HYDROGRAPHY AND WATER CIRCULATION IN THE SOLENT

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Introduction

The Solent, as it is more precisely defined, extends for a distance of 30km from Ryde-Gilkicker in the east to Hurst Castle in the west. For the purposes of this review, however, it is deemed to include the more open waters of Spithead which stretch a further 10km or so to the east and to which are connected through narrow entrances the large basin-like harbours of Portsmouth, Langstone and Chichester and the relatively small harbour of Brading on the Isle of Wight. Of the estuaries linked to the Solent, by far the largest and most important is Southampton Water with its tributary estuaries of the Hamble and Itchen. The others are the Beaulieu and Lymington Rivers on the mainland, and the Western Yar, Newtown River, River Medina, and Wootton Creek on the Isle of Wight.

The width of the Solent is about 4km in the western portion and 5.5km to the east and increases to around 10km at the eastern end of Spithead. The narrowest parts are at Hurst Castle (1km), Egypt Point-Stone Point (2.5km) and Ryde-Gilkicker (5km). Southampton Water has a width at high water of about 2km. Water depths are favourable to navigation, the main channels having a depth of 20m or so in the more open waters with 60m in the narrow western entrance at Hurst Castle. These depths are indicative of the "drowned river" origins of the estuary system and the beneficial effect of two seaward entrances.

Physical conditions along the shoreline range from the coastal to the estuarine reflecting the varying degree of exposure to waves and tides. Along the Spithead portion there are large areas of sandy foreshore exposed at low tide at the Winner (off Hayling Island) and at Ryde Sand on the southern shore of the Isle of Wight. In the sheltered estuaries and harbours, considerable areas of intertidal mudflats, some of which have been colonised by saltmarsh vegetation, are to be found.

This review outlines the present state of knowledge of the hydrographical features of the Solent including the configurations, tides, currents, hydraulic regime, the interaction of fresh and salt water and the wave climate.

Chart history

Hydrographic surveying has been practised with some authenticity since the latter part of the 18th century. The first such charts of the Solent area are those based on the surveys of Lieut. Murdoch Mackenzie conducted in 1783 to 1785 and subsequent surveys of note were carried out by Capt. Sheringham (1847), Capt. Parson (1879), Commander Cary (1929-30), and Commander Monk (1951). There are currently seven Admiralty charts, at scale 1/20,000 or larger, covering the area under consideration.

The approaches to the port of Southampton have been surveyed in meticulous detail over the past 100 years or more, initially by the Southampton Harbour Board and since 1966 by their successors the British Transport Docks Board. The first capital dredging was carried out in 1889 when the approach channel from Fawley to the Docks was deepened to 7.5m below present chart datum (Southampton Harbour Board, 1953). By 1909, further capital dredging had been undertaken to bring the minimum depth to 9m. Between 1931 and 1936, the capacity of the port was considerably

Spithead looking towards the Solent

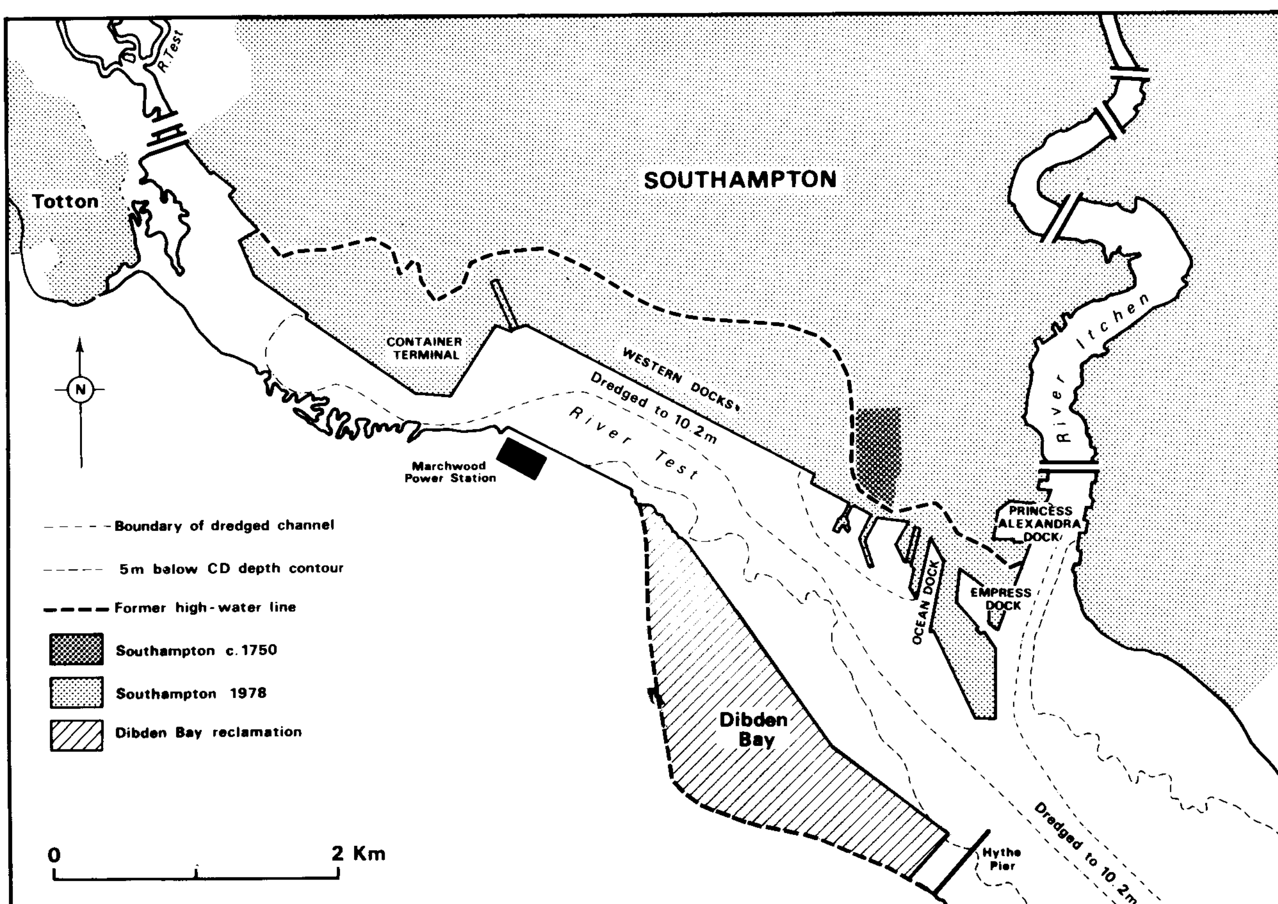
enlarged by the provision of 2400m of new quay in the Test Estuary with a dredged depth of 11.7m at the berths. This work involved the reclamation of about 130ha on the Southampton side of the estuary and the creation of spoil deposition areas on the western side up-river of Hythe. In addition, the approach channel to the docks was improved by deepening to 10m and widening to 300m, entailing the removal of about $2 \times 10^6 m^3$ of material. A further large capital dredging scheme was undertaken between 1950 and 1951 in which the navigability of the Western Approaches was considerably improved by widening in the vicinity of the bends. Nearly $3 \times 10^6 m^3$ of material were dredged, much of which was used to reclaim some 80ha of intertidal mudflat near Fawley. During the years 1967-1977, the British Transport Docks Board undertook a massive programme of constructional development in the upper Test Estuary for the handling of container traffic (Rowe, 1977). A total length of 1800m of quay frontage was provided with dredged depth of up to 12.8m. Approximately 80ha of the estuary was reclaimed, the fill being derived almost entirely from the $7 \times 10^6 m^3$ of material dredged for the approach channel, 450m diameter turning circle, and new berths. Figure 1 illustrates the comparison between present-day conditions and those of nearly 200 years ago. Coughlan (1979) has outlined in greater detail the various reclamations. The maintenance dredging in Southampton Water has averaged about $10^5 m^3 y^{-1}$ mostly in and around the berths, but some siltation is also experienced along the margins of the approach channel.

