P.O.L.

National
Environment
Research
Council

POL Internal Document No, 121

THE UK NATIONAL SEA LEVEL NETWORK

G. Alcock, E. Spencer & D. Smith

Proudman Oceanographic Laboratory
Bidston Observatory, Birkenhead.

July 1998

PROUDMAN
OCEANOGRAPHIC
LABORATORY

PROUDMAN OCEANOGRAPHIC LABORATORY

Bidston Observatory
Birkenhead, Merseyside, L43 7RA, UK
Tel: 0151 653 8633
Telex: 628591 Ocean B
Fax: 0151 653 6269

Director: Dr. B.S. McCartney

Natural Environment Research Council

Proudman Oceanographic Laboratory

Internal Document No.121

THE UK NATIONAL SEA LEVEL NETWORK

G. Alcock, E. Spencer & D. Smith

Proudman Oceanographic Laboratory
Bidston Observatory, Birkenhead

July 1998

1. Introduction

1. The Ministry of Agriculture, Fisheries and Food (MAFF) funds a national Storm Tide Warning Service (STWS) for the coast, and ensures that adequate flood warning procedures exist. MAFF contracts NERC's Proudman Oceanographic Laboratory (POL) to modernise and maintain a network of sites for measuring sea level. (The present network is sometimes referred to as the "A Class Tide Gauge Network", but in this **report** we use the term "UK National Sea Level Network", or "National Network".)

2. The gauges provide real-time data to check the operational tide/surge forecast model, and are of value in tidal and mean sea level research; in extreme level design limits and in assessing effects on return periods with changing sea level scenario (MAFF, 1992).

3. During the course of several contracts over the years, changes have been made in the number and location of sites, in recognition of users' needs following specific events. For example, there was the addition and/or upgrading of gauges on the south coast after the storms of 1989/90 and on the west coast after the "Towyn" storm of 1990.

4. Although some improvements have been made over the years, the Network's existing technology is from the 1970s and imposes restrictions on the use and accessibility of the Network and its data. For example, only two users can have access to real-time data (POL and the STWS). Consequently, other users, especially the Environment Agency (formerly the National Rivers Authority), have had to install completely separate systems or "tap-offs" from the Network transducers at some National Network stations.

5. Recently POL has developed a new data logger system and new software packages, based on its development of its sea level network in the South Atlantic; with the means of recording more parameters, providing additional user access, two-way communication and control and automatic monitoring of system faults.

6. It was decided by MAFF and POL that it was timely and necessary to reconsider the needs for a National Network, and how best those needs could be met; especially as **MAFF's** budget for the Network has remained fixed at the 1996/97 level, i.e. a decrease in real terms. Hence this report was commissioned.

7. Users' needs were supplied mainly via a Workshop held at MAFF on 20th May 1997, and via follow-up meetings with the Environment Agency on 10th - 1lth June, 14th July and 2nd October 1997 (with MAFF and STWS representatives present at the June and October meetings). User contributions are given in Annex 2, but the main report comprises Summary points and Conclusions and Recommendations. Input from the EA has been supplied also through its review of Tidal Flood Forecasting EA, 1998b), following the introduction of new flood warning dissemination targets.

2. Background

1. The coastline of England and Wales is approximately 4,500 kilometres long. A significant proportion of the population of England and Wales lives in areas at risk from flooding and coastal erosion. Over 5% of the population live in areas below the 5 metre contour and many of these areas are protected by defences. Over 50% of Grade 1 agricultural land is also below this level. Without defences, urban areas with **key** infrastructure, businesses, homes and agricultural and recreational land would be vulnerable to flooding and coastal erosion. In addition a number of historic sites and buildings, some of which are protected by statute, and environmentally valuable areas such as Sites of Special Scientific Interest are at risk (MAFF, 1993).

2. Thus flood and coastal defences are assets of great economic significance and high capital value, and successive Governments have made a substantial investment in flood defence and coastal protection measures in partnership with local authorities and other bodies. In 1996/97, the Environment Agency's Flood Defence Resources Profile totalled over £256m, of which over £130m was spent on capital flood and coastal defence works (EA, 1998c), with sea walls costing around £5,OOO per metre run. Planned figures for 1998/99 are about £260m and £134m respectively. This represents only a fraction of the value of the assets at risk from flooding.

3. There is a threat of marine flooding to parts of the UK due to the inundation of low-lying land by a combination of tides and storm-surges; and there are incidents of varying severity every winter. This threat was recognised by the last appraisal of research and development for flood and coastal defence (MAFF, 1992); with the observation that "There is a continuing need to monitor coastal sea levels and an unfulfilled need for simultaneous information on waves, which provide the destructive energy." The threat remains, and the need to monitor sea levels continues. There is no routine national collection and archiving of representative inshore wave data.

4. There are frequent remainders of the high social and material costs of flooding, highlighting the need for adequate protection and warning. For example, very recently severe storms brought havoc to many parts of the country in January 1998. Hurricane force winds met with high tides to batter the south west coastline. A breach of sea defences at Selsey on 4th January led to the evacuation of 30 people and the flooding of 20 chalets and 100 caravans (EA, 1998a). There was extensive flooding of low lying land in the EA's Southern region, particularly affecting roads and farmlands. Storm surges on the 1lth January caused £400,000 worth of damage to the EA's sea defences at Pevensey.

5. The Flood and Coastal Defence R & D report (MAFF, 1992) also stated that "NO coastal engineering problem can be solved without a good understanding of the. past and present behaviour of the coastline. This demands not only detailed measurements of the physical properties of the shoreline over many years, but also adequate records of the environmental loading parameters such as sea levels, wave and current conditions." This demand still applies.

6. The aim of the Government's flood and coastal defence policy (MAFF, 1993 and EA, 1998c) is "to reduce risks to people and the developed and natural environment from flooding and coastal erosion by encouraging the provision of technically, environmentally and economically sound and sustainable defence measures." The **objectives** and means of this policy include the provision of adequate and cost-effective flood warning systems, by funding a Storm Tide Warning Service (STWS) and funding a national network of tide gauges on sea levels at key positions for use by the STWS and in national and international R&D (MAFF, 1993).

7. The STWS was set up in the wake of the 1953 floods to provide warnings of high **surge** tides on the east coast. It has since been extended to cover the south and west coasts. The STWS is funded by MAFF; and the Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD) make a consolidated contribution to the running of the STWS (including operation and maintenance of the tide gauge network), based on an agreed formula (Personal communication, David Richardson (MAFF Flood and Coastal Defence Division), 1998).

8. The Environment Agency came into being in 1996, replacing the National Rivers Authority. The Agency is responsible, within England and Wales, for the dissemination of flood warnings to the public; for the improvement and maintenance of flood defences; and for prompt and effective operation of the flood defence system when floods or high tides are predicted. (The Agency does not have any flood defence responsibilities in Scotland - those lie with local authorities. However, the Scottish Environment Protection Agency (SEPA) has a duty to provide advice on flood risk). It's principal aim for flood defence is (EA., 1998c) "to provide effective defence and warning systems to protect people and property against flooding from rivers and the sea".

9. The EA's Tidal Flood Forecasting (TFF) infrastructure comprises the National Storm Tide Warning Service (operated by the STWS) and a number of Local Storm Tide Forecasting and Warning Centres operating in real time for all tidal flood risk **periods.** The EA's interests in the National Network are primarily for flood forecasting and monitoring. At present, the general arrangement takes into account a National gauge nearby and also gauges run by other authorities, including the EA. The STWS forecasts are used and monitored locally, noting tide and other local conditions, which are incorporated into the warning. The system of flood warning has been developed over a number of years, and is inconsistent - some warnings are made regionally and others are made at a local level (EA, 1998b).

10. A national tide gauge network was set up following the 1953 east coast flood, in which over 300 people were drowned in the UK. In the early years, hourly water level observations were made at key locations by harbour Authority staff and passed by telephone to the nearest meteorological office; then by teleprinter to Bracknell. In 1976, the Tide Gauge Inspectorate (TGI) was established at POL (then the Institute of Oceanographic Sciences, Bidston) to rum the national network as a centralised service. By March 1991, 31 stations had been modernised, and a further 6 by March l993. Over the years, all new sites have been identified and requested by the

National Tide Committee, the STWS or the Environment **Agency.** Annex 1 gives details of the 44 gauges presently on the Network.

