

The Humber Observatory: Monitoring, Modelling and Management for the Coastal Environment

J. Hardisty and H.L. Rouse

School of Geography & Earth Resources
The University of Hull
Hull, HU6 7RX, U.K.

ABSTRACT

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The Humber Observatory consists of VHF receiving stations, and control and analysis computers located within the University which interrogate one hundred sensors located in, around and off the Humber Estuary on the east coast of England. The sensors include a standard meteorological station, tide gauges, oceanographic instruments and a "flux curtain" deployed on navigational marks across the mouth of the estuary measuring tidal flows, sediment fluxes and some water chemistry parameters. Sensors are sampled at hourly intervals and up to 256 measurements are logged on each instrument during each sampling. Preliminary flux calculations suggest that Neap and Spring tides transport 0.8 and 1.6 km³ of water on the flood and 0.9 and 1.6 km³ of water on the ebb respectively and that the corresponding figures for suspended sediment transports are 80, 160, 90 and 160 × 10⁶ kg respectively.

ADDITIONAL INDEX WORDS: *Remote monitoring, sediment flux.*



INTRODUCTION

The Humber Observatory has been established within the School of Geography and Earth Resources at the University of Hull as a resource for environmental monitoring, modelling and management and includes some one hundred instruments in and around the Humber Estuary. This paper describes the estuary, and then the Humber Observatory's instrumentation, data collection and archival systems and also details first results from the Natural Environment Research Council's (NERC) Land Ocean Interaction Study (LOIS) special topic *Modelling and in situ measurement of sediment flux in the lower Humber with particular reference to freshwater controls, tidal and storm forcing* programme. The programme involves the development of a flux curtain across the mouth of the Humber Estuary which measures, for the first time, the net water and sediment movements into and out of the estuary.

THE HUMBER ESTUARY

The Humber Estuary drains a catchment of some 25 000 km² which is about one fifth of the land area of England (IECS, 1987). The tidal reaches of the Humber extend some 120 km inland on the River Trent and 110 km inland on the River Ouse, and the plan shape of the estuary flares from about 1 km wide at the Ouse-Trent confluence to over 8 km wide at Spurn Head (Figure 1). The geology of the region is relatively simple: the prominent, eastwards dipping chalk of the Yorkshire and Lincolnshire Wolds once formed the western margin of the North Sea system and, some 120 000 years ago, the mouth of the estuary was close to the Humber Gap,

the site of the modern Humber Bridge (IECS, 1987). During the last glaciation, glacial tills, moraines and periglacial channel sediments were deposited to the east of the chalk escarpment as the ice retreated towards the north-east. Waters from the Humber Basin (the present day Vale of York) were diverted south from the Humber Gap leading to the distinct and rather un-natural change in the orientation of the estuary to the east of Hessele. Rising sea-levels flooded the river valley about 6 000 years BP and gave rise to the present day estuary shape. Natural and artificial accretion of peripheral sediments and erosion of the coastline has occurred since the flooding so that the estuary mouth, which was probably once some 25 km wide and about 20 km seawards of the present day mouth, is now only 8 km wide between Spurn Head and the south bank. Natural siltation has been accelerated by reclamation of land along the estuary particularly in the outer estuary around Sunk Island (east of Saltend) and by 'warping' (the use of low sea-walls for trapping sediment) in the inner estuary (IECS, 1987). The modern coastal geomorphology of the estuary is restricted almost entirely to depositional forms (IECS, 1987). There are few salt marshes, most have been reclaimed and converted to agricultural use. Mudflats are evident along the periphery on both banks and are a vital food source for the migrating bird community. Typical accretion rates on the mud flats are estimated at 1 to 10 cm yr⁻¹ (IECS, 1987). There are sand dunes on Spurn Head to the north, and on the coastal strip south of Cleethorpes on the south bank, and there are sand beaches on Spurn and at Cleethorpes on the south bank.

Meteorological Conditions

The following is based upon limited existing data from a variety of sources, although information regarding meteoro-

