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PROPOSALS FOR THE DEVELOPMENT OF THE UK NATIONAL TIDE GAUGE NETWORK

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ABSTRACT

This report provides proposals for the development of the UK National Network of tide gauges over the next few years. Our approach has been to recognise that the network is a mature one, and that the future emphasis has to be on consolidating and enhancing its quality and reliability, without ignoring the potential for improvements in technology and data management. While concentrating on aspects of the tide gauge network itself, the report refers to the important related issues of geodetic, meteorological and other types of measurements and of numerical modelling for storm tide forecasting. Some of the obligations of the UK to the international sea level community are emphasised. The report concludes with recommendations for improving the organisation of the UK National Tidal & Sea Level Facility and for its interactions with other organisations interested in sea level measurements.

1. INTRODUCTION

Any country with marine and coastal interests needs a sea level network. A good network constitutes a valuable strategic asset, providing data for a range of practical and scientific applications including:

- Production of precise tidal prediction.
- Provision of flood warning during periods of high tide and storm surge.
- Provision of data aids to navigation (e.g. via automatic updates to electronic chart depth information) and to port operators and other coastal industry.
- Assimilation of data into a range of numerical ocean models for operational monitoring of marine ecosystems and water quality.
- Geodetic studies including datum determination for land and hydrographic applications.
- Determination of the heights of extreme sea levels for coastal engineering design.
- Oceanographic studies of circulation change in the adjacent deep ocean on various timescales.
- Studies of sea level variability including determination of long term changes in mean and extreme sea levels as a consequence of climate change.

It can be seen that data from such a network serves a number of communities across the sciences and within the commercial marine world. With the correct technology, data from the same stations can provide information in both ‘fast’ (or ‘real-time’) and ‘delayed’ modes, thereby serving different types of users.

It was the recognition that the UK needs the asset of such a network, and the infrastructure that complements it, that led to the establishment by the Proudman Oceanographic Laboratory (POL) and British Oceanographic Data Centre (BODC) of the UK National Tidal and Sea Level Facility (NTSLF) in 2002. The NTSLF is centred around our operation of the UK National (formerly the ‘A Class’) Tide Gauge Network, accompanied by a smaller network in the British Dependent Territories of the South Atlantic and Gibraltar.

A function of the NTSLF is to provide a management oversight of the present National Network, and also to enable an ongoing mechanism for forward looks of how the network might develop. The last time that a forward look of the network was published was in 1998, and was based on notes taken at a workshop held at the Ministry of Agriculture, Fisheries and Food (MAFF) Flood & Coastal Defence Division in 1997 (Alcock et al., 1998). That workshop was commissioned by MAFF and was attended by representatives of all of the main agencies and institutes with an interest in UK sea level recording.

The present report has been produced at our own initiative (i.e. it has not been commissioned by the Department for Environment, Food and Rural Affairs (Defra) which replaced MAFF) and has taken a different production route, with a first version being written by people associated with the NTSLF and circulated for comment to each of the other main agencies concerned. By this means we have tried to ensure the receipt of as wide a range of inputs as possible. Persons to whom the report was sent directly are shown in Annex I. The report was also accessible by any interested person via the NTSLF web site. Any comments which we believed to be particularly useful have been included in this version of the report.

It is hoped that the report will provide an informed set of opinion on how the National Network should evolve over the next few years, and thereby supply a source of guidance for a major component of the NTSLF activities.

2. SOME HISTORY

The UK has a number of major achievements in the history of sea level recording. Examples include William Hutchinson's measurements of high waters at Liverpool for almost 30 years in the late 18th century, and the development of the first automatic tide gauge with a stilling well, float, clock and paper chart at Sheerness in the late 1820s (Cartwright, 1999; Woodworth, 1999). However, although other important UK time series began in the late 19th (Aberdeen, Belfast) and early 20th (Newlyn) centuries, it is a mistake to believe that the UK had a better, coordinated sea level network, or greater expertise in sea level recording, than several other European countries throughout the 20th century. Scandinavian countries in particular developed major national networks, which nowadays result in some of the finest sets of long term sea level records in the world.

The National Network evolved out of an uncoordinated set of gauges operated by many different authorities for different purposes (Woodworth et al., 1999). Some of these purposes were scientific, such as the Ordnance Survey's installation of gauges at Newlyn and Dunbar. Practical purposes included the requirements of British Railways and the Royal Navy for data for port operations. The 1953 floods led to the recognition that a coherent monitoring system was required for flood defence, and technical developments, including the perceived superiority of bubblers over traditional float gauges, eventually resulted in the early 1980s in what is now called the National Network. This network is operated by POL with funding from the Department for the Environment, Food and Rural Affairs (Defra) which superseded MAFF. It consists of 44 sea level stations, almost all of which are bubbler gauges, and of which 2 are in Northern Ireland, 1 is in the Isle of Man and 1 is in the Channel Islands (Figure 1). Lerwick, Stornoway and Newlyn are nominated Global Sea Level Observing System (GLOSS) Core Network (GCN) stations, which are sites at which it is thought sea level changes are most likely to reflect open ocean variations (see below).

The network developed primarily to meet the requirements for data to support flood defence activities, such as the understanding and predicting of storm surge levels. It is probably true to say that MAFF/Defra did not, until perhaps 10 years ago, consider topics such as long term sea level change to be particularly important (although, of course, they do now). Such studies require typically 1 cm accuracy (the 'GLOSS standard', see IOC, 2002), compared to the typically several cm accuracy adequate for flood warning.

Nevertheless, the National gauges were always maintained by POL at the cm accuracy level because of POL's scientific interests.