11. There are two independent measuring systems; most sites have a pneumatic bubbler system but there are still a few float-type gauges. Output from the transducers was transferred to the "Dataring" system developed by POL in the early 1980s as a centralised sea level data collection system. This became the **primary** telemetry system for the STWS. The Bracknell Dataring system uses a PC as a base station to dial out through a modem over the Public Switched Telephone Network (PSTN) to recover data from a data logger at each site.)

12. In 1962, an AGA telemetry system was installed at 10 stations down the east coast using the Defence Teleprinter Network (DTN) to provide real time data in the STWS office. The AGA company withdrew from the tidal telemetry business in the 198Os, and maintenance support was lost and spare parts became a problem. Also, in the mid 198Os, the PSTN was considered less robust than today, with periodic overloading of the system, resulting in inability to obtain key data using Dataring at crucial times.

13. Therefore POL designed the "Dataflow" system, using existing private telephone wires to deliver real time data from Wick, North Shields, Immingham and Lowestoft to Bracknell. (Dataflow produces digital signal at 75 baud for transmission over a 80 volt telegraph line). The digital dataflow signal is converted to analogue signals for the Thames Barrier Operations Centre, which also needs data from Newhaven and Dover. A Dataflow system has been installed at Newhaven, but the old AGA system at Dover has now ceased and a replacement is pending.

14. Through the Tide Gauge Contract, MAFF funds POL to modernise and maintain the National Network. The costs of processing, banking, analysing or supplying the sea level data is not covered by the Contract. Unless covered by specific Contracted or Commissioned Projects, these activities are funded by NERC, with costs recovered according to the NERC Data Policy.

3. Summary of Users' Inputs

General

1. There is a continuing threat of marine flooding to parts of the UK due to the inundation of low-lying land by a combination of tides and storm-surges; and therefore a continuing need to monitor coastal sea levels and a need for simultaneous information on waves (MAFF, 1992).

2. No coastal engineering problem can be solved without a good understanding of the past and present behaviour of the coastline. Amongst other things, this demands adequate records of sea levels (MAFF, 1992).

3. A national network of tide gauges on sea levels at key positions for use by the STWS and in national and international R&D is needed to meet the objectives and means of the Government's flood and coastal defence policy (MAFF, 1993).

4. The existence of a modernised national sea level network, maintained to high standards, is crucial for the provision of good quality sea level data relevant to the understanding of the impact of the sea on the coast of the United Kingdom.

5. Sea level data is necessary for the study of tides, surges, mean sea level (MSL) and extreme levels. This includes scientific and engineering research and development, but in particular the operational needs of the STWS and the Environment Agency.

6. The Dataflow network is to go out of service as it is becoming progressively more difficult to maintain.

7. Authorities in Belgium, Denmark and Holland access UK tide gauge data via the Thames Barrier.

Needs of the Storm Tide Warning Service (STWS)

8. The STWS have a requirement for observations of sea level <u>in real time</u>

   (i) as part of the surge residual elevation forecasting process

   (ii) for monitoring the development of the storm surge as it moves down the coast

   (iii) in support of Ministry of Defence surveying operations.

9. Off-line, observed sea levels are needed by the STWS to

(i) validate the accuracy of forecasts and warnings; thus producing reports on storm surge events, maintaining an overview of the accuracy of predictions and urging refinements where necessary.

(ii) issue warnings for the southern North Sea and the Dover Straits when meteorologically-induced reductions in tidal levels (negative surges) might result in a navigation hazard to shipping.

10. The STWS use 30 of the 44 gauges routinely, classified as "key" gauges. They are Stornoway, Wick, Aberdeen, North Shields, Immingham, Cromer, Lowestoft, Felixstowe, Sheerness, Dover, Newhaven, Portsmouth, Bournemouth, Weymouth, Plymouth, Newlyn, Ifracombe, Hinkley Point, Avonmouth, Newport, Mumbles, Milford Haven, Fishguard, Barmouth, Holyhead, Llandudno, Liverpool, Heysham, Workington, and Millport. In addition, the gauge at Moray Firth is used by the STWS to support its service to Highland County Council.

Another 4 "secondary" gauges (Kinlochbervie, Leith, Whitby and Portpatrick) provide useful information when data are not available from adjacent key stations.

Six others (Lerwick, Jersey, St. Mary's, Port Erin (IOM), Portrush and Bangor) are considered by the STWS to be of use when a model which assimilates sea level data is developed and implemented.

1 I. Three gauges are not of immediate use to the STWS (or to the EA, see below): Port Ellen, Islay; Tobermory and Ullapool.

I 12. STWS has a need for gauge coverage around the whole coastline, but the required density varies with local circumstances. Factors that require greater density me:

(a) significant local risk of flooding
(b) large changes in tidal range or surge amplitudes over short distances
(C) slow speed of propagation of tidal energy along a coastline.

Spacing should be considered in terms of both spatial distance and High Water Interval (the difference in time of High Water at adjacent gauges). Gauges in low risk areas should not be more than 3 hours apart in HWI terms. In high flood risk areas, they should not be more than 90 minutes apart temporally or 50 nautical miles Spatially.

In areas of high flood risk where changes in tidal range are large, the spacing between gauges will need to be reduced such that gauges are located at about every 2m variation in mean spring range.

Gauge sites are from time to time out of action for lengthy periods, either as a result of planned associated works or otherwise. The network spacing needs to be such that adjacent gauges will provide adequate cover when a gauge is **temporarily** not available.

13. STWS needs a gauge on the south shore of the Isle of Wight (St. Catherine's Point?), which is more representative of the area, because Portsmouth is subject to the friction effects of the Solent and therefore not representative of the area in general. A gauge in the Wash area is also needed, to replace King's Lynn.

14. STWS considers that there is a need for wave measurements in near real time, in support of wave forecast data.

Needs of the Environment Agency (EA)

15. The EA has a need for observations of sea/tide level in real time to:

- monitor levels associated with local flood risk zones in periods of tidal surges.
- monitor the accuracy/timeliness of national surge residual forecasts
- revise the Agency's colour phase flood warnings.

A recording accuracy of about 1 cm is required.

16. The Agency's ability to reliably meet flood warning targets and provide adequate response times to the emergency authorities and the public is constrained, amongst other things, by deficiencies related to insufficient local Utilisation of real time sea level data from the National Network.

17. The EA uses 30 of the 44 National gauges for tidal flood forecasting and monitoring. The sites are Wick, Aberdeen, North Shields, Whitby, Immingham, Cromer, Lowestoft, Felixstowe, Sheerness, Dover, Newhaven, Portsmouth, Boumemouth, Weymouth, Devonport, Newlyn, St Mary's, Ilfracombe, Hinkley, Avonmouth, Newport, Mumbles, Milford Haven, Fishguard, Bat-mouth, Holyhead, Llandudno, Liverpool, Heysham and Workington. Sixteen gauge sites are monitored by 1 region, 10 sites by 2 regions, 2 sites by 3 regions and 2 sites by 4 regions.

18. At 18 of these 30 sites, there are duplicate sensors or duplicate outstations. The real time requirements of the EA and the STWS are similar, so there are opportunities for cost savings in access to common data, especially given the proposed POL outstation replacement programme (EA, 1998b).

19. Wind speed and direction are associated parameters needed by the EA. Local wind measurements at exposed tide gauge sites give useful indication of forecast wind accuracy. There is an extensive network of coastal wind monitoring sites (principally MetO sites), but in certain areas wind recording at National Network sites could be developed where there are gaps in the current network (EA, 1998b).

20. Wave height, period and direction are associated parameters needed by the EA. There are opportunities to make better use of wave monitoring facilities installed for design and other purposes by the EA and others (EA, 1998b); and this includes the new POL logger system at National Network sites.

21. Both the STWS and the EA need a high level of confidence in forecasts, i.e. in predictions versus observations, and therefore in monitoring.