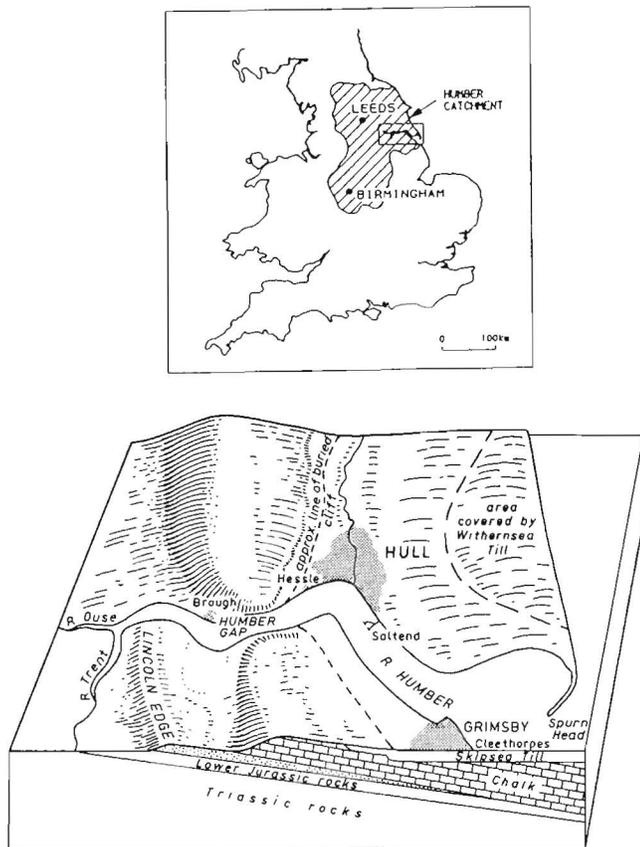


Figure 1. Map of the Humber Estuary.

logical conditions in the region is improved with the establishment of a meteorological station at the University of Hull as part of the Observatory in 1994. Winds have been recorded at Spurn Head itself, at Teesmouth to the north and at Gorleston to the south (MOTYKA, 1986). Meteorological Office data show that both the most frequently occurring and the strongest onshore winds at the mouth of the estuary are from the North (SHELLARD, 1976; PALUTIKOF *et al.*, 1985 and WARD, 1987) and these generate the waves described in the following section. The central and upper estuary are dominated by prevailing south-westerly winds. The mean annual days of gale (DOG: wind speed in excess of 34 knots or Beaufort Force 8 for at least a few minutes) increase from 2.45 at Hull to 23.69 at Spurn Head.

In general the estuary experiences a climate which is an amalgam between the dry east-coast lowland weather and the maritime influence of the North Sea. Rainfall in the area is low—rarely rising above 650 mm yr^{-1} and dropping to less than 600 mm yr^{-1} close to the coast. Analysis of a thirty five year period from 1916 to 1950 showed that the months of November, December and January have the most days of rain but that the total rainfall during these months is equalled by that occurring during July and August (IECS, 1987). Other forms of precipitation are relatively rare with snow being recorded on only five days per year and hail on only four days

per year during the period 1960–1970. The mean annual days of fog (DOF: visibility less than 1000 m in the direction of worst visibility) decrease slightly from 17 at Spurn Head to 12 at Hull and there appears to be a steady, longer term decrease in annual DOFs in the upper estuary between 1954 and 1980 (IECS, 1987). Temperatures in the Humber area show a typical winter-summer contrast. A Summer average of 15.2°C is succeeded by winter averages of 3.5°C . In general daily average temperatures rise late, the 10°C daily average only being attained in May, but do not then fall until November.

Wave Conditions

There are two sources of waves which affect the Humber: those generated in the North Sea and those generated in the estuary. North Sea waves are larger and have been recorded at the Dowsing Light, approximately 25 km off the estuary mouth, by the Institute of Oceanographic Sciences (FORTRUM, 1980; BACON, 1989). Analysis of data give fifty year return values of the significant wave height (H_s) as 8.23 m (using a Fisher-Tippett Type I (FT-1) distribution), 7.49 m (using a Weibull 2-parameter distribution) and 6.76 m (using a Weibull 3-parameter distribution) with this winter maximum for the FT-1 distribution reducing to 7.41, 6.91 and 5.35 m for autumn, spring and summer respectively. The waves are relatively short in period as evidenced by the association of the maximum recorded H_s of 6.29 m in February 1979 with a zero crossing period of 9.23 s. More recent results from deployments of Wave Rider buoys off Holderness are reported by Bacon and Carter (1988) and suggest an FT-1 fifty year return H_s of 5.99 m for all data. North Sea waves approaching the mouth of the estuary are refracted as they enter the shallow water and, for the north easterly storm conditions, incoming wave energy is focused on the southbank around Cleethorpes. Waves within the estuary are locally generated and substantially smaller. IECS (1987) suggests that a north westerly wind blowing westwards along the estuary might generate waves of 1–2 m height.

Tidal Conditions

The Humber tides form part of the southern North Sea systems and are principally dominated by the M_2 amphidromic point in the eastern-central North Sea (DOODSON and WARBURG, 1941) with a phase lag angle of 120° with respect to lunar transit at Greenwich. In general, the tidal wave progresses in a southerly direction down the coasts of Holderness and Lincolnshire (HARDISTY, 1990) and enters the mouth of the estuary some 6 hours before High Water (HW) Dover. The tide takes about 3 hours to progress up the estuary from Spurn Head to the Ouse-Trent confluence and higher order harmonics are generated during the transition. Spring tidal range in the Humber is 6.5 m at the mouth rising to a maximum of 7.2 m at Saltend and then decreasing progressively upstream. The pattern is semi-diurnal with a pronounced neap-spring inequality (IECS, 1987); for example at Saltend the tidal range varies from 3.9 m to 7.9 m for a Neap-Spring cycle. The tide at Spurn Head is sinusoidal whilst at Brough the flood lasts for 4.5 hours, and on the River Trent the flood

