Vulnerability and Adaptation to Extreme Coastal Flooding: An Example from the South Ford Area, Scottish Outer Hebrides

David Muir, Comhairle nan Eilean Siar, Balivanich, Isle of Benbecula, Scotland
Alastair G. Dawson, Aberdeen Institute for Coastal Science and Management, Department of Geography and Environment School of Geoscience, University of Aberdeen, Aberdeen, Scotland
Alexandre S. Gagnon, Centre for Environmental Research, School of Science, University of the West of Scotland, Paisley, Scotland
Cathal O'Mahony, Coastal and Marine Research Centre, Environmental Research Institute, University College Cork, Co. Cork, Ireland

Introduction

Coastal change and climate adaptation

Coastal areas are characterised as dynamic environments where physical change is constant; and in the case of extreme hydro-meteorological events, changes can be dramatic and catastrophic (Carter, 2002). The vulnerability of coasts to the impacts of climate change (e.g. sea level rise, changing weather patterns, increasing intensity of storms and precipitation) (Nicholls et al., 2007), which in turn drive changes in environmental and social systems, pose significant challenges to those living in coastal locations. It is widely recognised that the coasts of northern Europe will be exposed to an increased risk of extreme events (Beniston et al., 2007). As a result, there is pressing need for adaptation in coastal locations as is becoming increasingly apparent. In Scotland, the consequences of climate change for coastal communities such as the Outer Hebrides will present significant challenges (Scottish Government, 2009). Advancing adaptation requires a focus on capacity building and experimentation as many communities and organisations essential to the process do not possess extensive experience of adaptation. Similarly, incorporation of the findings arising from the adaptation process (e.g. action plan, strategy) into local and regional planning policy and decision-making will need to be given consideration.

Coastal planning and management to offset the impact of coastal (and climate-related) change on human uses of coastal areas can include both engineered and non-engineered responses. In the context of climate change, the projected changes are now locked in for decades to come, regardless of mitigation efforts undertaken (Falaleeva et al., 2011). Therefore an awareness of the necessity to adapt to climate change is becoming increasingly evident in policy and management discourses relevant to coasts (e.g. European Commission, (2007), Snover et al. (2007), Swart et al. (2009)).

Adaptation and coastal management can be simultaneously progressed as both are underpinned by participatory approaches, and both processes are likely to have common elements and constituents. In the context of understanding how coastal systems work and function, the participatory element can yield benefit by bringing together various data and

information (e.g. tacit knowledge, scientific studies, monitoring datasets) held by the many stakeholders. Adaptation to climate change is context specific and participatory approaches bring in local knowledge and experience that are regarded as valuable for understanding specific context conditions and the capacity to adapt (Carter et al., 2007). The dual challenge of coastal management and climate adaptation is very evident in the case of the Outer Hebrides - described below. The purpose of this paper is to report on the changing approaches to coastal protection practices in the Outer Hebrides of Scotland that have resulted from climate change adaptation research.

Coastal infrastructure in the Outer Hebrides

The Outer Hebrides is a chain of islands 200 km long situated off the west coast of Scotland (Figure 1). Over seventy islands compose the archipelago with a combined coastline of 2500 km. A population of 26500 is distributed among 15 islands; Stornoway on the Isle of Lewis is the most populated town. The Outer Hebrides are a remote and rural area with a low population density that is predominantly engaged in non-industrial activities (Outer Hebrides Community Planning Partnership, 2009). The inhabited islands are linked by a network of causeways, ferries and air routes. Low-lying areas of machair protected by a coastline of dunes dominate the landscape of the west coast, and due to an eroding soft coast, this land is vulnerable to flooding. Hence the main risk of flooding in the Outer Hebrides is from the sea. Machair is a wind-blown shell rich sand deposit, extending in places over a mile from the coast (Ritchie, 1966). It is one of the rarest habitats in Europe and is listed in the EC Habitats and Species Directive (Redpath-Downing et al., 2012) with some 50% of its spatial extent having the international designation of Special Area of Conservation and about 80% the national designation of Site of Special Scientific Interest (Hansom and Angus, 2005).

