In Allsop W. ed Coasts, Marine Structures and Breakwaters: Adapting to Change - Proceedings of the 9th International Conference Organised by the Institution of Civil Engineers and Held in Edinburgh on 16 to 18 September 2009, p614-625.

Coastal flooding in Scotland: Past, Present and Future

Tom Ball, School of Social and Environmental Sciences – Geography, University of Dundee, UK
Laura M. Booth, School of Social and Environmental Sciences – Geography, University of Dundee, UK
Robert W. Duck, School of Social and Environmental Sciences – Geography, University of Dundee, UK
Anton Edwards, School of Biology, University of St. Andrews, UK.
Kieran Hickey, Dept of Geography, National University of Ireland, Galway
Alan Werritty, School of Social and Environmental Sciences – Geography, University of Dundee, UK

Introduction

Coastal floods and their associated storms have caused considerable socioeconomic impact in Scotland over recent history (Hickey, 1997; Jones, 2003). In 1953, parts of the north east coast, the Orkney and Shetland Islands and the Forth Estuary were severely affected by floods best remembered for their impact in southeast England and the Low Countries (Hickey, 2001). More recently, the January 1991 floods on the west coast and Clyde Estuary caused damage equivalent to £10.5M. This incident led directly to the establishment of an early warning scheme for storm surges in the Clyde Estuary (Kaya *et al.*, 2005), the promotion of flood prevention schemes at Saltcoats, Largs, Rothesay and Renfrew, and ongoing redevelopment of flood defences along the banks of the Clyde.

The severe coastal storm on the west coast of Scotland in January 2005 affected much longer stretches of coastline than in 1991. Storm surges occurred of a magnitude not seen in living memory, in excess of 2 metres at Corpach, near Fort William. Many of the communities inundated were located away from flood warning coverage and isolated from the emergency services. Since 2005 a consensus has emerged within the Scottish Government, SEPA and other public bodies that managing coastal flooding has been severely hindered by a dearth of key information specifically on high risk locations. Informed prioritisation of spending on coastal flood risk management requires this situation to be remedied. Accordingly in 2007 the Scottish and Northern Island Forum for Environmental Research (SNIFFER) commissioned a scoping study on coastal flooding in Scotland (Ball *et al.*, 2008). The aims of this study were to assist in filling the information gap and contribute to the development of new coastal zone management policy by (1) characterising the nature and pattern of past, present and future coastal flood risk; (2) assessing the management options for managing the risk, based on stakeholder interviews, and (3) making recommendations for minimising the risk in the future. This paper reports on the main findings of these tasks and focuses on their potential significance for emerging coastal zone management approaches, policy and legislation in Scotland.

Historical coastal flooding in Scotland

Spatial patterns

The study of historical flood events initially used the database compiled by Hickey (1997), which provides a comprehensive archive of floods from 1500 to 1991. We regarded 1849 as an appropriate starting date for the SNIFFER study, since following the advent of both the telegraph and widespread daily local newspapers, accounts of flooding became more reliable and contemporaneous by the mid nineteenth century. GIS was used to georeference and collate the database, which also permitted spatio-temporal analysis (see Figure 1). Sources for data after 1991 comprised Biennial Flood Reports (compiled by Scottish Local Authorities as a statutory obligation under the Flood Prevention and Land Drainage (Scotland) Act 1997), contemporaneous media accounts, consultants' reports (eg flood defence appraisal risk analyses and feasibility studies) and information gleaned from direct consultations with coastal zone stakeholders. The resulting database contains 304 floods in total, of which six affected so large an area that it was not possible to georeference them specifically to sites (these appear on Figure 1 at locations away from the coast).

Figure 1. Spatial distribution of historical coastal floods in Scotland, 1849-2005. Left panel shows the corresponding monthly North Atlantic Oscillation (NAO) Index where the index was negative, right panel when it was positive

Thus, the actual number of site-specific floods is considerably higher (for example, the 2005 event is in this category and was sufficiently widespread to be classed as ‘Scotland-wide’). While many of the zones of greatest flood density are known to be high risk (such as the Clyde and Solway coasts), there are significant clusters of events on the Aberdeenshire and Moray coasts, as well as the Moray and Cromarty Firths, zones often assumed to be away from significant storm surge activity. Many of the affected north east sites have not experienced a major flood event for several decades. Figure 2 shows the breakdown of historical floods by region.