3. PROPOSALS FOR NATIONAL NETWORK DEVELOPMENT

In each part of this section, we refer to a particular aspect of the National Network and we suggest how that aspect can evolve over the next few years.

Number of Stations

The Alcock et al. (1998) report described how the National Network evolved in response to various MAFF requirements, primarily for checking numerical model surge forecasts provided to the Storm Tide Forecasting Service (STFS, then called the Storm Tide Warning Service) at the Met Office. Gauges were added from time to time in response to perceived need for more reliable local sea level information. The report concluded that, in spite of the somewhat *ad hoc* historical development of the network, the 44 gauges provided an adequate coverage of the UK coastline for most scientific and practical user needs. Two possible gaps were identified, around the Wash area and along the south coast of the Isle of Wight (IoW). The case for a gauge near the Wash has still not been actively pursued. However, so far as we know, it has not been argued for strongly since the 1997 workshop and can probably not be considered as a priority. An IoW gauge might be provided in the near future through the English Channel Observatory programme operated from the Southampton Oceanography Centre. We understand that the Observatory will install several gauges along the south coast of England and that the gauges should be operated to similar standards as National Network sites. (It is not clear if they will route their data to the STFS.)

The Alcock et al. (1998) report contained a number of Recommendations which we list in Annex II. It is interesting to see that in 6 years there have been innovations which we have now come to take for granted, and that report is out-of-date in some respects. Nevertheless, the NTSLF believes that there has been no essential fundamental change since 1997 which would modify a conclusion of the workshop that the National Network is an effective, mature one and that the emphasis should now be on improving data flow to users in its many aspects. The network provides a good mixture of long-established sites for monitoring of changes in mean and extreme sea levels due to climate change, sites which are ideal for monitoring the flows through straits (Dover, North Channel etc.) and in the nearby open Atlantic, and sites operated primarily for gathering statistics of surge levels and for monitoring the performance of surge models. Indeed, if we ignore the fact that the network grew 'organically', and ask what sort of spatial distribution of gauges we would choose if we could start from scratch, then the network would probably not be very different from what we have now.

However, there are certain special cases requiring particular attention with respect to further installations. For example, the problems identified recently with Thames Barrier operations suggest that either redundant gauge systems should be installed at Sheerness, or that an additional gauge should be provided at Southend (Flather et al., 2003). In addition, the utility and practicality of operating gauges off-shore (on oil rigs and other structures) for studies of surge model performance have never been properly investigated. A conclusion of an early study by Woodworth and Jarvis (1991) was that, if further National Network sites are required in future, then attention should be paid to where measurements have been made in the past, and gauges installed as far as possible at the same locations.

Recommendations

- Gather opinions of other stakeholders on the number and locations of gauges required for an optimum UK network.
- In particular, conduct a review of sites where both National Network gauges and those of other agencies (e.g. Environment Agency) are operated, with potential for overall cost reduction (without compromising sea level time series accuracy).
- At certain sites dual systems with different technologies should be installed to ensure data flow.

Accuracy (and Cost)

We have mentioned that the UK and other networks provide data for a range of applications. This leads to the important point about 'multi-use' which is always stressed in GLOSS correspondence between the Intergovernmental Oceanographic Commission (IOC) and Member States:

- That, when gauges are installed for practical purposes, there is relatively little extra cost if good quality equipment is installed and if gauges are maintained to scientific (GLOSS) standards.

This significant improvement in quality for a modest increment in total cost stems from the high cost of the manpower needed for the planning, installation and maintenance of any system, even of a poor one. That is why, throughout POL's management of the UK network, we have resisted the separation of a 'super-set' of GLOSS and the major long-term stations from the remainder of the 44, with the latter relegated to a 'B Class' network operated to lower standards. In the last decade, MAFF and Defra have recognised the need to monitor sea and land levels to accuracies needed to identify long term change, such as that identified by the Intergovernmental Panel on Climate Change (IPCC) (Church et al., 2001). This is reflected in Defra support for additional datum control hardware at GLOSS and UK long record sites, and a programme of Continuous Global Positioning System (CGPS) at a subset of National Network stations (Figure 2, Bingley et al., 2002; Teferle et al., 2002a, 2002b).

A corollary of significant improvement in quality with a modest increase in cost is that quality can be impaired in a very major way if costs are reduced. Any future cutting of corners in costs could lead to either a reduction in the size of the network and/or to unacceptable accuracies for the stations which remain. For example, one could imagine a scenario in which Defra requirements reverted to the pre-IPCC situation in which the network was funded almost exclusively for surge warning and prediction purposes. This could be achieved by striving for only the several cm accuracy required for flood warning compared to the 1 cm needed for long term studies. An argument for costs savings could then be made by, for example:

- The use of cheaper transducers in bubbler gauges and/or by the use of very cheap (absolute) pressure sensors (as often used for monitoring river levels), with air pressures taken from the Met Office models in order to convert pressures to sea levels.
- The scrapping of rigorous tide gauge datum control of sea level records, 'anomalies compared to a norm' being all that is required for flood warning.
- The scrapping of regular (typically annual) levelling of benchmarks at gauge sites.
- The scrapping of GPS and Absolute Gravity monitoring of slow changes in land levels.
- The scrapping of rigorous, delayed-mode data quality control, as detailed scientific-quality inspections of data would hardly be justified given poor data input.

Such cost savings would result in a 'B Class' network for flooding, which might be acceptable in its own terms, but which would be inadequate for the provision of data sets for oceanographic and climate change science. The reduced network would also be inadequate for a number of practical applications (e.g. land and marine datum determination). In our opinion, the cost savings would not be more than 20%, and would result in the need for a case being made to NERC to establish its own scientific-quality instruments at a number of National Network sites, thereby adding to the total costs to the taxpayer.