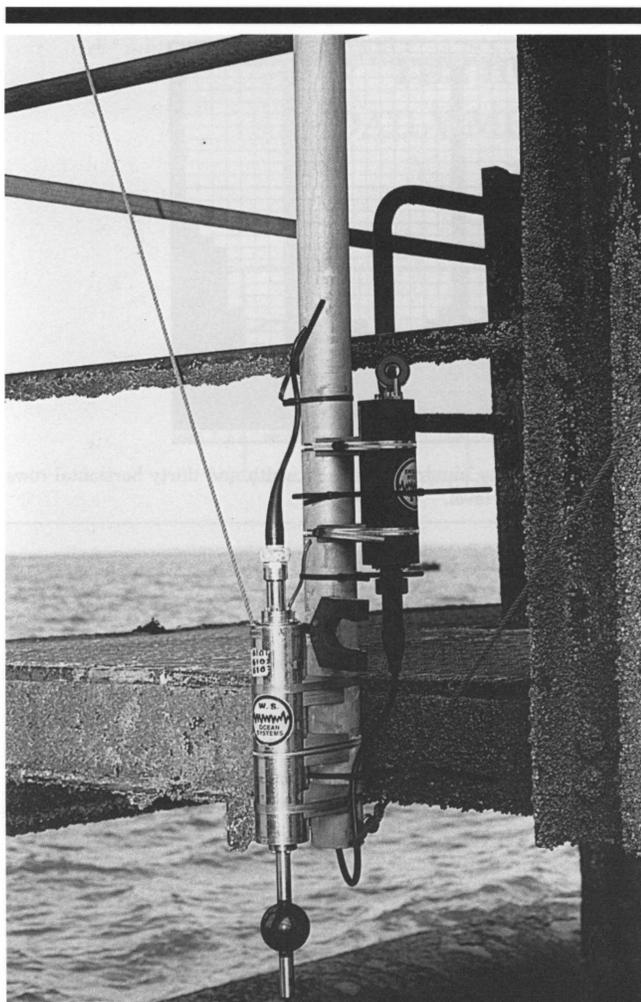


Plate 1. A typical current meter, CTD probe and transmissometer MEMSsys package as deployed on the Humber flux curtain.

lasts for only 2 hours. Analysis of bathymetric data (PETHICK, 1994) suggests that some $1.2 \times 10^9 \text{ m}^3$ of water passes into the estuary through the mouth of the Humber during the flood tide. The water moves about 5 km inland before reversing and spring tidal current velocities can exceed 3 ms^{-1} at the mouth of the estuary (IECS, 1987). The tidal asymmetry causes increased velocities on the flood tide because of the shorter flood tide period and the velocity also varies with depth, decreasing rapidly towards the bed. Earlier work (IECS, 1987) suggests that, at the mouth of the estuary, the northern Hawke Channel is ebb dominated, whereas the southern Haile Channel is flood dominated.

THE INSTRUMENT SYSTEMS

The Humber Observatory consists of more than one hundred instruments arranged in three phases and linked *via* VHF radio telemetry to command and control computers located in the School of Geography and Earth Resources at the University of Hull. In general, all instruments are sampled

at hourly intervals and most instruments are sampled for 128 s at 2Hz. The details and locations of the instruments and a description of the acquisition and archival systems are given in Hardisty & Rouse (*in prep.*), and Middleton (*in prep.*).

Phase I: The Regional Environment

Phase I consists of sixteen instruments including the meteorological station located on the University campus; two Associated British Ports' (ABP) tide gauges (at Spurn Head and Blacktoft near the Ouse-Trent confluence); the National Rivers Authority gauging stations on the Trent and Ouse; a wave recorder on the Binks outside Spurn Head; and a small instrument package on the Redcliffe light float about 1.5 km upstream from the Humber bridge.

The meteorological station consists of a Casella rotating cup anemometer and potentiometric wind direction indicator, a modified tilting bucket rain gauge and Vector Instrument's temperature, humidity, sunlight and atmospheric pressure sensors. The tide gauges are operated by ABP and consist of acoustic travel path devices and the Observatory uses a Magenta radio receiver to decode the signals into a small PC. The river gauges are standard weirs. The Binks station consists of a buoy based electronic and logger package which is cable linked to a seabed pressure transducer in about 5 m charted depth some 2 km west of the Spurn Head light house. Finally the Redcliffe Station consists of a radio linked Partech transmissometer for the measurement of suspended load concentration, a current meter and a flux gate compass.