Portsmouth Harbour has also been extensively developed for shipping over the past 100 years or so (Department of the Environment, 1973) and this has necessitated a considerable amount of dredging in the vicinity of the berths. The port approach channel is naturally scoured to a depth of about 9m and the maintenance dredging requirement for the port is quite small. In recent years (1967-73) an extensive reclamation scheme in the upper reaches has been completed involving the inning of some 200ha (Birch, 1973).

Other harbours that have been surveyed regularly because of their commercial importance are Lymington, Yarmouth and Cowes, and the Itchen Estuary and the lower reaches of the Hamble River are looked at periodically. The Hamble River, which affords berths for about 3000 yachts, is now managed by the Hampshire County Council. The estuary of the Eastern Yar, which now outfalls at Bembridge on the Isle of Wight, once extended to Brading and beyond. It has been reclaimed in stages by a number of separate schemes carried out since 1562. The last major works were completed in 1874 and involved the construction of the railway embankment between St. Helens and Bembridge with the subsequent enclosure of about 300ha of land. It has been estimated that the volume of water available to oppose littoral drift and siltation was reduced by at least 50% as a result of these extensive reclamation works. Brading Harbour dries out almost completely at low water and at high tide is only accessible to relatively small craft.

In recent years, there have been other activities of man which have resulted in some change in the local hydrography of certain areas. The construction of about 10 large yacht marinas, mostly in the estuaries of the Lymington, Hamble and Medina, has involved the dredging of the

Fig. 1 Development of the Test Estuary



intertidal mudflats in order to provide adequate berthing at all states of the tide (Webber, 1973a). Secondly, there has been the inning of sand and gravel from a number of offshore banks, mainly from the Solent Banks (West Solent) and the Hamilton Bank (Spithead). In the period 1971-72 about $1.2 \times 10^6 m^3$ of sand was dredged from an area west of Horse Sand Fort for the construction of road embankments in the reclaimed area of Portsmouth Harbour referred to earlier. Man's influence apart, there seems to have been very little change, if any, in the overall bed configuration of the Solent. Among the local changes worthy of note are a recession of the low water mark on the mainland side of the West Solent and a landward swing of the eastern spit (East Head) at Chichester Harbour entrance (Searle, 1975). Although in historic times accretion has been much less in evidence than erosion, there has been significant accumulation of shingle along the eastern coastline of Langstone Harbour entrance (Gunner Point) and to a lesser extent at Eastney (Harlow, 1979).

During the past 2000 years or so, sea level has remained fairly stable apart from small eustatic changes, which in Southern England amount to a relative subsidence of the land of the order of 0.1m per century (Rossiter, 1972). More recent evidence suggests that the current rate of rise may be about 0.2m per century (Blackman and Graff, 1978), and in many of the estuaries, the mudflats are probably making up at about this rate. *Spartina townsendii* which first appeared in Southampton Water around 1870 and has since spread to the other estuaries in the Solent area, must have resulted in a significant rise in the level of the mudflats that it has colonised.

