Institution: University of Plymouth

Unit of Assessment: UoA7

Title of case study: Enhancing Coastal Resilience to Extreme Storms and Sea-Level Rise

Period when the underpinning research was undertaken: 2009 - 2017

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Gerd Masselink	Professor in Coastal Geomorphology	2004 -present
Tim Poate	Senior Research Consultant	01.10.2015 - present
Christopher Stokes	Senior Research Consultant	01.02.2009 - present

Period when the claimed impact occurred: 2014-11.11.20

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

The Coastal Processes Research Group (CPRG)'s research has resulted in the development of methods, tools and the provision of expert guidance that has assisted GOs and NGOs with enhancing coastal resilience to sea-level rise and storms. CPRG's research led to the development of a coastal overtopping early-warning-system (OWWL) that is utilised by regional flood risk managers to deliver EA flood warnings and has influenced national coastal forecasting strategy. CPRG research on storm impacts has resulted in the development of a storm-response model for gravel beaches (XBeach-G) used by consultancies worldwide and the UK Environment Agency (EA) to inform beach management and flood risk assessment. CPRG research has created a blue-print for defining Coastal Change Management Areas (CCMAs) which has fundamentally changed planning policy at regions in southwest England.

2. Underpinning research (indicative maximum 500 words)

In 2010 and 2011, CPRG started studying extreme storm impacts on beaches by means of fieldwork and numerical modelling, funded through two EPSRC grants, with a focus on gravel beaches and coastal locations with nuclear power stations. A unique capability was developed as part of this research: a rapid coastal response unit (RCRU), comprising of a van and trailer equipped with a large variety of oceanographic instruments able to be mobilised and deployed at very short notice to monitor extreme storm events. Over ten storm surveys were carried out using the RCRU during two winter seasons. The hydrodynamic and morphological measurements showed that wave runup can be significantly higher on gravel beaches than on sandy beaches, which has significant implications for coastal erosion and flooding. The data were used to develop a wave runup equation specific to gravel beaches (3.1), as well as adapt an existing and widely used morphodynamic storm response model (XBeach) for use on gravel beaches, XBeach-G (3.2).

The XBeach-G model simulates both the hydrodynamics (waves, nearshore currents, wave runup and overwash volume) and morphological (beach erosion and lowering of barrier crest) response of gravel beaches and barriers to storm waves. The model was extensively validated using proto-type scale laboratory data and the field data, some collected under 8 m high storm waves, and is the only model currently available that specifically addresses storm response on beaches and barriers consisting of gravel. Such coastal settings are extremely common in the UK, where gravel barriers are considered natural forms of coastal defence. The

gravel beach runup equation has led to the possibility of forecasting coastal overtopping at gravel sites and fed into further research through the NERC funded South West Partnership for Environment and Economic Prosperity (SWEEP) to develop the OWWL coastal flood warning system for southwest England (3.3).

At the end of the two EPSRC grants, the Atlantic coast of Europe experienced the most energetic winter (2013/14) since at least 1948 (3.4) and the SW coast of England experienced unprecedented storm damage (3.5). Funded by two NERC grants (an Emergency grant and a Strategic Highlights Topic grant), ongoing monitoring by CPRG of various sites in the region, including deployment of the RCRU, provided unique insights into the geographic variability of the storm impacts, and the subsequent recovery of the beaches. Specifically, a very significant difference in response was identified at beaches with different shoreline orientations relative to the prevailing storm wave direction (3.6). Storm impacts during the 2013/14 winter were not limited to the SW coast of England, but affected the entire Atlantic coast of Europe (3.4). Collaborative research with colleagues from France led to the formulation of a new climate index, the West Europe Pressure Anomaly (WEPA) that explains the variability in the Atlantic storm wave climate (3.6). This climate index is similar to the well-known North Atlantic Oscillation (NAO), but performs better as a storm wave predictor for the SW coast of England, as well as France, Portugal and Spain, and can potentially be used to forecast winter wave conditions one year in advance.

3. References to the research (indicative maximum of six references)

CPRG's research has been presented at key international conferences (International Conference on Coastal Engineering, Coastal Sediments, International Coastal Symposium) and published in the most prestigious journals in coastal science, each demanding the highest levels of rigour and originality. For example, *Coastal Engineering* and *Geophysical Research Letters* have annual acceptance rates of 32% and 57%, and 5-year Impact Factors of 4.3 and 4.7, respectively.

3.1 ***Poate, T., Masselink**, G* and McCall, R., 2016. A new parameterisation for runup on gravel beaches. Coastal Engineering, 117, 176-190. [http://dx.doi.org/10.1016/j.coastaleng.2016.08.003]

3.2 McCall, R.T., ***Poate, T.G., Masselink,* G**. Roelvink, J.A., Almeida, L.P., Davidson, M. and ***Russell, P.E***., 2014. Modelling storm hydrodynamics on gravel beaches with XBeach-G. Coastal Engineering, 91, 231–250. [http://dx.doi.org/10.1016/j.coastaleng.2014.06.007]

3.3 ***Stokes, C., Poate, T., Masselink, G***., (2019). Development of a real-time, regional coastal flood warning system for southwest England. *Proceedings Coastal Sediments*, ASCE, Tampa, Florida, 1460-1474.