Phase II: The Humber Estuary

The instruments deployed in Phases II and III are designed to be completely interchangeable and are based upon the Observatory's Marine Environmental Monitoring System: MEMSsys. The system consists of a shore based, computer linked VHF radio transceiver and an outstation package. The outstation package consists of a waterproof enclosure housing three 36 Ah batteries supplemented by an Aerogen 3 wind generator, an analogue to digital converter and telemetry system with its own 3.5 m whip aerial, and a sixteen channel data processing module. The basic system uses the Alec Electronics two component electromagnetic current meter and compass for current speed and direction, the WS Ocean System CTP-4 sensors for water depth (at probe), water temperature, conductivity and computed salinity, the Partech IR40C 40 cm path length transmissometer for suspended sediment concentration (Plate 1). In general, the current meter and chlorinity-temperature sensors are mounted 2 m below the still water surface and the transmissometers are mounted at 0.5, 1.5 and 2 m depths. The precise locations are, necessarily, a compromise between the relative factors of depth beneath the wake from the float and representative depth in the water column. In addition, there are six spare data channels for further probes such as dissolved oxygen and pH, and an instrument status channel. Identical systems are being deployed on the Bull lightship and the Holme light float for Phase II of the Observatory.

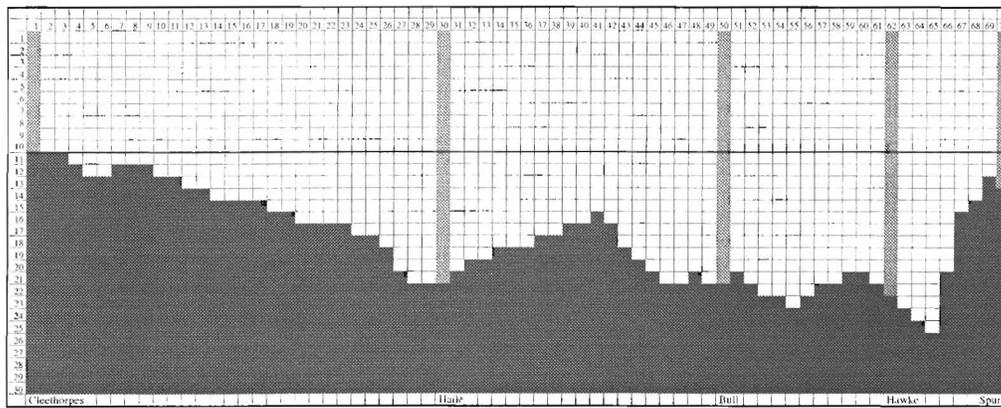


Figure 2. Definition diagram of the flux curtain consisting of seventy vertical columns each one hundred metres in width and thirty horizontal rows each 1 m in depth giving a total of 2 100 cells, approximately half of which are 'wet' at mid tide level.

Phase III: The Flux Curtain

MEMSys is used on all stations in Phase III: on the Pilots' jetty on the west of Spurn Head; on two light floats at the entrance to the Haile and Hawke channels; and at the southern end of the cross section a system is being installed on-shore close to Cleethorpes. These four, along with data from the Bull station described earlier, represent a sediment "flux curtain" which runs in a NNE-SSW line across the mouth of the estuary (Figure 2).

Data telemetry and archiving

All of the MEMSys outstations are interrogated from a single base station located within the Observatory and all data acquisition and transfer is controlled from software running on a PC linked to the base station. Typically, each outstation is contacted at hourly intervals and collects and stores 256 measurements at 2Hz on each of its sixteen channels. The data are then transmitted to the base station in either *full* (4096 measurements) or *condensed* (last 100 readings on selected channels) mode. The base station operates some error and transcription checks and, if necessary, can automatically ask for the data transmission to be repeated. Once the data have been successfully received the outstation moves into quiescent mode until next interrogated and the base station moves on to a different outstation. There are six MEMSys packages in Phases II and III, and data transfer operates for about half of each hour. Data are automatically checked and calibrated, and are archived on mass storage devices where they are available for further analysis.

The Observatory can thus produce: a Daily Meteorological Report with a page of statistics and a page of results in graphical form (as shown in Figure 3); a Daily Tide Gauge Report displaying tidal elevations from eight sites moving from the mouth of the estuary inland (Figure 4); and a Daily Estuary Report with a page of statistics and a graphical report (Figure 5). These form the basis of further data analysis over varying time scales.

SUSPENDED PARTICLE FLUX MODELLING

The Humber has a high suspended sediment concentration rising from about 200 ppm at Spurn to 1000 ppm at Hull and 3000 ppm at Brough, before falling off very rapidly towards the upper reaches (IECS, 1987). One of the first scientific objectives of the Observatory involves working on the NERC-LOIS special topic to determine suspended sediment flux rates through the mouth of the estuary on a daily, monthly, seasonal and annual basis and to attempt to model such fluxes as functions of the other environmental parameters which are monitored in the Observatory.