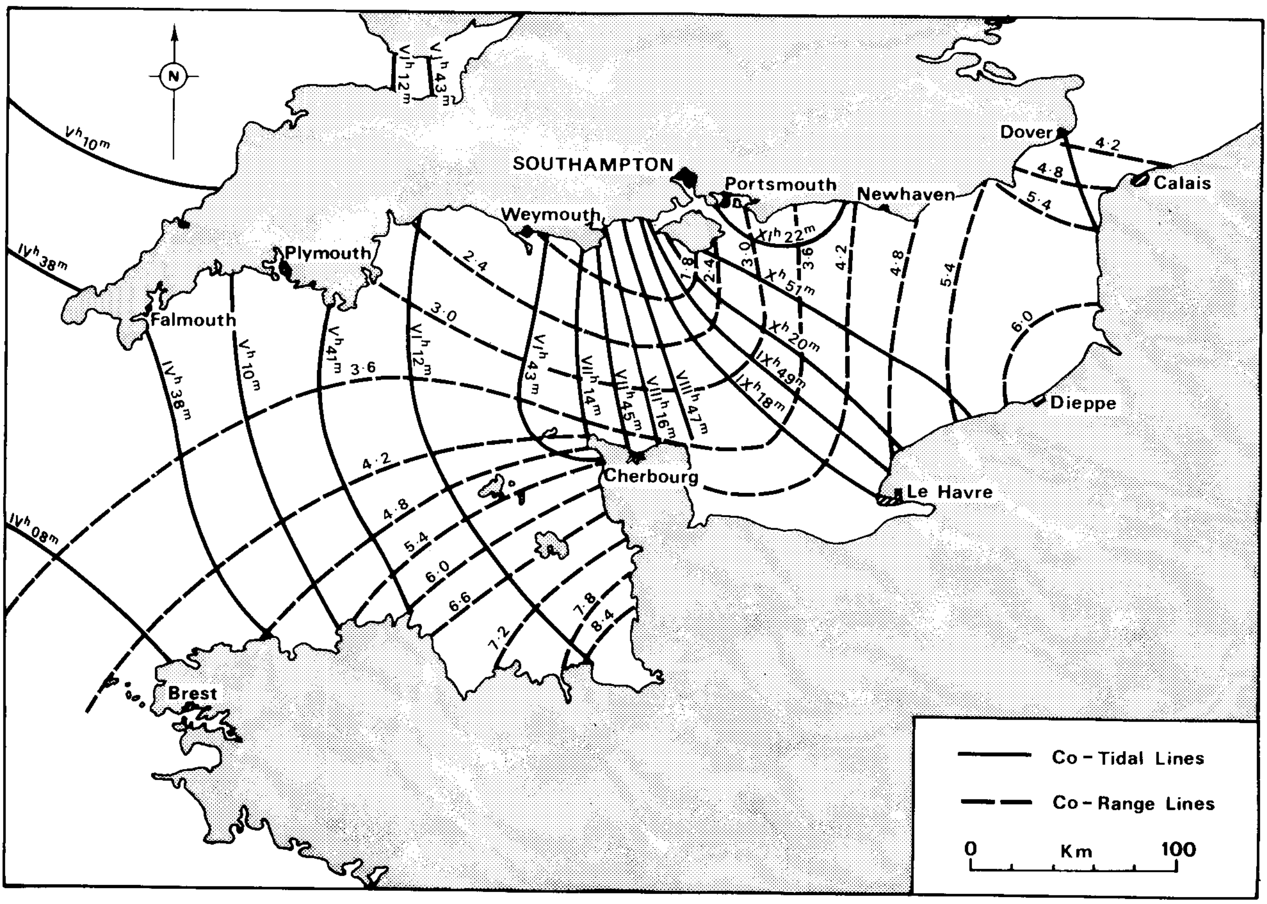
Tidal features

(a) *Regime*

The tidal features of the Solent area are some of the most complex in the world. As a result of the great deviation from the normal shape of the tidal curve and the behaviour at the standard port (Portsmouth), the Admiralty Tide Tables include a special table entitled "Swanage to the Nab Tower" which sets out the hourly variations at 18 places in the area. As early as 1845, the unique shape of the tidal curves at Southampton was discussed by G.B. Airy, the Astronomer Royal (Airy, 1843) and since then, the general characteristics of the Solent area have been the subject of study and speculation by hydrodynamicists (Doodson and Warburg, 1941), hydrographers (Macmillan, 1964) and others (Webber, 1973b). The tidal characteristics of the English Channel are the controlling factor with respect to the Solent, and the co-tidal lines for the Channel are shown in Figure 2 with the pecked lines indicating the average tidal range. Evidently, high water in the eastern portion occurs at about the same time as low water at Penzance and the range is a minimum half-way along the Channel in the vicinity of Poole Bay. This pattern of behaviour indicates a degree of resonance with the semi-diurnal oceanic tide and, in fact, the natural period of oscillation of the English Channel is about 10 hours. Higher tidal ranges occur on the French side and are attributed, except for the pronounced local effect of the Cherbourg peninsular, to Coriolis force.

Characteristically, although the range of tide to the west of the Isle of Wight is relatively small, there is considerable water movement (maximum currents of 2.5 knots or more). It is a further feature of a standing

Fig 2. Co-tidal and co-range lines for the English Channel.



wave oscillation that the amplitude increases rapidly with a distance from the nodal point or line. Indeed, it will be noted from Figure 3 in which the tidal curves for the Christchurch Bay area and the Nab Tower (about

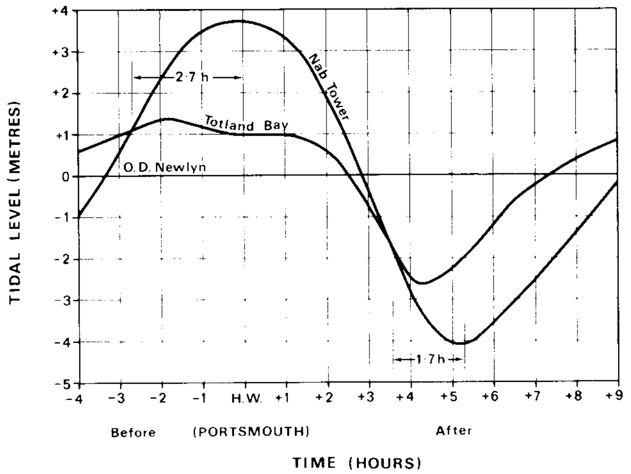
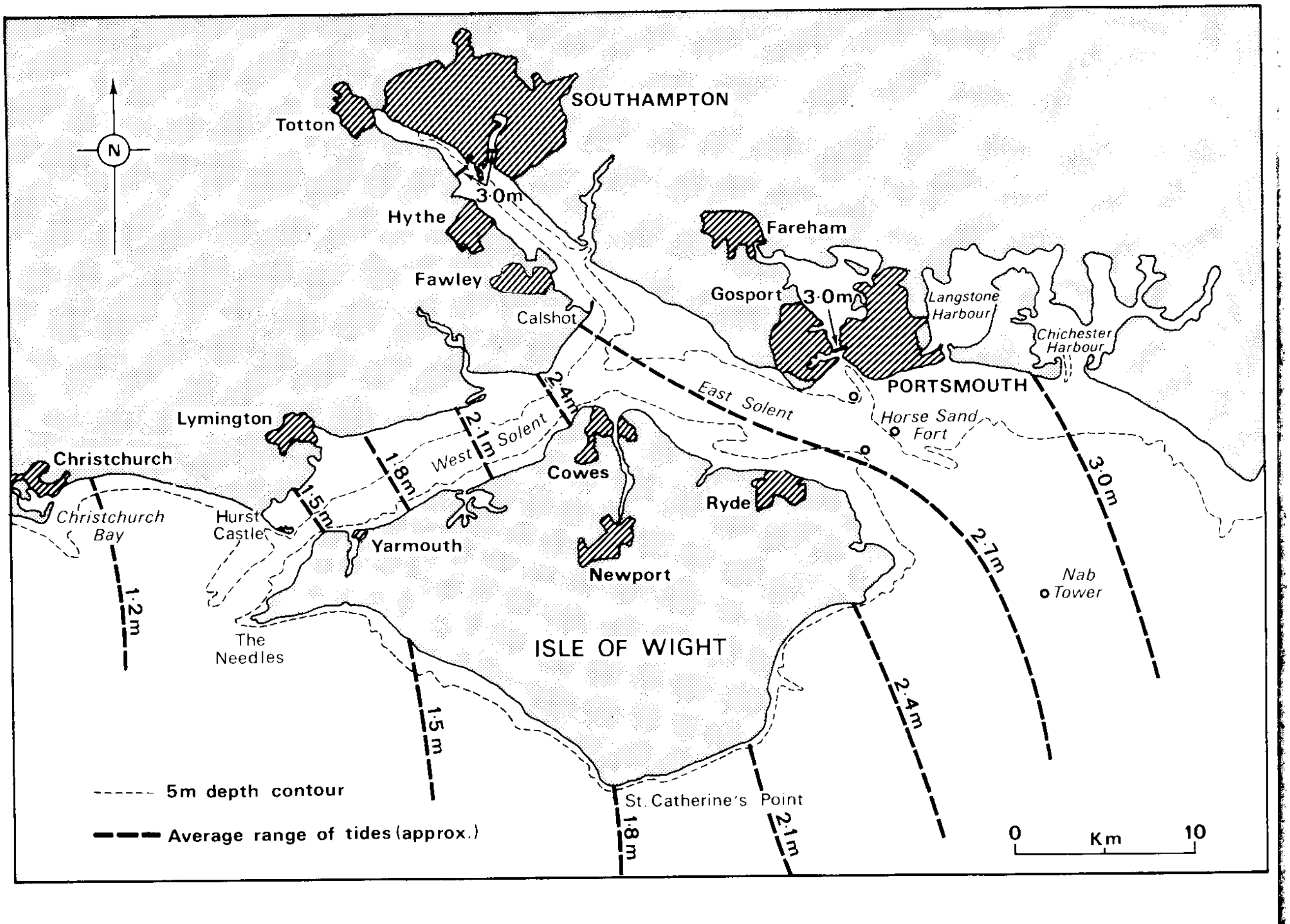


Fig. 3 Superimposed tidal curves (springs) for the two ends of the Solent system.