Underpinning scientific needs

22. In order to underpin the operational and design needs of the EA and the STWS, sea level data is needed to help understand the generation and propagation of surges, to check the accuracy of models in areas where there is a danger of flooding - for modelling development and for operational purposes during real time events; to provide estimates of sea level trends; and the analysis and prediction of extreme sea levels. For operational purposes, data is needed for assimilation into the model forecast to correct initial data and so improve forecast accuracy.

3. Data from the National Network are used in a number of study areas involved in sea level; including climate change, geology and inter-annual variability. Long rds of best quality are needed - 50/60 years for studies of inter-annual and inter- variation, about 50 years for computation of decent trends; greater than 10 years for quality control and the annual cycle, Only 4 UK gauges have Permanent Service for Mean Sea Level (PSMSL) “Revised Local Reference” (RLR) records greater or **equal** to 50 years (1 in Ireland), unlike other European countries which have many more. There are only approximately 25 UK and Irish **gauges** which have PSMSL RLR data for more than 15 years.

24. For mean sea level studies associated with climate change (i.e. long term trends), a number of gauges need to be well maintained and geodetically connected to primary standards. Long term monitoring is needed to determine the validity or otherwise, of the Present relative sea level trends advised to consulting engineers by the EA and FF

EA Region	Allowance
Anglian, Thames, Southern	6mm/year
North West, Northumbria	4mm/year
Remainder	5mm/year

(Operating authorities were advised of these trends by MAFF and the Welsh Office in November 1991 (MAFF, 1991)).

25. Tide gauges only measure mean sea level changes relative to a **local land** benchmark. Decoupling of the sea and land signal is necessary to understand more about processes and trends of absolute sea level. Therefore, the use of geodetic techniques, such as GPS and Absolute and Relative Gravity, is essential. The strategies for using these techniques need to be built around the distribution and quality of the available sea level data from coastal tide gauges.

26. Good UK mean sea level measurements are needed in order to contribute to the European dataset; especially as some UK gauges are most representative of open ocean conditions. In turn, the European data set is a crucial contribution to the global mean sea level data set. However, the European and global data sets are not adequate as a UK mean sea level 'indicator', because of its spatial variation.

27. Special 'European' mean sea level needs for a UK national network include:

- the global GLOSS programme (gauges and GPS) requiring input of sea level observations from the UK
- the densification of gauges and GPS stations for more regional networks like EuroGLOSS
- the set up of mechanisms for 'regional' GPS data processing
- the set up of mechanisms for centrally-distributed data collections of sea level information cross-linked to GPS time series information.

28. European funding is usually for a three year period - the National Network needs long term national funding.

e analysis and prediction of extreme sea levels is not possible without data e National Network. The latest methodology, based on spatial statistical techniques, requires estimation of the 1 year 'return period' level. However, continuous monitoring around the coast is needed to overcome the problem that any one year is highly year specific. Long term monitoring at reference sites around the coastline is important to relate events at intermediate sites to the long term values. The present network is sparse along the east coast, e.g. Immingham is not representative of an open coast.

Other scientific needs and uses

30. Flow through the North Channel, measured in detail in 1993 - 94, has been related to elevation differences between gauges in Ireland, Isle of Man and Scotland (Bangor, Portrush, Port Erin, Port Ellen, and Portpatrick). The Department of : Environment (now Department of Environment, Transport and the Regions) funded the above analysis, and the continuing measure of flow, via the elevation differences, is of interest to the Centre for Environmental, Fisheries and Agricultural Studies (CEFAS), formerly the MAFF Fisheries Laboratory, Lowestoft.

It is probable that NERC will have a concerted experiment on productivity in the Irish Sea, during which time the gauges will serve as a continuing monitor of in/out flows. This work will be an important contribution to the international GLOBEC Programme.

31. The Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD) have a model of the Minch, in support of their environmental and fisheries policy interests. The gauges at Kinlochbervie, Tobermory and Ullapool should provide validation data, and those at Stornoway and Ullapool should provide a means to monitor flow through the Minch.

32. SOAEFD, and NERC's Centre for Coastal and Marine Sciences (CCMS), are interested in the flow into the North Sea around Scotland, affecting North Sea circulation and the transport of plankton, fish larvae etc. The flow can be monitored to some extent by the difference in levels between Lerwick and the Scottish mainland (Wick, Kinlochbervie).

Engineering studies

33. Engineering studies/applications require sea level data for:
- mathematical modelling of coastal processes,
- the assessment of flooding extent and damage,
- detailed design of flood defences/coast protection works,
- estuary, shoreline and beach management plans,
- design of port and harbour works,
- navigation and freight handling studies, and
- pollution studies.

34. Essential components of sea level required for the above studies include mean and extreme astronomical tides and joint probability analyses. Tide level and surge as separate components are desirable. Additional parameters are continuously monitored offshore wave heights, periods and directions at selected inshore sites (for the purpose of calibrating wave models); wind speed and direction (for hindcasting waves and determining long-term wave climate); and water quality.

Other parameters such as temperature, salinity and atmospheric pressure should be monitored at a selected number of sites.

35. Spacing between monitoring sites should be about 50km and include estuaries.

36. At a recent scheme at Pevensey, an additional one cm on top of the defences would have cost £300,OOO extra; and 10 cm would have been £3 million extra.

37. There is a practical requirement for statistics of sea level variations and trends in order to achieve an understanding of events in past decades. At several locations trends in Mean Tidal Range, Mean High Water and Mean Low Water levels are sufficiently large that they should be taken into account in investigating impacts of sea level change and in extreme level engineering studies.

38. The distribution of gauges is poor, especially along the south coast.

39. The provision of hourly sea level data (and waves) is crucial for the estimation of the joint probability of sea level and waves, particularly levels at the time of High Water. However, the present cost of obtaining processed sea level data is preventing joint probability studies at many sites.

40. Real or simulated concurrent time series data is required for engineering Purposes.

41. There is a paucity of measured wave data - synthetic data from numerical models usually has to be used.

42. Estuarine studies need good sea level data, as well as river flows and meteorology, salinity and suspended solids.

43. There is no general requirement for real-time data access, but processed data should be easily accessible in usable formats from a national or regional data centre.

4. Conclusions and Recommendations

1. There is a continuing threat of marine flooding to parts of the UK due to the inundation of low-lying land by a combination of tides and storm-surges; and therefore a continuing need to monitor coastal sea levels (and a need for simultaneous information on waves).

2. No coastal engineering problem can be solved without a good understanding of the past and present behaviour of the coastline. Amongst other things, this demands adequate records of sea levels.

3. A national network of tide gauges on sea levels at key positions is needed to underpin the operational and design needs of the EA and the STWS, and hence meet the objectives and means of the Government's flood and coastal defence policy. The network should be robust and secure, with:

   a) links to local gauges and local models

   b) common data points and

   c) access by areas /regions.

4. Thirty five of the existing 44 National Network gauges are of direct and routine use to the EA and STWS. Six others (Lerwick, Jersey, St. Mary's, Port Erin (IOM), Portrush and Bangor) are considered by the STWS to be of use when an assimilated model is developed and implemented.
Recommendation: The development and maintenance of these gauges should continue to be funded from the EA/MAFF operational budget, at an adequate level; estimated as £400,000 at 1999/2000 prices. Additional gauges should be added, according to EA and STWS requirements.

5. Three gauges are not of immediate use to the EA or STWS: Port Ellen, Islay; Tobermory and Ullapool. These are of use for scientific studies to understand and predict shelf sea flows to the west, north and east of Scotland. These are relevant to environmental (particularly contaminants) and fisheries policies, and hence to CEFAS, DETR and SOAEFD.
Recommendation: MAFF should discuss the funding of these gauges with these organisations, and SEPA, unless it already receives a contribution from them.

6. This report has identified the characteristics of the existing network, i.e. the primary purpose, length of record, spacing, tidal parameters and siting of each gauge (see Annex 1). Taking into account the STWS criteria on gauge spacing (see paragraph 12 above), and EA's assessment of high risk areas, the present Network spacing is adequate and necessary; except for the Wash area and the IOW south coast.
Recommendation: Maintain the present coverage, and add necessary additional gauges.

7. Inevitably, different generations of equipment are in use at different sites.
Recommendation: As opportunity permits, all National Network gauges should be updated, to operate to the same standards; with a recording accuracy of about lcm and three minutes.