A simple calculation of the product of $1.2 \times 10^9 \text{ m}^3$ for the flood discharge quoted earlier (PETHICK, 1994) with a mean suspended sediment concentration of 100 ppm (0.1 kg m^{-3}) suggests that the flood (and ebb) sediment flux through the curtain is in the order of 120 000 tonnes ($120 \times 10^6 \text{ kg}$). The most useful work on the sediment concentrations (as opposed to fluxes) in the Humber is reported by JACKSON (1964) for the British Transport Docks Board (now Associated British Ports—ABP). Measurements from a long term deployment of a silt meter off the entrance to King George Dock, Hull were analysed and suggested that the sediment concentration is influenced by water temperature, freshwater inputs and tidal range. Jackson's correlation equation is:

$$S = 907 - 18.21T + 6.04Q + 26.67R \quad \text{Eq. 1}$$

where S is the averaged concentration in milligrams of dry solid per litre of estuary water (i.e. ppm.)

T is the river temperature in °F

Q is the combined freshwater entering the Humber from the Rivers Ouse and Trent in thousands of cubic feet per second on the day in question

R is the tidal range.

Eq. 1 demonstrates that the sediment concentration is sensitive to freshwater inputs (even though mean freshwater discharges are very much smaller than tidal discharges), to water temperature and, as expected, to tidal range.

THE HUMBER OBSERVATORY DAILY METEOROLOGICAL REPORT 20th November 1994

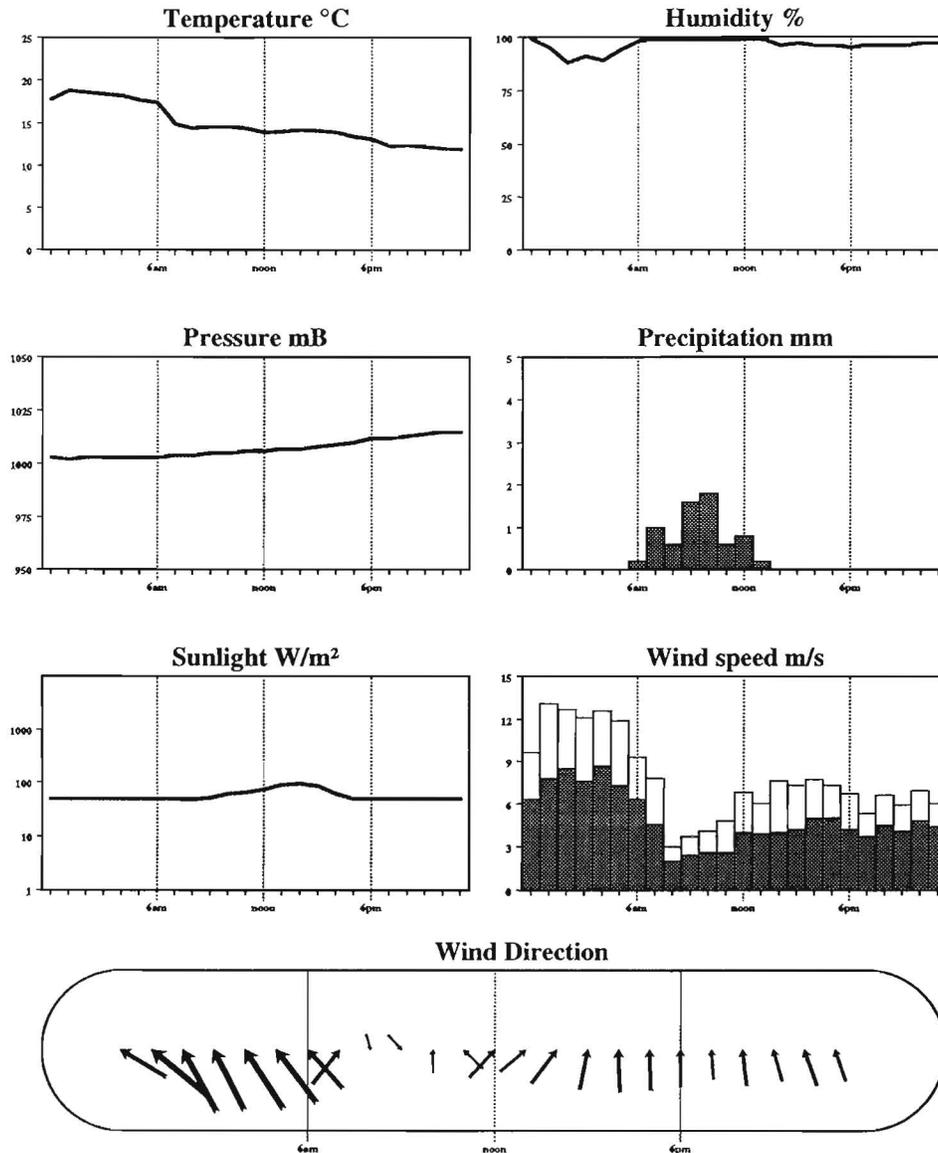


Figure 3. An example of the Humber Observatory's Daily Meteorological Report.

The second stage of the flux curtain work involves setting the empirical results monitored by the systems described above against increasingly sophisticated numerical simulations. In the first instance correlations are being sought between flux curtain results and other environmental measurements from Phase I and II.