8km east of the Isle of Wight) have been superimposed, that over a distance of only some 80km the range of tide is nearly doubled. Furthermore, the co-range lines for the Solent (Fig. 4) indicate that the major change occurs in the West Solent over a distance of only 16km. The same relationship is to be found at neaps, when the tidal range is typically half that at springs. In regions such as the vicinity of a node where the amplitude of the semi-diurnal (M2) constituent is weak, combination with a powerful shallow-water constituent (M4) is liable to result, subject to favourable phase difference, in double high or double low waters. Configuration and depths in the Christchurch Bay area are certainly conducive and double high waters occur, whereas in Spithead and further east they do not although the tidal curves exhibit a prolonged period of high water. What happens inside the Solent is dependent upon these external conditions, and on the hydraulic characteristics of the waterway system. The latter include the configuration (length, width, depth, alignment) of the various estuarine components and the resistance to flow which they offer.

It will be seen from the tidal curves (Fig. 3) referred to earlier that there is an east to west gradient of water commencing at about 2 hours before high water Portsmouth such that the ebb is running fast whilst water levels within the system are still rising. This means that the last of the flood enters estuaries such as the Medina, from the easterly direction rather than from the west. The reversal to a west-east gradient occurs at a corresponding, but shorter, time before low water Portsmouth. Characteristically, with the closer proximity to a tidal node and because of the smaller sectional area of the channel, tidal streams in the West Solent are much faster (up to 4 knots) than in the East Solent (up to 2.5 knots) and the open waters of Spithead and beyond. In the narrows at Hurst Castle, which have been maintained by scour to a depth approaching 60m, the maximum tidal stream at springs is recorded as 4.5 knots. These values have been taken from Admiralty data (Hydrographer of the Navy, 1974) and refer to the average current over a depth of about 9m; surface currents would be higher. The appreciable velocities and consequent high frictional loss in the West Solent are evidenced by the considerable

Fig. 4 Co-range tidal lines for the Solent system.



hydraulic gradient which, on a spring tide, is as much as 1.2m in 23km.

Flow conditions in the West Solent have been investigated by Dyer and King (1975) and more recently by Blain (1980), the latter study involving the recording of tidal levels at six stations between Calshot and Totland for a minimum period of one year. The maximum ebb and flood flows at Hurst Narrows during a typical spring tide were found to be 59000 and 36000m^3 sec^{-1} respectively. The mean residual flow was assessed at 1400m^3 sec^{-1} east to west, with meteorological influences having an important effect and sometimes reversing the direction.

The general form of the tidal curves for the Solent region is of interest and the curves for Cowes (Fig. 5) are probably as representative as those for any other place. There is a long period of "stand" around high water, extending to about 3 hours. In the estuaries, this is of advantage to those that are dependent on adequate depth of water for the movement of vessels or the enjoyment of a recreational pursuit. The effect of the high water stand is to shorten the period of ebb to around 4 hours instead of the customary 6 hours.

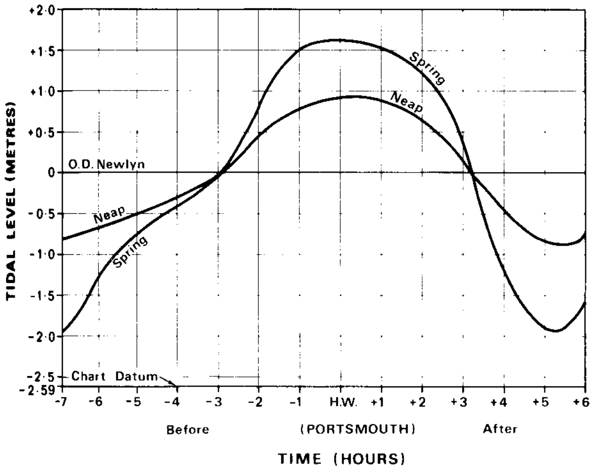
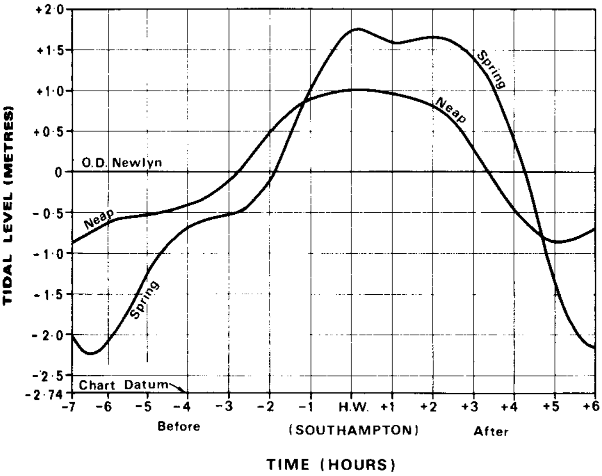


Fig. 5 Typical tidal curves for Cowes.

The flood has a normal duration, but there is an intermediate near stand of about an hour which commences approximately 2 hours after low water. In consequence, contrary to normal estuarine behaviour, the ebb currents are faster than the corresponding flood and, therefore, provide a beneficial flushing of silt and contaminants in a seaward direction. However, as with tidal flow generally,

Fig. 6 Typical tidal curves for Southampton Water (Town Quay).



the locations of the dominant ebb and flood currents may well differ, being influenced by configurations and particularly those in the approaching flow direction. In the tidal curves for Southampton (Fig. 6) these characteristics are seen to be accentuated and the double high water feature is pronounced. An harmonic analysis of this curve (Doodson and Warburg, 1941) shows that it is composed of many shallow-water constitutents and that the sixth diurnal (M6) rather than the quarter diurnal (M4) is an important factor in the second high water. This is perhaps attributable in part to some resonance effect within Southampton Water itself. Certainly, the unique shape of the Southampton Water tidal curve demonstrates how the various influencing factors have combined to make the Solent tidal regime one of the most complex and difficult to explain in the world.

(b) *Tidal Volumes*

When considering tidal behaviour in an estuary it is useful to have some knowledge of the tidal prism, (i.e. the change in water volume between high and low water) since it indicates the volumetric flush that is available. The net change in tidal volume for the Solent (Hurst Narrows to Ryde-Gilkicker) has been estimated (Blain, 1979) at 540 x 10^6 and 270 x $10^6 m^3$ for a typical spring and neap tide, respectively. Southampton Water contributes about 20% of these total volumes. The volume of water entering and leaving the West Solent at Hurst Castle (Blain, 1979) is 900 x $10^6 m^3$ for a typical spring tide and 550 x $10^6 m^3$ for a typical neap and corresponding volumes (not in phase) for the eastern entrance, Ryde-Gilkicker, are 650 x $10^6 m^3$ and 430 x $10^6 m^3$, respectively. There is thus an appreciable throughput of water. The tidal volume curves for Southampton Water which is of reasonably uniform depth, are shown in Figure 7. The horizontal lines give some indication of the likely maximum particle travel in flood and ebb direction consequent upon a release at a particular cross section although it must be emphasised that uniform velocity distribution is an inherent assumption.