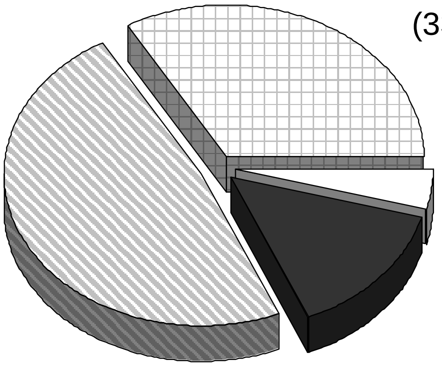

Figure 2. Regional breakdown of the spatial distribution of historical floods around the coast of Scotland, 1849-2005.

The physical magnitude of historic floods could be gauged in terms of water height and inundation extent. From contemporaneous reports, an assessment of the water height was available in less than 10% of cases and, where present, was generally anecdotal. As examples of some of the information on higher water levels recorded: ‘1907, Helensburgh, 5 m high tide, not been exceeded since’ and ‘1956, Kirkcaldy, ‘highest tide for “many years”’. Socio-economic impacts could also be gauged from these accounts, again mainly in anecdotal terms. Substantive figures for economic damage were only available in a few cases.

By cross-referencing the contemporaneous Lamb weather types (Lamb, 1972), to the recorded events, the synoptic correlation for floods in each region can be identified. As expected, floods along the north east coast were typically driven by storms associated with a north or north easterly weather type; prime examples being recorded on 31st January 1953, when 17 sites reported flooding on the Highland, Moray and Aberdeenshire coasts, and two events in 1958 and 1959, when easterly airflows caused flooding in the Forth Estuary. However, these events are rare compared to floods generated by south west and westerly weather types. The south west coastal incidents around the Argyll, Clyde, Ayrshire and Solway coasts tended to be more spatially confined but also more frequent, with the notable exception of events in 1991 and 2005.

Patterns though time

A major question of interest is whether flood incidents have been increasing in frequency and magnitude over time. Although the number of floods for individual years in the 1849-2008 database follow a Poisson distribution (implying no clustering of floods in specific years), Hickey (1997) identified a number of trends over longer time periods. In addition to a general increase in the frequency of floods since 1500, he also identified specific ‘flood-rich’ and ‘flood-poor’ decades since the mid nineteenth century. Part of the explanation lies in cyclicity of the NAO index. Notably, flood-rich decades occurred in the 1850-60s, 1890s, 1970s and 1990s: Figure 3 shows these decades to have been periods of generally high positive NAO index in the months in which the floods occurred (Figure 3). During such periods, the pressure differential between Iceland and the Azores is maximal, causing stronger average circulation in the arc between south west and north west directions. However, notable exceptions to this trend are found, particularly earlier in the record. Floods associated with high negative NAO indices tended to be associated with floods in the south west and north east regions (Figure 1). A 1869 flood, which affected the north east, was the most extreme with an NAO index of -6: it coincided with a north/ north easterly circulation and caused significant damage at Wick. This event came toward the end of a notable period of ‘negative NAO’ floods, a feature repeated again in the 1890s. Dawson *et al*. (2002) noted that the latter was, by historical standards, a period of exceptional storminess, similar in terms of gale days to the more recent flood-rich period of the 1980-90s, but with a negative NAO index. They further suggested that ‘negative NAO floods’ are associated with a southward displacement of polar atmospheric and oceanic fronts in the North Sea, linked in turn to a growth of sea ice around Greenland. What is significant in terms of flooding is that, as Figure 1 shows, ‘negative NAO’ floods are generally associated with flooding on the North, Moray and Aberdeenshire coasts, whereas ‘positive NAO’ floods, as well as causing more widespread flooding, are more closely linked with events along the north west and south west coasts.