Flux Curtain Data Interpolation

The flux curtain (Figure 2) experiments are designed to progress, *via* a set of well defined interpolation stages, towards an accurate assessment of the daily, monthly, seasonal and annual sediment exchanges between the Humber Estu-

THE HUMBER OBSERVATORY DAILY TIDE GAUGE REPORT 20th November 1994

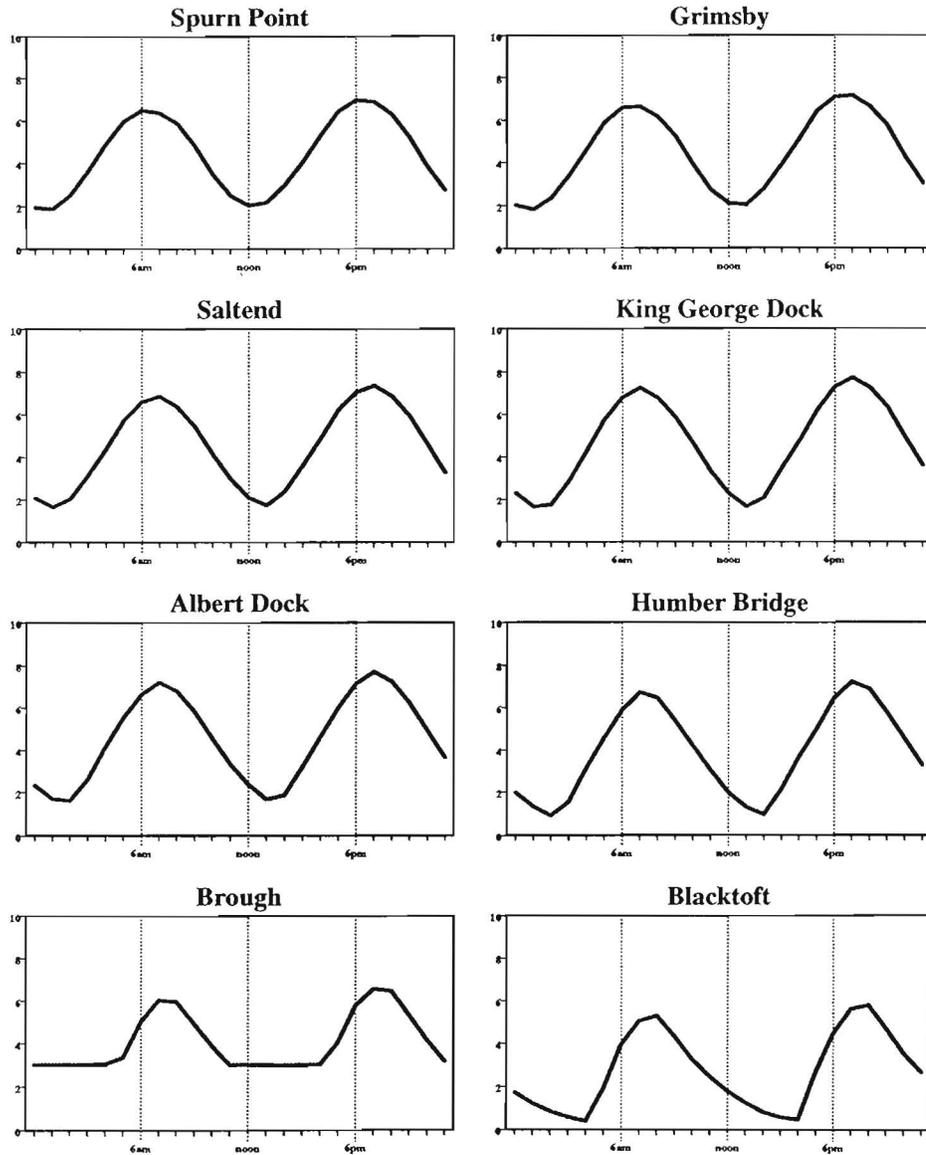


Figure 4. An example of the Humber Observatory's Daily Tide Gauge Report.

ary and the North Sea system. The flux curtain is a conceptual grid across the mouth of the estuary, through which all water and sediment must move in the exchange between the estuary and North Sea. The computation of the net sediment flux through the flux curtain, I_s , is based upon the triple integration of the product of the sediment concentration, C_{ijt} and the vector flow velocity resolved normal to the flux curtain, U_{ijt} :

$$I_s = \int_{t_1}^{t_2} \int_{j=1}^{30} \int_{i=1}^{70} (100C_{ijt}U_{ijt}) \, di \, dj \, dt \quad \text{Eq. 2}$$

where i horizontal column number
 j vertical row number
 t time integrated over the time interval t_1 to t_2 .