In spite of the considerable changes brought about by man in Southampton Water during the past century, the practice of "cut and fill" has meant that the tidal prism has not been greatly altered. For example, the recent extension of the western docks has only reduced the spring tide prism for Southampton Water by about 1%. The estuary regime is probably only marginally changed although slightly higher water levels may now be experienced in the upper reaches of the Test. In Portsmouth Harbour, the recent large project for reclaiming 200ha of the upper estuary was not accompanied by any compensatory dredging and, in consequence, the tidal prism for the harbour has been reduced by about 6%.

(c) *Tidal monitoring and tidal surges*

In the Admiralty Tide Tables, the standard port for tidal predictions in the Solent area is Portsmouth, and there are nine additional places (including Southampton) for which tidal data are quoted. Southampton, in view of its importance, receives as detailed a treatment as Portsmouth. In the national network for the geodetic establishment of mean sea level, Portsmouth is one of the stations. High and low waters have been recorded at Portsmouth since 1813. Regrettably, there are many gaps in the data but 106 years of relatively complete records have survived, which is a very long period as compared with the majority of ports around Britain. Autographic recording was commenced as early as

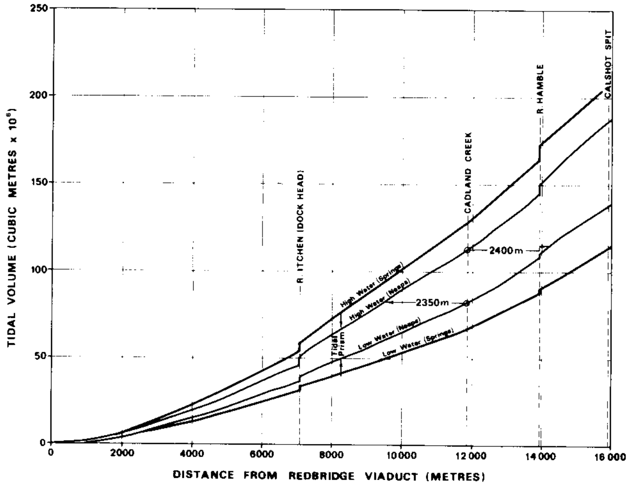
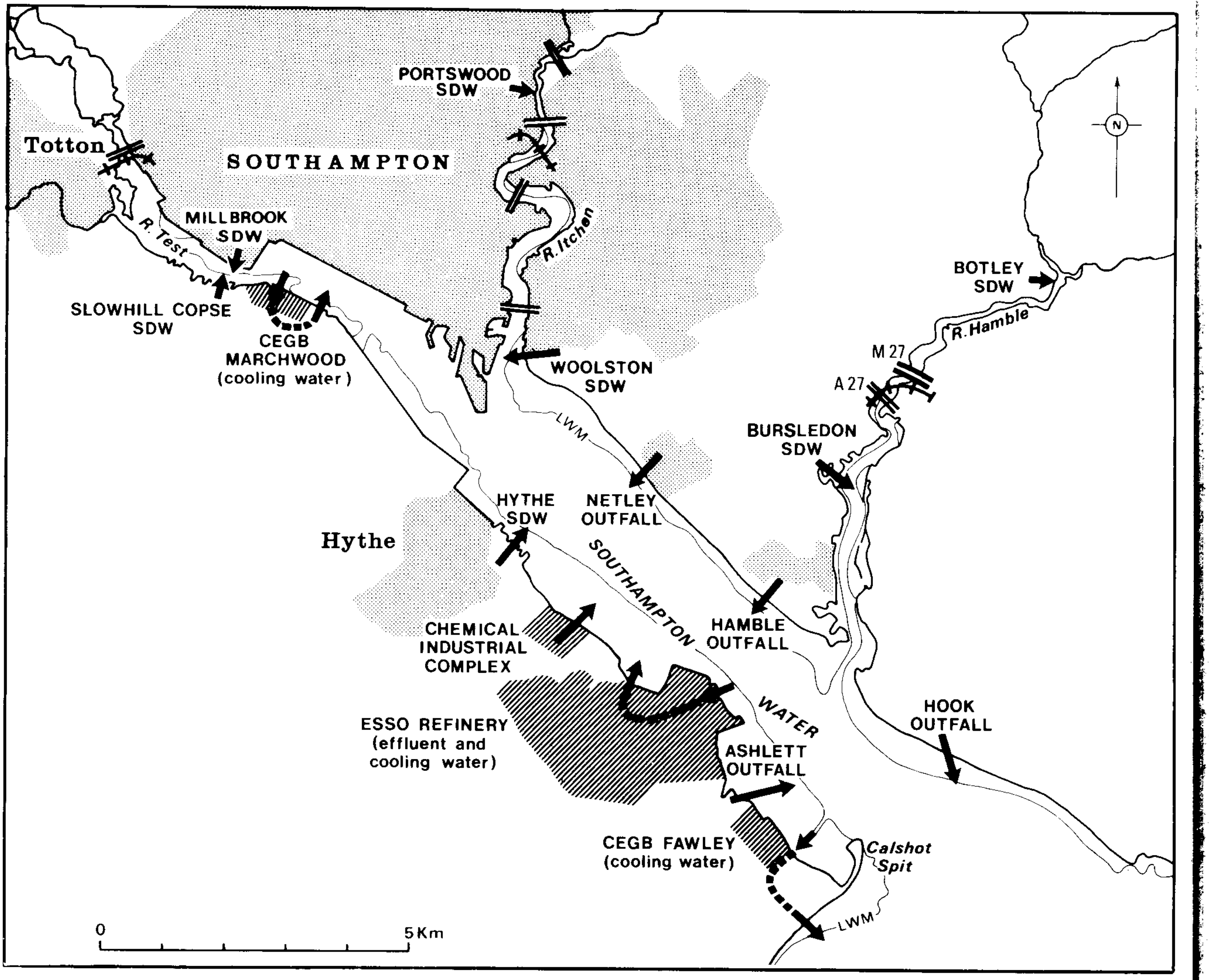


Fig. 7 Tidal volume curves for Southampton Water and Test Estuary.

1886 but again there are many gaps in the data except in recent years. The tide records for Southampton (Town Quay) effectively commence in 1935 and those for Calshot in 1936. Other bodies besides the two principal port authorities have maintained tide recorders at various places for relatively limited periods of time, with the exception of Brading where a tide recorder has been maintained by the land drainage authority (now Southern Water Authority) since 1947. As is the case universally, deviations from predicted values due to meteorological factors are a common occurrence. Fortunately, significant departures in the form of positive and negative surges are of a much lesser magnitude than those characteristic of the southern sector of the North Sea where surges of up to 3m have occurred in certain coastal areas. The effect of these surges, however, as well as the more customary storm surge proceeding from the Atlantic eastwards up the English Channel, is felt in the Solent area.

