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PROPOSALS FOR A SEA LEVEL NETWORK IN IRELAND

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Study conducted for University College Cork on behalf of the Department of Communications, Marine and Natural Resources

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CONTENTS

Abstract	3
1. Introduction	4
2. Global and Regional Contexts	4
2.1 GLOSS	4
2.2 Implications of GLOSS for Ireland	5
2.3 ESEAS	6
2.4 The UK National Network	7
3. Proposed New Tide Gauge Stations in Ireland	8
3.1 Introduction	8
3.2 Technical Specification of Gauges: General Remarks	9
3.3 Selection of Suitable Southern GLOSS Site and Technical Specification	11
3.3.1 Site Surveys	11
3.3.2 Technical Specification	11
3.4 Additional Gauges for Storm Surge Monitoring and Prediction in the Irish Sea	12
3.5 GPS and Meteorological Data Requirements at the GLOSS Sites	14
4. Data Centre Requirements	15
5. Organisational Aspects	18
6. Complementary Activities	20
7. Concluding Remarks	21
Acknowledgements	21
References	22
Annex I: Notes on Possible Tide Gauge Sites in County Cork	29

1. INTRODUCTION

This report contains recommendations for a new network of sea level stations in the Republic of Ireland with emphasis on the establishment of a small number of high quality stations. Sea level stations consist of tide gauges together with ancillary sensors to provide meteorological data. In certain cases they also contain Global Positioning System (GPS) receivers.

Sea level recording has a long history in the island of Ireland. Examples of long records can be found from Belfast (tide gauge charts from approximately 1885-1950 archived at the British Oceanographic Data Centre, BODC), while the international Permanent Service for Mean Sea Level (PSMSL) contains long records from Malin Head (1958) and Dublin (1938). However, the island has never possessed a coordinated network around its coastline similar to those operated in most other European countries.

We believe that such a new network would constitute a valuable strategic asset. It would provide data for a range of practical and scientific applications including:

- Production of precise tidal predictions.
- 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).
- Geodetic studies including datum determination for land and hydrographic applications.
- Determination of the heights of extreme sea levels for coastal engineering design.
- Studies of Atlantic and Irish Sea sea level variability including determination of long term changes in mean and extreme sea levels as a consequence of climate change.
- Oceanographic studies of circulation change in the adjacent deep Atlantic on various timescales.
- Assimilation into a range of numerical ocean models for operational monitoring of marine ecosystems and water quality.

It can be seen that data from the network would serve a number of communities across the sciences and within the commercial marine world. Data from the same stations would provide information in both 'fast' (or 'real-time') and 'delayed' modes, thereby serving different types of users. Two-way data exchange with the UK and France (and in principle with more distant European countries) would provide further benefits through combined analysis of information.

The following sections of this report address a number of issues with regard to an Irish network including:

- The justification for gauges in Ireland within global and European contexts.

- The similarity of the histories of the Irish and UK networks.
- The design of a baseline Irish network from the perspectives of long term sea level change, flood defence and oceanographic studies.
- The suitability of sites for inclusion in the network.
- The technical specification of gauges to be used in the network.
- The need for efficient 'fast' and 'delayed' mode information to a data centre.
- The automatic and off-line quality control procedures and data management methods to be employed.
- The requirements for ancillary meteorological data, geodetic levelling at gauge sites and GPS equipment.

The report documents the contributions of POL to a much more comprehensive network proposal document by Murphy et al. (2003).

2. GLOBAL AND REGIONAL CONTEXTS

2.1 GLOSS

The Global Sea Level Observing System (GLOSS) was conceived in the mid-1980s as a network of tide gauges (sea level stations) around the world, providing the key data needed for international sea level programmes related to oceanography, geophysics and climate change. GLOSS was until recently a programme coordinated by the Intergovernmental Oceanographic Commission (IOC). Along with other ocean programmes, it is now an activity of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of IOC and the World Meteorological Organisation (WMO).

The main objective of GLOSS, as originally-envisaged, was to improve the quality and quantity of monthly mean sea level (MSL) data provided by countries to the PSMSL which had received data from countries for many years but on a rather *ad hoc* basis. The GLOSS Core Network (GCN) was envisaged as providing a 'global baseline' around which more dense regional and national networks would be constructed for local and practical purposes (Figure 1). The GCN would be operated with high quality gauges and to common standards, and each country would contribute to the collaborative international programme out of national funds with coordination from IOC. Even though GLOSS is now formally a JCOMM activity, rather than a purely IOC one, the ethos of its organisation remains the same.

By the mid-1990s, major technological developments had taken place, especially in satellite radar altimetry and GPS, which meant that the need for the GLOSS *in situ* network had to be reconsidered. This was accomplished by means of the GLOSS Implementation Plan 1997, which was approved by the IOC Assembly the same year (IOC, 1998). The Plan confirmed the need for the GCN and for specialised sub-networks required for long term sea level change studies, altimeter calibration and ocean circulation monitoring. It also required that GCN stations deliver higher frequency data (i.e. raw data, typically hourly values) in 'delayed mode' form to GLOSS Centres (in

practice either the PSMSL again or University of Hawaii Sea Level Center, UHSLC) with a maximum delay of 6 months. The higher frequency data are required by the programme for good reasons: (i) to provide the possibility for essential quality control checking of the monthly and annual MSL values to common, modern standards; (ii) to provide access to the higher frequency section of the sea level variability spectrum, thereby aiding interpretation of interesting signals which may be less evident in the monthly means; and (iii) to enable long term archiving of irreplaceable GLOSS data sets.

The major development which has arisen since the 1997 Plan has been the recognition of the need for 'fast' (near-real time) data sets in addition to the 'delayed mode' MSL and higher-frequency sets described above. 'Fast' means different things in different applications. For example, fast data should be provided within several days to one week if required for assimilation into the new generation of deep ocean models (e.g. within the Global Ocean Data Assimilation Experiment, GODAE) and for ready use in altimeter calibration. On the other hand, fast data are needed within an hour or two for use in local flood warning schemes. In 1999, GLOSS established the GLOSS Fast Centre at UHSLC as a logical evolution of UH's previous fast role for the World Ocean Circulation Experiment (WOCE). It was realised that 'fast' data could imply expenditure in both upgrades to gauge hardware and data transmission methods and in staff resources.