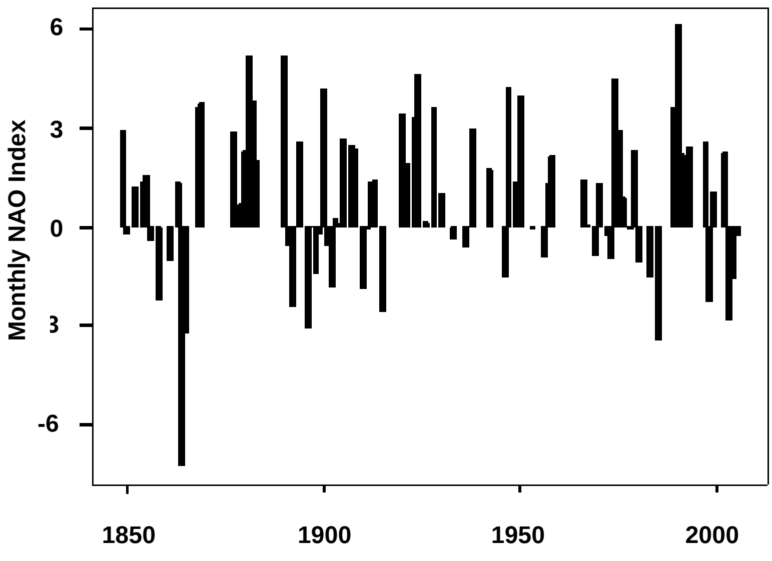

Figure 3. North Atlantic Oscillation (NAO) Values 1849-2008 corresponding to recorded flood events in the historical flood database

An inherent weakness in analysing floods solely by their occurrence is that, for a flood incident to be recorded at a given site in the database, some degree of socio-economic impact had to have occurred. This raises two issues in terms of database consistency. Firstly, coastal infrastructure exposure may change by progressive reinforcement of defences at risky sites.

Secondly, the database can hide progressive changes in the causal factors mentioned above that may not have caused a flood, but were (and are) nevertheless increasing flood risk.

To circumvent this difficulty, and to assess more accurately the recent changes in risk factors, we analysed recorded water height and storm surge trends from Admiralty tide gauges at four ports chosen to represent both open coast or estuary sites: Aberdeen (1930 onwards), Lerwick (1959 onwards), Millport (1978 onwards) and Stornoway (1976 onwards). The data were quality controlled, with years where data were partially missing removed from the record to avoid the introduction of seasonal bias.

Descriptive statistics of storm surges are reported in Table 1. The standard deviation of surge levels was substantially higher at Millport (~206 mm *cf.* ~150 mm elsewhere), caused by the effect of wind acting along the Clyde Sea inlet. Separate analysis showed that the standard deviation of surges levels is remarkably constant from year to year with only very weak upward or downward trends accounting for changes of a few tenths of one mm per year, around 0.1% of the general standard deviation. It suggests that the variance of surge levels – and therefore the potential energy in the systems – has not changed significantly over the periods of these records. There is thus no evidence in this analysis of “increased storminess”, insofar as it affects surge levels, in the past several decades.

Port	**Period**	**HAT m**	**Mean HPT m**	**Slope of annual mean, mm yr^{-1}**	**P (slope mean) > 0**	**Standard deviation, mm**	**Slope of standard deviation mm yr^{-1}**
Aberdeen	1946-2007	4.84	4.72	+1.21	<0.01	~155	-0.15
Lerwick	1959-2006	2.47	2.42	-0.36	0.27	~135	+0.18
Millport	1978-2007	3.84	3.74	+1.17	0.13	~206	-0.07
Stornoway	1976-2007	5.52	5.38	+2.18	0.02	~165	+0.43

Table 1. Summary of storm surge statistics. HAT – highest recorded astronomical tide. HPT – highest predicted tide.

The analysis of trends in mean surge levels is shown in Figure 4. Annual values are apparently increasing at Aberdeen, Millport and Stornoway by around 1 to 2 mm yr^{-1}, with Stornoway reporting the highest rate of increase. However, only at Aberdeen and Stornoway are these increases statistically significant. At Lerwick, the annual mean surge level has decreased slightly but not significantly (P=0.27). There is close agreement between these trends and those for overall mean sea level provided by the National Tide and Sea level Facility (NTSLF). The figures in the table obscure many of the details of inter-annual variability. One prominent example occurs in the Aberdeen record where there was a small rise in the mean level during the first thirty years, followed by a period of over 2 mm yr^{-1} from 1980 onwards – giving an overall rate of 1.21 mm yr^{-1}.