The highest high-water levels recorded at Portsmouth and Southampton were 3.02m above O.D.N. in the year 1840, and 2.83m above O.D.N. on 27 November, 1924 respectively whilst the lowest low-water level at Southampton was 3.14m below O.D.N. on 6 Feburary, 1935. The exceptional high-water values may be compared with the H.A.T. (highest astronomical tide) levels of 2.47m O.D.N. at Portsmouth and 2.16m O.D.N. at Southampton. Suthons (1963) and, in more recent years, Webber and Davies (1976) and Blackman and Graff (1978) have analysed the data from the Portsmouth and Southampton tidal records and estimated the likely recurrence intervals of exceptional high-water levels. There are slight differences in the statistical evaluations but it would appear that the once-in-ten year maximum level at Portsmouth is 2.74m O.D.N., whilst at Southampton it is 2.67m O.D.N. The corresponding 100 year

Fig. 8 Effluent discharges into Southampton Water and its estuaries.



levels are 2.96 and 2.83m O.D.N., respectively. A comparison of recorded and predicted high waters shows that the maximum surge is of the order of 1.1m and there is some evidence to suggest that the amplitude may not differ greatly throughout the Solent area (Henderson and Webber, 1977). However, as with the North Sea, there are reasons to believe that the largest of surges will not coincide with exceptionally high predicted tides. Since strong winds are often associated with low barometric pressure, there is some likelihood of severe wave action being superimposed resulting in a greater risk of shoreline erosion and over-topping of sea walls due to the higher level of attack.

Freshwater inflow to the system

By definition, an estuary must have a source of fresh water, and the greater proportion is usually introduced at the head of the system. This inflow of water is important from the point of view of the net flow seawards, the behaviour and distribution of currents particularly in the upper reaches, and the sedimentary characteristics.

The total catchment area draining to the Solent is about $3000km^2$ of which rather more than half comprises chalk strata and the remainder mainly the coastal plain and New Forest tertiaries. Of this total area the Isle of Wight contributes run-off from about $200km^2$. The rivers deriving their flows from the chalk have fairly stable discharges as is evidenced by the data from the gauging stations on the Rivers Test, Itchen and Meon, where the ratio of the maximum/minimum flow over the years of record is 13.7, 4.7, and 80 respectively. By contrast, the run-off from drainage basins consisting of predominantly tertiary strata may have a peak discharge per 1000ha of up to 3.5 cumecs and a dry-weather flow of almost zero. Utilising the gauging station data and statistics of rainfall and evaporation, the annual inflow of fresh water to the Solent is computed to be of the order of $10^9 m^3$ which is equivalent to $1.4 \times 10^6 m^3$ per tidal cycle with marked variations according to the time of year. Of this, probably about 10% is in the form of sewage effluent discharging into the estuarine or coastal waters with or without treatment.

The largest rivers, Test and Itchen, enter at the head of Southampton Water and account for about 45% of the total inflow to the Solent. Even if one considers Southampton Water alone this is a very small proportion (about 1/75th) of the neap tidal prism, and, of course, for the Solent as a whole the proportion would be much less. The locations and estimated quantities of inflow (including sewage effluent) for Southampton Water are shown in Figure 8. In a typical year, the River Test would have a discharge of about 25 cumecs in mid-winter, diminishing exponentially during the summer to about 6 cumecs by the following October. The flow in the River Itchen would be about half these amounts.

Salinity

Salinity is an important physical parameter which is governed by the hydraulic conditions within an estuary and the fresh-water inflow. It is relatively easy to measure and has a useful role as a conservative tracer. The variations of salinity in respect of location and time, can be used as the basis of calculations involving turbulent exchange and estuarine circulation, both of which are highly relevant to the dispersion of contaminants or heated water (Jarman and de Turville, 1974). With respect to salinity characteristics, estuaries may be grouped into three classes (Simmons, 1966) according to the physical structure of the water and the net motions:

(i) Stratified: in which there is a fairly well-defined interface or discontinuity in the salinity distribution;

(ii) Partially-mixed: in which the local salinity varies a large amount in terms of the local mean salinity;

(iii) Well-mixed: in which the salinity variation over a vertical section varies only slightly from the local mean salinity.

Not surprisingly, all of the above conditions exist in the Solent system although the stratified state is only found in the upper reaches of estuaries where a sizeable river enters at the head (such as the Test Estuary) or in times of peak discharge of a flashy stream. In an investigation of thermal effects (Pannell *et al.*, 1962), it was found that opposite to Marchwood Power Station in Southampton Water, there was a three-layer stratification in which the fresh water from the river and sewage works at Millbrook overlay the warmed water from the power station, and this in turn, overlay the colder saline water from the seaward reaches.

Southampton Water appears to be the only estuary in the Solent region where salinity has been systematically recorded. This is undoubtedly because it is environmentally at greater risk and because the fresh-water influence is more pronounced making variations more readily discerned. In the course of water quality surveys extending over nearly ten years, the Southern Water Authority (and its predecessor the Hampshire River Authority) has acquired salinity data for the main channel of Southampton Water and for the tributary estuaries of the Test and Itchen. A typical representation of longitudinal salinity for the Itchen is shown in Figure 9 and the Water Research Centre has recently developed a mathematical model for this estuary.

Dyer (1973) made salinity observations in Southampton Water and compared them with the vertical distributions of tidal stream velocity. He identified a transverse variation of salinity with the fresher water on the eastern side. In recent research on mixing and dispersion in Southampton Water, Westwood (1980) carried out longitudinal and cross-sectional traverses and installed recording salinometers at Hythe, Hamble and Calshot. Both salinity and temperature were measured and the recordings extended over at least one year. A typical longitudinal salinity profile is shown in Figure 10. As part of this research, Westwood and Webber (1977) described a tidal exchange experiment at the entrance to Southampton Water in which, during the 13 hour period of a neap tide, salinity, temperature and velocity were recorded at 6 boat stations across the estuary mouth. It was found that the proportion of "new water" entering the estuary on a neap tide was 32% of the flood tidal prism.which indicates a reasonable degree of flush.

Wave climate

One of the attractions of the Solent for yachtsmen and others is the comparatively sheltered nature of the waters, although there are, of course, considerable variations in the wave climate depending upon the geographical setting. For example, where there is an exposure to the waves of the English Channel at the western entrance in the vicinity of the Needles or at the eastern end of Spithead, conditions at times can be quite severe according to the direction of the wind. At a wave recording site in Poole Bay, the maximum wave height registered during a period of 4 years was 8.8m (Henderson and Webber, 1977).

