OBSERVATIONS OF TIDES IN THE SEVERN ESTUARY AND BRISTOL CHANNEL

G A Alcock and D T Pugh

A report prepared for
the Department of Energy

REPORT NO 112

1980

NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE OF OCEANOGRAPHIC SCIENCES

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Wormley, Godalming,
Surrey, GU8 5UB.
(0428 - 79 - 4141)

(Director: Dr. A.S. Laughton)

Bidston Observatory,
Birkenhead,
Merseyside, L43 7RA.
(051 - 653 - 8633)

(Assistant Director: Dr. D.E. Cartwright)

Crossway,
Taunton,
Somerset, TA1 2DW.
(0823 - 86211)

(Assistant Director: M.J. Tucker)

OBSERVATIONS OF TIDES IN THE SEVERN ESTUARY AND BRISTOL CHANNEL

G.A. Alcock and D.T. Pugh

A report prepared for

the Department of Energy

REPORT NO. 112

1980

Institute of Oceanographic Sciences
Bidston Observatory
Birkenhead
Merseyside L43 7RA

CONTENTS

SUMMARY

Recent measurements of sea level at five sites in the Bristol Channel and Severn Estuary by the Institute of Oceanographic Sciences, associated with the possible Severn Barrage Scheme, are reported. Data are analysed for the principal harmonic tidal constituents, which are then adjusted for monthly variability by comparison with analyses from permanent coastal gauges. Estimates are made of the probable errors in these constituents. Data collected by the Hydraulics Research Station, Wallingford, at four coastal stations, as part of the same Scheme, have been analysed in the same way and adjusted for monthly variability. All these analyses are discussed in terms of their contribution to knowledge of the tidal behaviour of the region.

INTRODUCTION

Recent interest in the possibility of a tidal power scheme in the Bristol Channel and Severn Estuary has identified the need for an improved definition of the tidal characteristics of the region. The Institute of Oceanographic Sciences undertook to deploy instruments at six critical locations, for a period sufficiently long to enable the principal harmonic tidal constituents to be determined by analysis Normally a complete lunation of 28 days, or more, are required for this. The Hydraulics Research Station have also made sea-level measurements at four coastal sites, which are important for tidal definition. These levels have also been harmonically analysed by IOS, at the request of the Hydraulics Research Station.

The Energy Technology Support Unit, for the Department of Energy, requested IOS to review the data collected both by IOS and by HRS, and to place them in the context of existing data.

This Report contains details of the IOS measurements, and summarises the results of the harmonic analyses of both the IOS and HRS data. Details of the HRS measurements are given elsewhere. Comparisons of the data are made at the end of the Report, both for internal consistency, and for consistency with the present knowledge of the tidal behaviour of the region.

IOS MEASUREMENTS, FIELDWORK

Two separate phases of instrument deployment and recovery were undertaken. In the first phase, two bottom mounted pressure recorders were installed at three positions in the Bristol Channel. In the second phase, two bottom mounted pressure recorders and a coastal gauge were installed in the Severn Estuary at Lavernock Point, Steep Holme and Flat Holm respectively. The positions of these gauges are shown in Figure 1 and summarised in Table 1.

Narrative

The Bristol Channel deployment and recovery phase was completed using the University College, Swansea, vessel M.V. OCEAN CREST under charter to IOS. She cleared Swansea locks at 0715 GMT on 31 March and proceeded to the position for BC4, where a pop-up type rig was deployed at 1400 GMT in 59m water depth. The rig consisted of an IOS designed and manufactured Telecast bottom pressure and temperature recorder attached to a ballast frame. Temperatures and pressures are integrated for 15 minutes and then logged on magnetic tape under quartz crystal timing control. During deployment the wind was force 5-6 from the south-west and there was moderate swell. OCEAN CREST then proceeded to Padstow for overnight anchoring. Next day, 1 April, she sailed at 0600 GMT to position BC3, where a second pop-up rig was deployed at 1250 GMT. A third rig was deployed at BC5 at 1710 GMT, in conditions of heavy swell from the south-west, and a force 4 wind from the north-west. OCEAN CREST berthed in Swansea at 2000 GMT.

For the recovery, OCEAN CREST left Swansea at 0200 GMT on 28 April in conditions of moderate swell and a force 4 north-west wind. Rig BC4 was recovered at 0928 using the usual method of acoustic release for the pop-up rig. Following an overnight anchoring at

Padstow, OCEAN CREST proceeded to BC3 on 29 April, where the rig was released and recovered at 1256 GMT. There was mud attached to one side of the gauge frame. Transmitting to release BC5 began at 1640 GMT. The beacon pinger switched on at 1658 GMT, but the gauge failed to respond to the release command, despite prolonged transmission to 1840 GMT. Conditions were smooth seas and light airs. On 30 April OCEAN CREST returned to the site from Swansea and transmitted from 1020 GMT to 1330 GMT, which again switched on the locate beacon of the gauge, but failed to actuate the release. On 1 May conditions were too rough for further work. The site was visited again on 2 May, with additional acoustic expertise from Bidston. Transmission from 0555 GMT to 0800 GMT again succeeded in switching on the beacon but not the release. Conditions were a force 5 wind from the south-east, moderate swell, and the OCEAN CREST was rolling heavily.

More elaborate attempts at recovery were made on 21 May using a different vessel.The MARY GURINE sailed from Cardiff at 1030 GMT, reaching BC5 position at 1530 GMT. Buoys were dropped at the positions of original deployment, of loudest beacon signal, and where the beacon was first switched on. Conditions were ideal, with little wind, smooth sea and very low swell. MARY GURINE left for Cardiff at 1900 GMT and arrived at 0100 on 22 May. A similar attempt was made on 7 July, again using the MARY GURINE.

After leaving Cardiff at 1450 GMT, transmission begain at 1900 GMT. The beacon failed to respond to the acoustic command. Two hours trawling produced nothing except a few fish. After an overnight anchoring in Swansea, the site was revisited; dragging and acoustic transmission were continued from 0550 GMT to 1030 GMT. Weather conditions were again ideal, but nothing was recovered.

Further attempts at recovery were also made by NERC research vessels during IOS scientific cruises. On 16 June R.R.S. Challenger, using different acoustic equipment to that used previously, succeeded in switching the beacon pinger on twice, but was unable to effect recovery after four hours on station. On 9 September R.R.S. John Murray switched on the acoustic beacon and dragged unsuccessfully from 0600 to 1500. From all these activities it is apparent that there is a fault in the electronics which fires the release mechanism.

Gauges in the Severn Estuary were deployed using IOS divers and the MARY GURINE. Permission for the Steep Holme installation was obtained from the Steep Holme Trust. For the Flat Holm installation, permission for access was given by the City of Cardiff Estates Office, acting on behalf of the County Council of South Glamorgan. On 7 May equipment was off-loaded at Flat Holm and low-water inspections were made at the proposed sites of Lavernock Point and Steep Holme. The Steep Holme gauge was installed by divers at 0630 GMT on 8 May: the gauge was mounted within a steel box with lead ballast, and fixed with a Danforth anchor attached to 20m of chain in such a manner that the rig was aligned parallel to the flood and ebb tidal streams. Both tide gauge and anchor were buoyed so that the buoys were only visible at low water. A preventer wire was also attached to the box, led ashore and attached to ring bolts, drilled into the cliff face, to the west of the landing steps. The Lavernock Point installation was completed in a similar way by 1900 GMT, except that the preventer wire was attached to a sewer pipe.

The Flat Holm installation, consisting of a standard IOS pneumatic pressure point outlet, connecting tubing and pneumatic control circuitry, was completed on 9 and 10 May. The Aanderaa recorder was housed in the Trinity House magazine hut on the cliff above the

landing beach. From here the pneumatic tubing was led down to, and along the Trinity House jetty, to the pressure point, which was mounted on an angle-iron frame protruding some 2m beyond the end of the Jetty. The zero level of this outlet was levelled at 10.439m below the bench mark on the seaward side of the wall of the landing steps under the hut on the north cliff. The Hydrographic Department of the Navy have defined Chart Datum at 13.27m below this mark. Unfortunately this gauge zero level, which was the lowest practically obtainable, was some 2.8m above Lowest Astronomical Tide, so that on Spring tides the lowest levels are not recorded. A permanent pressure point could not have been installed in deeper water because of the unusual mobility of the large beach boulders. Special analysis techniques have been developed to cope with this data (see the section on data analysis). The gauge began recording on 10 May, but a serious fault with the logger was identified, whereby the pressures were logged continuously, rather than at 15 minute intervals. The gauge was left operating in this way until a replacement could be fitted.

On 14 May the IOS divers checked the installations at Steep Holme and Lavernock Point. At Steep Holme it was necessary to reposition the preventer wire, which had been removed from the ring bolt. The marker buoys had also disappeared. Two new Aanderaa loggers (Numbers 106 and 265) were fitted at Flat Holm and the system was checked to be working satisfactorily, before returning to Cardiff.

The Severn Estuary gauges were recovered on 18 June, again using the MARY GURINE and IOS divers. The Steep Holme gauge was removed at 1415 GMT, there being no sign of anchors, chain, buoys or rope; the gauge box appeared to have moved slightly from its position on 14 May, but there were no signs of drag marks on the underside. The Lavernock Point gauge was recovered intact at 1650 GMT. The Flat Holm

gauge was inspected, found to be in good operational order, and one recorder (265) was left running. The other recorder, and the magnetic tapes from both were then returned to Bidston for processing.

ANALYSES OF IOS DATA

The bottom pressure gauge records at BC3, BC4, Lavernock Point and Steep Holme were processed in a similar way. The coastal pressure measurements at Flat Holm were processed and analysed slightly differently.

For the bottom pressure gauges, each pressure and temperature recorder consisted of an Aanderaa current-meter type logger modified to accept input from a pressure sensor containing a Bell and Howell type 4-306 strain gauge pressure transducer and a platinum resistance thermometer. The pressure and temperature transducers and electronics were all mounted in the same aluminium heat sink for compatible data. Further details of the gauges are given in Alcock and Howarth, 1978.

Calibrations of the pressure and temperature sensor packs were made by members of the Bidston Research Technology Group. Pressure sensitivities for gauge 281 were 0.078 Hz mb^{-1} and 0.125 Hz mb^{-1} respectively for the BC3 and Lavernock Point sites; for gauge 284 they were 0.078 Hz mb^{-1} and 0.103 Hz mb^{-1} at BC4 and Steep Holme. The corresponding temperature coefficients, used to correct the sensor output, were -6.4 mb $^{o}C^{-1}$ and -5mb $^{o}C^{-1}$ for 281, and -23.0 mb $^{o}C^{-1}$ and -32.0 mb $^{o}C^{-1}$ for 284.