Horizontal column number is counted northwards from the

THE HUMBER OBSERVATORY

DAILY ESTUARY REPORT

Spurn jetty : 20th November 1994

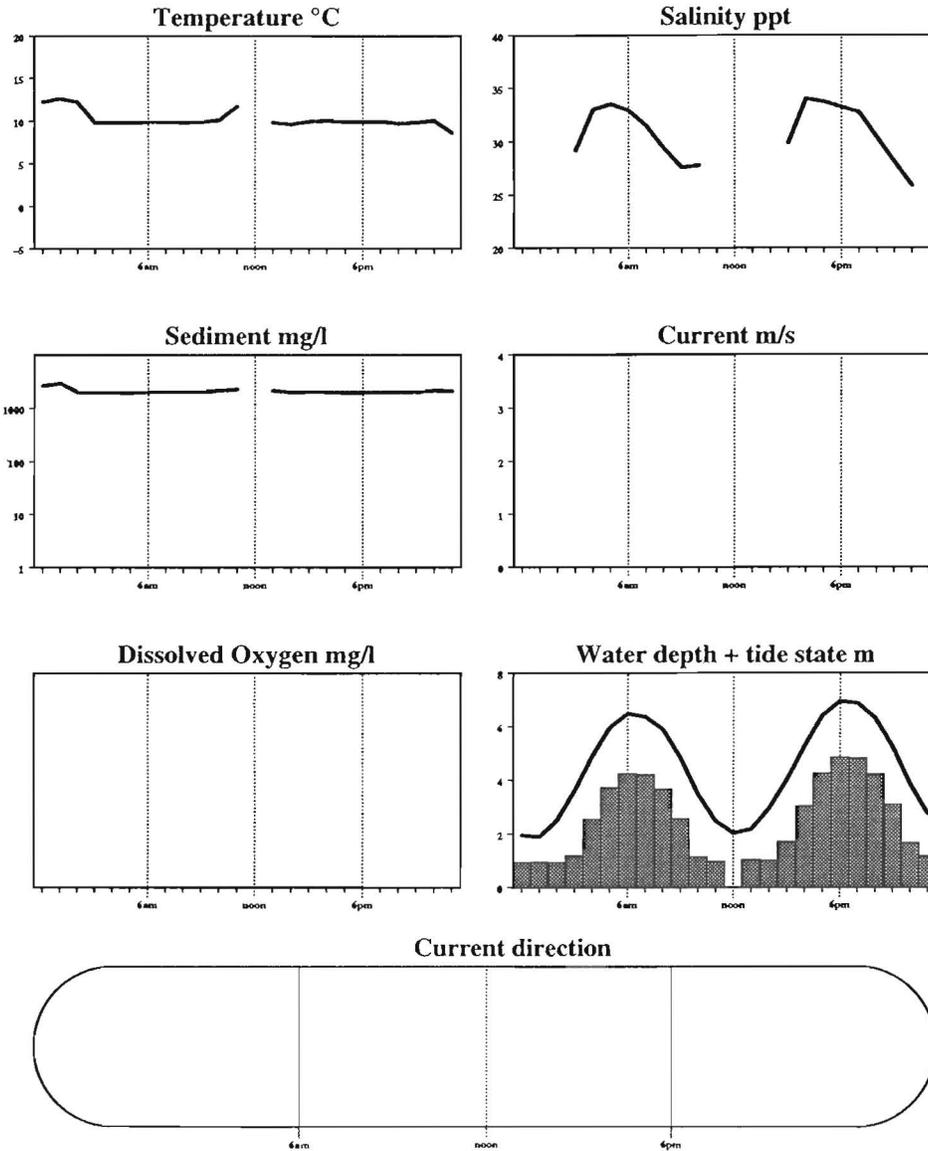


Figure 5. An example of the Humber Observatory's Daily Estuary Report.

southern end of the flux curtain and is a value of between 1 and 70; vertical row number is counted downwards from the top of the curtain, which is defined as +10 m Chart Datum (where CD is 3.9 m below Ordnance Datum Newlyn at Spurn Point) and is a number 1 to 30; and the cross sectional area of every cell thus defined is 100 m².

It was clearly impractical to address the problem with (poor) estimates of U_{ijt} and C_{ijt} in each cell and then achieve

flux estimates through the triple integration specified above. Instead, specification and development of the archival and processing software has been designed to progress alongside the development and deployment of the instrumentation, additional field surveys and the operation of one and two dimensional numerical models. Five stages have been formulated with the intention that, at the end of each stage, an improved estimate of the sediment flux will be provided and

Table 1. *Computation of suspended sediment flux.*

Stage I:	Horizontally and vertically averaged U_{0t} and C_{0t} for charted Spring and Neap tide
Stage II:	Horizontally and vertically averaged U_{0t} and C_{0t} for real time tidal heights
Stage III:	Horizontally and vertically averaged U_{0t} and C_{0t} for real time tidal heights and currents
Stage IV:	Horizontally averaged, vertically varying U_{0t} and C_{0t} for real time tidal heights and currents
Stage V:	Horizontally and vertically varying U_{0t} and C_{0t} for real time tidal heights, sediment concentrations and currents

the associated error bars will be reduced until, after the completion of the fifth stage, real time estimates of the sediment flux will be obtained and will be archived in order to examine, in greater detail, seasonal and inter-annual variabilities and to relate the variabilities to some of the controlling processes described earlier. The five stages are given in Table I, the results from the first stage are reported here.