This discussion can clearly be made more complicated if, in a hypothetical future, demands were made to continue operation of primary sites at National Network standards, while reducing others to 'B Class'. However, our experience has shown that it is efficient to operate the whole network as far as possible to the same standard, and that by complicating operations one increases costs. For example, there would be a major requirement to document fully the technicalities of each gauge's operations, so that there would be no danger of any analyst in future accepting 'B Class' data as if they were the higher 'A' quality.

There are potential extensions to the network which one could consider operating to different standards in future. For example, gauges on North Sea rigs have been considered for surge monitoring. However, they have never been taken forward as a priority. As these installations would clearly be different to National Network sites at the coast, especially with regard to datum control, and as they would clearly be allocated for surge purposes, then they could be operated to different standards. Another example concerns secondary gauges installed to increase the amount of information received for particular research (e.g. in a 'coastal observatory'). In such a situation, the National

Network sites would provide the data baseline to which it might be acceptable to relate nearby lower-accuracy data sets for particular purposes (e.g. data assimilation into ecosystem models). An example of such a densification already exists in the case of the Irish Sea Observatory, with data from the lower-accuracy Mersey Docks network complementing that from National Network sites at Liverpool, Llandudno and Heysham (Proctor and Howarth, 2003).

Recommendation

- The accuracy of the National Network of bubbler gauges must be maintained at the present 1 cm in height and 20 seconds in time, and any alternative technology adopted must also have the same (or better) accuracy.

Frequency

Until approximately 1990, most data from National Network sites were recorded at hourly intervals. This took the form of either hourly digitisations of chart recordings, or hourly integrations of pressure sensor data. Hourly values are still the GLOSS minimum standard (IOC, 1998, 2002) and provide an acceptable temporal sampling for most tidal, surge and mean sea level studies in many countries.

From the early 1990s, the frequency of National Network recording increased to 15 minute sampling, and this remains the standard at the present time. It contrasts with 6 minute (1/10 hour) sampling in the US (apart from the Great Lakes) and many other countries use 3, 5 or 10 minute sampling.

We suggest that National Network sampling be increased as soon as practical to 6 minutes or less. This will have little or no implication for technical operation, data management, accuracy or costs. It will benefit the temporal discrimination of seiches and similar high frequency motions which can be seen on many tide gauge charts (e.g. most Scottish harbours) and which to some extent we have forgotten about in the electronic era. These motions have timescales of several to 10s of minutes and will manifest themselves as a form of aliased noise in 15 minute values.

Recommendation

- TGI and BODC to consider measuring and data banking sea level data every 6 minutes.

Latency

Most data from the National Network are made available to users through the NTSLF web site which contains a catalogue of all data available. Data arrive at POL by means of downloads from gauges at roughly weekly intervals. For some gauges, a separate data stream, over which the NTSLF has no control, goes to the STFS at the Met Office.

Whether data can be obtained from the NTSLF immediately or not depends primarily upon its age :

- Data at least 3 months old, all of which will have been subjected to quality control to modern standards, are freely available via the NTSLF web site. The delay of 3 months allows full manual quality control by an experienced person to take place. At present, data back to 1990 are available in this way and more historical data will be added to the web as resources permit.
- Data older than 1990 have at present to be requested by email and will provided as soon as staff resources permit.
- Historical data from the 3 UK GLOSS sites back to the start of their records (i.e. pre-1990 data also) are available from the GLOSS Handbook web site. Recent data from the same 3 sites are available from the GLOSS Fast Centre at the University of Hawaii.
- Data newer than 3 months old, also have to be requested by email and will be provided with a short delay, quality-controlled or uncontrolled depending on whether staff resources have already been allocated to the task. Delivery of recent data to commercial users will incur a charge.
- Plots of sea levels from a small number of sites are available in real-time on the web without quality control. Modems have been purchased which will enable approximately 12 stations to be added to this set in the near future and which will provide a larger number of users with access to near-instantaneous UK sea level information. The corresponding data values are not made available in this way but can be obtained eventually via one of the above methods. (Another small set of real-time information is somewhat bizarrely available from Dutch and Danish web sites which receive information indirectly via the STFS.)

It can be seen that the main gap in data flow is concerned with making recent data (newer than 3 months) available to users. Our present philosophy, with which Defra is in full agreement, is to avoid as far as possible providing to users data which contain errors. The vast majority of National Network data are considered 'accurate' and are not deleted or modified in any way by subsequent quality control. Nevertheless, errors do occur, and we have no wish to be in a position of providing uncontrolled data to possibly inexperienced and unknown users via the web; delivery to users such as the STFS or oceanographers engaged in data assimilation exercises is quite a different matter as they are experienced enough to spot occasional errors. Therefore, the 3 month gap between data acquisition and provision on the web was intended to allow full quality control to take place.

Although this caution is understandable, it means that some users with a *bona fide* interest in access to recent data will be inconvenienced to some extent (and, in the case of commercial users, they will be subject to a charge). Consequently, future NTSLF development must work towards partial or full removal of the 3 month gap. This can be accommodated by either:

- Allocating more NTSLF staff resources so that the 3 month gap is reduced to perhaps 1-2 months. We do not consider this proposal acceptable as staff resources are limited and very few existing users would benefit from the a modest reduction in the gap (typically 25 per year compared to approximately 20 times more requests for data older than 3 months via the web).[1]
- Moving to daily, rather than weekly, downloads and investigating the use of Real Time Quality Control (RTQC) which is used by tide gauge agencies in Spain and USA. Such software searches for spikes, timing errors, datum shifts etc. and flags suspect data. In some circumstances, it could be dangerous to use. For example, one could result in a large, short-duration surge being flagged as suspect data. Therefore, RTQC cannot be regarded as a substitute for full manual quality control by an experienced person. Nevertheless, it could be used as an in-between product which, if suitably qualified, could be made available to different types of user who require data less than a day old. A form of RTQC is being considered for use by the STFS at the Met Office within data assimilation schemes. However, whether this software could be the same as that used by the NTSLF remains to be investigated.