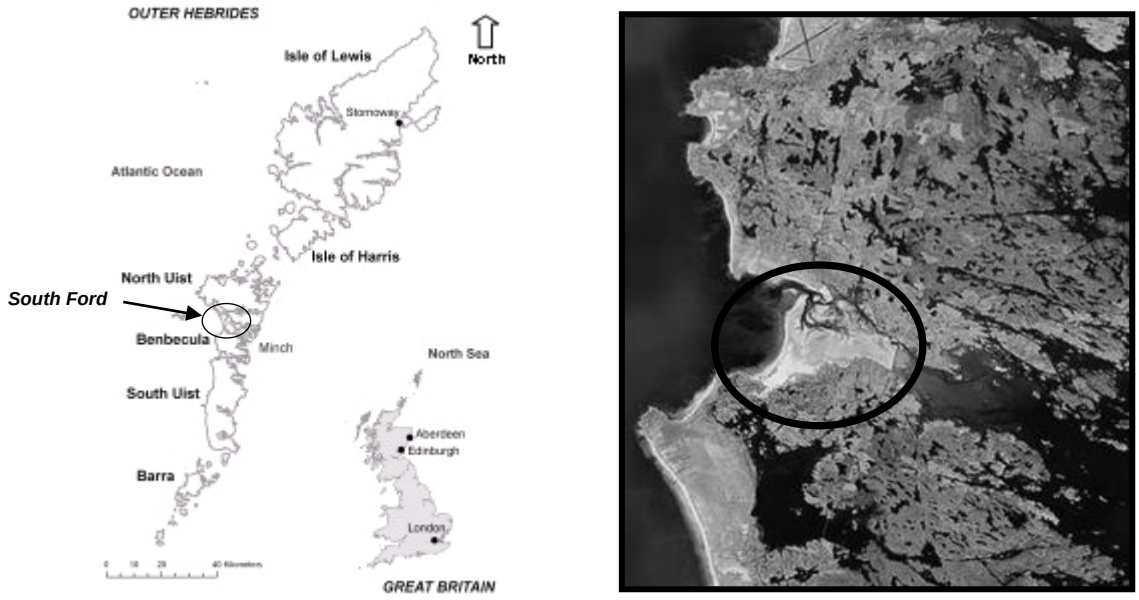

Figure 1. Location of South Ford, Outer Hebrides (left). Also shown are coastal protection schemes at Balivanich (A), Pol na Cran (B), Stoneybridge (C), Ludag Road (D), and Craigston (E). A satellite image of the area (right) shows its location at the western margin of a tidal channel that separates the islands of Benbecula (top) and South Uist (bottom). The machair landscape of South Uist is clearly defined (bottom left)

Comhairle nan Eilean Siar, the local authority for the Outer Hebrides, has the power to carry out coastal protection and flood prevention work it considers necessary to protect land and

reduce risk from flooding under the terms of the Flood Risk Management (Scotland) Act 2009. The Act provides the power for the local authority to carry out such work, but does not impose a duty to do so. Present local authority policy is that of managed realignment and the undertaking of coastal protection work is limited to where infrastructure such as council owned roads, buildings, and cemeteries are under threat of erosion. Coastal protection structures throughout the Outer Hebrides vary in construction from concrete or masonry sea walls, rock revetments, to gabion walls.

During January 2005 a highly destructive storm hit the west coast of the islands. This storm highlighted the vulnerability of the islands to severe weather events damaging houses, roads, and other infrastructure, ultimately leading to the loss of five lives. Many parts of the naturally-eroding coastline were subject to considerable erosion losses and flooding during the single event. A submission seeking funding assistance totalling £14.3m was made by the Comhairle to the Scottish Executive in June 2005 following the storm. By November 2005, Scottish Ministers had confirmed assistance of some £9m for the reimbursement of costs under the Bellwin Scheme, for a replacement school in Balivanich, for emergency planning equipment, for repairs to the Ceann a' Gharaidh Breakwater, for repairs and improvements to the North Ford Causeway and for a programme of repairs to existing transport infrastructure.

In addition, the Scottish Government has granted funding of £0.6m for construction of emergency access roads and flood alleviation schemes at Iochdar and Howbeg in South Uist. The Scottish Government also provided an 80% grant under the Coast Protection Act 1949 funding scheme towards the total cost of £4m for a programme of five coastal protection schemes in Benbecula, South Uist, and Barra. Figure 2 illustrates one of those five coastal protection schemes at Stoneybridge. The work at that location consisted of re-profiling the existing shingle ridge and construction of an armourstone rock wall. The latter was built as protection if future storms were to wash the shingle ridge towards the public highway, the wall will prevent the shingle crossing and closing the road to traffic.