The magnetic tape from each of the records was translated and the data stored on 9-track magnetic tape using a Camac system at Bidston. The data were then read into tape and disk storage on the NERC Honeywell 66/60 computer. Temperature and pressure counts were converted to frequencies, and plotted to check for anomalous values. A second program calculated the corresponding temperatures, which were stored on disk. A third program calculated the temperature - corrected pressure frequencies, which were then converted to sea-bed pressures in millibars. The 15-minute values were stored on disk,

punched on cards and plotted.

Hourly values of pressure (GMT) were computed from these stored values using a low pass filter (FLP03) of half-length 18 values and a half-power point cut-off frequency of 0.35 c h^{-1}; this reduced the amplitude response at the M6 tidal frequency by 1% but had negligible effect at other tidal frequencies. The resulting series was then interpolated, using a cubic spline, to obtain the hourly values, applying time corrections if the clock was fast or slow. Errors due to interpolation are of the order of 0.02 mb. Records contained sensor drift and meteorological surge data at this stage. For the recorders deployed at Steep Holme and Lavernock Point sufficient data were available to allow high pass filtering of the hourly values to remove these elements. The filter used (FHP53) had a cut-off frequency at the half-power point of 0.027 c hr^{-1} and a half-length of 72 values. This process could not be applied to the series from BC3 and BC4 due to the short length of data. Although ideally a slightly longer record would have been desirable, it was necessary to restrict the length to slightly under 28 days because of the availability of OCEAN CREST and because of the need to take advantage of suitable weather for working.

For the coastal Aanderaa record from Flat Holm, the gauge counts were read using the Camac system and transferred to magnetic tape. The values were then edited on the Honeywell 66/60 computer using an interactive program, and converted to water head pressure in millibars using the laboratory calibration and a field check of zero stability. The 15-minute values would normally have been filtered to produce hourly pressures in GMT, but application of the 7-point Lagrangian filter to the drying-out data would have produced wrong

values for two hours before and after the drying out of the gauge sensor, in addition to those during the dry period itself. Instead, it was necessary to develop a special program to input 15-minute values into the tidal analysis programs. Therefore, the 15-minute values were converted directly to 15-minute sea levels using a modified version of an existing program to correct for the seawater density, and the dynamic and static pressure heads in the tube connecting the recorder to the pressure point outlet at the end of the jetty. These corrections are of the order of 1.0 mb. It should be realised that this coastal gauge records the water head pressure alone, whereas the bottom mounted gauges recorded water head plus atmospheric pressure.

Analyses to obtain the tidal constituents of the records were carried out using the IOS TIRA package, which performs a least-squares fit to the data. From one month of data, many constituents are not separable and so have to be related to larger tidal constituents using values from longer analyses at nearby permanent coastal stations. In order to produce systematic analyses for the Bristol Channel and Severn Estuary a standard set of 27 major and 8 related constituents was required. The regional relationships for the eight constituents were determined by using analyses from Milford Haven, Ilfracombe, Swansea, Newport and Avonmouth, as summarised in Table 2.

Analyses were made of the filtered hourly values of bottom pressure at Lavernock Point and Steep Holme, and of the 15-minute bottom pressures at BC3 and BC4.

For Flat Holm it was necessary to analyse by fitting a least-squares curve only to those 15-minute values of sea level which were above the drying level. Dr J M Vassie (personal communication), IOS Bidston, has developed a program which treats data in this way, and

has found by numerical experiments that stable tidal constituents are obtained for such data losses, even for losses which extend over the whole of the lower half of the tidal cycle. For Flat Holm only the bottom part of the curve is missing, so that confidence in the results obtained is justified.

Appendix 1 contains a summary of the installations for the four bottom-pressure stations, with the values of the harmonic constituents given in millibars and degrees. The analysis for Flat Holm is also given, but in this case the values of amplitude are in metres. Plots of the observed values are also included.

HYDRAULICS RESEARCH STATION MEASUREMENTS

Measurements of coastal sea levels at sites around the Bristol Channel and Severn Estuary have also been made by the Hydraulics Research Station, Wallingford, as part of the Severn Barrage Scheme. These data have been analysed by IOS at the request of the Hydraulics Research Station, in a way which was consistent with the analyses of the IOS observations. Full details of the observations which were made with Neyrtec bubbler gauges are published by HRS (1980a and b). The positions of the stations are shown in Figure 1.

In order to produce a coordinated account of all the measurements for the Severn Barrage Scheme, IOS has been asked to include the analyses of HRS data in this Report. Details of the analyses, which used the same constituents and relationships as the analyses of IOS data, are given in Appendix 2.

Note that the analysis of the Port Isaac data contained in this Report is different to that contained in IOS, Internal Document No. 114, because HRS subsequently reprocessed the data in order to correct small errors.

ERROR ESTIMATES AND COMPARISON OF ANALYSES

The requirement of producing a coherent set of tidal constants from a limited area, where differences are small, is best met by having a set of simultaneous observations. However, the analyses reported here are of data collected at various times during 1979/80.

Identical analyses of different one month periods of sea level data, even from the same site, will produce different values of the harmonic 'constants'. Small changes in the astronomical forcing functions are incorporated in the analyses, and so cannot account for the variability. It is well known, for example, that the principal semi-diurnal lunar constituent varies seasonally (Pugh and Vassie, 1976) for sea levels on the shallow waters of the continental shelf. In the North Sea, at the Inner Dowsing Light Tower, M2 amplitude varied from 1.92m to 2.01m, with a standard deviation for the monthly determinations about the mean of 0.029m, or 1.5%. Phases varied from 160.5^{o} to 163.5^{o} with a standard deviation of 1^{o}. It is likely that interaction between tides and meteorological inputs, including surges, is responsible for the variability. It is also likely that the shallow water areas of the Severn Estuary will be particularly liable to such interaction.

Pragmatically it is possible to approach the problem by applying two processes:

a) estimate the standard error in the analysis of a month of data by comparing the coherent and non-coherent energy at the tidal frequencies.

b) adjust the amplitudes and phases of the major constituents for monthly changes by comparing a simultaneous analysis at a nearby Standard Port with a longer term analysis at the same port.

a) Estimation of standard errors in a harmonic analysis

The appropriate formulae are:

$$\text{Standard error in amplitude (H)} = \frac{N}{\sqrt{2}}$$

$$\text{in phase} = \frac{N}{H\sqrt{2}}$$

where N^2 is the background noise variance - that part of the signal at tidal frequencies which is not coherent with the tidal forcing. N^2 is the variance in an 'elemental band' around the constituent frequency. For a time series of length T, the 'elemental band' has a frequency span of $\frac{1}{T}$. However, normally it is better to average the noise level over a series of bands, for example the whole of the diurnal or semi-diurnal frequency band might be considered. If the tidal residual variance in the averaging band, of width ΔF, is S^2, then the noise density is $S^2/\Delta F$. Then the value of N^2 to be used to calculate standard errors is given by

$$N^2 = \frac{S^2}{T.\Delta F}$$

Averaging over a whole tidal band for S^2 will tend to underestimate N^2, because it assumes a uniform noise density across the band, whereas the noise background in practice rises around the major tidal lines - presumably because of incoherent interactive effects as discussed above. In the absence of a relevant study of these effects, our errors are, however, based on the average residual energy in each tidal band.

Spectral analyses were made on the residuals left after tidal analyses at the four IOS bottom pressure stations and the four HRS stations. For Flat Holm, because of the drying out of the pressure point, spectral analysis of the data was not possible. Instead the average levels of simultaneous background noise levels at Steep Holme and Lavernock Point were used to estimate standard errors.

Table 3 shows the results of these estimates.

b) Empirical adjustment using standard ports

Two standard ports where chosen for this comparison. Milford Haven was selected for the four stations close to the $5^{o}W$ line, and Avonmouth was chosen for the four stations in the Severn near $3^{o}W$. Minehead data were adjusted using Avonmouth as a standard port. Data were obtained from the local authorities, processed and analysed in the standard way described earlier. Because of the spread in time of observations, severalmonths of records had to be reduced for these analyses. Table 4 shows the adjusted values of the principal constants at the $5^{o}W$ sites and Minehead, and Table 5 shows the adjusted values for the Severn Estuary stations. Where bottom pressures in millibars are the units of the original analysis, adjustment to centimetres water head has been made using the appropriate values of water density and gravitational acceleration, according to the static relationship:-

$$\text{water head} = \text{pressure}/(\text{density} \times \text{gravitational acceleration}).$$

One millibar is equivalent to 0.01m to better than 1% accuracy, so numerical changes in amplitudes are only significant for the largest constituents.

DISCUSSION

It is appropriate to compare the new analyses with previous analyses and with each other, and to consider how the extended data set describes the tidal behaviour of the region. Previous descriptions of tidal behaviour include Bowden (1955) and the recent unpublished Hydrographic Department Chart (Commander N. C. Glen, personal communication).

Tables 4 and 5 summarise the principal newly determined constituents; the detailed full analyses with amplitudes in centimetres and phases in degrees relative to Greenwich, are given in the final two columes of Tables A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8:2 and A_9:2. Standard errors based on the residual variance in each band after tidal analysis, are presented in Table 3, but these error estimates are very small compared with monthly variability and associated other errors. Table 6 summarises previous analyses and gives the values of amplitude and phase for the M_2 and S_2 semidiurnal constituents and for the main shallow-water constituent, M_4. The locations of these sites are shown in Figure 2.

Taking first the Stations along the $5^{o}W$ line, for which the constants (after adjustment in the case of M_2 and S_2) are shown in Table 4. These give a consistent set of constants for M_2, confirming the propagation from a south-westerly direction of a progressive Kelvin wave: the coamplitude lines are tending to be orthogonal to the cophase lines. The Stackpole Quay analysis fits well into the pattern established by a recent IOS one-year analysis at nearby Tenby. The time delays relative to Port Isaac for BC4, BC3 and Stackpole Quay are 14, 40 and 51 minutes respectively.

The failure to recover the gauge at BC5, although unfortunate, was less important in terms of the tidal behaviour of the Channel than would have been the loss of gauges at other sites. The Minehead analysis is consistent with the previous Hydrographic Department analysis for Watchet, but the Porlock analysis, based on only 15 days of data, now appears suspect.

The closely spaced line of Stations (Table 5) from Lavernock Point to Birnbeck shows fair agreement and established trends. The three simultaneous data sets at Lavernock Point, Flat Holm and Steep Holme, are in particularly good agreement. This agreement is especially satisfactory because the methods of measurement and analysis at Flat Holm were quite different from the methods used for Lavernock Point and Steep Holme. The Birnbeck analysis, using data obtained using a chart recorder, and at a different time, gives reasonable agreement in the amplitude of M_2, after empirical adjustment, but the phase is difficult to reconcile with the other analyses. The values of M_2 and S_2 phases in Table 5 appear to be some 10-20 minutes earlier than the extrapolation of the other phases would predict. In addition, the amplitude of the N_2 constituent at Birnbeck is much larger than the other new analyses, or previous analyses would indicate. Even an empirical adjustment based on the simultaneous Avonmouth analysis, which reduces it to 96cm fails to remove the anomaly.