Wave recording has been carried out in the Solent area at a number of sites and for various purposes, ranging from hovercraft trials to tests on wave machines and floating breakwaters. At Lee-on-Solent, the Inter Services Hovercraft Unit has made systematic visual

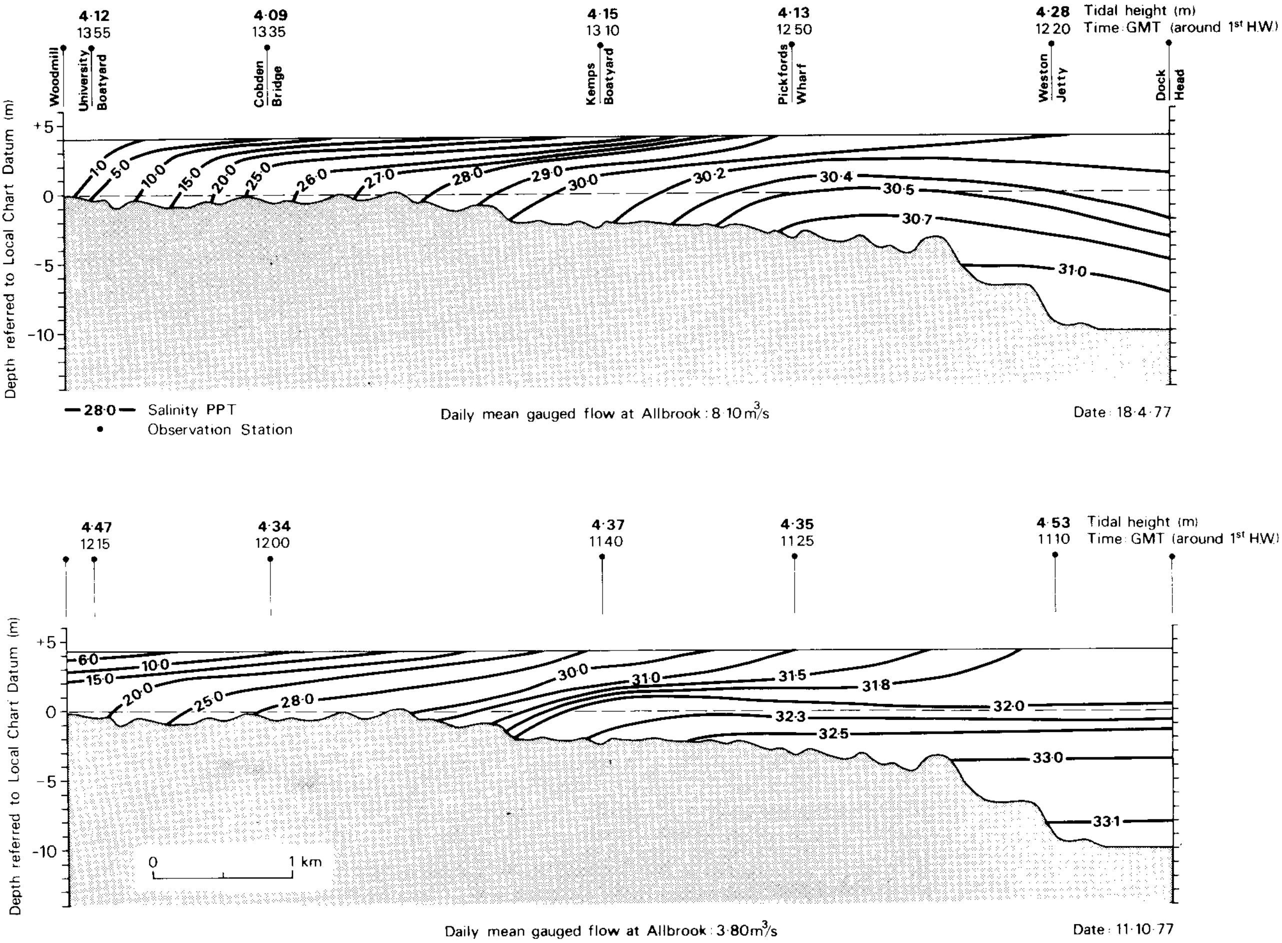
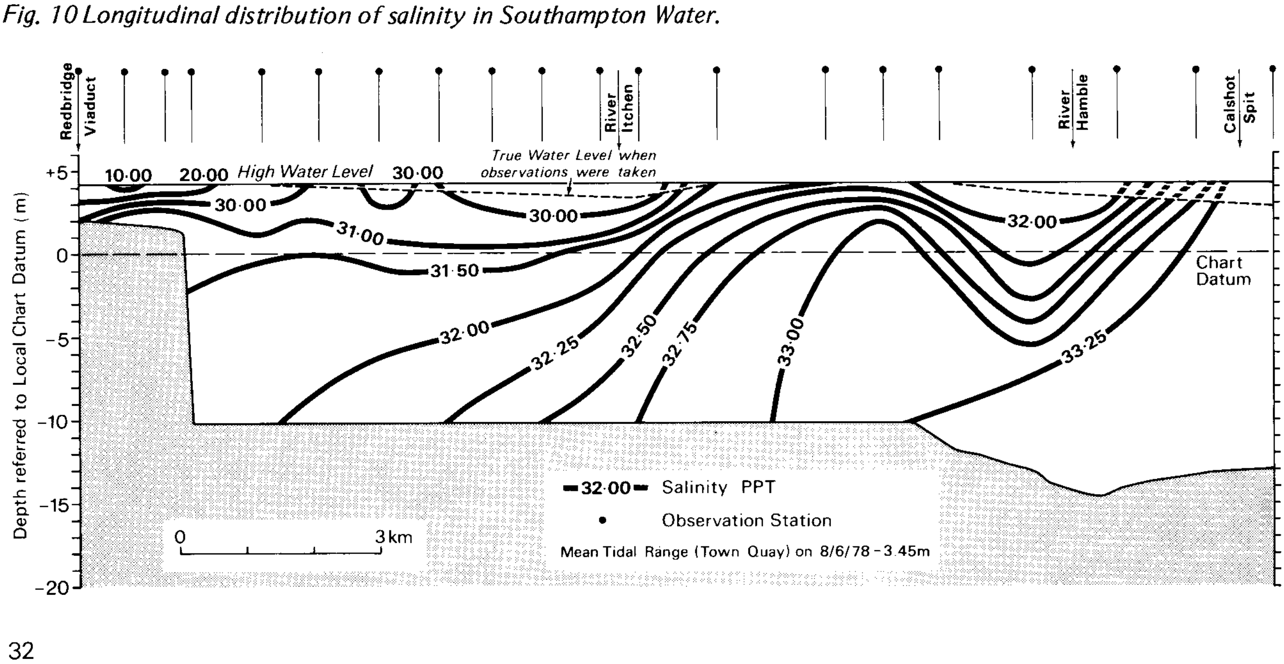


Fig. 9 Longitudinal distribution of salinity in the Itchen Estuary.

observations of wave height off their slipway over a period of years (Russell, 1974). This site is particularly exposed to winds from the S.S.W. direction where the fetch is as much as 15 nautical miles. A maximum significant wave height (the "significant" wave height is the average of the highest third of the waves in any period of record, usually about 20 min.) of over 1.2m has been observed on a number of occasions during the autumn or winter months. It has been concluded that the likelihood of significant waves of up to 0.6m in height at any time of the year is high.

In general, unless a wave recording device is installed and maintained for a year or more, the wave climate at specific locations in the Solent area can only be established by the conventional empirical methods based on wind-wave relationships and taking into account shallow water effects. In the case of the Solent, duration is generally of only minor importance since, with short

Fig. 10 Longitudinal distribution of salinity in Southampton Water.



fetches, a "fully risen sea" quickly develops for any given wind speed. However, for the more exposed areas, conditions may be affected much more by what is happening in the English Channel, and possibly over quite an extensive area of it. There are fairly comprehensive wind data available for the Solent area. At Thorney Island a recording anemometer has been maintained for over 30 years by the Meteorological Office but measurements were discontinued in 1977 on closure of the R.A.F. station. There is also a quite lengthy period of recording for the Meteorological Station at Calshot.