Figure 2. Coastal protection scheme at Stoneybridge, South Uist, showing reconstruction of the shingle ridge damaged during the 2005 storm (left) and rock armour (right)

At the South Ford, in 1983 a rockfill causeway almost 1 km in length with a 15 m single span bridge was constructed to replace an 82 span single lane concrete bridge originally built in 1942 to serve the Royal Air Force (RAF) Coastal Command airfield in Benbecula. The causeway links the islands of Benbecula and South Uist in the Outer Hebrides, which are separated by an area of inter-tidal sands known as the South Ford (Figure 3). The severe storm of January 2005 mentioned above led to coastal flooding that caused significant impacts in the area around the South Ford causeway (Figure 1). Anecdotal evidence pointed to the replacement of the open deck bridge by a single opening in the causeway as being the

cause for this extensive flooding; although other factors such as overtopping of a barrier island (Gualan Island) to the west were also involved.

Figure 3. Single-lane concrete deck bridge (left) replaced by double-lane causeway (right) with a 15 metre span bridge

The January 2005 storm

Meteorology

The hurricane-strength winds of 11/12 January 2005 were the result of a deep Atlantic depression moving from SW to NE with its central pressure having fallen to 944 mb at a distance of some 200 km west of the Outer Hebrides (Figure 4) (Angus and Rennie, 2006). Records for Benbecula show air pressure falling to 959 mb at 6 pm on 11 January and maximum gust speeds of up to 164 km/h at 9:50 pm. Average hourly wind speed reached 118.5 km/h with wind speeds in excess of 100 km/h occurring over a 7 hour period with gust speeds in excess of 140 km/h recorded over a 5-hour period.

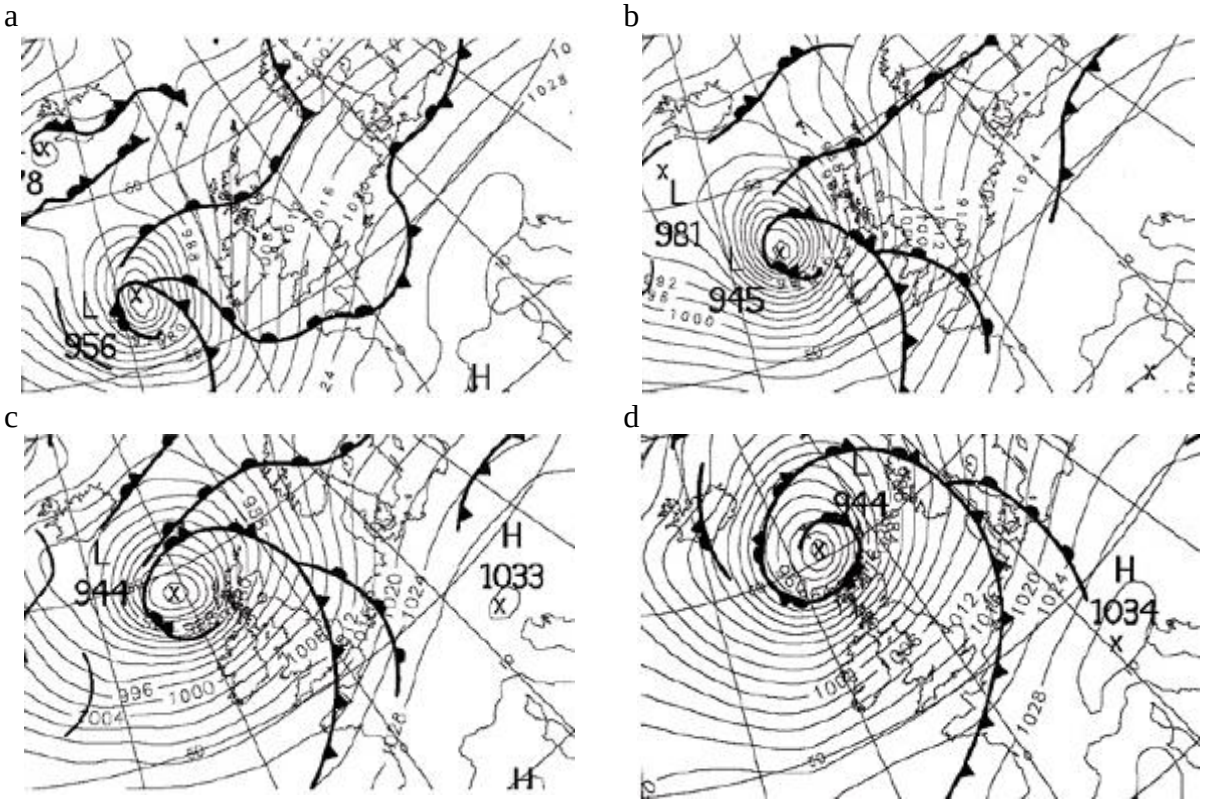

Figure 4. Met Office synoptic charts showing the progress of the January 2005 storm. 0600hrs 11th Jan (a), 1200hrs 11th Jan (b), 1800hrs 11th Jan 2005 (c), and 0000hrs 12th Jan 2005 (d)