The empirical adjustment to the monthly-determined values of the M_2 and S_2 harmonic constituents has certainly produced a more coherent data set, but the level of variability is surprisingly high. Analyses of a year of data from Avonmouth (day 195, 1961 to day 194, 1962) in 29-day blocks, with a 7 day increment, showed variations of $\pm$ 3% in M_2 amplitude and $\pm 2^{o}$ in M_2 phase. The corresponding varia-

tions for S_2 were $\pm$ 5% and $\pm$ 3°, and for N_2, $\pm$ 26% and $\pm$ 16°. To avoid the inevitable uncertainty involved in empirical adjustment, it is more satisfactory to plan a survey of tidal conditions in a confined shallow-water region, with simultaneous instrument deployment. It should be remembered that previously published one-month analyses have not been empirically adjusted, and so they have the range of variability quoted above for Avonmouth, associated with their constants. This is very important when running numerical models to fit published data. The mechanism which causes the variability is not properly understood: some changes are seasonal, but in general terms the variability in the results of 29-day analyses is thought to be due to the analysis procedure also fitting to the unstable tide-surge interaction component in the sea-level changes, rather than to the true tidal signal alone. The variability from year to year will certainly be much smaller than this, but a long-term data set from the Severn Estuary is not available for analysis.

Returning to the tidal behaviour of the Bristol Channel as a whole, the transition between the dominantly progressive wave regime at 5°W, and the dominantly standing wave regime of the Upper Estuary, extends over a large region, but is substantially completed at 3° 40'W. Near the Flat Holm section the cophase and co-amplitude lines are nearly parallel, indicative of a standing wave. The diurnal tidal constituents, which also show monthly variability, are too small to be of practical significance in the region. A proper quantitative description of tides in the Bristol Channel, probably in the form of a series of charts, would require treatment of all available current meter data in conjunction with the level

data; this would be a major research undertaking, beyond the scope of the present requirement, and one which would also require data from the Celtic Sea to be incorporated.

Measurements at Flat Holm will continue until a complete year of data is available for analysis. The results of these analyses will be reported separately. However, it is interesting to compare the modern M_2 amplitudes and phases in Table 5 (389.3 cm, 188.8°) with the values obtained from three 29-day analyses of daylight readings in the period 4 May to 14 October 1885 (399.8 cm, and 192°). Within the limits of monthly variability, no secular trend in the tidal conditions is determined, but the large monthly variability puts rather wide limits on this apparent stability.

ACKNOWLEDGEMENTS

The IOS measurements were made using instruments prepared by Mr. A. J. Harrison, and deployed by Mr. D. L. Leighton and his colleagues. Flat Holm processing and analyses were carried out by Mrs. J. J. Evans. The analyses of the Hydraulics Research Station Data were effected by Mr. D. L. Blackman. The cooperation of the staff of the Hydraulics Research Station in the preparation of these comparisons is appreciated. The summary of existing tidal analyses was prepared with assistance from Commander N. C. Glen, Hydrographic Department, Taunton.

References

Bowden K. F., 1955, Physical Oceanography of the Irish Sea, Ministry of Agriculture, Fisheries and Food, Fisheries Investigation Series II, No. 8, HMSO, London.

Alcock G. A. and Howarth M. J., 1978, Offshore tide gauge and moored current meter records from the Irish Sea, 1977. Institute of Oceanographic Sciences, Data Report No. 15, 199 pp.

Hydraulics Research Station, 1980a, The Severn Estuary, Recording of tidal levels in 1979. Report No. EX 912.

1980b The Severn Estuary, Recording of tidal levels in 1980. Report No. EX 943.

Pugh D. T. and J. M. Vassie, 1976. Tide and surge propagation in the Dowsing region of the North Sea. Deutsche Hydrographische Zeitschrift, 29, 163-213.

Uncles R. J. and M. B. Jordan, 1979. Residual fluxes of water and salt at two stations in the Severn Estuary. Estuarine and Coastal Marine Science, 9, 287-302.

TABLE 1

Summary of IOS installations

Station	Latitude	Longitude	Deployment	Recovery	Water Depth (m)	Comments
BC3	51°24.6'N	5°0.6'W	01/04/80	29/04/80	60	Teleost Gauge No 281
BC4	50 55.1'N	4 59.9'W	31/03/80	28/04/80	59	Teleost Gauge No 284
BC5	51 23.0'W	3 58.9'W	01/04/80	-	36.5	Teleost Gauge No 280 Not recovered.
Lavernock Point	51 24.4'N	3 9.7'W	08/05/80	18/06/80	4	Teleost Gauge No 284; at end of sewer pipe.
Steep Holme	51 20.3'N	3 6.2'W	08/05/80	18/06/80	5	Teleost Gauge No 281; west of landing steps.
Flat Holm	51 22.8'N	3 7.1'W	data from 14/05/80	continuing		Aanderaa pneumatic gauge outlet at end of jetty.

TABLE 2

Comparison of related harmonic constituents in the Bristol Channel and Severn Estuary.

α is amplitude ratio. β is (G related - G standard)

	MILFORD HAVEN (5°01'W)		ILFRACOMBE (4°07'W)		SWANSEA (3°55'W)		NEWPORT (2°59'W)		AVONMOUTH (2°43'W)		AVERAGE VALUES	
	α	β	α	β	α	β	α	β	α	β	α	β
π_1/K1	0.100	94.6	0.042	-11.34	0.077	110.5	0.223	-139.3	0.084	62.21	0.105	23.3
P1/K1	0.261	18.4	0.371	3.90	0.492	8.6	0.328	-0.8	0.470	8.55	0.384	7.7
ψ_1/K1	0.052	75.7	0.072	-19.41	0.022	127.7	0.113	62.8	0.069	103.49	0.066	70.1
ϕ_1/K1	0.109	88.8	0.019	-9.54	0.098	-30.0	0.126	-20.9	0.054	23.30	0.081	10.3
2N2/N2	0.097	0.7	0.162	21.52	0.128	-3.7	0.136	-35.4	0.100	4.50	0.125	-2.5
ν_2/N2	0.241	11.7	0.271	12.88	0.219	13.1	0.250	15.2	0.270	35.65	0.250	17.7
T2/S2	0.044	-6.4	0.061	19.93	0.067	4.9	0.053	6.5	0.049	18.75	0.055	8.7
K2/S2	0.284	4.0	0.291	2.32	0.274	0.5	0.302	0.7	0.294	1.29	0.289	1.9

Average values have been used for all analyses except that the K2/S2 relationships have been represented as a linear function of longitude.

5°W, Stackpole Quay, Port Isaac	α = 0.277	β = 3.1°
Steep Holme, Lavernock Point, Flat Holm Weston super mare	0.295	1.0
Minehead	0.2905	1.5

For details of standard port analyses, see Table 6

TABLE 3

Amplitude standard errors

STATION	Residual Variance	Diurnal 0.033-0.047 cpd	Semi-diurnal 0.073-0.087 cpd	4-diurnal 0.145-0.177 cpd	6-diurnal 0.225-0.257 cpd
BC3	20 mb^2	0.2 mb	0.6	0.1	0.1
BC4	21 mb^2	0.2 mb	1.0	0.1	0.2
Lavernock Point	69 mb^2*	0.3 mb	1.6	0.5	0.3
Steep Holme	68 mb^2*	0.3 mb	1.5	0.5	0.3
Weston-s-mare	643 cm^2	0.8 cm	3.1	0.6	0.6
Minehead	187 cm^2	0.4 cm	2.4	0.2	0.1
Port Isaac	111 cm^2	0.3 cm	1.6	0.4	0.3
Stackpole Quay	91 cm^2	0.4 cm	1.4	0.3	0.2

* highpass filtered before spectral analysis.

Table 4 Comparison of principal harmonic constants, Bristol Channel.

		Port Isaac	BC4	BC3	Stack-pole Quay	Mine-head
O1	H(cm)	7.2	6.5	7.0	7.1	7.9
	G°	342.9	347.6	352.8	348.7	5.6
K1	H(cm)	7.1	4.3	4.5	5.7	6.1
	G°	109.2	115.7	124.7	109.4	151.9
M2	H(cm)	244.4	235.9	232.7	248.0	361.4
	G°	143.0	149.9	162.3	167.5	179.5
S2	H(cm)	86.3	86.1	85.2	94.0	128.7
	G°	180.8	193.4	206.5	212.2	233.8
N2	H(cm)	51.3	42.4	41.7	47.1	66.3
	G°	127.9	128.4	140.4	150.9	160.7
M4	H(cm)	6.6	4.9	4.9	5.5	10.4
	G°	239.1	268.0	302.7	314.5	21.7
M6	H(cm)	0.6	0.6	0.4	1.1	1.3
	G°	60.4	98.6	81.3	50.8	271.0

Table 5 Comparison of principal harmonic constants, Severn Estuary.

		Birn-beck	Steep Holme	Flat Holm	Laver-nock Point
O_1	H(cm)	7.1	8.5	9.2	8.3
	G^o	335.7	359.0	359.3	359.3
K_1	H(cm)	3.6	7.5	7.4	7.4
	G^o	117.4	124.5	120.5	127.0
M_2	H(cm)	390.0	387.5	389.3	393.1
	G^o	180.7	186.1	188.8	189.5
S_2	H(cm)	147.6	137.4	137.2	138.8
	G^o	234.0	239.7	243.1	243.8
N_2	H(cm)	104.6	60.7	60.0	61.4
	G^o	172.1	176.0	179.6	180.0
M_4	H(cm)	12.3	8.1	12.7	12.3
	G^o	344.7	30.0	32.1	13.1
M_6	H(cm)	4.7	5.6	4.1	6.4
	G^o	201.5	224.2	225.4	231.7