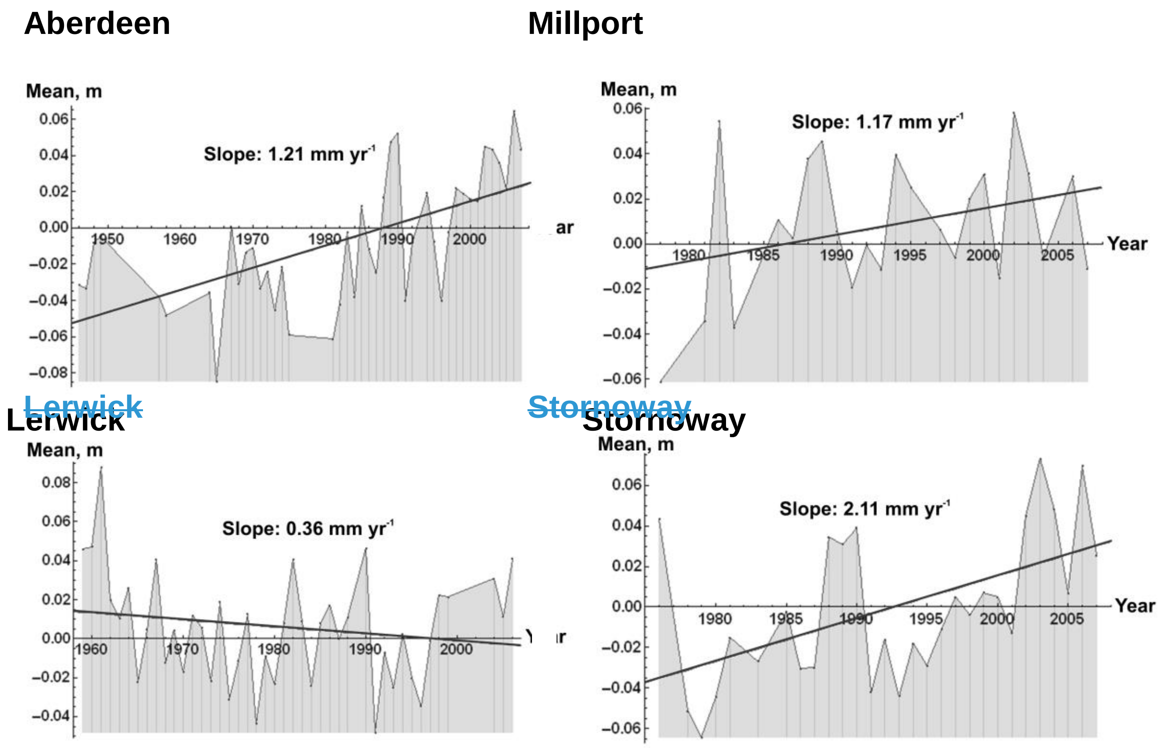

Figure 4. Trends in mean surge level from analysis of the four site gauges. Note the variable time periods between stations covered by the analysis

The analyses from the tidal records at the four ports indicate that, while peak water heights have increased in the recent historical past, they are largely doing so in concert with gradually rising sea levels, not because of any change in storminess. Present surge residuals are sufficient to cause 34.1% (1 standard deviation) of peak water heights over 206 mm above predicted high tide, and 2.2% (2 standard deviations) over 412mm above predicted high tide level at Millport, the site with the highest standard deviation of surge water heights. Although it is too early to attribute this to an acceleration in global sea level rise, such a trend has been noted by the IPCC in Chapter 5 of the Fourth Assessment Report (Bindoff *et al.*, 2007). Data on peak wave heights also show an increase offshore in recent decades. Annual mean significant wave heights in the Northeast Atlantic increased between 1955 and 1994 at a rate of 0.25-0.75cm yr^{-1} or about 0.2% yr^{-1} (Gunther, 1998). The increase was not continuous but, rather, varied on a decadal scale. Additionally, Gunther (1998) reported that the hindcast maximum, 90th and 99th percentile waves increased steadily in the Northeast Atlantic (by a dramatic 7 to 10cm yr^{-1} for the maximum wave), but this increase did not propagate into the near-coastal regions, where the storm wave climate was not found to have worsened significantly. Our conclusion is that the recent rate of increase in coastal flood risk in Scotland has been gradual, and hard to detect over time periods of less than three decades at some locations since it is exceeded by the typical annual spread of peak water heights resulting from local scale surges.