Recommendation

- ➢ BODC to consider a RTQC system for the provision of a partly-QC'd data less than 3 months old.

<u>Other BODC Data Management Issues</u>

Sea level data have been collected from the National Network extending back to the beginning of the 20th century and earlier for some sites. With funding provided by Defra, BODC have quality controlled and documented the 1990s National Network data to modern standards, and made these available through the NTSLF web pages, together with their site histories. However, there is still much data held by BODC which needs to be quality controlled and documented to these same high standards, and over the next few years consideration will turn to these. Further funding from Defra will allow the tide gauge data from the 1980s, 1970s etc. to be quality controlled and documented. Some long time series exist which do not form part of the National Network, and, where possible (i.e. if resources allow), these will also be quality controlled and made web-accessible. Most of the historical data are in digital form, but some only exist in the form of original paper charts (e.g. recently-rediscovered and chemically-treated Belfast charts which span mid-1880s to 1950s and which when digitised and quality controlled will provide one of the longest UK sea level records).

In addition to the data from the National Network, other data from short term tide gauge installations around the UK (and elsewhere) have been banked with BODC. These short data series, usually hourly values collected over the course of a year, also need to be

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[1] Between November 2002 and November 2003 there were 624 requests for data via the NTSLF web including 173 categorised as Commercial, 56 Government, 25 NERC, 49 Private, 204 University/Academic, 95 non-UK and 22 Unknown.

made more readily accessible, and could be of value to people engaged in a number of studies. A web-searchable catalogue is under development, and it is intended that eventually these data will also be available for download.

Recommendations

- BODC to progressively extend the provision of historical data via the web to data prior to 1990.

- BODC to compile a catalogue of all UK paper-based sea level information (charts, tabulations etc.) which could be potentially converted to computer form. (A similar proposal has recently been made to colleagues in Ireland.)

Tide Gauge Technology

The bubblers used for the National Network have provided valuable service and there is no immediate need to consider wide-scale replacement. However, the GLOSS Technical Workshop held in Paris in October 2003 demonstrated that:

- New, cost-effective, off-the-shelf, accurate technologies are becoming available
- The UK and New Zealand are the only major countries using bubbler systems, the USA (the previous major user) having converted to acoustic technology more than a decade ago.

The advantages and disadvantages of bubblers are well-known (Pugh, 1972, 1987; IOC, 2002). Their main disadvantages, as for all pressure gauges, are the need to know well the density of the sea water above the pressure point (Figure 3), and to identify any long term drift in the pressure measurements, which in this case are performed by a differential (compared to atmospheric pressure), temperature-corrected Paroscientific Digiquartz transducer. At a number of National Network sites, any drifts in the differential pressure (i.e. sea level) measurement are monitored by a variant of the 'mid-tide pressure sensor' method involving the use of a second bubbler pressure point at approximately mean sea level (Woodworth et al., 1996).

The density changes which are present at sites near to major rivers mean that other types of gauge might either be preferable, or could be used to provide a parallel data set for comparison to the bubbler stream. Similar redundant recording could also be considered at important sites, such as the 3 GLOSS sites and at Sheerness where data from the bubbler are used to control operations of the Thames Barrier. At the time of writing, a suitable alternative technology would be radar. Radar tide gauges are positioned several metres above the surface of the sea (or river or lake). The OTT Kalesto system, with which we have the most experience, measures changes in sea level by means of a Frequency Modulated Continuous Wave (FMCW) method in which the transmitted signal is compared to the signal reflected from the sea surface, with the phase shift of the signal used to compute range (Figure 3). It transmits pulses within a ± 5º cone, with a range accuracy claimed by the manufacturers to be ± 1 cm over a measuring range of 1.5

to 30 m. The Kalesto and other radar gauges offer several advantages over float, pressure and acoustic gauges, of which the main advantage is the ease of installation and maintenance; they require neither extensive fixings to a harbour wall or pier (as for a stilling well), nor the involvement of divers (as for underwater pressure gauges).

Woodworth and Smith (2003) presented a comparison of data from a Kalesto and from a conventional bubbler at Gladstone Dock, Liverpool for a period of over a year. Liverpool is a demanding location for a comparison, with a tidal range of almost 10 m at some spring tides. Therefore, for a successful test, the radar range measurement had to be shown to be equally precise over distances of several metres to over 10 m, with the 1 cm accuracy demanded for use within the GLOSS (IOC, 2002). In brief, the test demonstrated that the Kalesto is indeed capable of providing data of this quality, and therefore is a suitable potential candidate for use in the National Network and in GLOSS. However, several improvements were noted, including in particular the need for an ongoing, *in situ* calibration system. POL has since purchased 3 Kalesto gauges: one for installation in Gibraltar; one for use at Cananeia in Brazil in cooperation with the University of São Paulo; and one for test in the POL laboratory. We envisage that they will have great application in developing countries, where installation and maintenance can be difficult, and they are being considered by several of our major partners in GLOSS.