Specific investigations

(a) Nature of studies

Nowadays, no major engineering project about which there is any doubt concerning the best design or the environmental effects, would be undertaken without thorough investigational study. This would include the analysis of field data and a detailed examination of the various problems aided, quite possibly, by hydraulic and/or mathematical model tests.

In 1957 a large hydraulic model of the Solent was constructed in the Department of Civil Engineering at the University of Southampton (Wright and Leonard, 1959). This was used in a number of specific practical investigations, the more important of which are listed in the succeeding section. The model which was demolished in 1979, embraced the area Hurst Castle to Ryde-Gilkicker, together with the tributary estuaries. It was of the fixed-bed type with scales 1/1250 horizontal, 1/100 vertical, and, in accordance with the Froude relationship, the velocity scale and time scale were 1/10 and 1/125, respectively. Model studies, however, whether of the hydraulic or mathematical type, are no substitute for purposeful field investigations and, even in the case of fairly minor projects such as a sewage outfall serving a small township, hydrographic surveys would normally be undertaken in order to confirm that the environmental effects would not be detrimental. Quite a number of these *ad hoc* studies have been performed for the Solent area and they have added usefully to the knowledge of hydraulic conditions. The hydrodynamically more fruitful of these investigations are summarised in the following sections.

(b) Investigations for constructional projects

The major engineering works undertaken prior to the Second World War were the construction of the Western Docks at Southampton and the improvement of the approach channel to the port. Although the investigational work in these earlier days was normally much narrower in scope than would be the case today, hydrographic surveys were quite detailed. In recent years, the investigations have included:

(i) The hydraulic effects of a proposed dredging scheme at the entrance to Southampton Water (Wright and Leonard, 1959);

(ii) The effects of reclamation on Portsmouth Harbour and its Approaches (Hydraulics Research Station, 1959);

(iii) The possibility of a new approach channel to Southampton Water (Webber and Shaw, 1960);

(iv) The circulation of cooling water at the proposed power station at Fawley (Webber, 1961);

(v) The hydraulic effects of the proposed scheme for extending Southampton Docks (Webber, 1966);

(vi) The hydraulic effects of a proposed reclamation project along the Western shoreline of Southampton Water (Webber, 1972);

(vii) A feasibility study for reclamation of the West Winner, Eastney (Grontmij, 1973).

All of the investigations, except (vi) and (vii) involved hydraulic model studies, but the scope of the field data acquired was fairly limited. Projects (i), (iii), (vi) and (vii) have not materialised. Further field work, at a later date, was performed in connection with the reclamation of the upper reaches of Portsmouth Harbour and the results showed that the flow in the channel linking Portsmouth and Langstone Harbours was west-going for almost the entire tidal period. The feasibility study for reclamation of the West Winner entailed the collection of quite detailed field data over the locality concerned. The investigations included echo-sounding, current metering (14 stations), float tracking, bed sampling (100 samples), and wave recording.

(c) Investigations for sewage outfalls

On behalf of the relevant drainage authorities, float-tracking surveys have been carried out in connection with a number of outfall sites already in existence or proposed. These include Eastney, Browndown, Hook, Ashlett Creek, Pennington, Norton (I.W.), and Gurnard (I.W.). The data from these surveys provide useful information concerning the behaviour of surface currents along the likely path of the effluent and are, of course, most important from the point of view of pollution.

By far the most embracing and informative studies have been in connection with the proposal for a very large outfall as part of the rationalisation scheme for the main drainage of south Hampshire. After some preliminary tests in the Solent model (Helliwell and Webber, 1973) a wide-ranging investigation was conducted by the consulting engineers, J.D. and D.M. Watson, with a view to ascertaining the most suitable sites for outfalls and the appropriate methods of discharge. In their report (Watson and Watson, 1972) it was concluded that an outfall at Horse Sand Fort at the eastern end of Spithead was a feasible proposition. During the course of the investigation a considerable amount of field work (current observation, float tracking, dye releases, bed and surface drifter releases) was undertaken, principally in the area East Solent to the Nab Tower, and the data collected constitute a valuable addition to the knowledge of the area. One of the most interesting hydrographical features observed was a net north to south drift of surface current across the East Solent.

In connection with this investigation a two-dimensional mathematical model, embracing the area East Solent to the Nab Tower, was developed by the Hydraulics Research Station. The model was based on the velocity and direction of water movement at points 1km apart for half-hourly intervals throughout the tidal cycle for any required wind speed or direction. The introduction of appropriate dispersion coefficients enabled computations to be made as to the likely extent of the sewage field. The South Hampshire Main Drainage Board, and its successor the Southern Water Authority, decided that a full-treatment works discharging only purified effluent should be constructed and that the outfall should be in the East Solent. This very large project is now in the course of construction.

(d) Environmental surveys

Some of the field studies in connection with the environmental quality of certain estuaries have thrown light on the hydraulic behaviour particularly in respect of estuarine circulation patterns.

Both Portsmouth and Langstone Harbours have been the subject of radio-active tracer surveys, in which the effluent discharged from outfalls at the heads of these estuaries has been labelled and its behaviour observed over several tidal periods. The results have shown that in each case, even on a neap tide, a proportion of the effluent discharges to the open sea through the estuary mouth, giving some indication of the considerable tidal excursion and degree of turbulent exchange. Radioactive tracer surveys have also been conducted in connection with the outfalls at Eastney (entrance to Langstone Harbour) and Pennington (between Lymington and Keyhaven).

In 1977, workers from Portsmouth Polytechnic made a detailed physical and biological survey of Langstone Harbour which, on the physical side, entailed aerial mapping (including contours at 1m intervals) of the intertidal zone together with extensive echo-sounding, bed sampling, and current meter measurements. During the course of this investigation it was found that there was a marked residual flow from Chichester Harbour to Langstone Harbour around the north side of Hayling Island.

(e) Minor researches

Over the years, many small investigations of a hydraulic nature in the various estuaries have been carried out by public authorities, consultants, research students and others. In most cases, they have included a study of the chart history and a limited amount of field measurement, but they have been by no means exhaustive.

Conclusions

The waters of the Solent constitute a coastal and estuarine system of considerable complexity. It would require much more than a brief review such as this to adequately set forth the present state of knowledge of the hydrographic features.

Although the area has, for the most part, been well charted, factual data concerning tidal variations, currents, salinities and wave heights are by no means comprehensive or well collated. Indeed, apart from the official surveys conducted by naval and port authorities, most of this information is of a rather piecemeal nature having been obtained in the course of specific engineering investigations.

Some research on the physical aspects has been, and is being conducted, but compared with estuarine systems such as the Thames, Mersey and Tees where there has been major concern with regard to water quality and a consequent willingness to finance expensive field research projects, the amount of such study has been fairly limited. This is particularly so in the case of estuaries such as Chichester Harbour, where there are few, if any, commercial or industrial interests involved. Here the hydrographic information, apart from soundings in the main channel, is very meagre indeed.

If the challenges posed by the physical phenomena in these widely cherished waters are to be vigorously met, much more research is needed on all of the various aspects. However, such studies must be based on adequate factual data and it is in this area of field observation and monitoring where support is greatly required.

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