TIDES AND WATER LEVELS IN THE FLEET

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INTRODUCTION

Although the Fleet is effectively isolated from the English Channel along the whole of its length by Chesil Beach, it is open to Weymouth Bay and the influence of the open sea through the narrow entrance at Smallmouth. This not only permits the inflow of salt water to produce the marine/brackish character of the Fleet, but enables tidal fluctuations of the sea level to penetrate into the Lagoon, sometimes as far as Abbotsbury. The periodic rise and fall of water level is itself an important factor in the ecology of the Fleet, whilst the association flood and ebb streams are the dominant water motion, contributing to the distribution of saline water, the flushing out of fresh water and pollutants, and the control of sedimentation.

Tidal fluctuations at a typical U.K. coastal location are relatively easy to comprehend, with the dominant period between successive high waters being 12 hours 25 minutes, and the tidal range (the height between a successive high and low water level) fluctuating from large values (Spring tides) to small values (neap tides) and back to large values in a fourteen day cycle. Although the tides never exactly repeat themselves, they are related to the astronomical variables linking the orbits of the moon, earth and sun, and can therefore be predicted with a fair degree of confidence. Weymouth and Portland are no exceptions, and accurate predictions of tidal heights are available for the mouth of the Fleet. However, inside the Fleet itself such regularity of the sea level fluctuations is not immediately apparent, particularly in the West Fleet. Local naturalists, having observed on one occasion the time lag between low tide at Weymouth and the exposure of some mud flats in the Fleet, have applied the same time lag a few days later only to find the flats under two feet of water! Under different circumstances, heavy equipment has been stranded on Chesil Beach because the water level has fallen unexpectedly below the draught of the pontoons used to ferry it across the Narrows. Such first-hand experiences have led some authors (eg Bird 1972) to conclude that the water level fluctuations are due more to wind effects than the regular astronomical tides, and may even be strongly influenced by seepage through Chesil Beach. However, a recent study of several months of tidal data for the Fleet (Robinson, Warren and Longbottom, 1981) has been able to demonstrate that the astronomical tides are the dominant cause of the rise and fall of the Fleet water level, but are distorted by the shallowness of the water.

TIDAL FLUCTUATIONS

In the winter of 1967/68, a thorough hydrographic survey of the Fleet was performed by Messrs G. Wimpey and Co. Ltd. on behalf of the Central Electricity Generating Board. Some years later, the data collected in the survey were made available by the CEGB for scientific analysis (see Whittaker 1980). Amongst the data were tide gauge records collected at Smallmouth, Bridging Camp, Chickerell Hive, Moonfleet Hotel, Morkham's Lake and Abbotsbury (Figure 4). These consist of readings of water height every half hour, for periods of between one and three months, and provide a basis for objective analysis of the tidal regime.

Time series of these tidal data are plotted in figure 7, along with the observed tides at Portland Dockyard. Gaps in the record occur where instruments malfunctioned, and in certain cases this occurred when sea level fell so far below what was expected that the tide gauge "dried out". Plotted in this way, the records show that the tidal fluctuations at Smallmouth, Bridging Hard and Chickerell are very similar to the "normal" record of Portland, for which predictions are available.