With regard to the operation of GPS receivers at tide gauge sites, in 1997 the PSMSL, GLOSS and the International GPS Service (IGS) established a joint working group called the Continuous GPS at gauges (CGPS@TG) group. The IGS has since initiated a Tide Gauge GPS project (TIGA), which aims to collect data from as many gauge sites as possible and to learn how measurement errors in the determination of rates of vertical land movements can be reduced.

To summarise, there are 4 data streams within GLOSS:

(1) MSL data to the PSMSL
(2) Delayed mode higher frequency data to UHSLC or PSMSL (GLOSS Archiving Centres)
(3) Fast higher frequency data to UHSLC (GLOSS Fast Centre)
(4) GPS data to the TIGA (IGS) data centre at Potsdam, Germany.

and organisations and countries participating in the programme should contribute to all 4 streams. A recent review of GLOSS status worldwide can be found in the GLOSS Adequacy Report (IOC, 2003a).

2.2 IMPLICATIONS OF GLOSS FOR IRELAND

Ireland is a developed nation with important marine and coastal interests. It is a Member State of IOC and has voted for (or at least has not voted against) GLOSS developments at every IOC Assembly for the last 20 years. Therefore, one would have hoped for greater participation in the programme than has taken place so far. Some implications of Ireland's membership of IOC and GLOSS can be mentioned:

- In the original GLOSS Implementation Plan and in its 1997 revision, Ireland was asked to install and maintain stations in the north and south which would provide data to the GCN as described above. Gauge sites were selected primarily on the basis of their historical record, although it was recognised that local expertise would be important in deciding upon alternative locations along the coast if other sites were more appropriate for long term monitoring. Malin Head was selected in the north and Castletownsend was selected in the south.
- In the north, Malin Head has been operated by the Ordnance Survey of Ireland and mean sea level data have been provided to the PSMSL regularly. Higher-frequency delayed mode data have been contributed to GLOSS on an irregular basis (most recently via Queen's University, Belfast) but a fast data stream has not been established. CGPS has not been installed. Float gauges were used from 1958 which were replaced by a pneumatic water level gauge HBe 20.501 in 1990. We understand that the Malin Head station has recently been upgraded with an OTT Nimbus bubbler gauge and we hope that GLOSS data streams 1-3 can now be formalised
- In the south, a gauge at Castletownsend was selected on the basis of a set of bubbler gauge measurements by POL in 1977-78. However, a new gauge was not installed. The situation was reviewed by University College Cork (UCC) a decade ago and a technical visit was made to the site by one of us (Smith). The absence of a suitable location for a gauge of float, acoustic or radar type, and the probable necessity of once again operating a bubbler gauge over a rocky shore, together with funding limitations, led to the question of a gauge installation at Castletownsend being again postponed. The case for a GLOSS site in this area is a main topic of the present report.
- Any sea level specialist in Ireland has access to GLOSS reports and software concerning tide gauge installation and maintenance, data quality control and management. Irish specialists are welcome to apply to attend GLOSS training courses, held at typically yearly intervals. GLOSS Experts meetings also provide a forum at which Irish specialists are welcome and within which experiences can be shared and common high standards transferred.

2.3 ESEAS

GLOSS has always stressed the importance of regional networks to provide components of the GCN and to effectively densify it. The first major attempt to define a European regional network was called EuroGLOSS (Baker et al., 1997). This proposal resulted in a European Union (EU) COST Action called the European Sea Level Observing System (EOSS) which was replaced more recently by the European Sea Level Service (ESEAS) (http://www.eseas.org). Ireland took part in EOSS activities (represented by Dr. Peter Bowyer of University College Galway) but has not taken part in ESEAS. During 2002, a 3 year EU FP5 programme called ESEAS-RI (ESEAS-Research Infrastructure) was initiated which provides a number of European countries with the hardware and community links to, in effect, fill holes in the regional GLOSS network. Irish groups did not participate in ESEAS-RI.

The objectives of ESEAS can be summarised as the installation of modern networks of gauges around Europe, optimised for regional needs but also satisfying global (GLOSS) requirements. Data will be shared and quality controlled to the same standards. ESEAS has been endorsed by the IOC/JCOMM GLOSS Experts Group as the European regional mechanism by which GLOSS can be established. It would be ideal if Ireland could participate in ESEAS by means of sharing data from the proposed network.

2.4 THE UK NATIONAL NETWORK

Consideration of a network in Ireland might benefit from experience in the UK. The UK National (formerly the 'A Class') 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 the Ministry of Agriculture, Fisheries and Food (MAFF). It consists of 44 sea level stations, almost all of which are bubbler gauges, and of which 2 are in Northern Ireland (Figure 2). The nominated GCN stations are Lerwick, Stornoway and Newlyn, which are sites at which (it is thought) sea level changes reflect open ocean variations.

It is probably true to say that MAFF did not, until perhaps 10 years ago, consider topics such as long term sea level change to be particularly important. Such studies require typically 1 cm accuracy (the 'GLOSS standard', see IOC, 2002), compared to the typically 5-10 cm accuracy needed for flood warning. Nevertheless, the National Network gauges were always maintained by POL at the cm accuracy level because of POL's scientific interests. This leads to an important point about 'multi-use' which is always stressed in GLOSS correspondence between IOC and Member States:

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

That is why, throughout POL's management of the National Network, we have always resisted separation of the GLOSS and long-term sites into a 'super-set', with the remainder of the 44 relegated to a 'B Class' network operated to lower standards. We suggest that the same philosophy is adopted with regard to the deployment of any new stations in the Irish network.

More recently, MAFF (and now Defra) have taken on board 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 (Church et al., 2001). This is reflected in support for UK GLOSS activities, dual redundancy instrumentation at GLOSS and other UK long record sites, and a programme of CGPS at a subset of network gauge sites (Figure 3, Bingley et al., 2002; Teferle et al., 2002a, 2002b).

The Irish tide gauge history has some similarity with that of the UK. In both countries the Ordnance Surveys took the main lead in the 20th century from the perspective of national datums. Elsewhere, harbour authorities provided data as by-products of port operations. In both countries many poor-quality gauges are operated by power stations, river agencies etc. which provide sea level data of relatively little long term value. Therefore, it is to be hoped that some of the UK network history has a parallel in Ireland in leading to a national network. Discussion of the two networks together is also highly relevant as the possibilities of data sharing with regard to topics such as flood forecasting (Flather, 2000) and Irish Sea Observatory studies (Proctor and Howarth, 2003) are very attractive.