8. Decoupling of the sea and land signal is necessary to understand more about the processes and trends of absolute sea level.
Recommendation: Relevant sea level stations should be equipped with instruments capable of decoupling land and sea movements, e.g. based on geodetic techniques like GPS and Absolute Gravity. Information necessary to establish a relevant network will be provided by existing projects in MAFF's Flood Protection Commission with NERC.

9. Wind speed and direction, and wave height, period and direction are associated parameters needed by the EA. There are gaps in the current coastal wind monitoring network, and very few wave monitoring stations.
Recommendation: Suitable National Network sites should be identified, and contemporary wave and wind measurements made at them, exploiting the capabilities of the new POL logger system.

10. Estuarine studies and management plans need good sea level data.
Recommendation: The forthcoming estuary programme should take into account the necessity to monitor sea level and other parameters, and hence make recommendations for appropriate density of monitoring.

11. There needs to be a more effective way for the EA's Local Storm Tide Forecasting and Warning Centres to access sea level data from the National Network.
Recommendation: There should be two national data centres in addition to the Met. Office STWS, receiving all sea level data in real time; with provision for EA access.

12. Adequate funding of the National Network is needed in order to meet the requirements of the EA and the STWS, and hence meet the objectives and means of the Government's flood and coastal defence policy.
Recommendation: MAFF should continue to seek adequate funding for the maintenance and development of the National Network, based on the needs of the EA and STWS. This is estimated at £400,OOO at 1999/2000 prices.

13. UK sea level data is supplied to other European countries; there are no reciprocal arrangements.
Recommendation: Such reciprocal arrangements should be encouraged, including the Republic of Ireland.

14. The MAFF Tide Gauge Contract does not cover the costs of processing, banking, analysing or supplying sea level data from the National Network.
Recommendation: Reassess the pricing policy of supplying processed sea level data for use in publicly funded projects.

5. References

Environment Agency, 1998a. “Environment Action”, February/March 1998, 12pp.

Environment Agency, 1998b. “Tidal **Flood Forecasting Project Report”, Executive** Summary, Draft Version 3, 5pp.

Environment Agency, 1998C “An Action Plan for Flood Defence”, 24pp.

MAFF, 1991. MAFF advice on allowances for sea level rise. Issued November 1991.

MAFF, 1992. “Flood and Coastal Defence Research and Development: Report of the Advisory Committee”. MAFF Publications, London, PB 0864,78pp.

MAFF, 1993. “Strategy for Flood and Coastal Defence in England and Wales”. MAFF Publications, London, PB 1471,39pp.

A N N E X 1

Characteristics of tide gauges on the existing Network

NATIONAL SEA LEVEL NETWORK

Site	Purpose	Other measurements	Real time access	Length of Record
St Mary's	Assimilation			1966-86, **1987, 1994-**
Newlyn	Key	GPS	Yes	**1915-**
Ilfracombe	Key			**1968-1971, 1977-**
Hinkley Point	Key			**1990-**
Avonmouth	Key	GPS		1924-38, 1941-50, 1951-60, **1961-62, 1972-76, 1979-84, 1986-**
Newport	Key			**1993-**
Mumbles	Key			**1989-93, 1997-**
Milford Haven	Key			**1953-54, 1961-62, 1964-65, 1967-**
Fishguard	Key			1966-67, 1969, **1971, 1973-**
Barmouth	Key			**1987, 1991-**
Holyhead	Key	Met, GPS		1908-1910, 1959-63, **1964-73, 1977-85, 1987-91, 1995-**
Llandudno	Key			**1971, 1994-**
Liverpool	Key	Met, GPS		1941-51, 1953-68, 1968-74, 1975-89, **1991-**
Heysham	Key	GPS		1959-63, **1964-69, 1971-**
Port Et-in	Assimilation			**1992-95, E491998-**
Workington	Key	Met		1956-57, 1962-63, 1972, 1975-80, **1992-**
Bangor	Assimilation			**1994-**
Portpatrick	Secondary	GPS		1965-67, **1968-**
Portrush	Assimilation			**1995-**
Port Ellen				**1979, 1980, 1991-**
Millport	Key	GPS		1965-73, 1974-77, **1978, 1981-83, 1985-**
Tobermory				1967, 1969-76, **1990-**
Ullapool		Met		1963-65, **1966-68, 1970-72, 1974-80, 1981, 1983, 1985-**
Stornoway	Key	GPS		1928-30, 1956-65, 1969-75, **1976, 1978-81, 1983, 1985-**
Kinlochbervie	Secondary			**1991-**

Lerwick	Assimilation	GPS		1953-58,1959-78,1980-
Wick	Key		Yes	**1965-70, 1972-**
Moray Firth	FW Highland CC			1975, **1994-**
Aberdeen	Key	GPS	Yes	**1930-32, 1933-36, 1946-58, 1960-62, 1964-65, 1967-75, 1980-**
Leith	Secondary			1969-72, 1980, **1981, 1989-**
North Shields	Key	Met, GPS	Yes	1895-1945, **1946-47, 1949-56, 1961, 1965-75, 1978-**
Whitby	Secondary			**1980-**
Immingham	Key	Met, GPS	Yes	**1953, 1956-58, 1963-**
Cromer	Key			**1973-74, 1976, 1982, 1988-**
Lowestoft	Key	Met, GPS	Yes	1955-63, **1964-**
Felixstowe	Key			**1982, 1984, 1986-**
Sheerness	Key	GPS		1832-58, 1891-1927, 1950-51, **1952-58, 1965-75, 1980-**
Dover	Key	GPS		1910-23, **1924, 1926, 1928, 1930, 1934-36, 1938, 1958-**
Newhaven	Key	GPS	Yes	**1982-87, 1991-**
Portsmouth	Key	GPS		1969-71, 1987, **1991-**
Bournemouth	Key			**1996-**
Jersey	Assimilation			**1992-**
Weymouth	Key			**1989, 1991-**
Devonport	Key			1956-60, **1961-62, 1967-68, 1987, 1991-**

Notes

1) Purpose: - This is a list of the STWS requirement. "Assimilation" sites may be useful if an assimilated CS3 or other models are developed.
2) Other measurements: - "Met " consists of wind speed and direction sensors interfaced to the Dataring system. "GPS" sites are part of the UKGAUGE III Project 1997-2000.
3) Real-time access: - These Dataflow sites provide real-time data to the STWS, Thames Barrier and the RIKS in Holland. This system is likely to be terminated with the closure of the Defence Telephone Network private wires.
4) Length of Record: - These records consist of high and low water values, hourly heights, charts, micro film and BODC data base data. The bold type indicates the BODC data base holdings.

NATIONAL SEA LEVEL NETWORK

Site	Distance to next gauge (miles)	***HW time***	Mean spring range (metres)	Comments on location of gauge
St Mary's	38	00:17	4.97	Harbour storeroom measuring point seaward end of Hughtown harbour jetty.
Newlyn	98	00:00	4.76	Tidal Observatory at seaward end of Newlyn quay.
Ilfracombe	46	01:17	8.43	GRP TG building on Ilfracombe pier a shallow site, the best location in a difficult area
Hinkley Point	26	01:48	10.99	Water intake tower for the Nuclear Power Station, (restricted access).
Avonmouth	15	01:55	12.36	Seaward end of disused oil jetty. Access to measuring point is by boat, jetty severed
Newport	60	01:42	11.78	ABP Newport TG building entrance to Newport Docks, best location in a difficult area.
Mumbles	45	01:36	8.50	GRP TG cubicle in RNLI boathouse.
Milford Haven	37	01:31	6.32	Storeroom, Port Authority jetty. A good site within the Haven.
Fishguard	70	02:51	4.04	GRP TG building in Fishguard harbour, protected by breakwater.
Barmouth	65	03:46	4.28	Toll booth Barmouth bridge on the Mawddach estuary, best site in a difficult area.
Holyhead	38	06:05	4.95	Brick TG building at the entrance to Holyhead harbour, protected by breakwater.
Llandudno	35	06:15	7.17	GRP TG building seaward end of Llandudno pier.
Liverpool	45	06:39	8.27	Brick building at the entrance to Gladstone dock, Mersey estuary.
Heysham	75	06:51	8.52	Temporary storeroom inside Heysham harbour close to the entrance.
Port Erin	63	06:53	4.87	Lifeboat station Port Erin Bay protected by a collapsed breakwater.
Workington	85	07:14	7.43	Brick building at the entrance to Workington docks on the River Derwent.
Bangor	28	06:40	2.86	GRP TG building inside Bangor Marina.
Portpatrick	67	07:05	3.39	GRP TG building inside Portpatrick harbour.
Portrush	36	03:23	1.75	RNLI boathouse inside Portrush harbour.
Port Ellen	51	09:03	0.67	Storeroom at the Port Ellen ferry terminal on Loch Leodumais.
Millport	75	07:52	2.96	Storeroom on the University Marine Biological Station jetty.
Tobermory	118	02:37	3.83	Ferry Terminal office Mishnish Pier
Ullapool	50	03:11	4.43	GRP TG building at Ullapool Harbour on Loch Broom.
Stornoway	52	03:06	4.12	GRP TG building on No2 jetty Stornoway harbour.
Kinlochbervie	180	Not available	4.19	Ice Plant Kinlochbervie harbour on Loch Inchard.