In order to place the storm in context in terms of the severity of previous storm events that occurred in other locations in the UK, comparisons show the centre of the depression of the storm that devastated SE England in October 1987 was 952 mb, and the Great North Sea storm of 31 January 1953 had a low of 968 mb (Angus and Rennie, 2006). In the Outer Hebrides historical documents identify three exceptional storm events during the last 150 years that are known to have caused severe coastal damage. During the first of these on 13 December 1869 air pressure at the Monach Isles lighthouse was registered as 953.3 mb falling later in the day to 947.9 mb in Stornoway. During the second storm on 6 January 1882, pressure fell to 948.2 mb. The third storm took place on 23 March 1921; during that month 29 of 31 days recorded wind velocities between Beaufort Force 4-7 and the most extreme category of sea state was recorded (Dawson et al. 2011).

Implications of the storm: community and policy drivers to adaptation

The 2005 storm increased awareness amongst community residents of the vulnerability of their low-lying islands to severe storms and concerns that such events might become more frequent under climate change together with sea-level rising initiated dialogue at local government and community levels regarding options for management response and intervention. The area has experienced a sustained rise in relative sea level over the last ca. 10,000 years. Tide gauge records for Stornoway point to this trend having continued throughout recent decades. This pattern of rising relative sea level is projected to continue into the future, exacerbating risk from natural hazards such as storm surge, salt water inundation, flooding and coastal erosion. This is particularly problematic in the Outer Hebrides where unlike most of Scotland which is still rising isostatically, the Outer Hebrides are experiencing submergence (Centre for Expertise for Water (CREW), 2012), thereby increasing the vulnerability of people living in low-lying areas, and impacting on agricultural land, the built infrastructure, and transportation links.

The Single Outcome Agreement (SOA) of the Western Isles recognises the vulnerability of exposed coastlines to coastal flooding and that impacts of storms are of increasing concern to community residents. SOAs refer to agreements between the Scottish Government and community planning partnerships at the local authority level setting out the way forward with regard to working towards a number of national outcomes, e.g. living in sustainable places, having strong and resilient communities. The Partners are committed to ensuring the safety of communities and recognise that work has been going on to mitigate the effects of climate change and coastal erosion (Outer Hebrides Community Planning Partnership, 2009, 2011).

Comhairle nan Eilean Siar leads the local flood risk management process in the Outer Hebrides under the terms of the Flood Risk Management (Scotland) Act 2009. The planning system provides one of the most important tools available for managing flood risk. In the case of new development the Comhairle has developed an approach based on guidance provided by SEPA which follows a course of action depending on the level of risk of flooding. This approach is tempered by taking a balanced view on a case by case basis rather than by applying ‘blanket bans’, and is followed through to extensions of existing properties where many may, in any case, fall within ‘permitted development’.

CoastAdapt

An international EU Project ‘CoastAdapt’, recently completed, has developed and implemented a range of adaptation strategies and tools to enable people living in coastal communities to take action and adopt strategies that deal with sea-level rise and reduce the

negative impacts and risks associated with climate change as well as take advantage of the potential benefit.

CoastAdapt was a trans-national approach which aimed to develop a range of adaptation strategies and tools to help enable people living in coastal communities to take action and adopt measures in response to climate change impacts (www.coastadapt.org). The partnership comprised local government organisations, regulatory bodies, and research centres under the leadership of Comhairle nan Eilean Siar. Over the course of the project, the partnership engaged with numerous community, civic, business (e.g. tourism enterprises) and special interest groups (e.g. conservation networks and coastal fora) at each of the study sites in Scotland, Ireland, Norway and Iceland in order to work towards achieving the project's objectives.