3. PROPOSED NEW TIDE GAUGE STATIONS IN IRELAND

3.1 INTRODUCTION

In this section, we make a proposal for upgrades to the Irish sea level network. This proposal has been constructed without the benefit of extensive discussion with the potential community of Irish sea level data users. Therefore, we realise that it may be only a first proposal which is subject to later refinement. Nevertheless, we believe that it contains most of the elements which any final proposal would contain.

These elements are:

- The north (Malin Head) and south (Castletownsend or nearby substitute) primary Irish sea level stations which will comprise the main Irish contributions to GLOSS and ESEAS. From discussion with colleagues at UCC and following a brief site survey (Annex 1), we believe that a suitable southern site at Castletownbere exists, west of Castletownsend and nearer the deep Atlantic, and thereby satisfying the GLOSS requirement for a European gauge as close to the open ocean as possible (and much superior to Newlyn or Brest in this regard). Castletownbere harbour is also reasonably sheltered against Atlantic swell. These two sites should be equipped with high quality tide gauges and meteorological packages and CGPS and would provide data of 'climate change' quality.
- A high-quality upgrade to the Dublin station which has one of the longest records in Ireland. This should also be equipped with CGPS.
- Two further high quality gauges along the west Connaght coastline to fill gaps between existing gauges and also to aid open-ocean oceanographic studies. The proposed sites would be Rossaveal, as it is an important strategic location in terms of the fishing industry and Island transport, and Belmullet Pier, again

for strategic reasons but also due to the existence of a long standing weather station. In addition, the Galway gauge should be repaired.

- A set of 4 additional stations on the south and east coasts, primarily for flood warning purposes as described below. This should include the upgrading of the Dunmore East Gauge, plus new gauges in Arklow, Howth or Ballycotton and Clogherhead.
- Installation of telephone lines or modems where required for currently operational gauges
- Real-time and delayed-mode data exchange between gauges in the Republic, Northern Ireland and the west coast of Great Britain.

3.2 TECHNICAL SPECIFICATION OF GAUGES: GENERAL REMARKS

We consider first the specifications for gauges at the 2 GLOSS sites and for the 3 other high quality sites at Rossaveal, Belmullet Pier and Dublin. The choice of tide gauge technology at such sites depends critically upon the locations at which they are to be installed, although some general principles can be found in the IOC Manual on Sea Level Measurements (IOC, 2002). Factors to be considered include:

1. Suitability of technologies for the environmental conditions at each site (currents, waves, temperatures, exposure).
2. As few different technologies as possible overall to keep installation and maintenance overheads to a minimum.
3. Need for ancillary ocean (waves, temperatures etc.) and meteorological measurements.
4. Good data transmission systems (almost certainly telephones in Ireland).
5. Site security.

Tide gauges come in four basic types (float, acoustic, pressure and radar), each of which have been reviewed in IOC (2002) and will be reviewed again in the near future in the proceedings of a GLOSS Technical Workshop held in October 2003:

i. Float gauges – these are the traditional gauge type. However, they are difficult to install, requiring a 'stilling well', and, while they can be adapted to provide real-time digital data by means of shaft encoders or potentiometers, they do not necessarily measure the same level as the outside water if installed in estuaries. They also tend to be labour-intensive, requiring frequent maintenance of float mechanisms and clearing of sediment accumulation in the well.

ii. Acoustic gauges – these come in two main types: the 'shining' of an acoustic pulse from a transducer to the sea surface and back to the transducer in the open air (or sometimes inside a stilling well); and the shining of a pulse inside a plastic tube equipped with calibration hole (called SEAFRAME systems in Australia and Next Generation systems in the USA). The GLOSS Technical Workshop demonstrated that the first type is to be avoided. The second type is

now the standard gauge in a number of countries and would probably be suitable at locations in Ireland where there is a harbour wall or pier on which to attach the acoustic sounding tube. Such systems are operated in Europe in Portugal and Turkey. One was tested by POL for a year at Holyhead with the conclusion that it was not suitable for most UK locations owing to the large tidal range and therefore the need for a long sounding tube: a long tube implies temperature gradients and therefore differential changes in the speed of sound along the tube (Vassie et al., 1992). Tidal range is modest along the Irish east coast and concerns on temperature gradients might not be so acute.

iii. Pressure gauges – also come in several types. Bubbler gauges form the UK standard and a bubbler system has been installed at Malin Head. There are also 'transducer in the sea' and 'B gauge' systems. The latter are used throughout POL's South Atlantic network but very expensive to manufacture and are not commercially available. The advantage of pressure systems (but not bubblers) is their ability to measure high frequency phenomena (wind waves, seiches, tsunami) as well as the conventional sea level recording with sampling intervals of several minutes. All pressure systems have the advantage of operating safely below the sea surface.

iv. Radar gauges – are relatively new and so there is only limited experience of their use within the community. Nevertheless, the GLOSS Technical Workshop included presentations by several speakers which indicated that they are capable of making measurements as well as other systems (e.g. Woodworth and Smith, 2003). Their main advantages are ease of installation and maintenance, and in most cases relatively low cost. Their main disadvantages at the moment appear to be their exposure (hence security and environmental damage concerns) and the need to develop *in situ* ongoing calibration methods. POL has experience only of OTT Kalesto radar gauges and possesses three at the moment. It plans to install them first at sites near river mouths where rapid density changes occur (e.g. Newport in south Wales and possibly Sheerness) and where bubblers occasionally provide inaccurate sea level data because of density uncertainties. A Kalesto will also be installed in Gibraltar before the end of 2004.

In our opinion, we would advise removing float and acoustic systems (i and ii) from the list of technologies under consideration for the GLOSS and other high quality sites. Float systems do not seem to be the modern way forward for a <u>new</u> network. The GLOSS Technical Workshop included presentations which demonstrated that, if a country already possesses stilling-well infrastructure, then there are cost-effective methods to provide digital, real-time data flow. However, this is not the case for Ireland. In addition, we would drop acoustic systems, as our experience with them has been limited and, so far as it goes, not favourable (although US and Australian colleagues would disagree). Ireland would also need to equip itself with a SEAFRAME calibration facility (or share such a facility with another country).