Site	Distance to next gauge (miles)	HW time	Mean spring range (metres)	Comments on location of gauge
Lerwick	137	17:54	1.72	Wooden TG building, Lerwick harbour close to harbour entrance
Wick	67	18:36	2.88	GRP TG building inside Wick harbour.
Moray Firth	120	18:51	3.63	GRP TG building McDermott rig construction yard on Whiteness Bay.
Aberdeen	95	20:30	3.64	Brick TG building inside Aberdeen harbour.
Leith	136	21:40	4.88	Wooden TG building at the entrance to Leith Docks on Firth of Forth.
North Shields	48	22:36	4.40	Brick TG building on the River Tyne.
Whitby	85	22:57	4.59	Harbour Master's office Whitby harbour on the River Esk.
Immingham	80	01:00	6.23	GRP TG building at the entrance to Immingham docks on the River Humber.
Cromer	40	02:02	4.75	Temporary cubicle on Cromer pier.
Lowestoft	43	04:32	1.98	GRP building inside the entrance to Lowestoft harbour.
Felixstowe	43	06:35	3.43	GRP TG building on Felixstowe pier.
Sheerness	52	07:36	5.27	Brick TG building at Sheerness docks at the confluence of Thames and Medway rivers.
Dover	63	06:37	5.82	GRP, TG building entrance to Dover Harbour Western docks.
Newhaven	52	06:28	5.97	Port Control at the entrance to harbour on the River Ouse, protected by a breakwater.
Portsmouth	35	06:58	3.90	Brick TG building King's Stairs, R N naval base (Restricted access).
Boumemouth	104	07:40	1.76	Electrical control room on Bournemouth pier.
Jersey	99	01:27	9.74	Brick TG building on Victoria pier inside St Helier harbour.
Weymouth	77	01:21	1.97	GRP TG building entrance to Weymouth harbour.
Devonport	63	00:48	4.75	Brick TG building Devonport dockyard (restricted access).
Newlyn	——	00:00	4.76	--

Notes

1) All sites contain the Dataring system, a datalogger recording data from two independent measuring systems and a datum probe. The data is accessible by modem telephone connection. The systems are housed in a variety of buildings. All GRP buildings are owned by MAFF.

NATIONAL SEA LEVEL NETWORK

Site	Suitable for met instruments	Representative of coastline sea levels	Representative for nearshore wave measurements	Comments on sea level and wave measurements
St Mary's	Yes	Yes	Yes	Gauge at the seaward end of the harbour jetty in an open location.
Newlyn	Yes	Yes	Yes	Gauge at the seaward end of the harbour jetty in an open location.
Ilfracombe	Yes	Yes	Yes	Gauge on the pier in an open location.
Hinkley Point	Yes	Yes	Yes	Gauge on water intake tower, Nuclear power station in an open location
Avonmouth	Yes	Yes	Possible	Gauge at seaward end of jetty in an open location in the Sevem estuary
Newport	Yes	Yes	No	Gauge at the entrance to Newport docks
Mumbles	Yes	Yes	Possible	Gauge in the RNLI boathouse in a partially protected site
Milford Haven	Yes	Yes	No	Gauge on the port authority jetty in an open location within the Haven
Fishguard	Yes	Yes	No	Gauge inside harbour entrance
Barmouth	Yes	Yes	No	Gauge on the rail bridge spanning the Mawddach estuary
Holyhead	Yes	Yes	No	Gauge inside harbour entrance
Llandudno	Yes	Yes	Yes	Gauge on the seaward end of the pier in an open location
Liverpool	Yes	Yes	Possible	Gauge in Mersey estuary
Heysham	Yes	Yes	No	Gauge inside harbour entrance
Port Erin	Yes	Yes	No	Gauge in the RNLI boathouse protected by a breakwater
Workington	Yes	Yes	No	Gauge inside harbour entrance
Bangor	Yes	Yes	No	Gauge inside harbour entrance
Portpatrick	Yes	Yes	No	Gauge inside harbour entrance
Portrush	Yes	Yes	No	Gauge inside harbour entrance
Port Ellen	Yes	Yes	Possible	Gauge inside Loch Leodumais
Millport	Yes	Yes	Yes	Gauge on the University jetty in an open location.
Tobermory	Yes	Yes	No	Inside the Sound of Mull
Ullapool	Yes	Yes	Possible	Gauge in Loch Broom
Stornoway	Yes	Yes	No	Gauge inside harbour entrance
Kinlochbervie	Yes	Yes	No	Gauge inside Loch Inchard

Site	**Suitable for met** instruments	Representative of coastline sea levels	Representative for nearshore wave measurements	Comments on sea level and wave measurements
Lerwick	Yes	Yes	No	Gauge inside harbour entrance
Wick	Yes	Yes	No	Gauge inside harbour entrance
Moray Firth	Yes	Yes	No	Gauge inside harbour entrance
Aberdeen	Yes	Yes	No	Gauge inside harbour entrance
Leith	Yes	Yes	Possible	Gauge at dock entrance, Firth of Forth in an open location.
North Shields	Yes	Yes	No	Gauge inside harbour entrance on the River Tyne
Whitby	Yes	Yes	No	Gauge inside harbour entrance on the River Esk
Immingham	Yes	Yes	Possible	Gauge at the entrance to the docks in an open location on the Humber estuary
Cromer	Yes	Yes	Yes	Gauge at the seaward end of the pier in an open location
Lowestoft	Yes	Yes	No	Gauge inside harbour entrance
Felixstowe	Yes	Yes	Yes	Gauge at the seaward end of the pier in an open location
Sheerness	Yes	Yes	Possible	Gauge in Thames estuary
Dover	Yes	Yes	No	Gauge inside harbour entrance
Newhaven	Yes	Yes	No	Gauge inside harbour entrance
Portsmouth	Yes	Yes	No	Gauge inside harbour entrance
Boumemouth	Yes	Yes	Yes	Gauge on the pier in an open location
Jersey	Yes	Yes	No	Gauge inside harbour entrance
Weymouth	Yes	Yes	No	Gauge inside harbour entrance
Devonport	Yes	Yes	No	Gauge inside harbour entrance

Notes

1) Suitable for met instruments: - Bold type indicates that met instruments are already installed.