It is perhaps a little too soon to state that we wish to move *en masse* to radar systems, and certainly too soon to say that they should be OTT systems. However, it is clear that the radar gauges already have application in UK situations where density is a possible issue (e.g. Newport, Sheerness) and may have wider uses. Moreover, they are possibly the only technology to be considered if we take into account the need to eventually upgrade the National Network and South Atlantic networks together with the same systems.

Therefore, in the short term, we recommend that the NTSLF purchases sufficient radar systems for UK use so that a core of experience can be acquired with them.

Data acquisition systems (data loggers) are equally as important as the gauge hardware itself. A number of commercial data acquisition systems are now available. These systems accept a variety of sensor inputs including radar gauges. POL needs to evaluate these systems in conjunction with the STFS and the EA. This work is required in anticipation of the replacement of the present acquisition system in a few years.

Recommendation

- The European ESEAS programme has demonstrated the value of an open ocean test site (in this case in Spain) at which a range of new types of tide gauge and data acquisition systems can be evaluated. Defra should consider whether to fund development of the POL test site at Holyhead and/or to consider part funding an ongoing collaborative European facility.

Other Parameters

The requirements for tide gauges in the GLOSS programme (IOC, 1998) specify that air pressure, sea and air temperatures be measured at a sea level station alongside sea levels. Winds are often more difficult to measure at ground level in ports owing to the many obstructions, while salinity is difficult to monitor without frequent maintenance.

The National Network contains meteorological stations alongside gauges at Holyhead, Liverpool, Heysham, Workington, Ullapool, Lerwick, Moray Firth, N.Shields, Lowestoft, Dover and Newhaven. These data are passed to BODC along with the sea level information. However, they are not quality controlled, are not made available via the web, and are even not widely advertised in data catalogues. We suggest that such data be made more accessible to interested users in future.

Wave parameters are obvious additional parameters which could be measured easily at gauge sites, as long as wave information at the coast is thought to be useful. Waves are now measured at 3 South Atlantic sites by means of sampling pressure transducers at 1 Hz, and with the 1 second 'wave mode' values integrated into 15 minute 'sea levels' by the data loggers. These measurements have recently been demonstrated to be useful to studies of deep ocean swell (Vassie et al., 2004).

Waves could also be measured at UK sites if additional pressure transducers were deployed in the sea at the stations, bubblers not being well-suited to measure waves. Relatively low cost transducers could be used, and there should be little impact with regard to data logging or management. Wave parameters may also be measurable with a development of the Kalesto radar gauge, and are already available with more expensive radar systems. All these suggestions need to be studied to see if they could result in data complementary to information from Defra's WAVENET and other wave networks.

More recently, oceanographic programmes other than GLOSS have sought to take advantage of the data logging systems at gauges as 'data platforms', with the suggestion that gauges also record a range of parameters (e.g. oxygen, chlorophyll) of interest to coastal research (IOC, 2003). This suggestion has yet to be widely adopted throughout GLOSS. However, in the case of the UK, there is no major reason why this development should not be made, especially at locations around the coast where ecosystems are of interest. The lead for this suggestion has to come from the proponents of the other parameters, but we suggest that the National Network be receptive to such needs.

Recommendations

- Meteorological data streams should be fully developed.

- The utility of wave measurements and of other ocean parameters at gauges should be further investigated.

Access to Data from Other Agencies

National Network data have for some time been more readily available in real-time to users in the Netherlands and Denmark than they have been to POL, owing to data flowing to the STFS via its special links to gauges, and then from the STFS via the EA and Thames Barrier to Europe. We understand that the STFS also transmit data directly to the Netherlands. Of course, in emergencies and other special cases, the TGI can access gauge data via its own dial-up system. In addition, access to more National Network data will be possible in real-time in the near future when more modems have been installed across the network. Nevertheless, it would be convenient if the means existed for the STFS to relay data to POL from the Met Office on a routine basis. This will be of particular use following major storm events when there is urgent need to validate the performance of surge models. For the same reason, there is also an occasional, urgent need for access to data from Environment Agency gauges. (Of course, if BODC were to move to daily, rather than weekly, downloads, as described above, then the need for a data relay to POL from STFS would be reduced.)

There is also a need for POL to have ready access to data from neighbouring countries. The exchange of data with Ireland is a current topic of interest (Woodworth et al., 2003) and we believe that real-time data are available on the web from European close neighbours which has not been fully investigated so far.

- ➢ STFS to investigate how relay of real-time data to POL may be achieved.

- ➢ POL to investigate how data from EA gauges may be accessed.

- ➢ Access to European real-time data to be investigated and links made to NTSLF web pages.

Surge Modelling and Prediction

Tide gauges and numerical models complement each other perfectly in the provision of information for the understanding and forecasting surge floods, and many countries now have operational schemes which make use of both sources of information (Flather, 2000). From the modelling/forecasting perspective, tide gauges are needed

- to help understanding of the generation and propagation of surges
- to check/monitor accuracy of model surge forecasts in areas prone to flooding
- to provide data for assimilation into models, correcting initial forecast data and so improving forecast accuracy.

Requirements are for both real-time data (e.g. for monitoring surge development in the flood warning system, and assimilation) and QC'd data later (e.g. for validation, understanding).

Gauges should be sited to be representative of the regional surge with some for local surge (where there is a local flood risk). These requirements have been appreciated for many years and have contributed to the evolution of the present system.

Long records providing good tidal analyses are also required to provide accurate tide predictions and hence accurate estimates of actual surge from the measured data. Therefore, gauges should not be sited where analysis problems are likely (e.g. in shallow areas where too much interaction renders surge data useless, or in estuaries where they do not measure the whole tidal range and may see the river level for a period near LW).