TABLE 6

SUMMARY OF AVAILABLE TIDAL ANALYSES

N = total pairs of harmonic constants

Site	Lat.	Long.	Data length (days)	Year of Data	N	Source	M2 H (m)	M2 G(o)	S2 H	S2 G	M4 H	M4 G
Avonmouth	51°30'N	2°43'W	365	1961/2	60	IHB 1126	4.22	201.9	1.475	260.9	0.34	346.8
Ilfracombe	51 13 N	4 7 W	1095	1968/71	120	IOSB	3.07	162.2	1.12	208.7	0.10	348.7
Milford Haven	51 44 N	5 2 W	365	1953/4	60	IOSB	2.23	171.5	0.83	215.6	0.06	306.5
Newport (Mon)	51 33 N	2 59 W	365	1962/3	60	IOSB	4.13	198.0	1.48	254.8	0.18	357.0
Swansea	51 37 N	3 55 W	365	1961/2	60	IOSB	3.15	173.2	1.13	220.0	0.06	29.2
Tenby	51 40 N	4 43 W	330	1977/8	104	IOSB	2.72	171.5	0.97	217.2	0.05	328.5
Appledore	51 3 N	4 12 W	29	1949	9	IHB 2201	2.54	165.0	0.92	211.0	0.17	272.0
Barry	51 23 N	3 16 W	29	1947	22	IHB 761	3.82	186.0	1.43	238.0	0.12	32.0
Beachley Pier	51 37 N	2 39 W	29	1929	9	IHB 2135	4.17	211.0	1.52	279.0	0.41	359.0
Cardiff	51 27 N	3 09 W	58	1956/77	32		3.92	192.0	1.46	247.0	0.13	19.0
Porthcawl	51 28 N	3 42 W	30	1949	9	IHB 2227	3.17	173.0	1.25	228.0	0.12	9.0
Watchet	51 11 N	3 20 W	30	1961	9	HD	3.62	179	1.26	239	0.11	39
Weston-s-mare	51 21 N	2 59 W	15	1953	9	HD	4.23	197	1.35	247	0.10	353
Flat Holm	51 23 N	3 7 W	87	1885	15	IOSB	4.00	192.0	1.31	250.0	0.11	29.0
Clevedon	51 27 N	2 51 W	87	1901	15	IOSB	4.15	196.0	1.38	258.0	0.15	355.0
Instow	51 4 N	4 10 W	30	1972	17	HD	2.51	172	0.84	224	0.22	293
Padstow	50 33 N	4 56 W	17	1972	12	HD	2.45	149.0	0.94	192.0	0.08	254.0

Boscastle	50°42'N 4°42'W	15 1972	12 HD	2.36	143.0	0.89	201.0	0.13	32.0
Lundy	51 11 N 4 40 W	28 1976	27 IOSB	2.58	162.6	0.93	207.6	0.04	308.7
Port Talbot	51 35 N 3 49 W	30 1965	18 HD	3.15	173.0	1.15	220.0	0.05	26.0
Porlock	51 13 N 3 38 W	15 1949	12 HD	3.42	189	0.78	221	0.04	58
Aust	51 36 N 2 38 W	30 1962	25 HD	4.15	210	1.34	272	0.39	358
Berkeley	51 42 N 2 30 W	30 1962	25 HD	3.01	234	0.94	303	0.80	65
Wellhouse Rk.	51 44 N 2 29 W	30 1962	25 HD	2.68	237	0.88	296	0.82	83
Inward Rocks	51 39 N 2 37 W	30 1962	24 HD	3.94	223	1.26	290	0.52	21
White House	51 40 N 2 33 W	30 1962	25 HD	3.54	224	1.14	287	0.63	53
Mumbles	51 34 N 3 58 W	29 1977	35 UCS	3.17	175.6	1.09	218.4	0.11	39.2
Rhossili	51 34 N 4 19 W	29 1977	35 UCS	2.79	170.6	0.99	214.2	0.06	1.2

Analysis source key:-

IHB	International Hydrographic Bureau Lists
IOSB	Institute of Oceanographic Sciences (Bidston)
HD	Hydrographic Department of the Navy, Taunton
UCS	University College Swansea.

Figures

APPENDIX 1:

Summary of IOS deployments and data analyses

Recorder position	:	Station BC3, Bristol Channel, 1980. Lat 51°24'35"N, Long 05°00'36"W. $g = 9.812\ ms^{-2}$.
Water depth	:	60m.
Recorder details	:	Teleost PR 281. 900s sampling and integration periods.
Time of launch	:	In water from M.V. "Ocean Crest" at 1250 GMT day 092 (01 April).
Time of recovery	:	On surface at 1254 GMT day 120 (29 April).
Water density	:	1027.0 Kg m^{-3} from measured temperatures and a regional salinity of 35.0‰ (Bowden, 1956).
Comments	:	On recovery, mud was found on one side of the frame as if the rig had been held in mud.

Timing	:	Scan no. 1 at 0930,00 GMT day 088. Scan no. 3458 at 0944,42 GMT day 124. Clock fast, gained 18 seconds in 36 days and 1/4 hour.
Raw data	:	Start 1307,28 GMT day 092 End 1237,14 GMT day 120.
Temperature data	:	As for raw data.
Hourly data	:	Start 1800 092) End 2300 120) Unfiltered. See Comments.
Tidal analysis	:	TIRA, 1307 GMT day 092 to 1237 GMT day 120, 27 days and 23.5 hours, using 27 major and 8 related constituents from average relations of Milford Haven, Ifracombe, Swansea, Newport and Avonmouth.
Comments	:	Original unfiltered hourly series was from 1800 GMT day 092 to 0700 day 120, 27 days and 13 hours. This was extrapolated to give a common period of data with the record from station BC4. The hourly series was not filtered due to the length of data.

Table A1

Station BC3, Bristol Channel, Lat 51°24·6'N Long 05° 0.6'W
Unfiltered bottom pressure (Millibars). PR 281/5.
1307 GMT day 092 to 1237 GMT day 120, 1980. 27 days and 23.5 hours.
* Related constituents using averaged relations.

Constituent	related to	H(mb)	G(°)	Period Adjustment factor α	factor β	H(cm)	G(°)
Q1		2.5	286.3			2.4	286.3
O1		7.1	352.8			7.0	352.8
M1		0.2	305.9			0.2	305.9
* π1	K1	0.5	148.0			0.5	148.0
* P1	K1	1.7	132.4			1.7	132.4
K1		4.5	124.7			4.5	124.7
* ψ1	K1	0.3	194.8			0.3	194.8
ϕ1		0.4	135.0			0.4	135.0
J1		0.8	125.1			0.8	125.1
OO1		0.5	203.7			0.5	203.7
* 2N2	N2	5.3	137.9			5.2	137.9
μ2		9.0	186.1			9.0	186.1
N2		42.0	140.4			41.7	140.4
* ν2	N2	10.5	158.1			10.4	158.1
M2		235.3	164.6	0.989	-2.3	232.7	162.3
L2		14.6	172.2			14.5	172.2
* T2	S2	4.7	218.3			4.6	218.3
S2		85.1	209.6	1.002	-3.1	85.2	206.5
* K2	S2	23.6	212.7			23.4	212.7
2SM2		2.8	36.9			2.7	36.9
MO3		0.6	173.6			0.6	173.6
M3		1.9	115.1			1.9	115.1
MK3		0.1	276.0			0.1	276.0
MN4		2.2	254.4			2.1	254.4
M4		5.0	302.7			4.9	302.7
SN4		0.5	108.7			0.5	108.7
MS4		2.4	1.2			2.4	1.2
2MN6		0.3	50.0			0.3	50.0
M6		0.4	81.3			0.4	81.3
MSN6		0.2	17.7			0.2	17.7
2MS6		0.5	92.9			0.5	92.9
2SM6		0.2	111.8			0.2	111.8

Recorder position	:	Station BC4, Bristol Channel, 1980. Lat 50°55'05" N, Long 04°59'54"W. $g = 9.811\ ms^{-2}$.
Water depth	:	59m.
Recorder details	:	Teleost PR284. 900s sampling and integration periods.
Time of launch	:	In water at 1405 GMT day 091 (31 March).
Time of recovery	:	On surface at 0928 GMT day 119 (28 April).
Water density	:	As for BC3.
Comments	:	

Timing	:	Scan No. 1. at 1345,00 GMT day 088. Scan No. 3441 0944,52 GMT day 124. Clock fast, gained 8 seconds in 35 days 20 hours.
Raw data	:	Start 1422,29 GMT day 091. End 0852,23 GMT day 119.
Temperature data	:	As above for raw data.
Hourly data	:	Start 1900 091) End 2300 120) Unfiltered. See Comments.
Tidal analysis	:	TIRA, 1422 GMT day 091 to 0852 GMT day 119, 1980, 27 days and 17.5 hours, using 27 major and 8 related constituents from average relations of Milford Haven, Ifracombe, Swansea,Newport and Avonmouth.
Comments	:	Original unfiltered hourly series from 1900 GMT day 091 to 0300 day 119, 27 days and 8 hours. This was extrapolated to give a common period of data with the record from station BC3. The hourly series was not filtered due to the length of data.

Table A2

Station BC4, Bristol Channel, Lat 50°55.1'N, Long 04°59.9'W.
Unfiltered bottom pressure (millibars). PR 284/2.
1422 day 091 to 0852 day 119, 1980. 27 days and 17.5 hours.
* Related constituents using averaged relations.

Constituent	related to	H(mb)	G(°)	Period Adjustment factor α	Period Adjustment factor β	H(cm)	G(°)
Q1		2.6	278.8			2.6	278.8
O1		6.6	347.6			6.5	347.6
M1		0.04	16.1			0.04	16.1
* π1	K1	0.5	139.0			0.4	139.0
* P1	K1	1.7	123.4			1.6	123.4
K1	K1	4.3	115.7			4.3	115.7
* ψ1	K1	0.3	185.8			0.3	185.8
* ϕ1		0.3	126.0			0.3	126.0
J1		1.0	130.7			1.0	130.7
OO1		0.04	237.2			0.04	237.2
* 2N2	N2	5.3	125.9			5.3	125.9
μ2		8.7	173.4			8.7	173.4
N2		42.7	128.4			42.4	128.4
* ν2	N2	10.7	146.1			10.6	146.1
M2		238.6	152.2	0.989	-2.3	235.9	149.9
L2		14.8	159.2			14.7	159.2
* T2	S2	4.7	205.3			4.7	205.3
S2		85.7	196.6	1.005	-3.2	86.1	193.4
K2	S2	23.7	199.7			23.6	199.7
2SM2		3.0	30.1			3.0	30.1
MO3		0.7	158.1			0.7	158.1
M3		2.0	92.8			2.0	92.8
MK3		0.2	259.6			0.1	259.6
MN4		2.2	217.4			2.2	217.4
M4		4.9	268.0			4.9	268.0
SN4		0.5	83.3			0.5	83.3
MS4		2.0	327.3			1.9	327.3
2MN6		0.5	70.6			0.5	70.6
M6		0.6	98.6			0.6	98.6
MSN6		0.2	7.6			0.2	7.6
2MS6		0.6	106.1			0.6	106.1
2SM6		0.3	121.5			0.3	121.5

Recorder position	:	Station BC5. Bristol Channel, 1980. Lat 51°23'00"N, Long 03°58'54"W. $g = 9.812\ ms^{-2}$.
Water depth	:	36.5m.
Recorder details	:	Teleost PR 280. 900s sampling and integration periods.
Time of launch	:	In water at 1710 GMT day 092 (01 April).
Time of recovery	:	Not recovered.
Comments	:	Extensive acoustic and dragging exercises have failed to recover this gauge.

