SECTION 2

TIDES, WAVES AND WATER LEVELS

2 TIDES, WAVES AND WATER LEVELS

2.1 Tide Levels, Surges and Extreme Still Water Levels

Tidal heights for St Mary's have been predicted by the Hydrographer of the Navy and are reproduced on Admiralty charts of the area. They are shown in Table 2.1. Chart Datum is 2.91 m below Ordnance Survey (Isles of Scilly) Datum.

Following the storms of 1989190, the Proudman Oceanographic Laboratory investigated sea level data recorded at several selected tide gauges around the western coast of the British Isles"'. Data relating to Newlyn (about 55 km east-north-east on the south Cornwall coast in the South West Approaches) abstracted from the paper by Flather is presented in Table 2.2 and gives surges with return periods up to 60 years; these have been extrapolated to 150 years.

As pointed out by MAFF[2], surges on the UK coast are a response to rapidly tracking depressions whose low pressure systems tend to increase tidal amplitude. Surges have long wave periods and their nodes may not necessarily coincide with those of the astronomical tide. By itself, therefore, knowledge of surge levels does not necessarily give sufficient information on which to assess extreme still water levels.

An analysis of the return periods of extreme still water levels at St Mary's (reproduced for convenience in Appendix 3)[3] was therefore commissioned from the Proudman Oceanographic Laboratory (POL) by the Council of the Isles of Scilly for the Porth Cressa coast protection project. Blackman comments that it was not possible to derive extreme still water level estimates for St Mary's directly because of the lack of good quality annual maxima at the site. It was possible, however, to derive relationships between Newlyn and St Mary's from the observations of non-extreme tides available from both sites. Estimates of extreme sea levels for St Mary's were then calculable from data of extreme sea levels measured at Newlyn and the results can be seen from Table 2.3 and Figure 2.1.

---

(1) *Storms of Winter 1989/90 - The Storm Surges and Sea Levels, R.A.* Flather, *Proceedings of the 25th MAFF Conference of River and Coastal Engineers, Ministry of Agriculture, Fisheries, and Food, London, 1990*

(2) *Coastal Defence and the Environment - A Guide to Good Practice, PB1191, Ministry of Agriculture, Fisheries and Food, London, 1993*

(3) *Extreme Still Water Levels at St Mary's, D.L. Blackman,* Proudman *Oceanographic Laboratory,* Bidston *Observatory, Natural Environmental Research Council, May 1994*

New techniques are being developed for the estimation of extreme sea levels by correlating land station observations with the output of tidal models[4]. These techniques still need to be refined further before they would be able to be used to improve the estimates currently used for the Isles of Scillies.

Analysis of the storms of Winter 1989/90[3] by the Proudman Oceanographic Laboratory indicates that the return period of the damaging storms were of the order of 50 years. This can only be approximate as reference must necessarily be made to the data record at Newlyn because of damage to the tide gauge at St Mary's during the storms. The extreme water level for a return period of 50 years at St Mary's has been calculated by POL to be 3.55 mAOD. For comparison, HAT is 3.39 mAOD and MHWS is 2.79 mAOD.

Further to the above discussion on water levels and variations between St Mary's and Newlyn, there are believed to be considerable water surface gradients throughout the archipelago caused by frictional effects of tidal flow. A comparison of simultaneously recorded levels in Hell Bay and St Mary's Quay (see Figure 2.2) showed a difference of almost one metre at mid-flood and mid-ebb.

2.2 Tidal Currents

The Isles of Scilly are subject to a semi-diurnal tidal regime with mean spring and neap tidal ranges of 5.0 m and 2.3 m respectively (see Table 2.1). The tidal rise and fall generates a complex flow of water through the archipelago which is summarised in Figure 2.3.

The tide in the open sea is a progressive wave, with slack water occurring four hours before and two hours after High Water. Tidal currents flow in a rotary fashion through the cycle. Table 2.4 (compiled from Admiralty Chart BA34) illustrates the spring tide streams to the northwest of Scilly (006°24.8'W, 049°59.4'N).