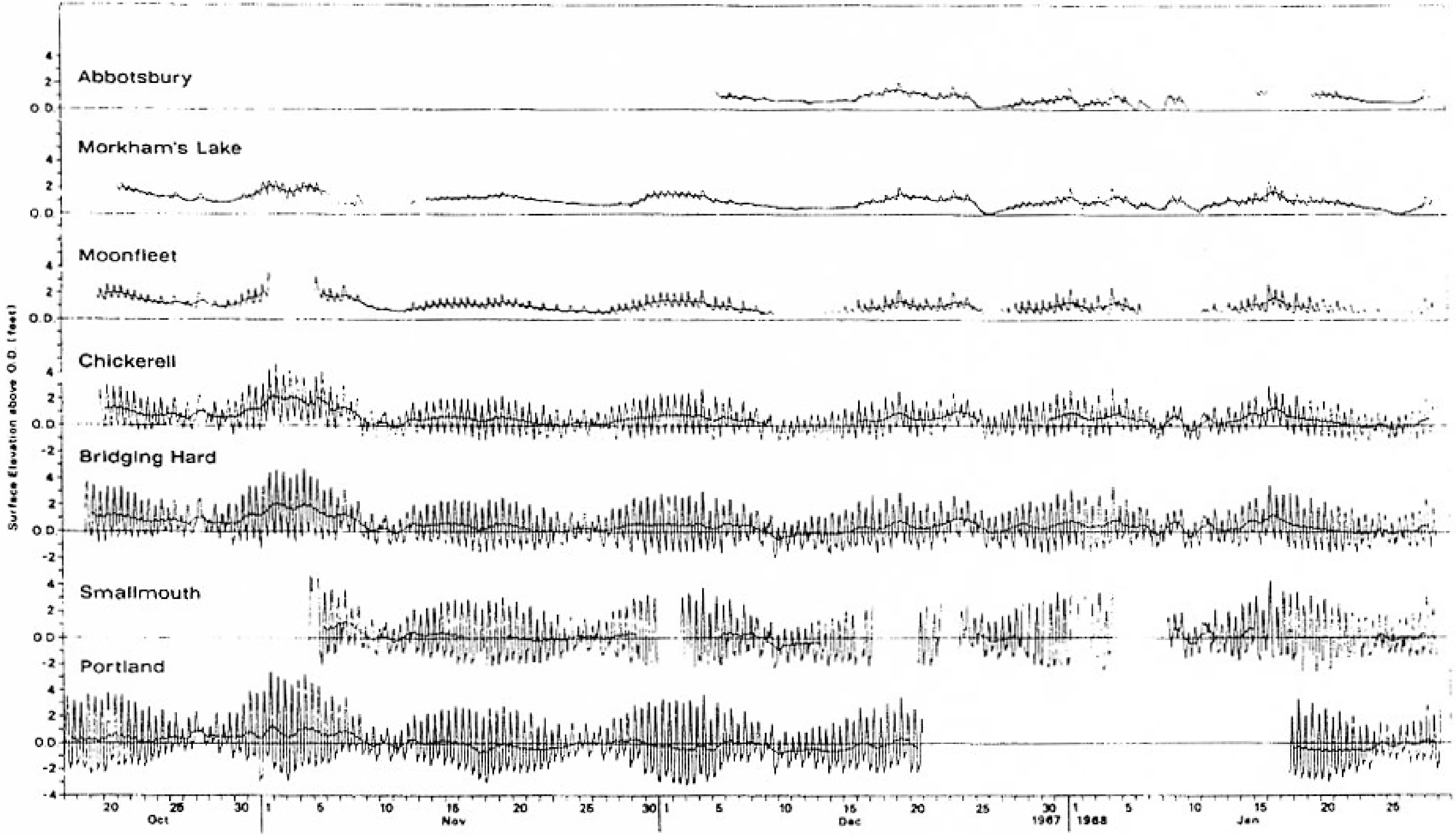

Abbotsbury
Morkham's Lake
Moonfleet
Chickerell
Bridging Hard
Smallmouth
Portland
Surface Elevation above O.D. (feet)
Oct
Nov
Dec
1967
1968
Jan

FIG 7

Moonfleet shows tidal fluctuations corresponding to those further east, although the shape of the tidal profile is distorted. Morkham's Lake and Abbotsbury records reveal an intermittent operation of the tide, but when sea level fluctuations of a $12\frac{1}{2}$ hours period do penetrate to the west end of the Fleet, they can be directly related to the tidally driven oscillations entering through Smallmouth. Occasionally there are particular peaks of water level (e.g. 16th/17th January 1968) which appear to stand out from the regular tidal pattern, but in general the astronomical tides appear to be the dominant cause of sea level fluctuations.

The shape of the tide curve for a particular spring tide and a particular neap tide is shown expanded in figures 8a and b. Once again the correlation of the tide from place to place along the Fleet is apparent, but certain features in which the tide curve differs from a normal coastal record demand explanation. Firstly the time of high water becomes later the further westward the tide gauge is located. The time of low water becomes later still, and the delay times also differ between spring and neap conditions. Table 1 summarises the delay times of high and low water after high and low water at Portland, and insofar as these two days are typical of spring and neap conditions, table 1 can be used as an approximate guide to predict times of high and low water relative to Portland predictions. The height cannot be so easily predicted.

The shape of the tidal curve also changes markedly from the profile at Smallmouth, where a double low water occurs, to Moonfleet and the West Fleet where a sawtooth shape is a more appropriate description, the double low water having disappeared. The tidal range also decreases rapidly on moving North Westward to the head of the Fleet. Interestingly enough, these features are to be found occurring over a much larger length scale in estuaries such as the St. Lawrence in Canada, and the Severn in the U.K. An explanation is demanded as to why they should occur over such a short distance in the Fleet.