That would appear to limit the choice for sea level technology for the 2 GLOSS sites and 3 other high quality sites to either:

(i) Bubbler gauges – these could be of the UK National Network type with a mid-tide bubbler datum control channel, and would have the advantage of sharing experience with the POL Tide Gauge Inspectorate. Alternatively, they could be provided by a company such as OTT, which supplied the Malin Head gauge (we have no experience ourselves of the OTT Nimbus bubbler).

(ii) Radar gauges – provided suitable locations exist.

Pressure gauges (transducer not bubbler type) would also be suitable if some kind of ongoing datum control could be ensured; they would be promoted to first choice if wave measurements are also required. There are a large number of such pressure systems on the market and some are relatively inexpensive. However, their low cost is achieved by means of the use of cheap transducers which will be liable to long term drift.

Whatever the choice of gauge hardware, it is important that the gauge sites are operated overall to GLOSS standards. Of particular importance are the specifications for datum control by means of precise and regular geodetic levelling within a local benchmark network (IOC, 2002).

As regards the new gauges suggested for installation for storm surge monitoring (see below), then almost any technology (even cheap pressure transducers) could be considered in the short term, although we repeat the point made earlier that in the long term it may be more efficient and cost effective to operate a coherent national network to the same high standard.

3.3 SELECTION OF SUITABLE SOUTHERN GLOSS SITE AND TECHNICAL SPECIFICATION

3.3.1 SITE SURVEYS

Annex 1 contains a summary of impressions of several potential sites in Co. Cork for the establishment of a new GLOSS site, based on a survey by David Smith (POL) and Jimmy Murphy (UCC) in November 2003. The conclusion is that Castletownbere offers the best location with a jetty on which a gauge and associated equipment can be mounted. Relatively open-ocean aspect and practicalities (adequate space, telephone, security etc.) appear to be satisfied (Annex 1).

3.3.2 TECHNICAL SPECIFICATION

The jetty at Castletownbere appears to be suitable for a bubbler system, while a radar or acoustic system would require more installation planning so as to fit into a busy area. Therefore, given that the Irish network already contains a bubbler system at Malin Head (although we are unfamiliar with the OTT Nimbus product) we suggest that a bubbler be also a first choice for Castletownbere. This could be either:

- Another OTT Nimbus (to be researched).

- A bubbler similar to those of the UK network. In this case, POL could provide such a system together with a mid-tide 'B gauge' datum control bubbler channel at some point during 2004.

We suggest that bubbler integrates sea level over either 15 minutes (as for most UK sites) or 6 minutes (as for US sites). Fifteen minutes should be adequate for most tide, surge and mean sea level studies.

As a duplicate, redundant backup to the bubbler, and as a potential source of information on wave conditions, we suggest that a relatively cheap pressure transducer be deployed in the sea alongside the pier, if the local sedimentation rate is not too great, so as to provide a second source of sea level information and data on wave conditions if made to sample at 1 Hz. The simple transducer would need to be levelled using a tide pole, which should be provided for general use anyway. The gauges should be connected to a data centre preferably by telephone land line or mobile phone if necessary.

Indicative installation costs are hard to estimate, but perhaps 10K€ could be set aside for costs associated with diver support, tide gauge hut, steelwork, bubbler tube installation etc. We understand that the price of a single channel Nimbus system is around 3.5K€ (for basic unit, bubbler head, power supply) without an analogue of the POL datum channel; this would have to make use of a tide staff for datum checks. A 2-channel POL bubbler would cost of the order of 15K€ (2 transducers, compressor, data logger etc.). Running costs for both systems should be small (few K€ per year). However, one needs to include staff costs for maintenance and for regular (annual) levelling exercises.

GLOSS standards require that sea level data are accompanied by air pressure, sea and air temperature data and, if possible, winds although they are often difficult to measure in a crowded port. However, this does not apply if there is a nearby meteorological station (e.g. Valentia).

Costs for establishing a local benchmark network and levellings should be a few K€. Costs for CGPS would be about 15K€ for the receiver and 10K€ for monumentation and data links.

3.4 ADDITIONAL GAUGES FOR STORM SURGE MONITORING AND PREDICTION IN THE IRISH SEA

As part of this study, we have considered the need for gauges in Ireland which could aid the monitoring and prediction of storm surges in the Irish Sea. The Irish Sea has historically had less of an association with flooding by storm surges than the North Sea. Nevertheless, they can be significant, as demonstrated recently (Flather, 2002). A Dublin Bay forecast scheme is under development using a UK Met Office (in effect POL) model for the Irish Sea together with a local nested model for Dublin Bay itself, and one might expect such schemes to be developed further in future.

From the perspective of modelling and forecasting storm surges, tide gauges are needed for the following reasons:

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

Data requirements are for information in both real-time (e.g. for monitoring surge development in the flood warning system, and for assimilation) and delayed-mode (e.g. for validation, and for research). Gauges should be sited to be representative of the regional surge, and even, for some cases, of the local surge where there is a local flood risk.

Long records providing good tidal analyses are required to enable accurate tide predictions and hence accurate estimation of actual surge from the measured data. Therefore, gauges should not be sited where analysis problems are likely to occur. Such locations include extensive shallow areas, where too much tide-surge interaction may render surge data unreliable; and in estuaries, where the measurement of the whole tidal range is not made, and maybe recording the river level for a period near low water.

A list of existing gauges in Ireland was provided to us by UCC (Table 1 and Figure 4). These gauges appear to surround Ireland quite well. However, there are gaps, such as on the east coast between Rosslare and Dublin, and gauges on the south coast are in inlets (e.g. Whiddy Island) or estuaries (e.g. Cork Waterford Harbours) which are not ideal for open-sea monitoring. The only true open-sea gauge is that at the Marathon Oil Platform which we believe will be in position for another 20 years and which already provides data on currents, waves and weather.

From the modelling perspective, additional gauges could usefully be deployed in the Irish Sea area:

<u>(i) Near regional model open boundaries.</u>

We understand that as part of the proposal to develop a surge forecast scheme for the Irish Sea, which would employ forecast data from UK shelf scale model together with local modelling (cf. Flather, 2002 Dublin Bay study), local gauges to Dublin at Dun Laoighre and Howth would be established. From colleagues at UCC, we also understand that the other main population centres (Waterford, Cork, Limerick and Galway) have already got operational gauges of sorts of their own.