Existing gauges generally meet present requirements. Relevant aspects for surge prediction, investigated recently, have been the possible use of fine grid models to provide more local detail where this can be of benefit (Flather et al., 2001), and of the treatment of seasonal variations in the flood warning procedure (Flather et al., 2000). Problems with predictions at Sheerness raised other concerns about the treatment of long-term variations (Flather et al., 2003).

A scoping study for Defra is in progress to advise on future development of the operational surge forecast models. The broad strategy suggested will be a) to use data assimilation to improve the accuracy of surge forecasts at large scales, and b) to introduce fine grid models to provide detail where this is needed. Assimilation of observed surge elevations into the forecast models will improve the accuracy of initial conditions and hence the following forecast. This requires the quality controlling and transfer of data from tide gauges to the Met Office supercomputer on which the models are run. High resolution local models have been run for the Bristol Channel/Severn Estuary for a number of years, and a similar 1 km grid model for the central South coast is being implemented now. Local gauges will be required for checking model predictions and in the local warning process. Many EA gauges exist which can meet this requirement, but need to be updated to National Network standards.

- Defra, STFS, NTSLF and other agencies to implement the findings of the surge forecast scoping study to be published in 2004.

Vertical Land Movements

Vertical land movements are important components of relative sea level change. This has been recognised by Defra and they are funding joint work by the Institute of Engineering Surveying and Space Geodesy (IESSG), University of Nottingham and POL to develop a network of CGPS and absolute gravity (AG) measurements at UK tide gauges. CGPS stations have been gradually installed at UK tide gauges starting in 1997 (Teferle et al., 2002, 2002b). The present CGPS network consists of Newlyn, Portsmouth, Sheerness, Lowestoft, Liverpool, North Shields and Aberdeen (Figure 2). POL has recently purchased 3 CGPS systems, which will be installed at the tide gauges at Millport, Stornoway and Lerwick. In addition, IESSG are installing new CGPS stations at Portpatrick, Dover and Holyhead. Thus, in the near future 13 UK tide gauges will have CGPS. These CGPS stations have replaced the earlier episodic GPS (EGPS) measurements which were made previously at these 13 tide gauges (EGPS measurements will continue to be made annually at Heysham, Immingham, Avonmouth and Newhaven).

The falling costs of GPS receivers have made the installation of permanent GPS receivers at the tide gauges feasible. The continuous GPS data will also enable a better assessment of noise sources and are essential for meeting the technical challenge of measuring vertical land movements to the required accuracies of a few tenths of a millimetre per year. The UK CGPS stations are integrated into a global network of CGPS stations coordinated by the International GPS Service (IGS). A major goal of the IGS network is to achieve a practical realisation of a global geodetic reference frame that is accurate enough in the vertical for achieving accuracies of a few tenths of a mm/year. Biases in vertical velocities still need to be reduced. The absolute gravity (AG) measurements that are being made by POL at Newlyn, Aberdeen and Lerwick (Williams et al., 2001) will determine the vertical land movements completely independently of GPS and will therefore be used for checking for any biases in the vertical velocities determined by GPS.

Global geophysical models of crustal movements due to the unloading of the surface of the Earth at the end of the last ice age have been developed by various research groups. Currently such models are used to correct sea level measurements from tide gauges for this component of vertical land movement. CGPS and AG measurements at suitable inland sites, particularly in Scotland, can be used for testing the validity of these models in the UK context. POL is planning to install new CGPS and AG stations in Scotland, which will be used for testing these models.

Recommendation

- Defra should maintain for the next decade its present level of funding for CGPS and AG research which should lead to a much better understanding of UK vertical land movements, especially at gauge sites.

International Aspects

Discussion of the National Network at times seems to be based on an assumption that the UK is self-contained and that all that is required is a network to monitor our own sea levels. For example, gauges seem to have been added to the network near to where flooding occurred in England and Wales, rather than where we can learn more about ocean processes which can lead to flooding (e.g. installation of a 'UK' gauge in SW Ireland). In addition, although many attempts have been made to inform MAFF and then Defra of the need for support for the South Atlantic network and GLOSS, their attitude seems to have been either that monitoring outside the UK is NERC's responsibility (although NERC is a research and not an operational agency) or that, in some unspecified way, an organisation such as the Intergovernmental Panel on Climate Change (IPCC) will provide the 'global context' information that decision makers in London will need.

The only international data exchange which appears to be supported by Defra is the *ad hoc* data flow from North Sea gauges to the STFS, and thereby to EA (Thames Barier) through to Dutch, German and Danish agencies (and not to POL!). The NTSLF, and therefore Defra, need to understand that sea level changes in one part of the world, and certainly in other parts of Europe, are of interest to the UK. An example concerns the need to understand, and probably assimilate into surge models, the non-barotropic, deep-ocean seasonal and interannual components of UK sea levels, which can be best understood by study alongside data from neighbouring countries. Further afield, the South Atlantic network needs to be better appreciated by Defra as being a UK contribution to a global programme, which will in the long term result in better IPCC predictions for use by UK coastal engineers.

In a European context, tide gauge data can be employed across the board within programmes such as EuroGOOS and GMES (the primarily space-based Global Monitoring for Environment and Security programme established by ESA and EC) which includes MERSEA (Marine Environment and Security for the European Area).

Recommendations

- Data exchange (both real-time and delayed mode) with neighbouring countries needs to better organised. Data exchange with the recently proposed Irish network (Woodworth et al., 2003) and with a modernised Isle of Man network (IOM, 2003) will be of particular importance to west coast surge forecasts which have historically been less precise than North Sea forecasts (Flather, 2002).

- Defra should recognise the importance of the Gibraltar and South Atlantic network as a UK contribution to the global GLOSS programme, and share financial support with NERC.