A final feature of figure 7 which must be explained is the appearance of fluctuations of sea level of periods larger than a day. These are shown by the curve drawn through the centre of the tidal curve. This is calculated from a 25 hour running mean and effectively represents the height of mean water level on a given day. It is seen to vary particularly over a fortnightly cycle, and to be more variable at Chickerell, Moonfleet and beyond, than closer to the mouth. There are also some occasional fluctuations with period about 2-3 days which occur at all the stations (e.g. 10-12 January 1968). These longer period fluctuations are in fact the most important feature of the sea level at Morkham's Lake and Abbotsbury. Because the semidiel tide is superimposed on them, it is not sufficient to be able to predict the time and amplitude of the semidiel tide, but a knowledge of the mean level is also required to determine the actual water depth and hence whether certain mud flats will be exposed or certain channels navigable. It is this combination of semidiel and long period fluctuations which has probably confused the casual observer into believing the water level fluctuations are not tidally regular. The observer tends to notice such things as exposure of mud-flats. It is possible to draw a straight line through the record at Moonfleet or Morkham's Lake, corresponding to a particular height of mudflat, and to note that for periods of several days at a time it may be completely exposed or completely covered, whilst for other periods it will be exposed twice a day in a typical tidal manner.

TIDAL EXPLANATIONS OF SEA LEVEL PHENOMENA IN THE FLEET

It is possible to give explanations of most of the features noted above, in terms of well established theory relating to the propagation of long waves in shallow water. What makes the Fleet so interesting is that these mechanisms should occur in such a short distance, compared with similar features in large estuaries, e.g. the St Lawrence (LeBlond, 1979).

TABLE 1

Phase lag of the tide relative to Smallmouth

Location	Spring tide (17-12-67)		Neap tide (25-11-67)	
	High water	Low water	High water	Low water
Bridging Hard	30 min.	3 h 40 min.*	15 min.	3 h 30 min.* (15 min.)
Chickerell Hive	1 h 20 min.	4 h 5 min.*	1 h 5 min.	4 h 15 min.* (1 h)
Moonfleet	2 h	5 h	2 h 20 min.	-
Morkham's Lake	4 h	7 h	-	-
Abbotsbury	5 h 15 min.	8 h	-	-

* This the time lag of the second low of the double low water behind the first low at Smallmouth. The bracketed figure is the time lag of the first low when it happens to be lower than the second.

Fig 8(a)