However, in addition to very local information, there is a need to constrain the open boundary inputs to such a model, which would cover the entire Irish Sea with boundaries at ~8°W, ~51°N, and ~56°N. Suitable tide gauges could include:

<u>North:</u> Malin Head with UK gauges at Portrush, Port Ellen and perhaps Tobermory.

South: Marathon Oil Platform, Cork or a new gauge near to Ballycotton, with UK gauges at Newlyn, St Mary's and possibly Ilfracombe.

(ii) To provide data for assimilation inside an Irish Sea model.

Given that existing harbour gauges near Cork and Waterford may not be very useful, then Rosslare, Dublin and new gauges at Arklow, Dunmore East and Clogherhead could be suggested, together with selected UK gauges. Pairs of gauges (e.g. Rosslare – Fishguard; Dublin – Holyhead; Clogherhead – Port Erin; Bangor – Portpatrick) should help constrain transports in the model.

In summary, assuming the availability of real time data from all the stations listed in Table 1 (of which we have no experience and which are probably a multiplicity of different types of technology), we suggest possible new gauges at:

- Arklow (or Courtown or perhaps further north at Wicklow, POL having conducted measurements at each of these sites in the 1970s, see Pugh, 1981). We understand that a gauge of some kind may already exist at Arklow.
- Dunmore East.
- Ballycotton (depending on the availability of data from the Marathon Oil Platform).
- Clogherhead (if there are continued flood prone areas north of Dublin: Dundalk looks a difficult site, but, if there is a flooding problem, then gauges in the are have to be considered).

It is important to stress that such investment would benefit both Irish and UK storm surge model developments.

3.5 GPS and METEOROLOGICAL DATA REQUIREMENTS AT THE GLOSS SITES

CGPS in Ireland

It is suggested that CGPS should be installed at the GLOSS tide gauges at Malin Head, Castletownbere and also at the long record site at Dublin. These will be important for the separation of vertical land movements from the climate related changes in mean sea levels. The CGPS measurements can also be used for testing geophysical models of vertical land movements due to post-glacial rebound and subsidence. These models suggest that in the north of Ireland the land is uplifting by the order of 0.5mm/year and in the south of Ireland the land is subsiding by about 1mm/year. The GPS measurements would also help to show whether there are any local movements near the tide gauges, in addition to the larger scale post-glacial movements. Absolute gravity measurements would also provide valuable data on vertical land movements.

The details of the methods of installation of CGPS at tide gauges are described in http://imina.soest.hawaii.edu/cgps_tg. This web page also gives case studies of the installation of CGPS at the UK tide gauges at Newlyn and Sheerness and the French tide gauge at Marseille. Most of the CGPS stations at UK tide gauges use Ashtech MicoZ Continuous Geodetic Reference Systems (www.thalesnavigation.com). Recent analyses of the time series from the UK CGPS stations show that the vertical rates can be determined to a precision of +/- 1mm/year from 6 years of continuous GPS data from a high quality station. The absolute accuracy of the vertical rates depends upon the stability of the global geodetic reference frame, which is currently being investigated in the International GPS Service (IGS) Pilot Project called TIGA (Tide GAuge).

Ancillary Met Data

As regards meteorological data, there is a GLOSS requirement for air pressure, air and sea temperatures to be measured normally alongside sea levels. However, meteorological measurements may not be necessary if there is a nearby weather station, and winds are one parameter which are often measured poorly in a port environment. The data loggers of tide gauges have been proposed as 'coastal data platforms' for the collection of a wide range of additional ocean parameters (oxygen etc.) by the Global Ocean Observing System Coastal Module (IOC, 2003b). However, the latter does not comprise a normal GLOSS requirement.

4. DATA CENTRE REQUIREMENTS

Although the Irish network will be a small one, it will need a data centre to process information received from the gauges and make them available to users. We strongly advise that the centre be located at the same place as the people responsible for gauge maintenance, so that proper information flow takes place.

In our opinion, the centre should not only be responsible for data flow and quality control from the GLOSS and other high quality sites, but also from each of the sites listed in Table 1, including data from Northern Ireland gauges. In addition, it would be responsible for all necessary metadata (data analysis reports, maps, benchmark details, levelling information, documentation, products etc.). GPS data is rather a separate issue and could best be coordinated by, for example, the Ordnance Survey.

UK NTSLF Experience

As an example, we can describe how data flow and quality control takes place in the UK network. Most data from the National Network are made available to users through the National Tidal & Sea Level Facility (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. A separate data stream for some gauges, over which the NTSLF has no control, goes to the Storm Tide Forecasting Service (STFS) at the Met Office.

Quality control is carried out in accordance with internationally agreed standards (e.g. GLOSS and ESEAS). The goal of the quality control is to detect and, if possible, correct errors, in order to maximize the data available. The basis of quality control of tide gauge data is the visual inspection of observed data and residuals (i.e. the difference between observations and predictions, calculated from a tidal analysis). This enables the detection of non-physical values, instrument faults and other problems including timing errors, datum shifts, spikes, gaps, etc. Suspect data is also checked against records of a nearby site, to detect if the suspect values are due to a tide gauge fault or to meteorological conditions. In case of a fault data may be corrected or interpolated, and flagged to indicate what action has been taken. Otherwise the data are kept as they are, and the event or unresolved problem documented. Quality-control also extends to other factors. For example, the documentation of datum information (relationship of the recorded sea levels to the level of benchmarks on land) is essential. Diagrams, maps and other meta-data are also stored along side the observed data.

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

- Data at least 3 months old together with accompanying documentation, 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 Sea Level Center.
- 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 receives its 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 possible providing data to users 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 clearly 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, we intend that 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 users would benefit from the modest reduction in the gap.
- 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 envisage 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 users.

Irish Data Centre

If we try to adapt the UK experience to the Irish network, then it is clear that data centre has to equip itself with computer and telecommunication resources to enable:

- Data to be received from all gauges in near real-time.
- RTQC and delayed mode software to quality control data.
- Data base management resources.
- Web management resources including a facility for keeping track of which users access which data.

From discussions with UCC, it seems that proportionately more users in Ireland will require access to real time data than in the UK. Therefore, the data transmission, RTQC and web aspects will need development to a level of sophistication that the NTSLF is itself just grappling with.