Recorder position	:	Steep Holme, Severn Estuary, 1980. Lat 51°20'16"N, Long 03°06'13"W. $g = 9.812\ ms^{-2}$.
Water depth	:	4.7m.
Recorder details	:	Teleost PR 284. 900s sampling and integration periods.
Time of launch	:	In water at 0636 GMT day 129 (08 May).
Time of recovery	:	Out of water at 1415 GMT day 170 (18 June).
Water density	:	1022.0 Kg m^{-3} from measured temperature and 29.2‰ salinity (Uncles and Jordan, Station A, 1979).
Comments	:	A Danforth anchor with 18m of chain was deployed connected to the recorder box so that the rig was parallel to the flood and ebb tide. Inspection of site at 1430 GMT day 135 revealed position of recorder had moved about 15m to east due to dragging when buoys removed.

Timing	:	Scan no. 1 at 1029,52 GMT day 124. Scan no. 6650 at 1644,40 GMT day 193. Clock fast, gained 12 seconds in 69 days and 6¼ hours.
Raw data	:	Start 0652,29 GMT day 129 End 1407,22 GMT day 170.
Temperature data	:	As for raw data.
Hourly data	:	Start 1100 GMT day 129) End 0800 GMT day 170) Unfiltered. Start 1100 day 132) Filtered End 0800 day 167) using FHP53.
Tidal analysis	:	TIRA, 0000 day 138 to 2300 day 166, 29 days of filtered data, using 27 major and 8 related constituents from average relations of Milford Haven, Ilfracombe, Swansea, Newport and Avonmouth.
Comments	:	

Table A3

Steep Holme, Severn Estuary, Lat 51°20'16"N Long 03°06'13"W.
Filtered bottom pressure (millibars). PR 284/6.
Days 138 to 166, 1980, 29 days.
*Related constituents using averaged relations.

Constituent	related to	H(mb)	G(°)	Period Adjustment factor α	Period Adjustment factor β	H(cm)	G(°)
Q1		2.9	314.9			2.8	314.9
O1		8.5	359.0			8.5	359.0
M1		1.0	161.3			1.0	161.3
* π1	K1	0.8	147.8			0.8	147.8
* P1	K1	2.9	132.2			2.9	132.2
K1		7.5	124.5			7.5	124.5
* ψ1	K1	0.5	194.6			0.5	194.6
* ϕ1	K1	0.6	134.8			0.6	134.8
J1		0.6	327.2			0.6	327.2
OO1		1.3	196.5			1.3	196.5
* 2N2	N2	7.6	173.5			7.6	173.5
μ2		29.8	250.2			29.7	250.2
N2		60.9	176.0			60.7	176.0
* ν2	N2	15.2	193.7			15.2	193.7
M2		402.0	185.9	0.964	+0.2	387.5	186.1
L2		28.3	197.7			28.2	197.7
* T2	S2	7.6	253.5			7.6	253.5
S2		138.0	244.8	0.996	-5.1	137.4	239.7
* K2	S2	40.7	245.8			40.6	245.8
2SM2		6.4	51.4			6.4	51.4
MO3		0.4	181.2			0.4	181.2
M3		4.7	189.8			4.7	189.8
MK3		1.5	179.6			1.5	179.6
MN4		5.0	328.2			5.0	328.2
M4		8.1	30.0			8.1	30.0
SN4		1.2	220.9			1.2	220.9
MS4		2.9	359.2			2.9	359.2
2MN6		2.2	202.4			2.2	202.4
M6		5.6	224.2			5.6	224.2
MSN6		2.2	262.0			2.2	262.0
2MS6		5.8	261.9			5.8	261.9
2SM6		1.4	324.0			1.4	324.0

Recorder position	:	Lavernock Point, Severn Estuary, 1980. Lat 51°24'25"N. Long 03°09'44"W. $g = 9.812\ ms^{-2}$.
Water depth	:	4m.
Recorder details	:	Teleost PR 281. 900s sampling and integration periods.
Time of launch	:	In water at 1856 GMT day 129 (08 May).
Time of recovery	:	Out of water at 1650 GMT day 170 (18 June).
Water density	:	As for Steep Holme.
Comments	:	Rig was similar design to that deployed at Steep Holme.

Timing	:	Scan no.2 at 1029,42 GMT day 124. Scan no. 6651 at 1644,22 GMT day 193. Clock fast, gained 20 seconds in 69 days and $6\frac{1}{4}$ hours.
Raw data	:	Start 1907,29 GMT day 129 End 1622,18 GMT day 170.
Temperature data	:	As for raw data. See Comments.
Hourly data	:	Start 0000 day 130) End 1100 day 170) Unfiltered. Start 0000 day 133) Filtered End 1100 day 167) using FHP 53.
Tidal analysis	:	TIRA, 0000 day 138 to 2300 day 166, 29 days of filtered data, using 27 major and 8 related constituents from average relations of Milford Haven, Ilfracombe, Swansea, Newport and Avonmouth.
Comments	:	Temperature record contained three blocks of errors between 1252,30 day 134 and 2037,30 day 135.

Table A4

Lavernock Point, Severn Estuary, Lat 51 24'25"N, Long 03 09'44"W.
Filtered bottom pressure (millibars). PR 281/6.
Days 138 to 166, 1980, 29 days.
*Related constituents using averaged relations.

Constituent	related to	H(mb)	G(°)	Period Adjustment factor α	Period Adjustment factor β	H(cm)	G(°)
Q1		3.0	318.2			3.0	318.2
O1		8.3	359.3			8.3	359.3
M1		0.9	157.3			0.9	157.3
* π1	K1	0.8	150.3			0.8	150.3
* P1	K1	2.8	134.7			2.8	134.7
K1		7.4	127.0			7.4	127.0
* ψ1	K1	0.5	197.1			0.5	197.1
* ϕ1	K1	0.6	137.3			0.6	137.3
J1		0.3	300.6			0.3	300.6
OO1		1.3	183.8			1.3	183.8
* 2N2	N2	7.7	177.5			7.7	177.5
μ2		31.5	254.8			31.4	254.8
N2		61.6	180.0			61.4	180.0
* ν2	N2	15.4	197.7			15.4	197.7
M2		407.8	189.3	0.964	0.2	393.1	189.5
L2		28.8	200.9			28.7	200.9
* T2	S2	7.7	257.6			7.6	257.6
S2		139.4	248.9	0.996	-5.1	138.8	243.8
* K2	S2	41.1	249.9			41.0	249.9
2SM2		6.7	56.3			6.7	56.3
MO3		0.6	180.2			0.6	180.2
M3		4.6	196.8			4.6	196.8
MK3		1.7	195.2			1.7	195.2
MN4		6.5	331.6			6.5	331.6
M4		12.4	13.1			12.3	13.1
SN4		0.3	317.3			0.3	317.3
MS4		6.5	16.2			6.5	16.2
2MN6		2.7	204.0			2.7	204.0
M6		6.5	231.7			6.4	231.7
MSN6		2.3	272.2			2.3	272.2
2MS6		6.4	270.3			6.4	270.3
2SM6		1.4	327.4			1.4	327.4

Recorder position	:	Flat Holm, Severn Estuary, 1980. 51°22'47"N 3°07'08"W. g = 9.812 ms^{-2}.
Datum	:	Gauge outlet 10.439m below benchmark on seaward side of wall of landing slope under hut on north cliff. Outlet at end of Trinity House jetty.
Recorder details	:	Aanderaa differential pressure logger with pneumatic bubbler configuration. Gauge 265. Integration 27s, logging at 15min intervals.
Recording started	:	Logger 265 connected 1700, 15 May.
Recording ended	:	Record 265/7 ended 1415, 19 June. Gauge fitted with new tape and left running.
Water density	:	1022.0 Kg m^{-3} as for Steep Holme and Lavernock Point.
Comments	:	Tube length 100m; tube radius 1.9mm; gauge 27m above outlet zero.
Timing	:	Scan no. 1 at 1700,16 GMT Day 135. Scan no. 3350 at 1415,17 GMT Day 170. Clock lost 1s in 35 days.

Hourly height data not available because gauge dries at low water. Analyses performed on 15m values, from 0000 Day 138 to 2345 Day 166, 1980. Constituents as for Lavernock Point and Steep Holme but with many data blocks.

Table A5

Flat Holm, Severn Estuary, 51°22'47"N 3°7'8"W.
15-minute water head pressures converted to centimetres.
Aanderaa gauge.
Days 138 1980 to 166 1980, 29 days.
*Related constituents.

Constituent	related to	H(cm)	G(°)	Period adjustment factor α	β	H(cm)	G(°)
Q1		3.5	325.8			3.5	325.8
O1		9.2	359.3			9.2	359.3
M1		0.7	172.0			0.7	172.0
* π1	K1	0.8	143.8			0.8	143.8
* P1	K1	2.9	128.2			2.9	128.2
K1		7.4	120.5			7.4	120.5
* ψ1	K1	0.5	190.6			0.5	190.6
* ϕ1	K1	0.6	130.8			0.6	130.8
J1		0.6	293.7			0.6	293.7
OO1		2.6	221.7			2.6	221.7
* 2N2	N2	7.5	177.1			7.5	177.1
μ2		31.1	255.3			31.1	255.3
N2		60.0	179.6			60.0	179.6
* ν2	N2	15.0	197.3			15.0	197.3
M2		403.9	188.6	0.964	0.2	389.3	188.8
L2		28.9	203.2			28.9	203.2
* T2	S2	7.6	257.0			7.6	257.0
S2		137.5	248.3	0.996	-5.1	137.2	243.1
* K2	S2	40.6	249.3			40.6	249.3
2SM2		6.4	60.8			6.4	60.8
MO3		0.3	244.7			0.3	244.7
M3		4.7	191.6			4.7	191.6
MK3		0.9	195.5			0.9	195.5
MN4		7.0	344.0			7.0	344.0
M4		12.7	32.1			12.7	32.1
SN4		0.5	9.8			0.5	9.8
MS4		4.9	31.4			4.9	31.4
2MN6		1.1	205.3			1.1	205.3
M6		4.1	225.4			4.1	225.4
MSN6		1.6	287.3			1.6	287.3
2MS6		5.2	266.6			5.2	266.6
2SM6		1.2	306.4			1.2	306.4

APPENDIX 2:

Analyses of Hydraulics Research Station data.