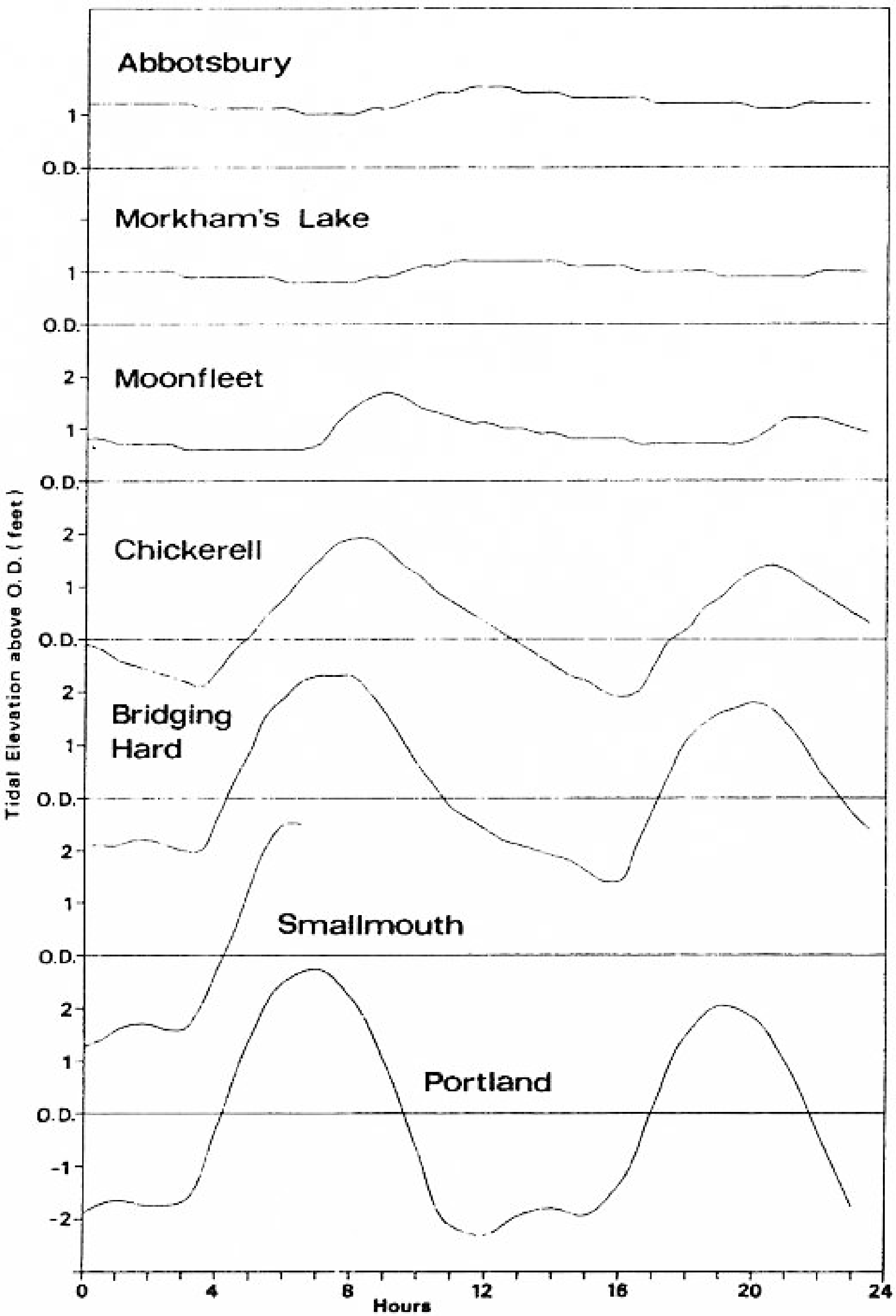
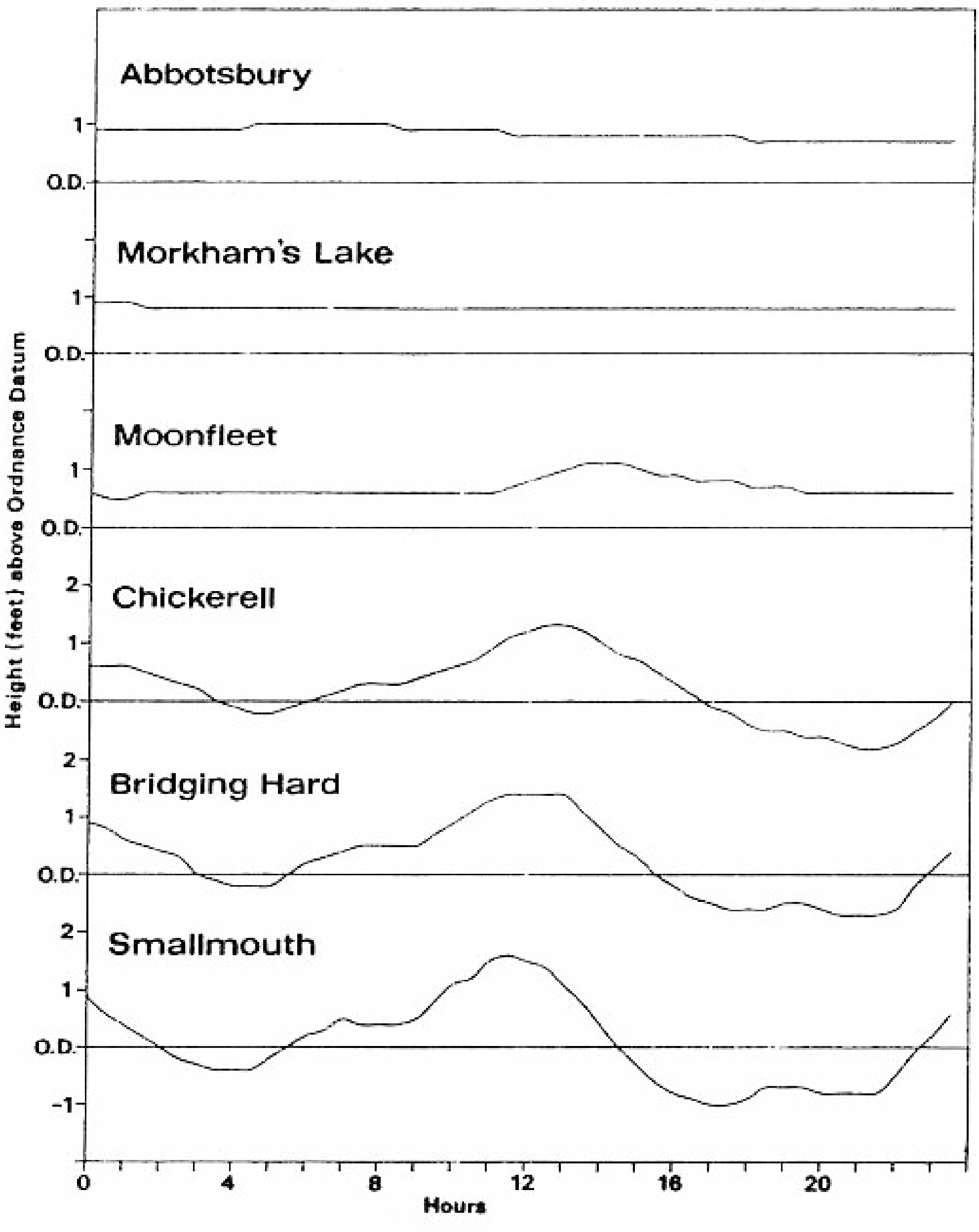