A series of current meter measurements have been made amongst the islands by the South Western Electricity Board (1984) for inter-island cable routes[5] and by

(4) *Extreme Sea Levels around the United Kingdom Coastline, M. Dixon, Proceedings of the 32nd MAFF Conference of River and Coastal Engineers, Ministry of Agriculture, Fisheries and Food, London, 1997*

(5) *Sooth Western Electricity Board - Isles of Scilly Off-Islands Cable Routes Hydrographic Survey, Report Nr C6621, Wimpol Ltd, London, 1984*

Coral Cay Conservation during conservation studies in 1991 and 1992'". These data have been analysed[6] and are presented in Drawing *1.*

The data indicate that asymmetry of flow commonly occurs between flood and ebb velocities due to the effects of flow deflection through the island channels. Where the flow exceeds the critical threshold for sand transport, an asymmetric distribution of velocities commonly results in the preferential transport of sand in the direction of strongest flow. This apparent residual sand transport direction at each meter location is shown in Drawing 1.

2.3 Waves

Data on wave statistics for the Isles of Scilly area are available from a number of sources (see Reference 1 in Nunny[7]) including:

- Institute of Oceanographic Sciences (IOS) recorder (lightship-based, subsequently ***Waverider)***at the Sevenstones, between the Isles of Scilly and Land's End;

  METWAVE wave hindcasting model output, based on historical directional wind and wave data, for the sea area west of Land's End.

It is considered that due to the possible sheltering effects of the Sevenstones reef on data recordings made by IOS at that location, the *METWAVE* data may best represent the wave climate off Scilly. A summary of this information is given in Table 2.5, fuller details are given in Appendix ***4.***

It can be seen from the *METWAVE* data that storm waves can attain in excess of ***14*** m in height (with a return period of 50 years) and that the commonest zero-crossing period is 9 s, with the longest waves exceeding 13 s. The directional data shows that the largest waves approach from between south-west and north-west with the highest approaching directly from the west. Large waves (of the order of 65-85% of the height of the largest waves from the west) however can also approach from the east. A summary of offshore significant wave heights from the eight principal compass directions at return periods up to 200 years are estimated by *METWAVE* and are reproduced in Table 2.5 (refer also to Figure ***2.4).***

---

(6) ***A Survey of Foreshore Erosion at Bar Point, St Mary's, R.S. Nunny, Isles of Scilly Expedition Report, Coral Cay Conservation Sub-Aqua*** Club, ***1992***

(7) ***Isles of Scilly Shoreline Management Plan: A Review of Physical Processes, Sea Sediments Ltd, Chard, Somerset, October 1995***

(*METWA* VE has been hindcast from a variety of sources. Wind measurement data from the Isles of Scilly has only recently become available and is presented in Appendix 5. It is for the ten years 1986-95 recorded at St Mary's. In order to obtain data for ten years it has been necessary for "spot" wind data to be used. There are missing observations but the Meteorological Office state that the wind roses produced are still representative of the site.)

The winter's gales of 1995196 were predominantly from the south-east which is usually the origin of the lowest wave heights. This is relatively unusual (see Figure 2.4, Table 2.5 and Appendix 4) and has led to a general change in sediment movement patterns in southward facing shores throughout the south Cornwall coast as well as in the Isles of Scilly. Those at Hugh Town (Porth Cressa) and Old Town (Old Town Bay) on St Mary's experienced a shift in sands towards the west while the eastern ends of beaches became temporarily thinned. South Beach on Tresco, which broadly faces in the same direction and which has already been reduced in volume owing to the activities of mineral extraction for building materials, has suffered further erosion. The change in predominant direction of winds has also led to damage at the east-facing Pentle Bay on Tresco with an average of 6 m of beach being lost over one tide.

The winter gales of I995196 may be a short-term effect with a longer term re-establishment of mean sediment transport direction repairing some of the erosion damage by redistributing beach sediments. However, at the time of writing there is little evidence of any re-establishment of the beach at Pentle Bay.

2.4 Joint Probability of Waves and Water Levels

It is difficult to derive the joint probability of occurrence of storm waves and still water levels as very much site specific data is required. It has been noted above (see Section 2.1) that historical observations of sea level maxima at St Mary's are insufficient for the prediction of extremes at the site and that, to derive estimates of extreme sea levels for St Mary's, recourse had to be made to extrapolating data recorded at Newlyn.

MAFF is currently devoting research resources to developing new methods for the determination of joint probabilities of occurrence of waves and water levels[8] but the accuracy of data from modern mathematical and modelling techniques are as

(8) ***The Joint Probability of Waves and Water Levels: A Rigorous bur Practical New Approach,*** M.W. Owen, P.J. Hawkes, J.A. Tawn & P. Bortot, Proceedings of the 32nd MAFF Conference *of* River and Coastal Engineers, Ministry of Agriculture, Fisheries and Food, London, 1997

yet insufficient for the derivation of more accurate estimates of extreme sea levels at St Mary's.