1*

NATIONAL SEA LEVEL NETWORK

Site	Accuracy of lcm	Modem speed 1200 baud	Mid tide datum probe	Tide staff	Comments
St Mary’s	Yes	Yes	Yes	Yes	
Newlyn	Yes	No	Yes	Yes	New modem to be installed 1998/99
Ilfracombe	Yes	Yes	Yes	No	No suitable site for a tide staff
Hinkley Point	Yes	No	No	No	New modem to be installed 1998/99
Avonmouth	Yes	Yes	No	No	No suitable site for a tide staff
Newport	Yes	No	No	Yes	New modem to be installed 1998/99
Mumbles	Yes	Yes	Yes	No	No suitable site for a tide staff
Milford Haven	Yes	Yes	No	Yes	
Fishguard	Yes	Yes	No	Yes	
Barmouth	Yes	No	No	No	New modem to be installed 1998/99. No suitable site for a tide staff
Holyhead	Yes	Yes	Yes	Yes	
Llandudno	Yes	Yes	Yes	No	No suitable site for a tide staff
Liverpool	Yes	Yes	No	No	No suitable site for a tide staff
Heysham	Yes	Yes	Yes	No	New tide staff to be installed 1998/99
Port Erin	Yes	Yes	Yes	No	No suitable site for a tide staff
Workington	Yes	Yes	No	Yes	
Bangor	Yes	Yes	Yes	Yes	
Portpatrick	Yes	Yes	No	Yes	
Portrush	Yes	Yes	Yes	No	No suitable site for a tide staff
Port Ellen	Yes	No	No	No	New modem to be installed 1998/99. No suitable site for a tide staff
Millport	Yes	Yes	Yes	Yes	
Tobermory	Yes	Yes	Yes	Yes	
Ullapool	Yes	Yes	Yes	Yes	
Stornoway	Yes	Yes	Yes	Yes	
Kinlochbervie	Yes	No	No	No	New tide staff to be installed 1998/99

Site	Accuracy of lcm	Modem speed 1200 baud	Mid tide datum probe	Tide staff	Comments on sea level and wave measurements
Lerwick	Yes	Yes	Yes	Yes	
Wick	Yes	Yes	Yes	Yes	
Moray Firth	Yes	Yes	Yes	No	No suitable site for a tide staff
Aberdeen	Yes	Yes	Yes	Yes	
Leith	Yes	No	Yes	Yes	New modem to be installed 1998/99
North Shields	Yes	Yes	No	No	New tide staff to be installed 1998/99
Whitby	Yes	No	No	No	New modem to be installed 1998/99. Tide staff vandalised
Immingham	Yes	Yes	Yes	Yes	
Cromer	Yes	Yes	No	No	No suitable site for a tide staff
Lowestoft	Yes	Yes	Yes	Yes	
Felixstowe	Yes	No	Yes	Yes	New modem to be installed 1998/99
Sheerness	Yes	Yes	Yes	Yes	
Dover	Yes	Yes	Yes	Yes	
Newhaven	Yes	Yes	No	Yes	
Portsmouth	Yes	No	No	Yes	New modem to be installed 1998/99
Bournemouth	Yes	Yes	Yes	No	No suitable site for a tide staff
Jersey	Yes	Yes	Yes	Yes	
Weymouth	Yes	Yes	No	Yes	
Devonport	Yes	Yes	Yes	Yes	

Notes

1) Mid tide datum probes:- Four probes are being installed each year (No new installations will be carried out during 1998/99)

ANNEX2

Workshop on National Sea Level Network

Tuesday 20th May, 1997

MAFF, London

Participant contributions

Existing network (D Smith, TGI)

The national tide gauge network was set up following the floods of 1953. The Tide Gauge Inspectorate (TGI) was established in 1976 and since then gauges have operated at 38 core sites. Six additional gauges have been added to meet specific local interest e.g. Barmouth and Llandudno after the 1990 floods at Towyn. Each site has two independent measuring systems, at most sites these are pneumatic bubblers, but there are still a few analogue float gauges in use; which are being phased out because of the high maintenance costs. The transducers are connected to the Dataring system which was developed by POL in the late 1970s as a centralised data collection system. The first Dataring system was installed in 1983 and now all sites have been refurbished with this system.

The present system has limitations such as all inputs have to be on the same sampling period and access is limited to one user at a time. There have been a number upgrades including development of electronics and higher speed modem links. Now there is significant potential for expansion and further development. Other organisations make observations, at national network sites for example the Environment Agency (EA) monitors at 18 sites. Some of their systems are independent of the national network but the majority use pressure tapping off the Dataring pneumatic system.

The present work includes the development of a new datalogger with the capability of monitoring more parameters on different sampling periods. New software packages, with fault diagnostic capability have also been developed. There are 14 sites which are open sea sites and suitable for measuring waves. (POL has recently had initial success with transmitting wave data from its ACCLAIM station in St Helena using telephone links.)

The cost of a new datalogger is approximately £2.5k which is similar to the present system. All existing instrumentation will link to the new logger. Second user access will be possible and the software developed at POL permits data access to the raw data as well as the processed data. Two prototype loggers are being developed for installation at Holyhead and Liverpool.

TIDE GAUGE WORKSHOP
STWS SEA LEVEL REOUIREMENTS

1. Uses of Sea Level Data

a. Predicted tidal levels and forecast surge residual elevations for the British coastline are required in order to issue warnings of coastal flood risk when pre-determined thresholds are expected to be reached or exceeded.

b. Observed tidal are required:-

ln real time:-

i As part of the surge residual elevation forecasting process.
ii Monitoring the development of storm surge activity.
iii In support of MOD surveying operations

Later: -

i Validating the accuracy of forecasts and warnings.
ii For use in the production of reports on storm surge events.
iii Maintaining an overview of the accuracy of tidal predictions and urging refinement where necessary.

c. Highest Astronomical Tide (HAT data are used as a basis for the establishment of warning threshold levels.
d. The data in a. and b. for the Southern North Sea and Dover Strait are also required in order that warnings can be issued to the appropriate marine authorities when meteorologically induced reductions in tidal levels might result in a navigation hazard.

2. Components Required.

a. Predicted Data - For site specific locations.

i Turning Points (Elevations and times).
ii Periodic elevations - Hourly used currently. Shorter period (15 min) may be necessary later.

b. Forecast Data - Currently for site specific locations.

i Periodic surge elevations. Currently hourly, 15 minute data may become necessary later.
ii Total tide plus surge - In general, tide levels predicted by shelf models are at present less accurate than site specific predictions produced by harmonic methods. In finer mesh models the reverse is true. Warnings are currently based on predicted high water plus forecast surge. This does not allow for any distortion of the tidal signal due to the presence of surge.

c. Extremes - A knowledge of extremes of both tidal and surge levels is desirable. This includes HAT and the return period data.

3. Other parameters.

Atmospheric pressure - The density of observations already available from existing key stations is considered adequate for meteorological forecasting purposes. However, additional data of proven quality from TG sites could be of value. The data would need to be readily available and suitable for automatic assimilation into the existing meteorological database. The Met. Office is progressing the development of systems that will obtain third party observations.

Wind speed and direction - Some TG sites will have suitable exposure for the measurement of these parameters. Others will be poor sites in respect of "wooding" by nearby buildings etc. There have been recent losses from among the long established coastal observing stations and new sites in appropriate locations could be of value. These data would also need to be readily and automatically assimilated into the existing database. The observations would then be available for use and display in conjunction with existing data. Data of this type of data are more useful when viewed as part of a field than as a single site.

Temperature - remarks as pressure apply.

Salinity - no requirement for this parameter.

Density - no requirement for this parameter other than for use within the water cohmm being measured.

Waves - These are required in near real time in support of forecast data.

Absolute gravity - no requirement for this parameter.

4. Accuracy

a. Predicted tidal data:-

Turning points -	Elevations	+/- 1 cm (currently not achievable in some location)
	Times	+/- 3 minutes
Periodic data -	Elevations	+/- 1 cm

b. Forecast tidal data:-

Surge residual elevations	95% probability of +/- 10 cms
Total tide plus surge	95% probability of +/- 10cms

c. Other parameters

	Range	Resolution	Mean Error
Air pressure	900-1050hPa	0.2hPa	+/- 0.5hPa
Wind speed	0-150 kn	1 kn	+/- 2 kn <40 kn +/- 5% >40 kn
Wind direction	0-360 deg	1 deg	+/- 10%
Air temperature	-20 deg to + 40 deg C	0.1 deg C	+/-0.2 deg C
Wave height	+/- 18m rel MSL	10cm	10% (or +/- 20cm If greater)
Wave direction	0-360 deg	1 deg	+/- 15 deg
Wave period	0-30 sec	0.1 sec	+/- 5% (or +/- 0.5sec If greater)

5. Spacing of gauges

Whilst there is a need for tide gauge coverage around the whole coastline the required density of coverage will vary with local circumstances. Factors that require greater density are: -

a Significant local risk of flooding.

b Large changes in tidal range or surge amplitudes over short distances.

c Slow speed of propagation of tidal energy along the coastline

Tide gauge sites are from time to time out of action for lengthy periods, either as a result of planned associated works or otherwise. The network spacing needs to be such that adjacent gauges will provide adequate cover when a gauge is temporarily not available.