Abbotsbury
Morkham's Lake
Moonfleet
Chickerell
Bridging Hard
Smallmouth
Portland
Tidal Elevation above O.D. (feet)
O.D.
Hours
0
4
8
12
16
20
24

Fig 8(b)



Abbotsbury
Morkham's Lake
Moonfleet
Chickerell
Bridging Hard
Smallmouth
Height (feet) above Ordnance Datum
O.D.
2
1
-1
0
4
8
12
16
20
Hours

Travel time of high and low water

Tidal propagation in the Fleet behaves like a long gravity wave propagating from the mouth, where it is forced by the tides of the adjacent English Channel. In an estuary as short as the Fleet the time for high tide to travel to the head would normally be no more than a few minutes, and the sea level would rise and fall in unison throughout the estuary. The propagation speed of a long gravity wave is proportional to the square root of the water depth. Because the Fleet is so shallow, the propagation speed is slow, and it takes hours rather than minutes to propagate through the whole length. The speed is further slowed by the capacitative effect of mud flats and shallow areas. The wave tends to propagate along the deeper channels, where the flood flows are strongest, but the water flowing through the channels is required to maintain a rising water level over a much larger surface area, and this restricts the speed at which the rise of high tide can propagate further into the lagoon. This is particularly true of Littlesea, off Chickerell Hive, where there are a few narrow deep channels through a wide area of mud flats. Because the tidal range is comparable in magnitude to the water depths, there is a considerable difference between the instantaneous water depth at high and low tide. The wave propagation speed at high tide is therefore greater than at low tide. Consequently high tide travels faster than low tide, as shown in figures 8 and table 1. The difference between spring and neap travel times of high and low water may also be explained in terms of the different water depths through which the tidal wave must propagate.

Tidal amplitude attenuation and intermittency

It is perhaps surprising at first sight to note how the tidal range decays rapidly from more than a metre at Smallmouth to a few centimetres at Moonfleet and beyond. This behaviour is in fact entirely consistent with what happens to a long gravity wave which is attenuated due to friction between the water flow associated with the wave and the sea bed. The effect of the sea bed friction on the tidal flow is inversely proportional to the water depth, and hence in such a shallow lagoon frictional drag rapidly extracts the energy from the tidal wave, in contrast to a deep estuary (eg Southampton Water has a similar tidal range at the mouth, and is of a similar length, but the tidal range is not noticeably attenuated along its length). Because the frictional dissipation is great, the wave barely reaches the end, and there is no reflection from the head as happens in deeper estuaries. Thus the wave is purely progressive, with no standing component, which leads to the time lag of high water already mentioned.

It is evident in figure 7 that the mean level in the West Fleet is lower during neap tides than spring, and so the frictional effect is particularly strong at neap tides, to the extent that for several days at a time the tide at Abbotsbury and Morkham's Lake is not measurable. This accounts for the intermittent nature of the tidal oscillations in the West Fleet; only when the mean level is high enough in the narrow section off Moonfleet Hotel can the tide penetrate to Abbotsbury.