Recorder position	:	Stackpole Quay, Bristol Channel, 1980. 51°37.5'N 04°54.0'W.
Datum	:	10.0m below O.D.N.
Recorder details	:	Neyrtec differential water level logger with bubbler configuration. Continuous recording. See Comments.
Recording started	:	0910 G.M.T. day 109 (18/04/80).
Recording ended	:	3340 G.M.T.. day 138 (17/05/80).
Comments	:	Observations supplied by Hydraulics Research Station, Wallingford at 10m intervals and subsequently smoothed and filtered to hourly values. Analysis performed in hourly values from 1500 Day 109 to 2000 Day 138 1980. Constituents from average relations of Milford Haven, Ifracombe, Swansea, Newport and Avonmouth.

Table A6

Stackpole Quay, Bristol Channel, 50° 37.5'N 04° 54.0'W
Hourly water levels in centimetres.
Neyrtec gauge. 1500 GMT Day 109 to 2000 GMT Day 138, 1980.
*Related constituents.

	Constituent	related to	H(cm)	G(°)	Period adjustment factor α	β	H(cm)	G(°)
	Q1		3.0	283.3			3.0	282.3
	O1		7.1	348.7			7.1	348.7
	M1		0.4	105.5			0.4	105.5
*	π1	K1	0.6	132.8			0.6	132.8
*	P1	K1	2.2	117.2			2.2	117.2
	K1		5.7	109.4			5.7	109.4
*	ψ1	K1	0.4	179.5			0.4	179.5
	ϕ1	K1	0.5	119.6			0.5	119.6
	J1		0.01	99.7			0.01	99.7
	OO1		1.0	181.1			1.0	181.1
*	2N2	N2	5.9	148.9			5.9	148.9
	μ2		7.4	236.6			7.4	236.6
	N2		47.1	150.9			47.1	150.9
*	ν2	N2	11.8	168.5			11.8	168.5
	M2		250.3	168.7	.991	-1.2	248.0	167.5
	L2		24.5	170.3			24.5	170.3
*	T2	S2	5.1	222.7			5.1	222.7
	S2		93.3	214.0	1.007	-1.8	94.0	212.2
*	K2	S2	25.8	217.0			25.8	217.0
	2SM2		2.3	24.5			2.3	24.5
	MO3		1.0	222.1			1.0	222.1
	M3		1.9	128.0			1.9	128.0
	MK3		0.4	215.9			0.4	215.9
	MN4		2.7	263.7			2.7	263.7
	M4		5.5	314.5			5.5	314.5
	SN4		0.6	51.9			0.6	51.9
	MS4		2.7	6.6			2.7	6.6
	2MN6		0.2	30.1			0.2	30.1
	M6		1.1	50.8			1.1	50.8
	MSN6		0.6	69.3			0.6	69.3
	2MS6		1.2	73.8			1.2	73.8
	2SM6		0.4	120.0			0.4	120.0

Recorder position	:	Port Isaac, Bristol Channel, 1980. Lat 50°35.3pN Long 04°50.0'W
Datum	:	10.0m below O.D.N.
Recorder details	:	Neyrtec differential water level logger with bubbler configuration. Continuous recording. See Comments.
Recording started	:	1620 G.M.T. day 156 (04/06/80).
Recording ended	:	1300 G.M.T. day 185 (03/07/80).
Comments	:	Observations supplied by Hydraulic Research Station, Wallingford at 10m intervals and subsequently smoothed and filtered to hourly values. Analysis performed on hourly values from 2200 Day 156 to 0900 Day 185 1980. Constituents from average relations of Milford Haven, Ilfracombe, Swansea, Newport and Avonmouth.

Table A7

Port Isaac, Bristol Channel, 50° 35.3'N 04° 50.0'W
Hourly water levels in centimetres.
Neyrtec gauge. 2200 GMT Day 156 to 0900 GMT Day 185, 1980.
*Related constituents.

Constituent	related to	H(cm)	G(°)	Period adjustment factor α	Period adjustment factor β	H(cm)	G(°)
Q1		1.9	299.0			1.9	299.0
O1		7.2	342.9			7.2	342.9
M1		0.8	172.0			0.8	172.0
*π_1	K1	0.7	132.6			0.7	132.6
*P1	K1	2.7	117.0			2.7	117.0
K1		7.1	109.2			7.1	109.2
*ψ_1	K1	0.5	179.3			0.5	179.3
*ϕ_1	K1	0.6	119.4			0.6	119.4
J1		1.1	37.1			1.1	37.1
OO1		0.4	85.7			0.4	85.7
*2N2	N2	6.4	125.9			6.4	125.9
M2		7.9	110.6			7.9	110.6
N2		51.3	127.9			51.3	127.9
*ν_2	N2	12.8	145.5			12.8	145.5
M2		246.6	143.9	.991	-0.9	244.4	143.0
L2		12.2	172.1			12.2	172.1
*T2	S2	4.5	193.8			4.5	193.8
S2		81.8	185.1	1.055	-4.3	86.3	180.8
*K2	S2	22.7	188.1			22.7	188.1
2SM2		4.4	99.3			4.4	99.3
MO3		0.3	35.3			0.3	35.3
M3		1.3	89.3			1.3	89.3
MK3		0.5	123.5			0.5	123.5
MN4		2.6	201.1			2.6	201.1
M4		6.6	239.1			6.6	239.1
SN4		1.1	305.1			1.1	305.1
MS4		1.9	280.3			1.9	280.3
2MN6		0.3	353.1			0.3	353.1
M6		0.6	60.4			0.6	60.4
MSN6		0.5	91.5			0.5	91.5
2MS6		0.7	96.5			0.7	96.5
2SM6		0.2	163.2			0.2	163.2

Recorder position	Minehead, Severn Estuary, 1979. Lat 51° 12.9'N, Long 03° 28.3'W.
Datum	Datum of observations was 10.0m below O.D.N.
Recorder details	Neyrtec differential water level logger with pneumatic bubbler configuration. Continuous recording. See Comments.
Recording started	1415 GMT Day 275 1979.
Recording ended	2325 GMT Day 307 1979.
Comments	Observations supplied by Hydraulics Research Station, Wallingford at 10 m intervals and subsequently smoothed. and filtered to hourly values. Analyses performed on hourly values from 1900 Day 275 to 1800 Day 304 1979 and 2000 Day 278 to 1900 Day 307 1979. Constituents from average relations of Milford Haven, Ilfracombe, Swansea, Newport and Avonmouth.

Table A 8:1

Minehead, Severn Estuary, 51° 12.9'N 03° 28.3'W.
Hourly water levels in centimetres.
Neyrtec gauge, October to November 1979.
*Related constituents

Constituent	related to	1900 275 to 1800 304 H(cm)	G(°)	2000 278 to 1900 307 H(cm)	G(°)
Q1		3.2	316.2	2.6	313.9
O1		8.1	4.5	7.7	6.9
M1		0.7	142.6	0.6	160.8
*π1	K1	0.7	173.5	0.6	177.2
*P1	K1	2.4	157.9	2.3	161.6
K1		6.4	150.2	5.9	153.9
*ψ1	K1	0.4	220.3	0.4	224.0
*φ1	K1	0.5	160.5	0.5	164.2
J1		0.6	290.7	1.2	287.9
OO1		1.0	240.3	1.8	251.5
*2N2	N2	8.2	160.7	8.4	155.8
μ2		30.0	243.3	30.6	232.0
N2		65.3	163.2	67.5	158.3
*ν2	N2	16.3	180.9	16.9	176.0
M2		358.2	183.5	359.6	182.5
L2		33.1	206.4	30.5	218.8
*T2	S2	7.0	243.8	6.7	243.1
S2		127.4	235.1	121.1	234.4
*K2	S2	37.0	236.6	35.2	235.9
2SM2		7.7	39.7	13.2	27.2
MO3		0.9	180.0	0.1	62.6
M3		3.6	174.8	3.4	185.3
MK3		0.5	332.3	0.5	265.6
MN4		6.4	332.6	6.1	325.7
M4		10.7	23.7	10.1	19.6
SN4		1.1	162.8	1.8	179.2
MS4		4.7	62.7	3.9	65.1
2MN6		1.5	231.2	1.3	221.1
M6		1.5	276.2	1.2	264.4
MSN6		0.3	197.6	0.3	124.2
2MS6		1.9	260.6	1.6	255.3
2SM6		1.3	274.1	1.0	279.0

Table A 8:2

Minehead, Severn Estuary, 51 12°9'N 03°28.3'W.
Hourly water levels in centimetres.
Neyrtec Gauge. Vector means of 2 * 29 days analyses,
October/November 1979.
*Related constituents.

	Constituent	related	H(mb)	G(°)	Period Adjustment factor α	Period Adjustment factor β	H(cm)	G(°)
	Q1		2.9	315.2			2.9	315.2
	O1		7.9	5.6			7.9	5.6
	M1		0.6	151.0			0.6	151.0
*	π1	K1	0.6	175.2			0.6	175.2
*	P1	K1	2.3	159.7			2.3	159.7
	K1		6.1	151.9			6.1	151.9
*	ψ1	K1	0.4	222.1			0.4	222.1
*	φ1	K1	0.5	162.3			0.5	162.3
	J1		0.9	288.8			0.9	288.8
	OO1		1.4	247.5			1.4	247.5
*	2N2	N2	8.3	158.2			8.3	158.2
	μ2		30.2	237.6			30.2	237.6
	N2		66.3	160.7			66.3	160.7
*	ν2	N2	16.6	178.4			16.6	178.4
	M2		358.9	183.0	1.007	-3.5	361.4	179.5
	L2		31.6	212.3			31.6	212.3
*	T2	S2	6.8	243.4			6.8	243.4
	S2		124.2	234.7	1.035	-1.3	128.7	233.4
*	K2	S2	36.1	236.2			36.1	236.2
	2SM2		10.4	31.8			10.4	31.8
	O3		0.4	174.1			0.4	174.1
	M3		3.5	179.9			3.5	179.9
	MK3		0.4	298.9			0.4	298.9
	MN4		6.2	329.2			6.2	329.2
	4		10.4	21.7			10.4	21.7
	SN4		1.4	173.0			1.4	173.0
	MS4		4.3	63.8			4.3	63.8
	2MN6		1.4	226.5			1.4	226.5
	M6		1.3	271.0			1.3	271.0
	MSN6		0.2	160.9			0.2	160.9
	2MS6		1.7	258.1			1.7	258.1
	2SM6		1.1	276.3			1.1	276.3

Recorder position	:	Birnbeck Island, Severn Estuary, 1979. Lat 51°21.5'N Long 03°00.0'W
Datum	:	Datum of observations was 10.0m below O.D.N.
Recorder details	:	Neyrtec differential water level logger with pneumatic bubbler configuration. Continuous recording. See Comments.
Recording started	:	1610 GMT Day 332 1979.
Recording ended	:	1430 GMT Day 363 1979.
Comments	:	Observations supplied by Hydraulic Research Station, Wallingford at 10m intervals and subsequently smoothed and filtered to hourly values. Analyses performed on hourly values from 2100 Day 332 to 2000 Day 361 1979 and 1100 Day 334 to 1000 Day 363 1979. Constituents as for Lavernock Point, Steep Holme and Flat Holm.