- More generally, UK Ministries (especially Defra and DFID) could give more energetic support to the European Sea Level Service (ESEAS) and GLOSS, especially with regard to training of scientists and technicians from developing countries.

Speculative Developments

A number of new technologies are becoming available which might significantly alter the way information on sea level changes is acquired in future. These include:

- GPS receivers on buoys (prototypes already tested in both the sea and rivers).
- GPS reflection methods from space.
- Multiple nadir-pointing altimeter constellations (e.g. GANDER type).
- Wide swath satellite radar altimetry which will be deployed in test mode on board the Jason-2 satellite in 2008.

- A simulation study needs to be conducted of the value of multiple nadir and swath altimetry to operational surge forecasts.

NTSLF Coordination

The following list of main points provides a brief overview of organisational aspects of the National Network:

- The physical tide gauge network, which is the responsibility of the Tide Gauge Inspectorate (TGI) at POL, together with the management of its data by BODC, together comprise a large part of what is now called the UK National Tidal & Sea Level Facility (http://www.pol.ac.uk/ntslf/).
- The costs of the NTSLF (tide gauges, data management, and to some extent GPS and Absolute Gravity data gathering) are provided to a large extent by Defra via an annual contract, with some costs provided from the Natural Environment Research Council (NERC) science budget.
- Defra approves major expenditure for new gauge installation or refurbishment, negotiates a ‘service level agreement’ for minimum acceptable delay for the TGI to remedy faults etc., and receives regular (quarterly) reports on financial expenditure, network performance and data delivery.
- The NTSLF is managed within POL/BODC by means of committee composed of the main people involved. (The committee also concerns itself with aspects of sea level recording by POL gauges at Gibraltar and in the South Atlantic.)
- Defra’s direct involvement in such management is low. We have ourselves tried to initiate a broader NTSLF Advisory Committee composed of Defra, Environment Agency, UK Hydrographic Office and other interested bodies. However, the suggestion has not been taken up so far. The STFS at the Met Office, which is primarily concerned with flooding issues, holds annual meetings which provide partial oversight of network performance. Nevertheless, we continue to believe that such an Advisory Committee would be useful for us.
- The NTSLF maintains a web page which gives users such as the Environment Agency information on which gauges are operating or have problems.
- The NTSLF has little administrative overhead. As explained above, we endeavour to make as much data as possible available via the web. To be consistent with European legislation, all such data are free of charge to users.

Recommendations

- A series of annual meeting of major uses of National Network data should be established at which problems and suggestions might be aired and at which advice to NTSLF and Defra might be given.

- A series of consultations needs to be undertaken of which technologies the Environment Agency and other UK agencies can transfer to the NTSLF (and vice versa). Such technologies include gauge equipment, data transmission, data management and data exchange.

- NTSLF should provide more information (metadata) on the network through its web pages and disseminate information as widely as possible via an Annual Report.

- In addition NTSLF should strive to provide more products derived from network data on its web pages (extremes, peaks-over-threshold (POT), MSL, comparison to altimetric sea surface topographies etc.) so as to maximise the number of users of its data.

- Defra is technically responsible for England and Wales only. Mechanisms need to be put in place such that a proper National Network can be maintained, without complications of separate funding from the Scottish and North Ireland Executives.

- NTSLF should position itself as the prime source of advice to Government on UK sea level change matters.

4. SUMMARY

This document has attempted to provide a summary of the main factors which should guide the development of a relatively-mature National Network over the next few years. It can be seen that there are challenges associated with the technology of tide gauges, data flow and data management, and network organisation. There are other challenges to do with measurements of vertical land movements and numerical surge forecast modelling, and with establishing effective linkage to other national, European and global activities. Each of these challenges must be addressed with full regard to the needs of the different user communities. However, we regard none of them as insurmountable.

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Note – Several of the above reports are available on-line from the NTSLF web site (http://www.pol.ac.uk/ntslf) while copies of all POL and BODC reports can be obtained from the POL Library.

ANNEX I: RECIPIENTS OF FIRST DRAFTS OF THIS REPORT

Defra/EA -	David Richardson Linda Aucott Sarah Nason
DEFRA/EA 'Theme Leaders' -	Mervyn Bramley Peter Allen-Williams Ian Meadowcroft
UK Foresight Programme -	Derek Flynn, Jim Hall
STFS Liaison Group –	David Smith
Met Office/EA liaison -	David Smith
Met Office Operational Modelling Group -	Martin Holt
Hadley Centre -	Geoff Jenkins
IESG, Univ. Nottingham -	Richard Bingley
Flood Hazard Research Centre, Univ. Middlesex -	Robert Nicholls
IACMST -	Trevor Guymer, David Pugh
European Sea Level Service -	Hans-Peter Plag
GLOSS -	Thorkild Aarup
Director POL -	Ed Hill
Director -	Juan Brown

The report was subsequently made publicly-accessible via the NTSLF web site.

ANNEX II: RECOMMENDATIONS OF THE ALCOCK ET AL. (1998) REPORT WITH REMARKS ON DEVELOPMENTS SINCE 1997

Section 4 of the Alcock et al. (1998) report is concerned with Conclusions and Recommendations. Conclusions 4-14 contain Recommendations for National Network development.

C4, 5 and 12 were concerned with the need for MAFF to continue funding the network. We do not comment on those.