In the meantime, the British Standard for maritime structures recommends that, where such data are lacking, "the assumption that they are dependent on one another should be made"[9]. Storms and surges are non-independent events as the pressure systems giving rise to storms also reduce barometric pressure - the pre-requisite for surges. BS6349 states, furthermore, that where the two events are inter-dependent, "it may be assumed that the significant wave height with a 50 year return period will occur with the abnormally high water level with a 50 year return period," and so on. The approach recommended by the British Standard is therefore conservative as it errs on the side of caution.

2.5 Sea Level Rise

Movement of sea level relative to land is caused either by movements of the land, the sea or by a combination of both.

MAFF summarises data showing isostatic changes in the South West (Plymouth) as -0.1 to -1.4 mm/yr. While MAFF quotes details of isostatic change on the mainland, this may not be quite true of the Isles of Scilly, separated as they are from Cornwall by Late Carboniferous wrench faulting running 155°-335° some 10 km offshore of Land's End[10].

Recent sea level changes around the British Isles have been analysed by a variety of means and a summary map is given by Carter[11]. The analyses discussed by Carter have been made from tidal data recorded from ports around the UK coast which necessarily reference against fixed topographical features - themselves moving as part of the isostatic change. The map (see Figure 2.5) therefore indicates relative sea level change at Newlyn (being a combination of isostatic change and sea level rise) as +1.7 mm/yr. However, there is noted to be inconsistency between the results reported across the region.

Sea-level change (see Figure 2.6), resulting from eustatic or isostatic processes, can be examined from tidal records, where long time-series exist, or from

(9) *BS6349: Part 1: 1984, British Standard Code of Practice for Maritime Structures, General Criteria, British Standards Institution,* 1984

(10) *The Geology of the Western English Channel and its Western Approaches. United Kingdom Offshore Regional Report BGS1835, British Geological Survey, HMSO, London, 1990*

(11) *Coastal Environments - An Introduction to the Physical, Ecological, and Cultural Systems of Coastlines, R.W.G. Carter, Academic Publishers, London,* 1988

geomorphological or archaeological dating of old sea levels. Examinations of the Newlyn tidal stage data (1972) have resulted in estimates of sea level rise of 2.2 mm/yr[12] (based on annual maxima) and, more recently (1988), 3.3 mm/yr[11] (based on hourly data).

Thomas[13] derived a minimum rise of 2.41 mm per year from study of archaeological remains over the last three millennia (see also Section 5.4.5), consistent with the higher estimate from the Newlyn records. However, more recent archaeological examination by Cornwall Archaeological Unit casts doubt on Thomas's analysis and suggests that a much lower estimate of sea-level rise of 0.7 mm/yr derived from data ranging from 4000 BC to 500 AD would be appropriate[14] (see Figure 2.7). However, the authors, Ratcliffe and Straker, suggest that detailed biostratigraphic analysis of intertidal peat deposits are required to confirm their tentative conclusions.

Given that the sea level rise currently causing grave concern is a modern post-industrial phenomenon, the observations of trends from the archaeological record are likely to be of little more than academic interest since the sea-level/time curve is undoubtedly steepening.

The Intergovernmental Panel on Climate Change (IPCC) has investigated the expected sea level change due to so-called "global warming" and has derived a best estimate of 6 mm/yr. Adding isostatic change to global warming results in changes to relative sea level which are of the order of 5 mm/yr. MAFF recommend[15] magnitudes of sea level change based on NRA Regions and advises 5 mm/yr for the South West. MAFF's recommendations exceed those estimated from other records and are therefore conservative.

(12) *Sea-level Observations and their Secular Variation, J.R. Rossiter, Philosophical Transactions of the Royal Society,* A272, 1972

(13) *Exploration of a Drowned Landscape. Archaeology and History of the Isles of Scilly. A.C. Thomas, B.T. Batsford Ltd, London,* 1985

(14) *The Early Environment of Scilly - Paleoenvironmental Assessment of Cliff-Face and Intertidal Deposits, 1989-1993, J. Ratcliffe & V. Straker, Cornwall Archaeological Unit, Truro,* 1996

(15) *Project Appraisal Guidance Notes, PB1214, Ministry of Agriculture, Fisheries, and Food, London,* 1993