CoastAdapt developed a stepwise methodological approach to building local capacity for climate adaptation, which fundamentally involved an initial step focused on awareness raising and assessment of vulnerabilities, followed by identification and assessment of adaptation options and actions in relation to resources, and finally guidance on how to incorporate or mainstream adaptation actions into policies and operations. Hence CoastAdapt followed a bottom-up approach, engaging stakeholders throughout the process of identifying vulnerabilities and the identification of key issues in the context of adaptation, as local people are best placed to describe their coastal environment and how the different components of the system, such as the physical environment and social and economic development, interact with one another. Undertaking an adaptation process at the local level allows for the opportunity to identify vulnerabilities to climate change impacts that are specific to any given coastal setting, as well as tailoring adaptation responses appropriate to the setting. This information can then be placed into context with the signals emerging from global, national, and regional analyses.
The project partnership gathered local knowledge through the use of community surveys and workshops, interviews with key stakeholders, and focus groups with local government officers, engineers and other officers from statutory and regulatory bodies (e.g. in Scotland: Scottish Natural Heritage (SNH) and Scottish Environmental Protection Agency (SEPA)). This local knowledge was further enhanced by the introduction of external experts on coastal geomorphology and erosion, for example, which were invited to give talks at the community workshops and participate in the discussion. The project also benefitted from the sharing of good practice across the pilot sites situated in different countries in Europe's northern periphery.

Hydrodynamics Study

Background and description

The hurricane-force winds of January 2005 together with a storm surge resulted in significant change in the coastal landscape along the entire western seaboard of the Uists and Benbecula. Coastal areas west of the causeways that link North Uist and Benbecula, Benbecula and South Uist and South Uist and Eriskay were severely impacted by erosion. Some protection was afforded to the coastal area, known as the South Ford, located between Benbecula and South Uist by Gualan Island, which acts as a barrier island that separate the South Ford basin from the Atlantic Ocean (Figures 1 and 5). Although the coastal areas between this island and the Benbecula-South Uist causeway were affected by extensive marine flooding, the flooding was not accompanied by significant coastal erosion. By contrast, coastal areas located to the west of Gualan Island were subject to significant erosion (Dawson et al., 2007).

In 2006 the local council made applications to the Scottish Government for funding under the Coast Protection Act 1949 for six coastal protection schemes. One of these schemes, for Gualan Island to the west of the South Ford, was not approved as it did not meet cost/benefit criteria specified by the Scottish Government. The scheme involved dune re-nourishment using sand sourced from the South Ford together with associated dune stabilisation and management. However, it was recognised that further study was required in order to develop an understanding of coastal change in the South Ford and the Scottish Government provided finance for a Hydrodynamic Study of the South Ford.

To provide management of the Study a Joint Client Group (JCG) was established having a membership of representatives from Comhairle nan Eilean Siar, the Aberdeen Institute of Coastal Science and Management (AICSM) at the University of Aberdeen, SNH, SEPA, and the Iochdar community of South Uist represented by the Iochdar Flood Action Group (IFAG). The IFAG was formed shortly after the January 2005 storm and members representing the local community were appointed by the second of two well attended public meetings. The Group had the remit to develop an understanding of what is happening to the local coastline and why; to develop an understanding of how man-made structures, i.e., the causeway carrying the road between Benbecula and South Uist, have affected coastal erosion, flooding and silt deposition in the South Ford; to investigate the available options which could improve the situation; and, to use the foregoing information to press for action in order to protect the safety of people and the integrity of the land. The Group held discussions with key officials from organisations such as the local authority, national government, the Met Office, SNH, SEPA, as well as academic institutions such as the University of Aberdeen, the Proudman Oceanographic Laboratory, and political representatives.

The Hydrodynamics Study report, (available online: http://www.coasthebrides.co.uk/index.php/south-ford-study-report.html), had the principle objective to establish the cause and effect linkages between coastal processes and coastal erosion and flooding across the South Ford area. The study sought to identify the key risks of coastal erosion and flooding in the future both in terms of probability and consequences to people and assets on the coast together with what effect possible future interventions would have on managing the risks. This was accomplished through discrete sections, notably the quantification of the physical changes that have occurred between 1984 and 2005 (Figure 5), and recommendations for further action, among others. With regard to the latter, the Study presented a range of recommendations in respect of what should be done to reduce the risk to life and property from future storms in terms of high, medium and low impact; and high, medium and low cost. Measures considered as high impact and low cost were subsequently explored and further developed by the CoastAdapt project.