Managing Future Changes in Flood Risk

Scotland's 11,800 km long coastline encompasses a huge range of environments, from highly-indented 'soft sediment' coasts (such as Dumfries and Galloway), indented rocky coasts with low-lying inlets, and mixed rocky and 'soft' open coasts (such as Angus) with complex erosional and depositional cells (Werritty, 2007). Linked to this variety is a diversity of processes – hydrological, geomorphological and ecological – and consequent management issues for local authorities and partners to address in terms of flooding and erosion.

Mean sea level change predictions for Scotland in the next 80 years are currently for a 40-60 cm increase depending on emissions scenario (Hulme *et al*., 2002). There is a slight but significant risk of sea level rise considerably higher than this, in excess of 1 m, although it is very difficult to establish its exact magnitude (Evans *et al*., 2008; Hansen, 2007). The increase in mean sea level will be highly variable across Scotland because of glacial isostatic adjustment (GIA) effects on relative sea level. GIA ranges from over 1 mm uplift on the Clyde Estuary and southern Argyll to zero in the Western Isles and North Coast (Shennan and Horton, 2002). From our analysis of recent trends in surge and sea level, it is reasonable to regard the major remaining drivers of coastal flood risk over the next several decades as surge and wave action. However, there are low-lying areas of the coast, where glacial isostatic uplift is minimal and where sea level rise will be of a magnitude to add significantly to flood risk. Estuarine locations, with the exception of the Clyde, all fall into this category. Even in the Clyde, net sea level rise can be anticipated in the light of future sea level change projections (Ball *et al.* 2008: p44). Surge effects may also increase in magnitude in conjunction with climatic change. Lowe and Gregory (2005) linked regional climatic models to a numerical model of storm surges and predicted a rise in surge height of around 0.25 m in the north and west of Scotland by 2050.

Planning for the future: legislative and policy reform, and the role of Shoreline Management Plans

At present the Flood Prevention (Scotland) Act 1961, as amended, gives discretionary powers to Scottish local authorities to construct and maintain flood defences for non-agricultural land. Close links with coastal protection legislation (the UK-wide Coastal Protection Act 1949) have always been present. Both legislation and policy are in the process of being adapted to implement the EC Directive on the Assessment and Management of Floods (2007/60/EC). In Scotland, the Directive is being transposed by the Flood Risk Management (Scotland) Bill 2009, which will repeal and replace the 1961 Act. The Directive and Bill require the preparation of flood risk management plans by 2015, which must include the coastal zone.

An issue in implementing the Directive is that neither flood prevention nor coastal protection legislation presently promotes a strategic approach. While there is no statutory requirement anywhere in the UK for formal plans or strategies to be prepared for coastal defence or flooding, the Scottish National Planning Policy Guideline (NPPG) 13 (Coastal Planning) encourages local authorities to prepare Shoreline Management Plans (SMPs) where coastal erosion is a recognised problem. SMPs give the opportunity for interested parties in the coastal zone, particularly landowners and NGOs, to promote information exchange and understanding between the relevant bodies and disseminate good practice. Flood risk is involved in such discussions, both directly (any decision not to protect land may well, depending on topography, increase flood risk) and indirectly (the plan, although non-statutory, should inform planning and development decisions). Their use in Scotland was advocated especially for coastal dune systems by Hansom *et al.* (2004), who also noted that they may not be appropriate for all parts of the coastline due to limited exchange of sediments. So far, areas that have implemented them in Scotland include Aberdeen, Angus, Fife, and Dumfries and Galloway.

Interviewees involved with the SMP process saw the resulting plans as valued information sources, particularly when they highlighted specific areas of flooding and erosion risk for further investigation. SMPs were also praised by interviewees for their potential to inform better development control. However, in lacking statutory authority, they do not hold binding planning influence in their own right. Thus Fife's SMP has been in existence since 1999, but the Council noted that, despite the Plan, planners do not always heed advice that certain areas of the coast are at risk of coastal flooding or erosion. Aberdeenshire's SMP, developed with the East Grampian Coastal Partnership, SNH and Aberdeen City Council, is soon to be updated, incorporating GIS information on coastal defences (everything inspected by the Councils) and protected sites. The SMP here will lead to action to investigate flood risk at particular sites and to set up monitoring programmes where required, taking into account sea level rise scenarios for that part of the coast.