The tide was divided into twelve intervals each of one hour's duration, and the corresponding number of submerged cells was calculated by comparing the tidal elevations given on the Admiralty Chart with the flux curtain. The submerged cells increment by seventy as the full width of the flux curtain is progressively submerged. The flow velocities were assumed normal to the flux curtain and taken from the charted tidal diamond located close to the centre of the flux curtain. The water flux for each time step was then simply calculated from the product of the number of submerged cells, the flow velocity and the cross sectional area of each cell (100 m^2) and the sediment flux was calculated by the product of the water flux and the mean sediment concentrations obtained from survey cruises carried out in early 1994 (100 mg l^{-1} corresponding to 0.1 kg m^{-3}). The calculations suggest that Spring and Neap tides transport 1.646×10^9 and $0.773 \times 10^9 \text{ m}^3$ of water on the flood and 1.616×10^9 and $0.947 \times 10^9 \text{ m}^3$ of water on the ebb respectively, and that the corresponding figures for suspended sediment transports are 165×10^6 , 77×10^6 , 162×10^6 and $94 \times 10^6 \text{ kg}$ respectively. These estimates correspond to net landward transport of $0.030 \times 10^9 \text{ m}^3$ of water and $3.0 \times 10^6 \text{ kg}$ of sediment on Springs, and $0.174 \times 10^9 \text{ m}^3$ of water and $17.4 \times 10^6 \text{ kg}$ of sediment on Neaps. We note that these figures are similar to the estimates of $1.2 \times 10^9 \text{ m}^3$ of water and $120 \times 10^6 \text{ kg}$ of sediment transported into the estuary on the flood as calculated from PETHICK (1994).

CONCLUSIONS

The Humber Observatory has been set up in order to study more closely the environment in and around the Humber Estuary. This paper describes the Humber Observatory, and introduces the results from the first stage of empirical modelling from the Humber flux curtain project. By developing more accurate estimates of sediment flux through the Humber flux curtain, and acquiring a long term data set, much can be learnt about the behaviour of the estuary and its sen-

sitivity to environmental parameters. Thus, for instance, knowledge of the sensitivity of the estuary system to freshwater inputs may play a role in water abstraction policy debates in the area.

ACKNOWLEDGEMENTS

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LITERATURE CITED

- BACON, S., 1989. *Waves recorded at Dowsing Light Vessel 1970-1985*. Institute of Oceanographic Sciences Deacon Laboratory. Unpub Report No. 262. 60pp.
- BACON, S. & CARTER, D.J.T. 1988. *Waves and wave spectra recorded at two sites off the Holderness coast*. Institute of Oceanographic Sciences Deacon Laboratory, Unpub. Report No. 260. 88pp.
- DOODSON, A.T. and WARBURG, H.D., 1941. *Admiralty Manual of Tides*. HMSO, London, 270pp.
- FORTNUM, B.C.H., 1980. *Analysis of waves recorded at the Dowsing Light Vessel between 1970 and 1979*. Institute of Oceanographic Sciences Unpub. Report 126.
- HARDISTY, J., 1990. *The British Seas: an introduction to the oceanography and resources of the North-West European continental shelf*. Routledge, London.
- HARDISTY, J., & ROUSE, H.L. (*in prep*). The Humber Flux Curtain Part I: monitoring and modelling systems. *Continental Shelf Research Special Edition*.
- IECS, 1987. *The Humber Estuary Environmental Background*. The Institute of Estuarine and Coastal Studies, The University of Hull for Shell UK, 59pp
- JACKSON W.H. 1964. Effect of tidal range, temperature, and fresh water on the amount of silt in suspension in an estuary. *Nature*, 4923, p1017.
- MIDDLETON, R. (*In prep*). Humber Observatory Computer Control Systems. School of Geography and Earth Resources Working Paper, The University of Hull.
- MOTYKA, J.M., 1986. *A Macro Review of the Coastline of England and Wales. Volume 2. The East Coast. The Tees to the Wash*. Report SR107. Hydraulics Research Station, Wallingford. 112pp
- PALUTIKOF, J.P., P.M. KELLY and T.D. DAVIES, 1985. An analysis of the spatial and temporal distribution of the wind field over the British Isles. In: Palz, W. (ed.) *Proceeding of the European Wind Energy Conference*. Stephens and Associates, Bradford, England. 65-70
- PETHICK, J.S., 1994. *Humber Estuary: Coastal Processes and Conservation*. Unpubl. Report to English Nature by the Institute of Estuarine and Coastal Studies, The University of Hull. 56pp.
- SHELLARD, H.C., 1976. Wind. In: CHANDLER, J.T. and S. GREGORY (eds.) *The Climate of the British Isles*. Longman. 39-73.
- WARD, R.C., 1987. Meteorology of the Humber Estuary. In: *The Humber Estuary: environmental background*. Institute of Estuarine and Coastal Studies, The University of Hull. 21-30.