3.4 ***Masselink, G***., Castelle, B., ***Scott, T***., Dodet, G., Suanez, S., Jackson, D. and Floc'h, F., 2016. Extreme wave activity during 2013/14 winter and morphological impacts along the Atlantic coast of Europe. Geophysical Research Letters, 43, 2135-2143. [http://dx.doi.org/10.1002/2015GL067492]

3.5 McCall, R.T., ***Masselink, G., Poate, T.G***., Roelvink, L.P. and Almeida, L.P., 2015. Modelling the morphodynamics of gravel beaches during storms with XBeach-G. Coastal Engineering, 103, 52-66. [http://dx.doi.org/10.1016/j.coastaleng.2015.06.002]

3.6 Castelle, B., Dodet, G., ***Masselink, G. and Scott, T***., 2017. A new climate index controlling winter wave activity in W Europe: the West Europe Pressure Anomaly (WEPA). Geophysical Research Letters, 44. [http://dx.doi.org/10.1002/2016GL072379].

4. Details of the impact (indicative maximum 750 words)

Informing beach management and flood risk assessment

Gravel beaches are widespread around the world and provide sustainable natural coastal defence for approximately 1/3rd of the beach-fronted coast in the UK. In 2014, CPRG's research

directly led to the development of a numerical model, XBeach-G, that predicts the impact of storms on gravel beaches. XBeach-G is used widely nationally and internationally by coastal managers, engineers and consultants to safeguard the resilience of coastal communities and infrastructure (5.1).

In the UK, the EA has used XBeach-G to assess coastal vulnerability to sea-level rise and extreme storms along the south coast of England (5.2 and 5.3). As highlighted by EA's senior coastal specialist, *"development of XBeach-G has had a very positive impact on improving understanding within our coastal projects"* (5.2). For example, at Chiswell beach, Dorset, the model "*influenced existing incident management procedures and understanding"* by improving existing EA operational criteria for flood alerts and beach profiling strategy and helped to *"programme future modelling improvements and upgrading of existing forecast systems within the EA"* (5.3). The EA now widely promotes the use of XBeach-G to assess coastal flood risk across the UK, and "*has actively encouraged external consultants to utilise the open-sourced XBeach-G model for additional work, e.g. Herrington Consulting used it for flood risk assessments at Medmerry and Climping"* (5.2), a £28 million project which directly resulted in flood defences being moved inland, creating 183 hectare new intertidal habitat on the seaward side whilst also providing 1000 times flood protection than the previous system. At Dungeness Nuclear Power Station, XBeach-G was used to assess coastal flood risk, providing the managers of the power plant the information to make substantial cost efficiencies at this critical coastal infrastructure, where the results, *"will ensure the defences are not over- or under-engineered to cope with a 0.5% annual probability event"* (2016, Dungeness Report in 5.1). XBeach-G has been utilised globally to assess coastal vulnerability to extreme storm events, including in Croatia, the Netherlands, Spain, and the US. In New Zealand, XBeach-G was used in the Hawkes Bay Coastal Hazard Inundation Assessment, where the model directly "*forms the basis of inundation mapping"* (5.1) used to safeguard coastal communities against flooding.

CPRG's >10 years of beach monitoring data and coastal research has contributed to the management of several beaches in SW England. CPRG influenced coastal management at Slapton Sands beach (South Devon) by contributing a detailed examination of coastal processes to the Beach Management Plan. Subsequently the Beach Management Plan was used by the local council to seek EA funding for coastal defence works, including allowing them *"to secure funding of £2m in 2018, to repair damage to the vital link road along the barrier"* (5.4). Another coastal processes consultancy undertaken by CPRG was an Environmental Impact Assessment for Network Rail in 2019 that contributed to the design of major rail infrastructure works costed at £500m at Teignmouth Beach, by determining the likelihood of the beach fronting the rail line being lost as a result of the works (5.5). At Westward Ho! CPRG's assessment of the gravel barrier dynamics has been deployed by the local council to produce revised plans for a proposed visitor centre at the site. It has provided Natural England with the evidence to *"advance the understanding of this feature and what likely change will happen in future epochs"* (5.6). CPRG consultancy work for the Scottish Environment Protection Agency (SEPA) helped them make a business case and undertake work to update coastal flood maps around the entirety of Scotland *"to include flooding due to waves where our coastal maps previously only considered still water flooding, underestimating flood risk to many coastal communities"* (5.7).