The spacing of gauges needs to be considered in terms both spatial distance and high water interval (The difference in time of high water at adjacent gauges)

Gauges in low flood risk areas should not be more than 3 hours apart in high water interval terms. In high flood risk areas they should not be more than 90 minutes apart temporally or 50 nm spatially.

In areas of high flood risk where changes in tidal range are large, the spacing between gauges will need to be reduced such that gauges are located at about every 2 m variation in mean spring range.

Site Selection

Chosen sites should as far as possible be those with a clean tidal signal subjected as little as possible to the vagaries of bottom friction. Portsmouth for example has a long history of data However, it is subjected to the friction effects of the Solent and is therefore not representative of the area in general. A gauge on the southern shore of the Isle of Wight, at St Catherine's point say, would be more representative of the area,

6. Access to data

Processed vs. raw data: -

Raw data often needs to be used with care. When displayed digitally the effects of waves and seiches may not be apparent as they are in a graphical display.

Real time and near real time data: -

An optimum system would have the capability to display up to the minute data from all locations. However, it has been found that an acceptable system can be operated where much of the data has an element of staleness of up to about 15 minutes.

For a small number of stations in areas where surges propagate the observed data at one location may play a part in the forecasting and warning process for downstream locations in these cases instantaneous data are desirable in order that delays of up to half an hour do not ensue whilst determining the occurrence of high water.

The advent of surge models that assimilate observed levels also brings the requirement for data that are very near real time in order that the initial conditions of the forecast process are as up to date as possible.

National and Regional Data Centres: -

STWS could operate from a National centre provided that the processed data were not more than 15 minutes stale (10 minutes would be better).

Quality control of data on a 24 hour basis is important and currently much of this is done manually. This requires STWS to have access to the raw data at the remote sites in order to localise problems.

Regional data centres are viewed with less favour. Primarily because of the quality control problems.

Environment Agency (A. Baxendale)

The Environment Agency is a user of the data from the national tide gauge network both directly and indirectly via STWS. It is responsible for the provision of local flood warnings which are delivered to the public and its principle role is flood warning forecasting. At present the general arrangement for considering an area of flood risk will take into account an A class gauge nearby and also gauges run by other authorities. The aim is for 8 out of 10 people to get 4 hours warning of a flood. The STWS forecast are used and monitored locally, noting tide and other local conditions; and these are then incorporated into a warning. A Red warning indicates a flood which poses a risk to people and property in the flood risk area. Lower level Amber and Yellow warnings are also used. The-system of flood warning has been developed over a number of years and is inconsistent as some warnings are made regionally and others are made at a local level. A review of this is now underway, with a final report due in October 1997. The review will start with an identification of flood risk areas, and include an assessment of the best methods available, or needed, to provide a flood warning system.

The interest of the EA are principally for flood forecasting and monitoring. Forecasts are used for flood warning and for the dissemination of flood warnings. Timing and accuracy is particularly relevant and the interest extends to specific flood risk areas. Interests are linked to understanding “danger” conditions. Tide data + forecasts are used for models for both planning and in real time. The EA interest also includes flow, circulation, water quality, wave damage and overtopping. There is a move to promote what is meant by “danger” and what constitutes issuing a warning.

The network of gauges as used by the EA now includes A class gauges and 78 other standardised gauges. All UK Network gauges are used and analysis shows that expansion of the network 6 gauges in England and Wales would be beneficial, particularly along the south coast. Associated parameters which are considered in determining the colour of a flood warning are:
The “astronomical” tide
surge levels - residual forecast
sum of above - total tide
wind speed and direction
wave height, period and direction
meteorological conditions.

Apart from the national network there are a number of local systems which in themselves have many variants. Generally some instrumentation lacks robustness, there is duplication of systems, data access can be a problem, some use is made of POLTIP/VARIANTS and there are many format types. It would be an improvement to have consistency in the installations and data retrieval procedure i.e. an Agency standard approach. The north west region of the EA was referred to as having a good system.

Local gauges need time series information and again there are variations in the installations, some standardisation would be beneficial. The EA is now looking at the whole arrangement of flood warning and tide gauge needs are one component. There is no outcome of this review yet but there are significant ideas of where additional gauges would be helpful starting with the flood risk areas. There is a clear need for wind and wave data and what constitutes danger areas.

The EA needs are linked to an overall review and additional A class sites are likely. Stronger links are needed to flood risk areas and “danger” conditions. A structured national data system is needed with a) links to local gauges and local models, b) common data points and c) access by areas/regions and which is both robust and secure. The EA needs a link to the forecasting system to utilise other parameters, maximise the use of existing facilities and sort data access. The EA would encourage MAFF to restructure the National Network.

Tide/Surge/Extremes (R. Flather, POL)

Tide gauges are needed to help understand the generation and propagation of surges, to check the accuracy of models in areas where there is a danger of flooding (for model development and for operational purposes during real-time storm events) and to provide data for assimilation into the model forecast to correct initial data and to improve forecast accuracy.

Measurement of tides for a minimum period of 1 year has been thought suitable but in reality much longer records are needed. This is because tides are not independent of other parameters such as storm surges, waves, river flows, circulation, stratification and ice conditions in some areas. The end result is that in shallow water distortions between tide, surge and waves are less clear and harder to separate. There is a need to understand the implications and significance e.g. for estimating tides from observations and in comparing model and observed surges,

With care, some models achieve good results for predictions compared with harmonic methods and give total tide. In the last year or two studies have been made on how storm surges relate to other conditions e.g. surge predicted by model compared with surge predicted by observations (tide gauge). This showed a large mean error because of inconsistencies in handling of the data. There is a lack of consistency in the products of models. The effects of waves on sea level can be +/- 0.5 m. There is a need to understand processes better which in turn needs very good quality sea level data and high consistent data analysis.

Extreme levels

The extreme levels work to date would not have been possible without the national tide gauge network. Several methods have been employed in various studies. The traditional method uses the annual maxima and the use of ‘r’ largest uses more than 1 maxima for a year, typically 5-7 to extend the annual maxima. The joint probability method (JPM) includes a dependence structure of sea level and improved probability density function (pdf). Spatial techniques fall into two categories: tides produced spatially by a difference interpolation scheme using stations in the national tide gauge network as reference stations and the 12 km model as the basis function; spatial distribution of surge component fitted to all stations around the coast, weighted to longer data sets.

Monitoring at some sites is clearly important for extreme levels, and while models may improve some degree of monitoring will always be necessary. The latest report to MAFF on spatial extremes shows the importance of estimating the 1 year return level. Continuous monitoring around the coast, together with some temporary sites, is needed to overcome the problem that any one year is highly year specific. Long term monitoring at reference sites around the coastline is important to relate events at intermediate sites to the long term values. In general the present national network is sparse along the east coast. Is Immingham representative of an open coast?

Examples of assimilation of the data from the national tide gauge network are the Thames Barrier model which uses data from the Tyne Entrance and Newhaven and the STWS model which uses Aberdeen and Newlyn.

Mean Sea Level (MSL) (P. Woodworth, PSMSL)

An assessment of the present UK tide gauge network indicates that there has been an improvement in the quality of the data since the start of the A class network and that the bubbler gauges, which comprise the majority, are successful. The UK has only 5 very long near-continuous records (Aberdeen, North Shields, Sheerness, Newlyn and Liverpool) unlike other European countries which have many more. There are only approximately 25 UK and Irish stations which have data for more than 15 years.

The data from the tide gauge network are used in a number of study areas including climate change, geology and inter-annual variability. Projects using the data are often cross-discipline collaborations which want to make use of the longest records of the best quality. Sea level change is a global issue as reflected in international programmes such as the Global Sea Level Observing System (GLOSS) and the TOPEX/POSEIDON altimetry mission.