<u>Distortion of the tidal curve</u>

Neither at the mouth nor further inside the Fleet does the tidal profile over 12½ hours resemble a normal sinusoidal profile typical of tides in the open ocean. The profile at the mouth is the same as in Weymouth Bay and is a feature of tides along the central southern coast of England. It occurs because the semidiel tide is relatively weak, this being a nodal area for the semidiel tidal oscillation of the whole English Channel, whilst the quarter and sixth diel tides are relatively strong, being generated in the central English Channel by the strong tidal currents that occur there. Thus the double high water occurs at Southampton, where the low of the quarter diel tide coincides with the high of the semidiel whilst at Weymouth the high of the quarter diel coincides with the low of the semidiel tide, to produce the double low water. The tide at Smallmouth may be thought of as the sum of the basic semidiel oscillation and higher harmonics. As the wave propagates into the Fleet, friction appears to attenuate the higher harmonics more rapidly, and the double low water has normally disappeared by Chickerell Hive.

At the same time, because high tide travels faster than low tide, the symmetry of the semidiurnal tide is distorted to produce the saw tooth shape of a rapid rise of the tide and long slow fall, which is most marked at Moonfleet. Linked to this, the flood streams are very strong and short lived, whilst the ebb is long and gentle. Another way of understanding what is happening is to consider the analogy of a wave running up a beach. A steep wall of water floods rapidly into the beach, spends itself and then slowly drains away. In the case of the West Fleet, Littlesea and the narrows by Moonfleet tend to act as a choke, allowing water to flood in with the high tide, but restricting its outflow once the water level starts to fall.

Fortnightly fluctuations of mean level

This choking effect also leads to the mean level being higher in the West Fleet than the East Fleet. Because friction acts more strongly on the ebb than the flood, the mean sea level slopes upwards to the north west to balance the mean frictional forces. Now at Spring tide the tidal streams are much more rapid and more energy is dissipated by friction, so that the mean surface slope becomes greater at Spring tide than neap tide. Thus the mean water level in the West Fleet is higher at Spring than at neap tide, and the mean level oscillates over a fortnightly cycle. Hence the fortnightly fluctuation of sea level is attributable to the semidiel tidal friction mechanism, operating in such shallow water.

NON-TIDAL EXPLANATIONS OF SEA LEVEL FLUCTUATIONS

The strongest, and the most regular features of the water level fluctuations in the Fleet can be accounted for by well established tidal theory. There remain two features which can be explained by meteorological forcing. The three to four day fluctuations of the tidal mean level are seen to occur in similar strength at all stations, including the mouth, and Portland itself when the record was available. It is concluded that these were storm surges (sea level fluctuations in addition to the astronomically driven tide) generated by atmospheric pressure and wind stresses in the whole of the English Channel, and not locally produced in the Fleet itself, nor even necessarily related to weather conditions in the immediately surrounding area of the English Channel. It is interesting to note that these fairly long period oscillations of a few days appear to penetrate the length of the Fleet without appreciable attenuation - in accordance with long wave propagation theory.

The occasional peaks or troughs of sea level, which appear to be out of line with the normal astronomical tide, are probably due to local wind stresses producing a short lowering or raising of sea level. A numerical model of the tidal dynamics of the Fleet described by Robinson, Warren and Longbottom (1981) indicates that a strong wind blowing along the Fleet could significantly raise or lower the water level, particularly in the West Fleet. However, it is not easy to distinguish between tidal and meteorological effects when they occur over similar time scales, and it is not clear from the record whether these short surges are driven by wind stress inside the Fleet, or are driven by a surge peak or trough in Weymouth Bay.

CONCLUSIONS

It may be concluded that the water level fluctuations in the Fleet are primarily due to the astronomical tide in the English Channel propagating into the Fleet as a long gravity wave. Times of high and low water are fairly predictable, but because of fortnightly modulations of mean level, it is not so easy to predict absolute water levels. Meteorological effects, mainly mediated through wind action in the English Channel, do cause a deviation from the regular tidal pattern, but their influence is not as dominant as casual observation might suggest. Furthermore, all the observed features of the tides can be explained simply by tidal propagation theory, and there is no reason to believe that seepage through Chesil beach contributes to the tidal regime, except of course on catastrophic occasions when the beach has been breached or overtopped by severe storms.

Quite a lot of tidal energy is dissipated in the Fleet, and this must contribute significantly to the stirring and mixing processes, allowing salt to penetrate to Abbotsbury, and to the balance of sedimentation and erosion. The strong tidal streams in parts of the East Fleet, and the fortnightly period of sea level rise and fall in the West Fleet must be important environmental factors in the local ecology. Indeed the maintenance of the existing ecological balance must be dependent on the persistence of the existing tidal regime.

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