C6 asked for the present network to maintained and suggests additional sites near the Wash and south coast of the Isle of Wight. *We have referred to this recommendation in the present report.*

C7 noted that different generations of equipment was in use at different sites and recommended that all gauges be operated to the same standards and accuracy: 1 cm in height and 3 minutes in time. *All sites now use the same bubbler systems and are accurate to 1 cm and 20 seconds (the 3 minute requirement was a poor one even for 1997).*

C8 asked that relevant sea level stations be equipped with GPS and Absolute Gravity (AG) equipment to decouple relative sea and land level movements within gauge records. *GPS benchmarks at 13 gauges have been surveyed on several occasions in 'campaign mode' while 7 gauges are equipped with CGPS receivers (soon to rise to 13, see text). Benchmarks at Lerwick, Newlyn and Aberdeen have been surveyed with AG on several occasions.*

C9 referred to the need for meteorological data to be recorded at gauges primarily for Environment Agency use. *Eleven gauges have meteorological stations with data routed to BODC along with sea level data; it is not clear who makes use of this information which does not go to the Met Office.*

C10 stated the need to monitor sea levels in the 'forthcoming estuary programme'. *No action taken so far as we know.*

C11 pointed out that there needed to be a more effective way for local STWS centres to access data from the National Network and that there should be two national centres in addition to the STWS at the Met Office which would receive data in real time. *This requirement has largely been satisfied by the deployment of new data loggers at all sites (not the loggers referred to as under development in the 1998 report).*

C13 referred to the need for reciprocal data exchange arrangements with neighbouring European countries. *This important issue is referred to in the present report.*

C14 stated that the practice of charging users for sea level data ('cost recovery') should be re-assessed. *Data are now available free-of-charge to any user via the NTSLF web site (a small charge is made for data within the '3 months gap').*

Figure 1: The UK National (or 'A Class') Network (November 2003).

Figure 2: The UK CGPS network maintained by the University of Nottingham and POL (as of November 2003. See text for plans for expansion of the network).

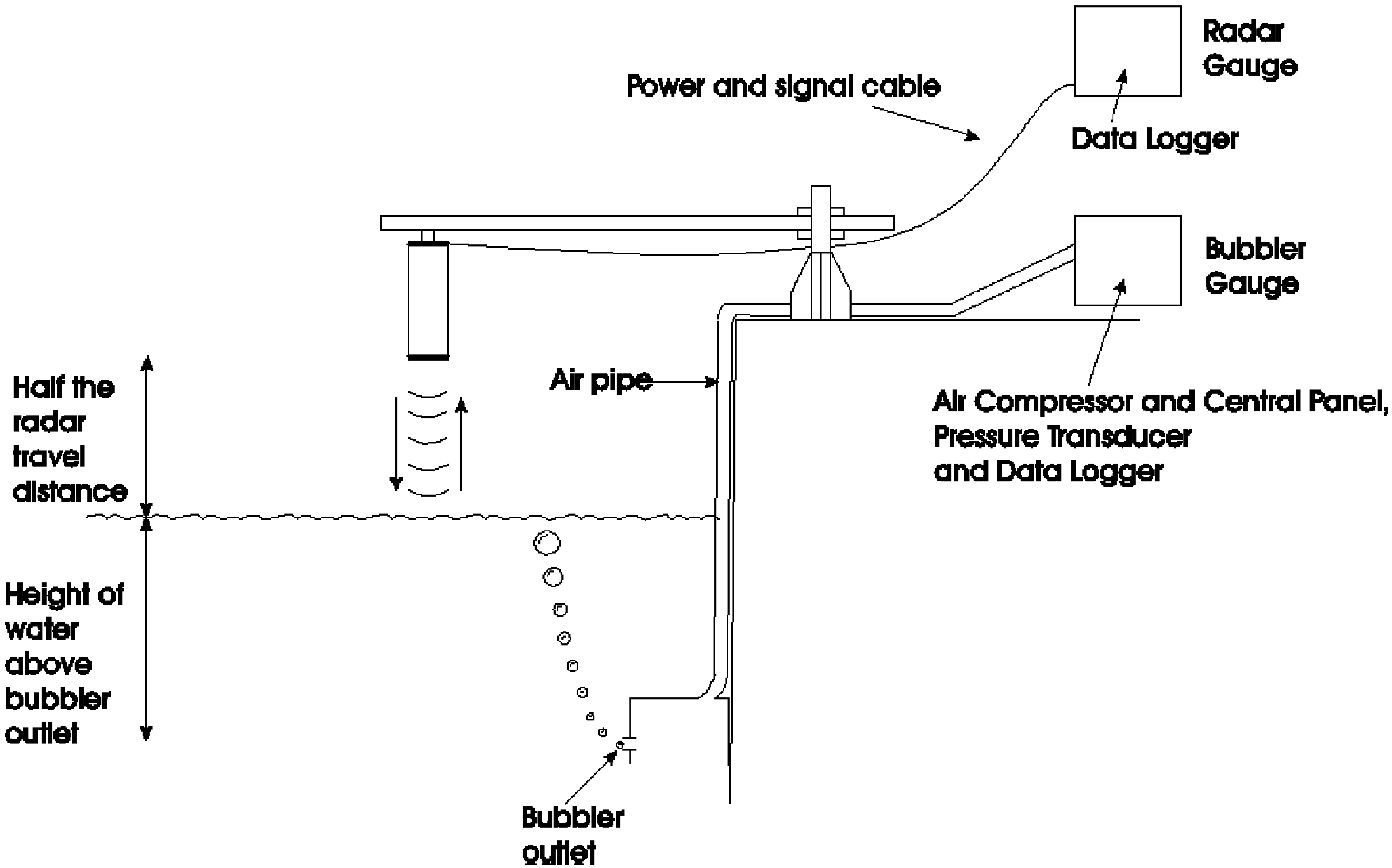

Figure 3: Schematic of a bubbler and radar gauge sea level station