Measurements of sea level in the UK are important for several reasons. Without national monitoring programmes there would not be a global dataset and as the UK plays a major role in global studies it is important that it ‘sets an example’. National measurements are also important for spatial variability - globally sea level doesn’t go up and down uniformly, so we can’t use a global “number” as an UK sea level indicator. Also the UK and Irish Coasts are the most open to the ocean in Europe.

For MSL work the most important sites in the A class network are those which have the longest records, e.g. for analysis of trends 60 years of data are needed, as the most likely indicator of long term changes. For accelerations even longer records are required. Sites with >lO years are useful for quality control and other MSL studies e.g. seasonal and annual cycles. Some sites have specific interest such as Newhaven because of its proximity to the laser ranger at Herstmonceux. GPS receivers have been installed at 5 tide gauge sites and expansion to include more established sites is necessary.

In a European context there are some special needs:
a) the global GLOSS programme (both tide gauges and GPS) and altimetry programme require the input of sea level observations from UK stations
b) a densification of gauges/GPS around Europe is needed for regional working groups such as EuroGLOSS
c) mechanisms for ‘regional’ GPS data processing outlined in March 1997 IGS/PSMSL GPS Workshop need to put in place
d) mechanisms for central or. organised distributed data collection of tide gauge information cross-linked to the GPS time series information are needed.

In addition, the UK needs to maintain its network of gauges in the South Atlantic and Antarctica which are required for altimeter calibration and for important studies for climate of Antarctic Circumpolar Current variability.

Geodesy/Geology (R. Bingley, Nottingham University)

Techniques using geodetic satellite measurements at tide gauges are used to verify and measure land movements to indicate global sea level rise. There is a need to monitor vertical land movements because tide gauges only measure MSL changes relative to a local benchmark and so there is contamination by land movements.

Following the recommendations of the First Workshop of the IAPSO Committee (Carter et al, 1989) 3 projects have been undertaken by IESSG and POL - UK GAUGE 1 (1990-94), EUROGAUGE (1992-95) and UKGAUGE II (1994-97). All three projects involve episodic GPS campaigns at tide gauge stations in the UK. These can position the tide gauge stations globally to within 1Omm in height. The GPS tracking network has only 150 stations worldwide and Herstmonceux in the UK is one of them.

The UKGAUGE I project developed GPS techniques for monitoring vertical land movements at tide gauges in the UK and included 9 tide gauges on the south/east coasts. The EUROGAUGE project (funded by the European Commission and NERC) used GPS to monitor changes in absolute sea level and used 16 tide gauge sites on the Atlantic coast of Europe. The UKGAUGE II project further develops GPS techniques for monitoring vertical land movements at tide gauges and uses 16 tide gauges around the UK. This contract is nearing the end and the work is now moving towards GPS at all tide gauge stations in order to detect movements of 1 mm/year. A new project is planned for 1997-2000, UKGAUGE III, for the continued monitoring of vertical land movements at tide gauge sites in the UK using a combination of continuously operating GPS receivers at 5 tide gauges and episodic GPS measurements at 11 tide gauges using a single "roving GPS receiver". The 5 stations with permanent receivers are Sheerness, Aberdeen, Newlyn, Portsmouth and Lowestoft. Of these three Sheerness, Aberdeen and Newlyn have long records which enables more accuracy in height values. Currently GPS sites are funded by various authorities e.g. MAFF and EA.

Geodesy/Geology (Y. Zong, Durham University)

The Environmental Research Centre of the Department of Geography at the University of Durham has 5 research areas:

a) long term sea level and crustal movement
b) sediment deposition, compaction and land subsidence
c) long term changes in tidal level
d) storm induced coastal erosion and deposition
e) climate change, storminess and flood risk

The study of long term sea level and crustal movement focuses on the last 2000 years and links to the present observations. Sites are not usually near A class gauges. It requires ongoing observations to extend the series. Summarised/synthetic data from closely spaced tide gauges is important. Study b) has the same requirement for summarised/synthetic data and there is collaborations with the IESSG. Study c) again has the requirement for summarised/synthetic data and uses models by R Flather e.g. Solway Firth, Bristol Channel. Study d) needs high resolution data with 0.01m accuracy at every 15 minutes. Study e) needs hourly height records from tide gauges and surge residuals.

Industry (A Brampton, HR Wallingford)

The main interests of HR Wallingford are:

a) the prediction of conditions in the medium term to far future. i.e. beyond weather forecasts, for the purposes of flood protection and the design and construction of defences. Its requirement is for information to help calibrate hindcasts in order to achieve an understanding of events in the past few decades.
b) Detailed tidal modelling using tidal level information e.g. to set boundary conditions for models of currents, salinity and transport in connection with engineering works.
c) The provision of information to improve forecasts of real time events - with STWS - e.g. overtopping.

HR has little interest in raw data and is more interested in processed data such as high water levels and trends. They are interested in a) the analysis of extreme levels, b) real, hourly total water level, c) components - phase and lag - for driving models of the coast. Their main concern with hourly heights is the estimated joint probability of water level and waves especially at high water. MAFF has recently funded HR/POL/University of Lancaster studies on joint probabilities. The lack of wave data is an ongoing problem and synthetic wave data is used for numerical models. 30 stations in the national network are of interest. The cost of buying sea level data (hourly heights) is prohibitive compared with wave data and is considered unacceptable, because it prevents joint probability studies at about 80% of sites

Data location and accuracy are acceptable but the distribution of gauges is poor especially in the south. In addition to the national network HR uses some local gauges e.g. Boygrift and Lymington. Surge models are irrelevant to HR work, total water level relative to ODN is wanted. In light of the vast computation effort why is there no synthetic sea level data from the models? Extra parameters, especially wind and wave observations, would be useful but the choice of site for such measurements is important. Estuaries form a newer part of interest which are showing some problems which are worse than the open sea.

It would be much better for all concerned to have more widely published total water levels and sea level trends. More short term exercises for surges to calibrate synthetic gauges would be useful. Corresponding wave data is needed. Local authorities could be interested in joint ventures which would reduce costs. Further development of instrumentation would be good and there is a preference to have wave observations. In estuaries there may be a need for additional observations e.g. salinity, suspended solids.

Industry (K. Riddell, Babtie Group)

The Rivers and Coastal division of the Babtie Group have 7 main uses of sea level data:

Mathematical modelling of coastal processes
Assessment of flooding extent and damage
Detailed design of flood defences/coast protection works
Estuary, shoreline and beach management plans
Design of port and harbour works
Navigation and freight handling studies
Pollution studies.

Essential components of sea level required for the above studies include astronomical tides around the coastline, extreme level predictions and joint probability analyses. Tide level and surge as separate components are desirable as surges are often causally linked with the same weather patterns as extreme waves. Additional essential parameters are

a) continuously monitored offshore wave heights, periods and directions in all the "main" sea areas and selected sites inshore for the purpose of calibrating models
b) wind speed and direction around the country for the purpose of hindcasting waves and determining long-term wave climates
c) water quality around the country

Other parameters such as temperature/salinity, atmospheric pressure are useful for measuring long term changes and calibrating ocean models and should be monitored though at a selected number of sites only. These parameters are not generally used directly by engineers. The essential and desired accuracy of each parameter was summarised.

Essential Accuracy		Desirable Accuracy	
Wind Speed	1 knot	Wind Speed	1 knot
Wind Direction	5 deg	Wind Direction	**2.5** deg
Wave Height	5 cm	Wave Height	**2.5 cm**
Wave Period	1 s	Wave Period	**0.5 s**
Wave Direction	**5** deg	Wave Direction	**2.5** deg
Tide Level	**5 cm**	Tide Level	1 cm
Surge Level	**5** cm	Surge Level	1 cm

The spacing of gauges should take local conditions into account with a suggested spacing of about 50 km around the country and including estuary monitoring, with river flows.

There is no general requirement for 'real-time' data access. However it would be very useful to have a national or regional data centre and desirable that recording instrumentation should be regularly and well maintained. In summary there is still a requirement for a clear separation of sea level effects and the land level changes for reasonable interpretation of long-term changes. A cognisance of a non-stationary statistical environment is necessary to be provided in a clear and understandable way. AU existing and future datasets need to be quality-assured and available in usable formats. Real or simulated concurrent time-series are **increasingly** required for modelling purposes.