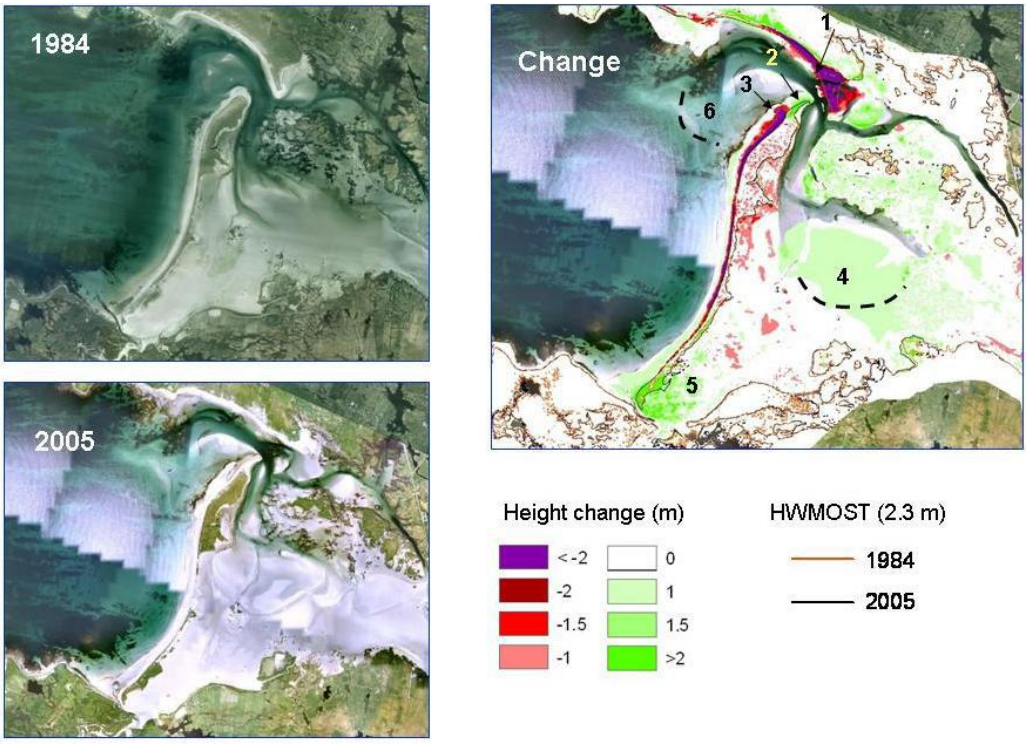

Figure 5. Digital Terrain Modelling (DTM) change map of case study area between 1984 and 2005. (HWMOST – high water mark of ordinary spring tides)

Recommended adaptation options

In making recommendations in respect of what should be done to reduce the risk to life and property in the future, the JCG was acutely aware of what is affordable and what is not, especially so during the present economic climate. Accordingly, the key measures that were identified were listed within a hazard management matrix. The measures range from the most expensive option of replacing a significant section of causeway with a bridge to a range of relatively inexpensive soft-engineering options. Of these, the causeway bridge construction is the only high-cost and high-impact intervention (Table 1). One high-impact and medium-cost measure that was proposed was the replenishment of the central part of Gualan Island with beach sand extracted from the area of the South Ford adjacent to the exit point of Loch Bi. Removal of sand from this area would have the further objective of re-opening the channel that separates the southern end of Gualan Island from South Uist.

The remaining high-impact measures proposed at low and medium cost include taking active adaptation measures as recommended by CoastAdapt such as initiating schemes for dune management of Gualan Island and the south coast of Benbecula, effective community participation in coastal flood warning systems, using planning policy to determine the suitability of sites for development through Flood Risk Assessment as well as the community participating along with the local authority in the development of longer-term storm and flood recovery planning. Implementation of all these measures with the exception of the high cost option of creating openings in the causeways, is being considered by the strategic appraisal process currently followed through Flood Risk Management legislation.

Table 1. Hazard management options matrix including those to emerge as a result of the research undertaken in the Outer Hebrides.

	HIGH IMPACT	**MEDIUM IMPACT**	**LOW IMPACT**
Low Cost	Many of the low cost measures have been identified taking the approach developed by CoastAdapt Dune management scheme for south coast of Benbecula Encourage local residents to sign up for coastal flood alert system Using planning policy to determine suitability of sites for development through Flood Risk Assessment Participate in development of long-term disaster recovery planning	Proactive and participatory approach by community to new Flood Risk Management legislation Strengthen community representation on the CoastHebrides Integrated Coastal Zone Management[1] (ICZM) Forum Undertake a Strategic Flood Risk Assessment (SFRA) for the South Ford area Include an assessment of public roads susceptible to coastal flooding as part of the SFRA	
Medium Cost	Beach replenishment scheme for Gualan Island		
High Cost	Create opening(s) at least 250 metres long in the causeway with bridged sections of carriageway		

[1]ICZM is an integrated approach to the management of the coast linking coastal waters and adjacent land areas, and which considers all relevant resource uses in a locality, with the aim of achieving sustainability.