Table A9 : 1

Birnbeck Island, Severn Estuary, 51°21.5'N 03°00.0'W.
Hourly water levels in centimetres.
Neyrtec gauge. November to December 1979.
*Related constituents.

Constituent	related to	2100 332 to 2000 361 H(cm)	(G°)	1100 334 to 1000 363 H(cm)	(G°)
Q1		5.4	309.4	5.9	325.7
O1		7.3	329.1	7.0	342.7
M1		2.8	162.2	2.6	181.5
* π1	K1	0.4	143.6	0.3	137.0
* P1	K1	1.6	128.0	1.2	121.4
K1		4.1	120.3	3.2	113.7
* ψ1	K1	0.3	190.4	0.2	183.8
* φ1	K1	0.3	130.6	0.3	124.0
J1		6.2	175.1	4.9	173.1
OO1		3.7	345.8	5.5	356.2
* 2N2	N2	13.2	171.1	13.0	168.1
μ2		31.5	272.4	34.2	267.4
N2		105.4	173.6	103.9	170.6
* ν2	N2	26.3	191.3	26.0	188.3
M2		395.0	180.9	395.9	180.4
L2		51.1	207.8	48.9	211.7
* T2	S2	8.5	243.7	8.4	245.5
S2		155.0	235.0	152.7	236.8
* K2	S2	45.7	236.0	45.1	237.8
2SM2		7.3	71.2	4.3	98.8
MO3		2.5	154.0	2.4	178.7
M3		4.8	188.0	5.5	186.9
MK3		4.0	248.1	3.4	240.3
MN4		6.8	317.8	6.9	318.0
M4		12.3	344.6	12.4	344.9
SN4		2.9	338.3	3.0	337.1
MS4		8.4	349.9	8.5	349.5
2MN6		3.4	193.5	3.4	189.6
M6		4.6	202.4	4.8	200.7
MSN6		5.0	234.9	4.9	238.7
2MS6		6.1	252.0	6.0	253.6
2SM6		1.3	326.1	1.5	315.2

Table A9 : 2

Birnbeck Island, Severn Estuary, 51°21.5'N 03°00.0'W.
Hourly water levels in centimeters.
Neyrtec Gauge. Vector means of 2 * 29 days analyses,
November/December 1979.
*Related constituents.

	Constituent	related	H(cm)	G(°)	Period adjustment factor α	β	H(cm)	G(°)
	Q1		5.6	317.9			5.6	317.9
	O1		7.1	335.7			7.1	355.7
	M1		2.7	171.5			2.7	171.5
*	π1	K1	0.3	140.8			0.3	140.8
*	P1	K1	1.4	125.2			1.4	125.2
	K1		3.6	117.4			3.6	117.4
*	ψ1	K1	0.2	187.7			0.2	187.7
*	φ1	K1	0.3	127.3			0.3	127.3
	J1		5.5	174.3			5.5	174.3
	OO1		4.6	352.0			4.6	352.0
*	2N2	N_2	13.1	169.6			13.1	169.6
	μ2		32.8	269.8			32.8	269.8
	N2		104.6	172.1			104.6	172.1
*	ν2	N2	26.1	189.8			26.1	189.8
	M2		395.4	180.6	0.986	0.1	390.1	180.7
	L2		50.0	209.7			50.0	209.7
*	T2	S2	8.4	244.6			8.4	244.6
	S2		153.8	235.9	0.959	-1.9	147.6	234.0
*	K2	S2	45.4	236.9			45.4	236.9
	2SM2		5.6	81.4			5.6	81.4
	MO3		2.4	166.1			2.4	166.1
	M3		5.1	187.4			5.1	187.4
	MK3		3.7	244.5			3.7	244.5
	MN4		6.8	317.9			6.8	317.9
	M4		12.3	344.7			12.3	344.7
	SN4		2.9	337.7			2.9	337.7
	MS4		8.4	349.7			8.4	349.7
	2MN6		3.4	191.5			3.4	191.5
	M6		4.7	201.5			4.7	201.5
	MSN6		4.9	236.8			4.9	236.8
	2MS6		6.0	252.8			6.0	252.8
	2SM6		1.4	320.3			1.4	320.3

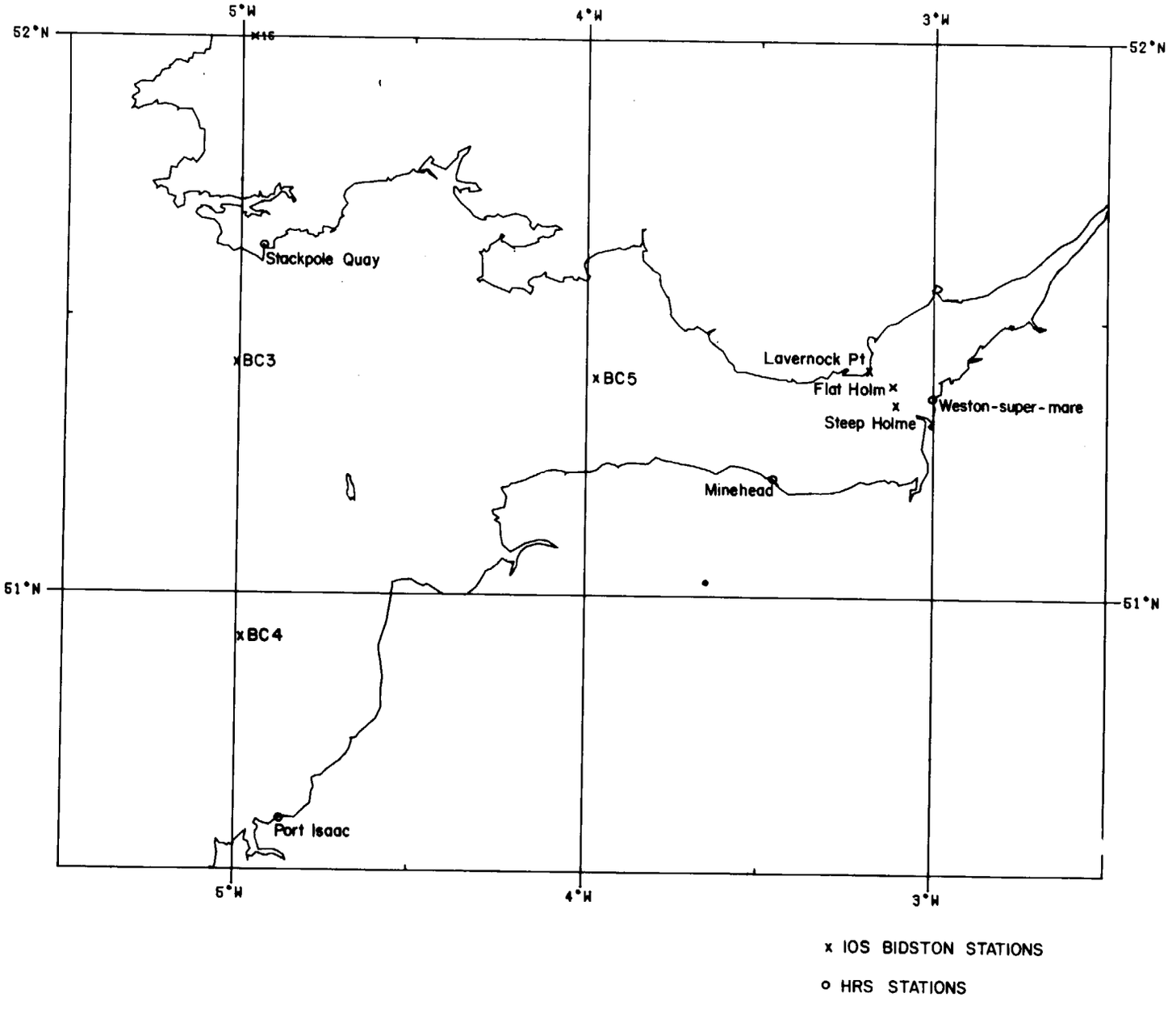

FIGURE 1 BRISTOL CHANNEL STATIONS

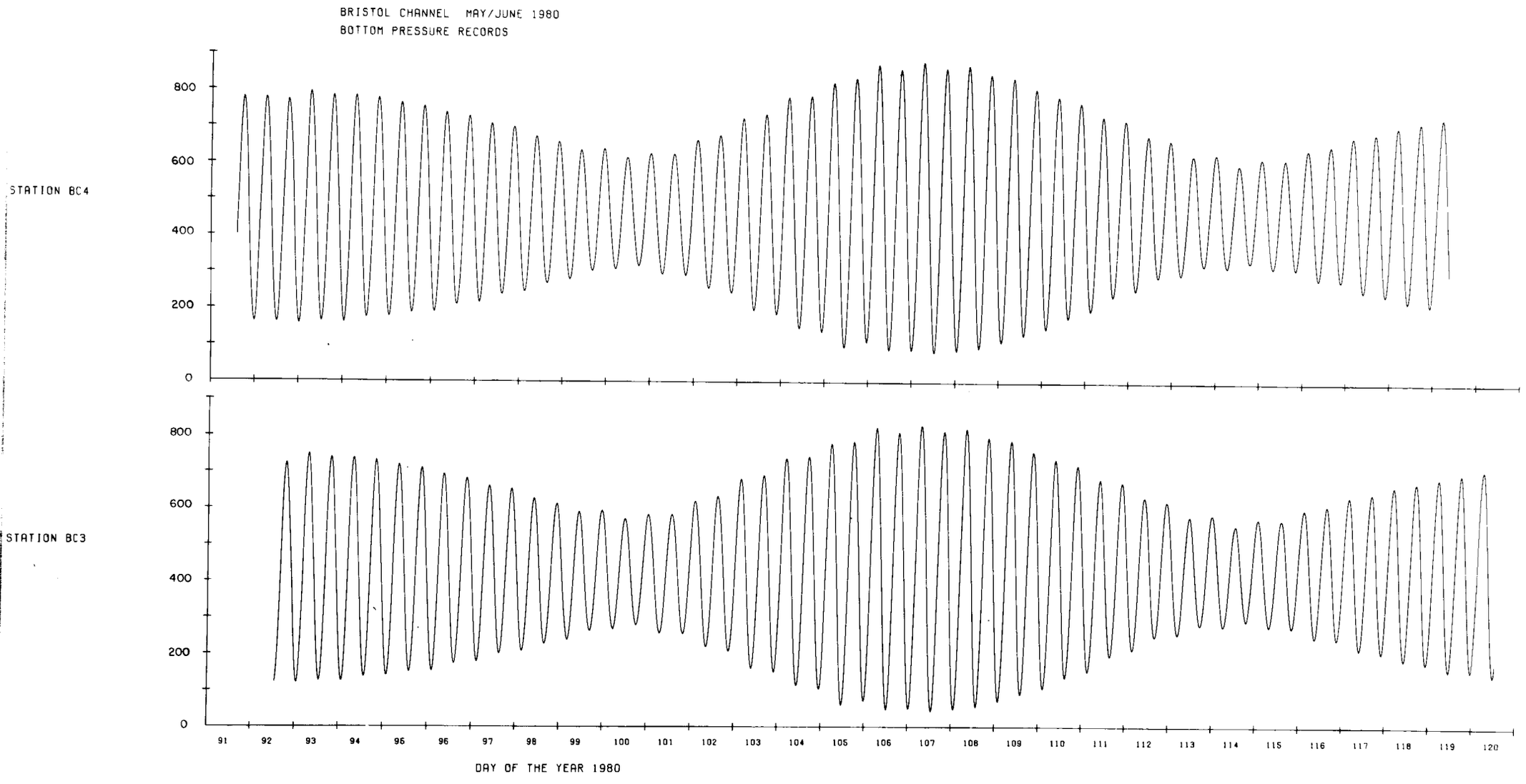
BRISTOL CHANNEL MAY/JUNE 1980
BOTTOM PRESSURE RECORDS
STATION BC4
STATION BC3
800
600
400
200
0
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
DAY OF THE YEAR 1980