Some hardware and software at the NTSLF could be replicated in the Irish data centre (e.g. data base and web management). However, BODC hardware is at present Silicon

Graphics (Unix) based with in-house SG-dependent software, which would not be easily transportable. A development programme is in place to convert most functions to run under Linux. Probably the whole Irish network could be controlled, quality controlled and web-manages with a small network of such machines (very approximate cost estimate 30K€).

Once data are into the data centre, then we refer to the need for international data exchange for ESEAS and GLOSS explained above. In addition, we suggest that special arrangements are made between the data centre and NTSLF for exchange of data around the Irish Sea.

In the UK, the separate real-time data stream to the STFS is merged with information from storm surge forecast models in order to generate flood warnings to operational agencies (e.g. closure of the Thames Barrier). Given that there are developments to construct surge models for the Irish coast, an important user of the real-time data into the centre would be a STFS in Ireland, which would itself be most logically located at the data centre.

5. ORGANISATIONAL ASPECTS

We were asked by UCC to describe how the UK network is organised, as a possible guide to how the Irish network could be managed. The following list of main points provides a brief overview of UK organisational aspects.

- The physical tide gauge network, which is the responsibility of the Tide Gauge Inspectorate (TGI) at POL (contact person David Smith), together with the management of its data by BODC (contact person Lesley Rickards), 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 is technically responsible for England and Wales only; we leave aside details concerning the Scottish and North Ireland Executives.)
- 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 in the network and chaired by Philip Woodworth. (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 Storm Tide Forecasting Service (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, and we suggest that a similar committee would also be useful in Ireland.

- 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.

As for resources which POL/BODC devote to the network, it has first to be recognised that POL has a long history and continued interest in tidal science and technology and hosts BODC with its extensive expertise in data management. Consequently, the operation of the National Network at POL fits easily into the wider laboratory activities, and POL remains the 'natural' home for the NTSLF. Nevertheless, the POL and BODC Directors are keen to see that costs for the NTSLF are transparent so that Defra-related activities (which are subject to full economic costing including agreed overheads) are not seen to be subsidised by science (or vice versa). Such a principle would be necessary for whichever organisation is chosen to manage the Irish network.

Staff associated with the routine operation of the network include:

- 2 people in the TGI who maintain the 44 tide gauges and perform ancillary measurements (e.g. annual levellings). One member of staff is always on call.
- 1 person-equivalent who is responsible for down-loading data from gauge data loggers to BODC and for subsequent QC.
- Fractions of several people who are responsible for data base activities and web management, and for workshop and electronics support (approximately 4 man-years per year).

Staff associated with scientific aspects of the network include:

- Approximately 1 person-equivalent who monitors the performance of the operational surge models at the Met Office by comparison to tide gauge data.
- Fractions of several people responsible for product generation (tidal constants, extreme levels etc.) from resulting data sets.
- POL senior scientists who provide a high level form of quality control by using network data within their own research. This aspect is clearly where Defra and NERC interests most obviously complement each other.

We are ill-equipped to say how well the above UK organisation model can be adapted to the Irish situation. However, we doubt that staff and other costs could be down-scaled significantly for the smaller Irish network. We would definitely advise that one home be

found for both tide gauge maintenance and data management so that the fullest interaction can take place.

In contrast to the UK situation so far, we also advise that an Advisory Committee be established with representatives of the main user agencies. We understand that these could include:

- Department of Communications, Marine and Natural Resources
- Marine Institute
- Met Eireann
- Ordnance Survey Ireland
- Office of Public Works
- Environmental Protection Agency
- Certain County Councils
- Academic sea level experts.

6. COMPLEMENTARY ACTIVITIES

In addition to the installation of a new network, we also suggest that Ireland embarks upon a major programme of data archaeology and maintenance of historic benchmarks.

We know that colleagues at Queen's University Belfast, UCC and other groups have recently begun the conversion from paper-based to computer-compatible form of historical data from Malin Head etc. which will provide valuable data sets. POL has recently discovered in its basement the original Belfast paper charts from the late 19th century onwards which have received recent chemical treatment, and which will eventually be digitised thereby providing one of the longest sea level records in the UK. We suggest that someone take responsibility to compile a catalogue of all Irish paper-based sea level information (charts, tabulations etc.) which could be potentially converted to computer form.

Ireland's different history of industrialisation to the UK has meant that many original benchmarks associated with historical tide gauge measurements still survive, even if the gauges were removed long ago. The most famous of these is the set of marks installed at over a dozen sites as part of Airy's tidal measurements in Ireland (e.g. Pugh, 1982). Some years ago, one of us (Woodworth) established through colleagues at the Irish Ordnance Survey that almost all of these marks still exist and are clearly marked on modern maps. A similar inventory of such marks associated with historical tidal measurements should also be constructed. That would allow the possibility to install temporary gauges near to the original sites to establish how sea level has changed over a century or more. That would provide interesting information on long term sea level change in Ireland, in the absence of continuous tide gauge records from most parts of the island.

7. CONCLUDING REMARKS

The main criteria for a sea level network in Ireland have been considered and recommendations for stations for monitoring long term sea level changes, ocean circulation and flood warning have made (Section 3.1). Technical aspects have been reviewed and the needs of the international sea level community for data from Ireland have been explained.

The main driver for a sea level network is the existence of user communities which recognise the need for the network, and can lobby Government to pay for it. The main user communities which need to be assembled to make use of the sea level data include:

- Climate change and oceanographic scientists.
- Operational oceanographers who can employ data together with numerical models: most obviously tide-surge models for flood forecasts.
- Coastal consulting engineers and local authority engineers.
- Mapping (Ordnance Survey) and charting (Hydrographic Office) specialists and port operators.

Our experience is that such communities will benefit from data to the maximum extent if the data are available freely on the web without restriction. By this means, other communities (e.g. school or university students) may also begin to make use of it in different ways. Then, with the widest use of data, the case for maintaining and strengthening of networks becomes self-perpetuating.

That means that the owners of the new network have to work hard to ensure the recognition of its importance as widely as possible. POL (and other groups associated with GLOSS and ESEAS) would be very willing to work with the owners to ensure that the new network is highly successful.

