position of the tide line greatly” (PRO OS 45/8 p. 5). These small changes in tidal level may well be crucial and the effects of the meteorological conditions would have been extremely important. Whilst the various guidelines suggest that the survey is only carried out when weather conditions are normal, it is unlikely that the surveyors would have cancelled the survey except in extreme conditions. Another important factor on tidal levels is the effect of barometric pressure on tidal levels. The Ordnance Survey Deputy Director of Field Surveys records in 1953 that the surveyors “do not allow for this and neither is there any way of doing so” (PRO OS 1/561). This is an extremely important fact as the same document acknowledges that a one inch difference in barometric pressure could make a difference of up to 12 inches in the tidal level, which as already noted would make a large difference on a flatter foreshore.

The instructions for this earliest period clearly outline the course to be followed by surveyors in the field. This suggests that in many areas the high water mark of ordinary tides would have been surveyed conscientiously whilst the low water mark would have been both surveyed and sketched. It is impossible to tell, no matter how well the instructions are laid out, how methodically the field surveyors stuck to these regulations. Indeed, it is possible that the quality of the survey would vary from area to area. A further problem is that, although the instructions are clear and precise, the high and low water marks still refer to a subjective indicator of change. It is entirely possible that different survey teams working on the same beach may have interpreted the high and low water marks as entirely different features. It is also clear that although the surveys may have been carried out correctly, the variability and unreliability of the tidal level introduces a significant degree of doubt into the reliability of these surveys for geomorphological investigations.

4. DISCUSSION

This research has shown that tidal lines represent a clearly defined attempt to map a regularly changing feature. The tidal lines were clearly defined and instructions to surveyors clearly outlined. However, by their very nature tidal lines were difficult features to map precisely. The plotting of tidal lines was further complicated by the uncertain variability of the tide. In particular, this research shows that the high and low water marks should be treated with caution because of the transient nature of the feature being surveyed, the problems in identifying the feature in the field, the difficulty of partial revisions and variations in tidal levels. Tidal lines, as conceded by the Ordnance Survey, simply recognise the position of the water line on a certain time and day and may, or may not be, indicative of coastal change which they were not intended to represent. There are considerable inherent problems in mapping something transitory. In particular, as the surveyors note, the tides are often irregular and do not necessarily conform to predicted patterns. This level of uncertainty was further compounded by the effects of the weather and in particular barometric pressure. Given the morphology of many beaches, small variations in tidal height would lead to large changes in the position of the feature being mapped.

For geomorphological research, it could be argued that the high water line may be a more reliable feature to be analysed as it does potentially leave a physical trace such as strand lines or beach ridges, although these may not necessarily be the mean high water line. As noted, the morphological position of the high water line can be severely affected by recent weather conditions and the surveyor had no way of knowing to what extent the morphological feature being surveyed was in an average representative state. Therefore, although it could be argued that the high water line is more reliable as an indicator of change, this cannot be stated with any degree of accuracy or certainty. The low water line position in contrast, especially on wide flat beaches, may often be unreliable due to the variables involved. Furthermore, it is often a difficult and dangerous feature to map in the field which is one of the reasons why ground survey was replaced with photogrammetric survey. The evidence suggests that this line is particularly unreliable for measuring beach width or changes in sea level especially on beaches which have a flatter lower shore area. It clear from the Ordnance Survey records, that significant changes occurred in the movement of the low water line often related to changes in weather conditions or tidal levels or short-term morphological changes.

This research is not an attempt to criticise the Ordnance Survey surveying teams. The purpose of recording the tidal lines was simply to mark boundaries which due to their nature are constantly shifting. These boundaries were measured to record the seaward extent of the parishes etc. and were not intended to measure coastal geomorphic change. As noted, when discrepancies appear in the surveyed lines, different surveys from similar periods which have different results, are both right at the time of data capture. It is clear from the records that the survey teams themselves followed well defined guidelines which would have minimised as far as possible any potential error. However, these guidelines alone could not change the variables involved in measuring a tidal line. By the 1960s aerial photography was being widely used to record the low water line. The photography was generally taken when the tide was within 0.3m of the predicted level, which when considered alongside meteorological factors suggests that analysis of the changes associated with this feature should be treated with extreme caution.

The extent to which the tidal lines can be used to measure coastal change will vary from area to area. Certainly on flatter coasts the probable errors may outweigh any potential change. In contrast, where wide beaches have clearly disappeared or on rocky coasts, the measurement may be more temporally and spatially reliable. It should be recognised that maps published *circa* 1879 may essentially be showing a different feature to those published before this date when the tidal line show is more likely to be related to an average spring tide. Researchers using these maps also need to be aware of the rationale behind the collection of these features and the inherent difficulties involved. These potential differences need to be considered alongside those traditionally associated with the use of cartographic data. In one letter to the Ordnance Survey, the question was raised as to the correct position of a particular tidal line. The response probably sums up the caveats which should be considered in any use of this data "Tidal lines marked on Ordnance Survey plans thus represent an honest attempt to portray the position of the High and Low Water Marks of mean tides on a certain date. The Department is legally bound to show these tide lines; but at the same time the impracticability of great precision and liability to frequent changes, in tide lines is recognised" (PRO 1/561).

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BIBLIOGRAPHIC NOTES

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