In terms of adjusting to future increase in flood risk and, potentially, erosion threat, a good example for 'soft' coastlines is given by the Dumfries and Galloway SMP (HR Wallingford, 2005). Here, taking into account expected sea level change, the plan recommended a 'hold the line policy' in the long term for only five out of 37 complete management units. For almost all the remaining units, little or no intervention is currently planned, except for some short stretches of coastline where the proposed defences may be justified by the value of assets at risk and the costs of proposed defences. Little scope was seen in the region for managed realignment of defences. The main reason was that the extra costs involved in the deliberate removal of defences, for example to create new areas of habitat such as salt marsh, were not felt worthwhile when "no active intervention" (letting the coastline recede landward naturally) would achieve the same effect. However, a small number of pilot studies for managed realignment elsewhere in Scotland have shown potential where such benefits do outweigh the costs (Tinch and Ledioux, 2006). Multiple benefits, particularly for bird life, may well encourage their wider adoption in Scotland.

Development control, planning and defence provision

A significant driving force behind the recent increase in coastal flood risk is sheer pressure for coastal zone redevelopment. Dockside regeneration in Dundee, Edinburgh and the Clyde has proceeded apace in the past 10 to 15 years. Cities which traditionally 'turned their backs' on the sea are now actively re-establishing the link. In the interviews, many local authorities reported that they felt considerable pressure to permit such development, even though it may result in the need for more protection at the coast. Although councils are able to influence developments to a certain degree, such as by imposing requirements for flood resilient construction, strategic plans do not always adequately consider that certain areas of coast are at high risk of coastal flooding or erosion. In part, this disconnect may reflect the lack of clear information on locally-specific flood risks. The interviews revealed that information sources on flood risk used by local authorities vary greatly. Some local authorities use the 5 metre OD contour as their indicative guide to judge when to send an application to SEPA for appraisal. This situation partly reflects scepticism over the accuracy of SEPA's Indicative River and Coastal Flood Map when informing fine planning judgments (such as flood heights). As a result of this pressure, several authorities are proactively incorporating future flood risk assessments in studies that inform their strategic planning. Thus, Dundee City Council recently employed Atkins Ltd. to investigated options to deal with the threat of coastal flooding given a range of sea level rise scenarios over the next 100 years. Renfrewshire Council has carried out an extensive LiDAR survey of the inner Clyde and HR Wallingford has investigated the future risk of overtopping by waves for Angus Council.

Capital funds for river and coastal flood defence are only granted to local authorities in Scotland. Until recently, the Scottish Executive Environment Directorate allocated grant aid centrally at 80% to eligible schemes, provided they had a minimum standard of protection to 1 in 100 years, allowed for future climatic change, and met cost/benefit criteria. With the Scottish Government's recent introduction of Single Outcome Agreements, this policy has changed and funding for flood prevention schemes is now included within each local authority's block grant. The interviews revealed that revenue spending on coastal protection rarely exceeds £150,000 per year, mainly on maintenance, which therefore has to be prioritised. Another general finding was that coastal defences are much more likely to be maintained where they protect against erosion as well as defend against flooding. Examples revealed during the interviews were the widespread coastal 'links' developed on soft coastlines, reported as being vital for flood prevention in, for example, Ayrshire, Fife, the Solway coast, Aberdeenshire and Moray.

Extending Marine Spatial Planning

While many uses of land in the coastal zone are subject to separate regulatory control, there are some uses that are currently not captured by strategic spatial planning. In particular, there is little control over land use activity in foreshore zones. This is of particular concern given the amount of infrastructure now present in these zones. This study has revealed abundant evidence of damage to foreshore structures in the historical flood record, and evidence of likely landward migration of the zone in the future, particularly on estuarine and sand dune coasts. Many interviewees commented that future changes in legislation and policy may bring benefits in this field. The proposed Scottish Marine Bill will implement Marine Spatial Planning in Scotland, interacting with a Marine Bill at the UK level. Most of the consulted stakeholders viewed this development very positively as giving the potential for consistent and coherent planning for the foreshore, informed by flood risk assessments from the Flood Risk Management (Scotland) Bill once brought into legislation.

The role of non-competent authority stakeholders

A key finding from the interviews was that coastal zone stakeholders realise great benefits from working in local and regional partnerships to lower flood risk. Combined fluvial or tidal flooding was an issue for most councils consulted. They also noted poor maintenance of culverts, sewers and drains,, particularly on private land, where it is clear that flood prevention measures depend on *ad hoc* co-operative arrangements.