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Table 1:

Currently Installed Tide Gauges in the Republic of Ireland
(Gauges listed anti-clockwise from Malin Head in the North)

Malin Head, Co. Donegal
Killybegs, Co. Donegal
Galway Harbour (currently not working due to a damaged tube)
Carrigaholt, Co Clare
Whiddy Island Terminal, Bantry, Co. Cork
Marathon Oil Platform off Kinsale Head, Co. Cork
Cork Harbour (2 gauges)
Waterford Harbour
Rosslare, Co. Wexford
Dublin Bay (up to 3 gauges)

Currently Installed National Network Tide Gauges in Northern Ireland

Bangor
Portrush

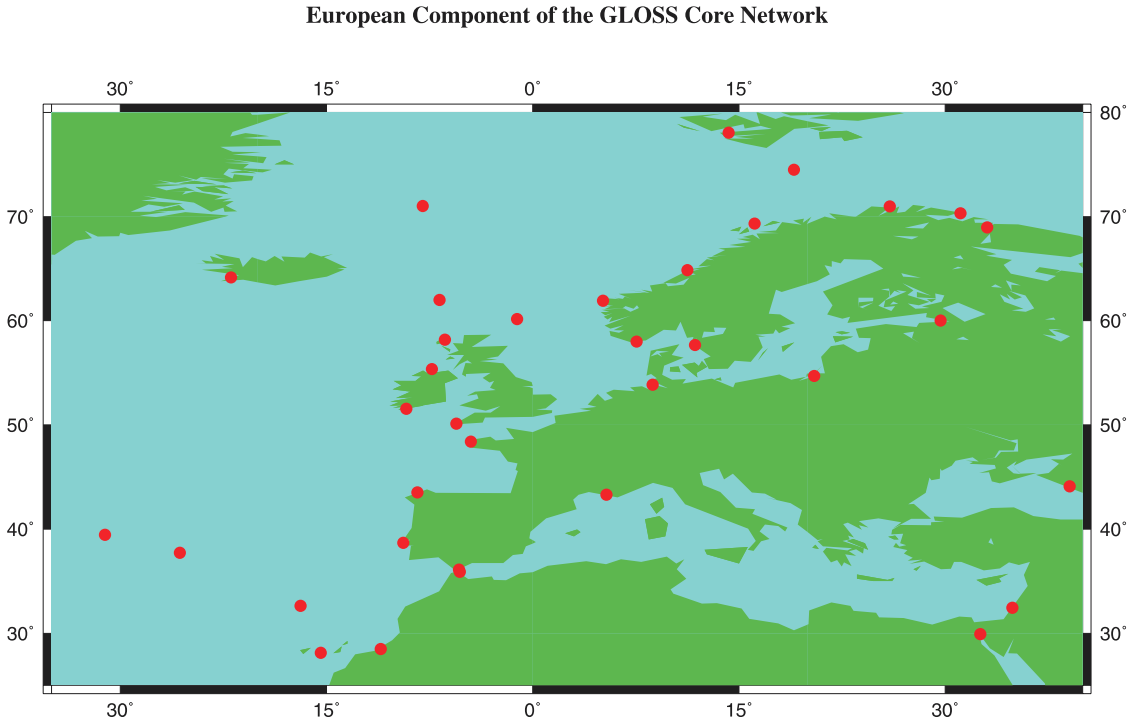

Figure 1: The European component of the GLOSS Core Network around which more densified regional and national networks can be constructed.

Figure 2: The UK National (or 'A Class') Network.

Figure 3: The UK CGPS network maintained by the University of Nottingham and POL.

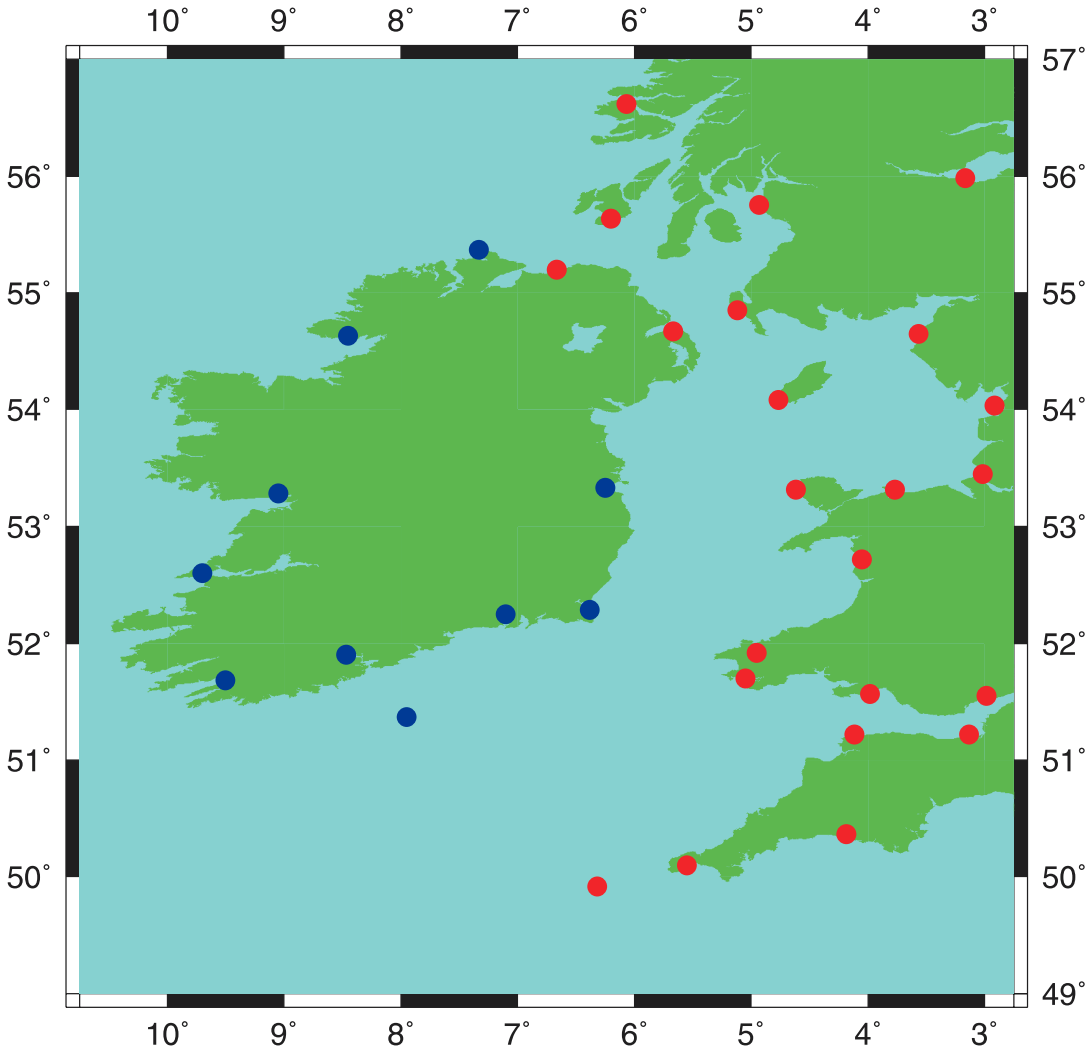

Figure 4: Currently Installed Irish and UK National Network Gauges (see Table 1).