Safeguarding coastal communities through coastal flooding alerts

In 2017, CPRG co-created a coastal flooding early-warning-system, OWWL, with EA and Met Office. The system provides alerts for 213 locations in SW England and south Wales and for the first time provides the EA with accurate forecasts of wave runup and overtopping along these coasts, which are received daily by 25 EA and Natural Resources Wales flood response officers. The alerts have enhanced the EA's capacity to respond to storm events in SW England, influencing decisions on how to "*prioritise where and when to deploy staff for reconnaissance and defence activities during storms*", such as where to place critical flood-defence infrastructure such as "*sandbagging, or deployment of temporary sea defences*" (5.8). This specific understanding of where and when overtopping is happening was not previously available, and

formerly the EA "*would have had a much wider response, a more reactionary response, or perhaps even not have responded at some of the key locations for wave overtopping*" (5.8). Nick Ely, EA's National Coastal Modelling and Forecasting Manager anticipates that this improvement in resource targeting "*will have saved the EA thousands of pounds during each of the six largest storms over the last two winters by being able to be more targeted in our working and reducing unnecessary trips and deployments*".
The SWEEP-OWWL model is directly used to inform EA's flood warning team in the SW of England to help them consider potential flooding impacts of extreme wave and water level events on coastal communities. For example, when the remnants of Hurricane Epsilon (2020) reached the coast of Cornwall, the EA flood warning systems did not raise any flags as the predicted water levels were modest; however, the SWEEP-OWWL model, which also considers wave-driven runup, did flag up several potential flooding occurrence that subsequently took place e.g. Perranporth. As a result, the flood warning team in Cornwall used SWEEP-OWWL as "*an obvious complimentary layer of information to our forecasting system, with locally tailored wave overtopping forecasts available for specific defence"*(5.10).

CPRG has directly influenced coastal forecasting strategy at the EA, with data from OWWL feeding into a national-level strategic review of coastal forecasting in 2019. OWWL has provided EA with a regional pilot system which the EA consider "*an exemplar demonstration of the sort of coastal forecasting that could be achieved around the whole of the UK*"(5.8)..

Influencing planning policy regarding future coastal change
CPRG has worked with Natural England (NE) and local coastal authorities in SW England to help develop Coastal Change Management Areas (CCMAs; 5.9), now required by the National Planning and Policy Framework (NPPF), to define locations likely to experience significant coastal change in the next 100 years – correctly and robustly identifying such regions is fundamental to sustainable coastal management. For example, A CCMA developed by CPRG in 2020 at Sidmouth, Dorset, has increased understanding within local planning authorities (LPAs) of the magnitude of coastal change happening, for the first time identifying that hundreds of houses there could be at risk of coastal erosion in the next 100 years. The CCMAs developed by CPRG (2020) are being directly used as evidence by LPAs in coastal planning applications to help decide where property and infrastructure can be built at the coast. Furthermore, the method developed provides a blueprint for national scale CCMA development, supporting the work of NE's Lead Advisor for Planning Policy as it *"has provided the confidence for us to have more informed CCMA conversations with our stakeholders across the south west as well as on a wider, national platform"* (5.9).

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1 XBeach-G applications e.g. papers and technical reports.
5.2 Letter of support from Uwe Dornbusch, senior coastal specialist at Environment Agency, regarding uptake and application of XBeach-G by the EA, including the following publication from the EA: Design requirement for mixed sand and gravel beach defences under scenarios of sea level rise, Uwe Dornbusch, Environment Agency, https://www.sciencedirect.com/science/article/pii/S0378383916303040
5.3 Letter of support from Dave Picksley (Environment Agency) concerning a project undertaken by CPRG with Wessex EA Team to identify storm thresholds at Chiswell Cove that relied heavily on the application of XBeach-G.
5.4 Letter of support from Alan Denbigh, Chair- Slapton Line Partnership and Dan Field, Senior Specialist – South Hams District Council and West Devon Borough Council with respect to the Coastal Processes Baseline assessment report done as part of the Beach Management Plan for Slapton Sands.
5.5 Report to Network Rail: Parsons Tunnel to Teignmouth Coastal Desk Study South West Rail Resilience Programme. Confidential.
5.6 Testimonial from Nick Williams (Natural England) on work undertaken by CPRG concerning Westward Ho! to help inform management approaches.

5.7 Letter of support from Scottish Environmental Protection Agency (SEPA) with reference to CPRG's report " Investigating Opportunities for improving SEPAs National Coastal Flood Hazard Dataset"

5.8 Testimonial Nick Ely, National Coastal Modelling & Forecasting Manager, Evidence & Risk - Incident Management & Resilience, Environment Agency

5.9 A statement of impact from Corine Dyke (Lead Advisor- Planning Policy at NE) on the SWEEP CCMA project

5.10 A statement of impact from Justin Ridgewell (Coastal Advisor, Partnership and Strategic Overview Team (West), Environment Agency, on the SWEEP OWWL model.