Transport authorities are important coastal landowners, especially in terms of emergency response and strategic defence. Of the 133 coastal defences protecting rail assets in Scotland, 42 are considered to be at risk of damage in adverse weather (Network Rail, pers. comm.). Among major transport infrastructure providers, internal emergency planning systems have close links with asset maintenance and inspection regimes. However, interviews with transport authorities revealed that many embankments protecting infrastructure are old, with few or no records of their original construction, making their suitability as flood defences sometimes questionable, even though they are often relied upon by landowners.

Integrated Coastal Zone Management (ICZM) to plan for Future Flooding

One route to formalise partnerships is by the non-statutory integrated coastal zone management (ICZM) process. ICZM has, according to our consultation, acted as a spur and funding mechanism for coastal stakeholder dialogue and information exchange. Local Coastal Partnerships (developing non-statutory plans) became widespread in Scotland in the early 1990s. They led, in turn, to the establishment of stakeholder fora, such as the Forth, Clyde and Tay Estuary Fora, with SNH's 'Focus on Firths' initiative providing financial support. In the late 1990s, ICZM began to be adopted as an EU-wide policy which led to further funding streams for several of the partnerships. In 1997, the then Scottish Executive set up the Scottish Coastal Forum (SCF) under an independent chair and it has since acted as a coordinating body for national level meetings. Research conducted for the SCF, ('A strategy for Scotland's Coast and Inshore Waters', 2005), commended linking the partnerships to a coherent set of national objectives, and providing further financial support. The Scottish Government considered that the information base obtained by coastal fora should be a vital input to district level flood management plans proposed in the current Flood Risk Management (Scotland) Bill 2009. Coastal partnerships were reported by several interviewees from local authorities to be important in raising public awareness of environmental issues in the coastal zone, including flooding.

One common opinion shared by the majority of consultees was the benefit to be had from a single, competent authority to coordinate coastal flood risk management. It was recognised that the establishment of such a body was a likely outcome of the Flood Risk Management (Scotland) Bill 2009, and this was generally welcomed. It was noted that such an authority might provide consistency and also streamline the two-stage procedure (Flood Prevention Order and Planning Permission) through which flood prevention scheme applications must currently pass. However, opinions were divided on the best way to implement the work of the body alongside delivery of Flood Risk Management Planning and Marine Spatial Plan developments. Some local authorities, whilst supportive of a strategic national approach, are wary of the competent authority re-directing or taking over flood protection schemes that are already being carried out in their areas. Concerns were also expressed over accountability. Some authorities with SMPs advocated a strong role for the partnership groups that had drawn them up, interfacing with the competent authority to encourage a consistency of approach without being too prescriptive. Flood Liaison Advisory Groups (FLAGs) for local authorities, set up under government guidance, were also endorsed as sources of information, with a national level 'super FLAG' proposed by some. However, there were concerns about potential duplication of policy at local and national levels as well as competition between local authorities for funds for flood management schemes. In general, clearer national guidance on implementing sustainable flood management and design was called for, together with better dissemination of information about the future risk of flooding in specific areas.

Conclusions

It is hoped that this paper's findings will inform future flood risk management policy. Thus investment should be targeted on those sites at greatest flood risk, and be informed by the best available information. Many locations, such as the Clyde Estuary, often flooded in the past, have also been flooded recently, but there are other locations with numerous historical floods that lack recent floods. There is a strong case that a future competent authority for flood risk management should increase the coastal component of public flood awareness campaigns for sites known historically to be at risk. In terms of trends in coastal flood risk, the national picture in Scotland is for no recent increase in storminess, but a gradual sea level rise, of 1 to 2mm $year^{-1}$, in most areas. This relatively modest pace of change may be a conservative estimate, but even slightly higher changes appear to be well within the management capacity of most coastal flood risk management authorities. SMPs are already informing the response of some Scottish local authorities to this future change. In terms of legislative and policy changes now in progress, the chief challenge is coordination, in which the future competent authority will need to play a major role by promoting best practice in partnership working among coastal stakeholders. Flood defence, and enhanced, targeted flood warning, may be justified at several sites, especially where key infrastructure is located. Better communication between strategic development planners, flood risk managers and key coastal stakeholders will inform the prioritisation of capital spend and promote a co-ordinated response to future coastal flood risk in Scotland.