Benefits of a participatory 'bottom-up' approach to coastal management and adaptation

The outputs of CoastAdapt illustrate a transition in the management approach undertaken to tackle coastal change, shifting from traditional management strategies to a participatory approach and the consideration of non-engineering and soft-engineering options working with natural processes. The CoastAdapt project found that a participatory approach to adaptation to coastal change allowed for increased amounts of information to be brought into the adaptation process and the integration of local knowledge into the decision-making process.

Ensuring involvement and gathering of the public and stakeholders' views was accomplished through the organisation of consultation workshops with the communities at different stages in the process, including sessions where the experts presented their management options and the community responded to them, in addition to providing their own options. The consultation approach was not limited to workshops but also through the Outer Hebrides Planning Partnership and the Outer Hebrides Coastal and Marine Partnership (CoastHebrides), the latter having representatives from the local flood action groups formed as a result of the 2005 storm described above. Views from community members contributed to the writing of the coastal adaptation report. In addition, discussion between the resident community, decision-makers and academic/scientific experts can assist in bringing community buy-in to management decisions. This is a departure from the more consultative form of engagement used by local authorities, involving community members having to

comment in writing on a selected management option rather than throughout its development, involving exchange of information in a workshop setting.

As mentioned above, the project focused on high impact/low costs interventions on the coast. The community workshops accomplished as a result of the CoastAdapt project revealed that communities in the Outer Hebrides have high expectation from their local authority in addressing coastal and climate change issues on the islands. People look at the authorities for guidance. However, there are inherent economic factors that constrain a rural community such as the Outer Hebrides to adapt to climate change: the local authority deals with large areas of coast, very small tax payer base, and a small and declining population (Outer Hebrides Community Planning Partnership, 2009). Hence the cost to the local government is well above their financial capacity to deal with those matters on their own and high impact/low cost options need to be favoured, which inevitably results in developing coastal defence systems following soft-engineering responses working with natural processes as well as non-engineering responses and a focus on community resilience.

Conclusions

In January 2005 a very damaging storm with hurricane-strength winds hit the archipelago of the Outer Hebrides with an associated storm surge causing significant change in the coastal landscape along the entire western seaboard of the Uists and Benbecula. This storm increased awareness within the affected communities of the vulnerability of their low-lying islands and concerns that such events might become more frequent under climate change together with sea-level rising initiated a dialogue between the local government and the affected communities regarding coastal management responses.

Using the 'bottom-up' methodology developed by CoastAdapt, consultation activities through coastal fora and workshops led to the engagement of the affected communities in the identification of coastal adaptation options and discussion with coastal experts and other stakeholders. In a remote and rural community with limited financial resources, adaptation as a process for increasing resilience provides an option for management response that is not limited to physical intervention. Accordingly, adapting to change through adjustments in both natural and human systems have been identified for the South Ford case study region.

It can be difficult for people to grasp the concept of making changes in human behaviour as a means of adapting to change. For example, if they face the prospect of losing land to coastal erosion rather than attempting to 'fix' the coastline by artificial means of intervention, as has been the case in several instances in the Outer Hebrides, people will show resistance to real adaptation. Experience has shown that making changes in the way people act which may result in short-term loss is difficult to put into practice. However, as is demonstrable since the 2005 storm, attitudes have changed, for example, instead of wanting to 'ring the island with rock', people are now more willing to consider 'soft' and more sustainable methods of managing the coast.

Options which have been identified have been listed in terms of affordability and efficacy and high impact/low cost interventions, although still requiring further development in practice, include: dune control and management; proactive and participatory approach by the community in flood risk management; use of planning policy; effective participation in the coastal flood alert system; strengthened community representation on the ICZM forum; and, development of a long-term disaster (storm and flooding) recovery planning to suit local conditions.