ANNEX 1: NOTES ON POSSIBLE TIDE GAUGE SITES IN COUNTY CORK, IRELAND FOLLOWING SITE VISITS BY D.E. SMITH ON 18 NOVEMBER 2003

Introduction

A visit was made to carry out a survey to find a suitable site to establish a GLOSS tide gauge in Co Cork, Ireland. Jimmy Murphy University College, Cork, provided background data on the possible sites. He also visited all the sites during the survey. The sites visited were: Rosscarbery, Mill Cove, Glandore, Union Hall, Castletownsend, Schull and Castletownbere.

Survey

Rosscarbery

The jetty is situated on the western entrance to Rosscarbery Bay 2.5km south of Rosscarbery. The jetty is built on a stone outcrop, made of stone with some sheet piling at the seaward end. It has concrete decking which is good condition. The majority of the jetty dries out at low water. There are no services (telephone lines and electricity supply) or habitation close to jetty. There is a strong mobile phone signal at the site. Any tide gauge installation would have to be self contained using a solar panel and a mobile phone. The site would be vulnerable to vandalism.

Mill Cove

This jetty is sited on the east side of the next inlet west of the Rosscarbery jetty. Access to the site is difficult along narrow lane. The jetty is built on a rock outcrop with a rough stone top. The outcrop extends on the seaward side and end of the jetty. The only site for measuring instruments is on the quayside of the jetty. There are houses close to the jetty with power and telephone services available.

Glandore

The stone jetty is in the village again built on a rock outcrop with deep water on the quayside and end. Although the quay was quiet on the visit the jetty is very busy during the holiday season. It should be possible to get power and telephone lines to the jetty. There is not a mobile phone signal.

Union Hall

This is modern concrete commercial fishing quay along side an older stone jetty on the opposite side of the estuary from Glandore. The stone jetty has suffered damage and appears to be unstable.

The fish quay is very busy with the only possible site for a gauge on the side of quay close to the ice plant. Getting a power supply and telephone line to the measuring site would be difficult and there is no mobile phone signal at the site.

Castletownsend

A square stone open jetty one side of it dries out at low water. There is no obvious place to establish a gauge at this site.

Schull

This is a modern commercial jetty which is busy with fishing vessels. The only possible site for a gauge is at the landward end of the jetty but it looks like that dries out at low water.

Castletownbere

A large fishing port with busy modern quays administered by the Department of the Marine. The only site for measuring instruments would be in the face of the quay in areas protected by fendering. A site for instrument housing was identified but it would be vulnerable to vandalism

Dinish Island

The department had operated a temporary tide gauge close by on Dinish Island. The site comprises of a maintenance boat lift incorporated into an open jetty supported on concrete legs.

A gauge could be safely sited under the jetty. On the jetty is a control building for the boat lift. The building has power, a telephone line and space is available to site the data logging and communications systems. The site is also secure.

Further information on Castletownbere and Dinish Ireland (from Murphy et al., 2003)

Aerial View of Castletownbere and Dinish island

Aerial View of Castletownbere Quays

The following general comments can be made about the two Castletownbere sites:

Pros

- Proximity of power and telephone lines
- Sheltered location
- Does not dry out
- Very good local support
- Building available for housing gauge instrumentation (Dinish Island location)
- No potential problems with GPS signals
- Good locations for siting gauge either on mainland or Dinish Island
- Important strategic location
- Good Security (Dinish Island Location)
- Opening in deck slab for instrument cables to pass through

Cons

- Busy fishing port
- Site not directly open to the ocean

Possible Installation Type

Two potential locations for a gauge were found. The first on the mainland on a section of quay near to where the Island ferries dock and the second on the Syncolift structure (open jetty supported on concrete legs) on Dinish Island. The site on Dinish Island was considered to be the more suitable as it is more secure, has better facilities and is on Department of Communications, Marine and Natural Resources property. Both locations would be unsuitable for radar or acoustic gauges as the high level of activity in the

harbour would increase the risk of damage. The other option is to use pressure type system, probably a bubbler. Therefore, given that the Irish network already contains a bubbler system at Malin Head (although POL are unfamiliar with the OTT Nimbus product) it is suggested that a bubbler be also a first choice for Castletownbere. This could be either:

- Another OTT Nimbus
- A bubbler similar to those of the UK National Network. In this case, POL could provide such a system together with a mid-tide 'B gauge' datum control bubbler channel at some point during 2004.

A temporary installation of a Valeport pressure gauge took place at the Dinish Island site for six months in 2003 so there is some experience of measurements at the site.

A gauge could be safely sited under the jetty. On the jetty is a control building for the boat lift. The building has power, a telephone line and space is available to site the data logging and communications systems. A GPS antenna could be installed on the roof of the control building and a number of benchmarks could be established at suitable locations on the jetty, island and mainland. There would also be staff of the Department of Communications, Marine and Natural Resources available to check the system.

Other Sites

Other sites suggested in the Murphy et al. (2003) report (e.g. Goleen) were not addressed in the 18 November visit.

Conclusion

The conclusion of the site visit was that Dinish Island site at Castletownbere would be the best place to site permanent tide gauge. The open construction of the jetty affords good protection for the measuring system with the data logging system housed in the control building for the boat lift. The other sites visited had problems with locating the gauge, or degree of exposure or lack of facilities and local support, which made them less attractive as tide gauge sites. In addition, Castletownbere is an important strategic location in terms of the fishing industry and a gauge here could also provide early warning of possible flood events along the south and east coasts. POL do not see its location behind Bere Island as being a problem given the openness and depth of the entrance channel and the absence of strong currents. In fact the site's closeness to the shelf edge is seen to be a particular advantage which makes it (according to POL) much superior to existing GLOSS sites in Newlyn (UK) or Brest (France) in this regard.