FIGURE 2

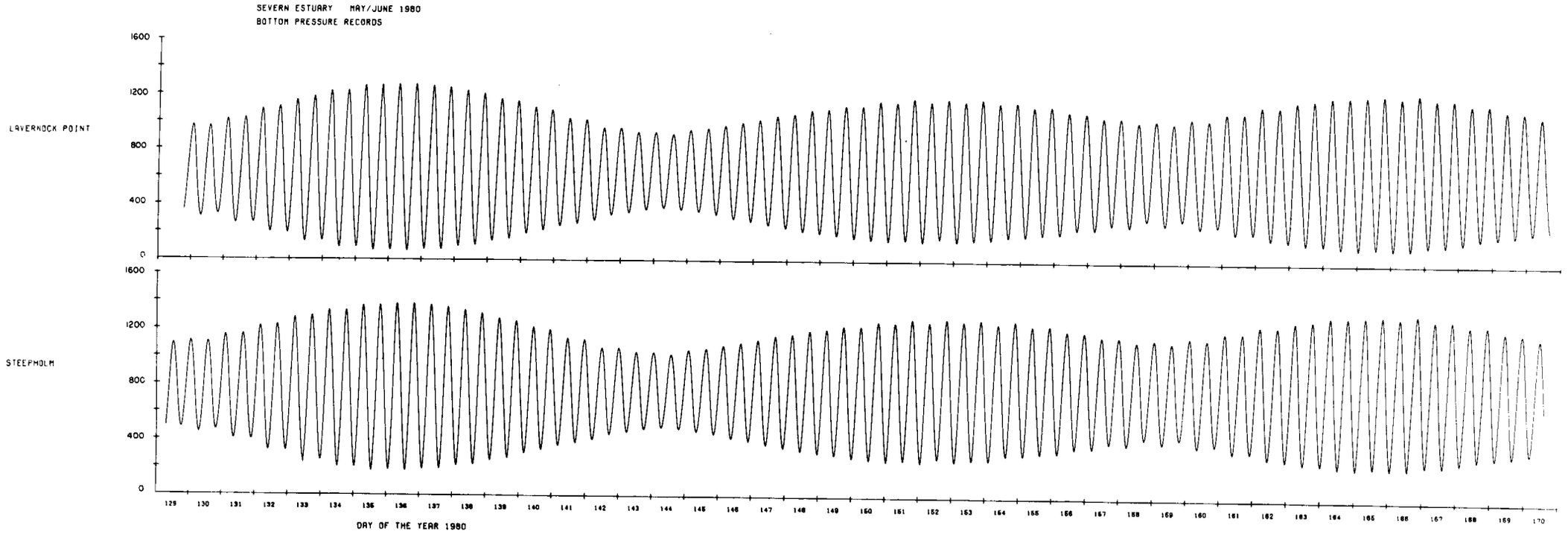
SEVERN ESTUARY MAY/JUNE 1980
BOTTOM PRESSURE RECORDS
LAVERNOCK POINT
STEEPHOLM
1600
1200
800
400
0
129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170
DAY OF THE YEAR 1980

FIGURE 3

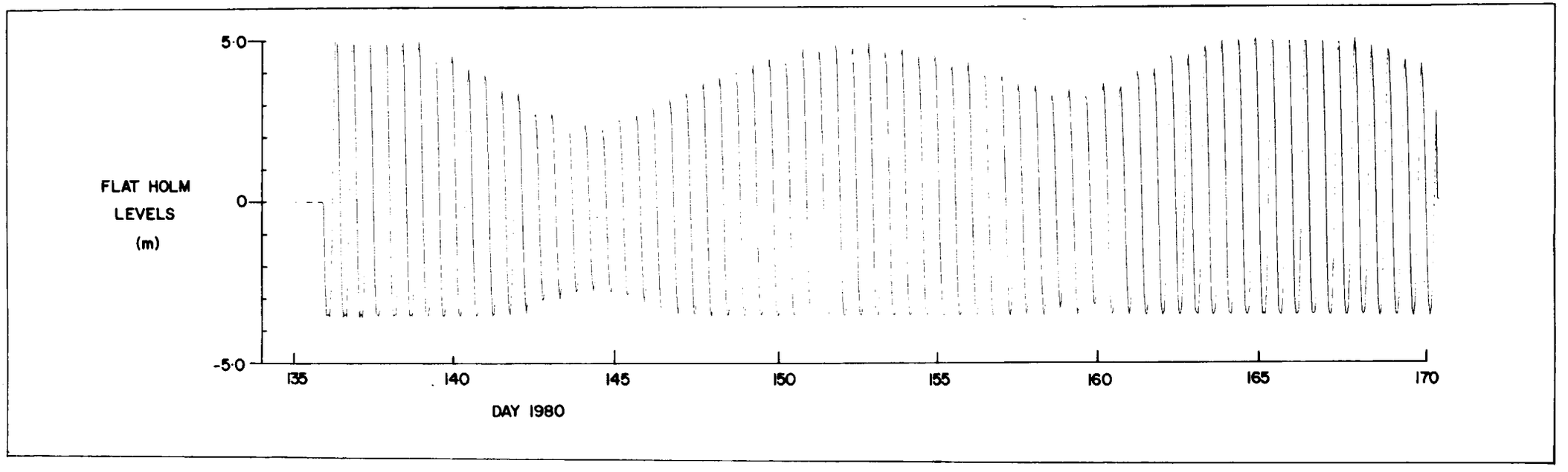
FLAT HOLM
LEVELS
(m)
5·0
0
-5·0
135
140
145
150
155
160
165
170
DAY 1980

FIGURE 4

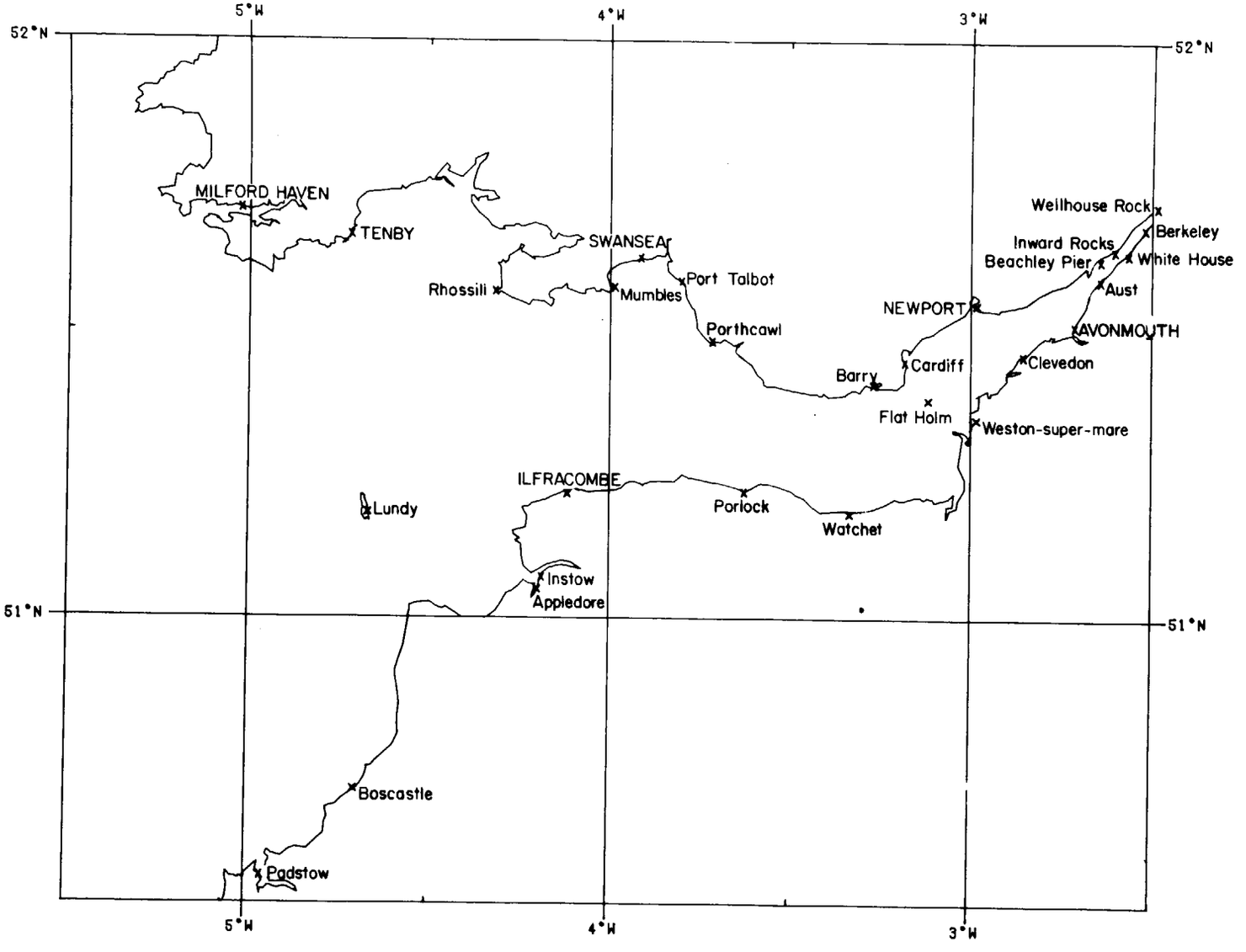

FIGURE 5 BRISTOL CHANNEL TIDAL ANALYSES