References

Ball, T., Werritty, A., Duck, R.W., Edwards, A., Booth, L. and Black, A.R. (2008) *Coastal Flooding in Scotland: A Scoping Study*. Report to Scotland and Northern Ireland Forum for Environmental Research (SNIFFER), Edinburgh, 96pp.

Bindoff, N.L., Willebrand, J., Artale, V. *et al.* (2007) Observations: Oceanic Climate Change and Sea Level. In Climate *Change 2007: The Physical Science Basis. Contribution of Working Group I to the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Dawson, A.G., Hickey, K.R., Dawson, S., Elliott, L., Foster, I.D.L., Wadhams, P., Holt, T. Jonsdottir, J., Wilkinson, J., Smith, D.E. and Davis, N. (2002) Complex North Atlantic Oscillation (NAO) index signal of historic North Atlantic storm track changes, *The Holocene*, 12: 363-369.

Evans, E.P., Simm, J.D., Thorne, C.R., Arnell, N.W., Ashley, R.M., Hess, T.M., Lane, S.N., Morris, J., Nicholls, R.J., Penning-Rowsell, E.C., Reynard, N.S., Saul, A.J., Tapsell, S.M., Watkinson, A.R., Wheater, H.S. (2008) *An update of the Foresight Future Flooding 2004 qualitative risk analysis*. Cabinet Office, London.

Gunther, H. (1998) The Wave Climate of the Northeast Atlantic over the period 1955-1994: The WASA Wave Hindcast. *The Global Atmosphere and Ocean System*, 6: 121-163.

Hansen, J.E (2007) Scientific reticence and sea level rise, *Environmental Research Letters*, 2: 024002..Available online at http://www.iop.org/EJ/abstract/1748-9326/2/2/024002

Hansom, J.D., Lees, G., McGlashan, D.J. and John, S. (2004) Shoreline Management Plans and coastal cells in Scotland. *Coastal Management*, 32: 227-242.

Hickey, K.R. (2001) The Impact of the 31st January 1953 Storm on Scotland, *Scottish Geographical Journal*, 117: 283-295.

Hickey, K.R. (1997) *Documentary Records of Coastal storms in Scotland 1500-1991 A.D.*, D.Phil Thesis, Coventry University.

Hulme, M. J., G.J; Lu, X; Turnpenny, J.R; Mitchell, T.D; Jones, R.G; Lowe, J; Murphy, J.M; Hassell, D; Boorman, P; McDonald, R. and Hill, S. (2002) *Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report*. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich.

Jones, G. (2003) Identifying Sites for Flood Protection- A Case Study from the River Clyde. pp. 149-161 in Green, D.R. and King, S.D. (eds) *Coastal and Marine Geo-Information Systems*. Kluwer, Amsterdam.

Kaya, Y., Stewart, M. and Becker, M. (2005) Flood forecasting and warning in the Firth of Clyde, UK. *Natural Hazards*, 36: 257-71.

Lamb, H. (1972) *Climate, present, past and future*, Methuen and Co, London.

Lowe J.A. and Gregory J.M. (2005) The effects of climate change on storm surges around the United Kingdom. *Philosophical Transactions of the Royal Society of London Series A*, 363:1313–1328.

Scottish Coastal Forum (2005) *A Strategy for Scotlands Coast and Inshore Waters*. Scottish Coastal Forum, Edinburgh. Available online at: http://www.scotland.gov.uk/Publications/2004/07/19639/40165, 24/02/09

Shennan, I. and Horton, B. (2002) Holocene land- and sea-level changes in Great Britain. *Journal of Quaternary Science*, 17: 511-526.

Tinch, R. and Ledoux, L. (2006) *Economics of Managed Realignment in the UK, Final report to the coastal futures project*, (led by RSPB and sponsored by DEFRA). http://www.coastalfutures.org.uk/pdfs/EconomicsOfManagedRealignment.pdf

HR Wallingford (2007) *Dumfries and Galloway Shoreline Management Plan.* Available online at. http://www.dumgal.gov.uk/index.aspx?articleid=4694, 24/02/09.

Werritty, A. (2007) Assessment of drivers: Scotland, in *Future Flood and Coastal Erosion Risks in the UK*, Thorne, C.R., Evans, E.P. and Penning-Rowsell, E.C. (eds.), Thomas Telford, London.