In the Outer Hebrides, CoastAdapt partners devised locally specific adaptation solutions through a participatory-based approach involving numerous coastal stakeholders, with inputs ranging from scientific studies to the incorporation of tacit knowledge. Despite the outcomes being tailored to the Hebridean situation, the process behind the step-wise approach of CoastAdapt to identify adaptation options is applicable and transferable to a range of coastal localities and situations; and is all the more relevant in light of the urgent need to balance the safeguarding of coastal communities with agreement on cost effective and appropriate solutions to the growing impacts of coastal climate change.

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References

Angus, S., Rennie, A., 2006. An Ataireachd Ard: The Great Sea Surge. The natural heritage impact of the storm of 11 January 2005 in the Uists and Barra, Outer Hebrides. Scottish Natural Heritage, Perth.

Beniston, M., Stephenson, D.B., Christensen, O.B., Ferro, C.A.T., Frei, C., Goyette, S., Halsnaes, K., Holt, T., Jylha, K., Koffi, B., Palutikof, J., Scholl, R., Semmler, T., Woth, K., 2007. Future extreme events in European climate: an exploration of regional climate model projections. Climatic Change 81**,** 71-95.

Carter, R.W.G., 2002. Coastal Environments: An Introduction to the Physical, Ecological, and Cultural Systems of Coastlines, Academic Press, London.

Carter, T., Jones, R., Lu, X., Bhadwal, S., Conde, C., Mearns, L., B., O.N., Rounsevell, M., Zurek, M., 2007. New assessment methods and the characterisation of future conditions, in Parry, M. L., Canziani, O., Palutikof, J. P., Van Der Linden, P. & Hanson, C. (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contributions of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 133-171.

Centre for Expertise for Water (CREW), 2012. Coastal Flooding in Scotland: A guidance document for coastal practitioners.

Dawson, A.G., Dawson, S., Ritchie, W., 2007. Historical climatology and coastal change associated with the 'Great Storm' of January 2005, South Uist and Benbecula, Scottish outer Hebrides. Scottish Geographical Journal 123**,** 135-149.

Dawson, A.G., Warren, J., Gómez, C., Ritchie. W., 2011. Weather and Coastal Flooding History: The Uists and Benbecula. Commissioned report for Comhairle nan Eilean Siar, South Ford Hydrodynamics Study, September 2011.

European Commission, 2007. Green Paper. From the Commission to the Council, the European Parliament, the European Economic and Social Committee, and the Committee of the Regions. Adapting o Climate Change in Europe -Options for EU Action. Commission of the European Communities, Brussels.

Falaleeva, M., O'Mahony, C., Gray, S., Desmond, M., Gault, J., Cummins, V., 2011. Towards climate adaptation and coastal governance in Ireland: Integrated architecture for effective management? Marine Policy 35**,** 784-793.

Hansom, J.D., Angus, S., 2005. Machair nan Eilean Siar (Machair of the Western Isles). Scottish Geographical Journal 121**,** 401-411.

Nicholls, R.J., Wong, P.P., Burkett, V.R., Codignotto, J.O., Hay, J.E., McLean, R.F., Ragoonaden, S., Woodroffe, C.D., 2007. Coastal systems and low-lying areas, in Parry, M. L., Canziani, O. F., Palutikof, J. P., Van Der Linden, P. J. & Hanson, C. E. (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 315-356.

Outer Hebrides Community Planning Partnership, 2009. Forward Together. Single Outcome Agreement 2009-2010. Comhairle nan Eilean Siar, Stornoway.

Outer Hebrides Community Planning Partnership, 2011. Forward Together. Single Outcome Agreement 2011-2013. Comhairle nan Eilean Siar, Stornoway.

Redpath-Downing, N.A., Beaumont, D., Park, K., Goulson, D., 2012. Restoration and management of machair grassland for the conservation of bumblebees. Journal of Insect Conservation**,** 1-12.

Ritchie, W., 1966. The post-glacial rise in sea-level and coastal changes in the Uists. Transactions of the Institute of British Geographers 39**,** 79-86.

Scottish Government, 2009. Scotland's Climate Change Adaptation Framework. The Scottish Government, Edinburgh.

Snover, A.K., Whitely Binder, L., Lopez, J., Willmott, E., Kay, J., Howell, D., Simmonds, J., 2007. Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments. In association with and published by ICLEI - Local Governments for Sustainability, Oakland, CA.

Swart, R., Biesbroek, R., Binnerup, S., Carter, T.R., Cowan, C., Henrichs, T., Loquen, S., Mela, H., Morecroft, M., Reese, M., Rey, D., 2009. Europe Adapts to Climate Change: Comparing National Adaptation Strategies. Partnership for European Environmental Research, Helsinki.