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Flood inundation uncertainty: The case of a 0.5% annual probability flood event

Thomas Prime[a,b,*], Jennifer M. Brown[b], Andrew J. Plater[a]

[a] *School of Environmental Sciences, University of Liverpool, UK*
[b] *National Oceanography Centre, Liverpool, UK*

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ABSTRACT

Aging coastal defences around the UK are challenging managers to redesign schemes to be resilient to extreme events and climate change, be cost-effective, and have minimal or beneficial environmental impact. To enable effective design, reduced uncertainty in the assessment of flood risk due to natural variability within the coastal forcing is required to focus on conditions that pose highest threat. The typical UK standard of protection for coastal defences is to withstand a 0.5% annual probability event, historically also known as a 1 in 200 year return period event. However, joint wave-water level probability curves provide a range of conditions that meet this criterion. We examine the Dungeness and Romney Marsh coastal zone, a region of high value in terms of habitat and energy assets, to quantify the uncertainty in flood depth and extent generated by a 0.5% probability event, and to explore which combinations of wave and water levels generate the greatest threat.

1. Introduction

Coastal managers must consider many different aspects when planning new coastal defence schemes to maintain resilience to coastal flooding in locations with aging defence structures. New structures need to be resilient to extreme events and the impacts of climate change over the defences' design life, typically 75–100 years (Buijs et al., 2007). However, new schemes also need to be cost-effective and implemented in a timely manner to reduce the economic impact of future extreme events. This means an understanding of the probability of both the extreme events occurring and a defence being exceeded is required (Buijs et al., 2007). To enable effective adaptation, better understanding of the uncertainty associated with the flood hazard of an event due to variability in conditions is required to enable implementation of cost-effective design (Wadey et al., 2013).

Sources of coastal flooding are varied and range from contributions to the water level, such as astronomical tides and storm surges (McMillan et al., 2011), to wave run-up and overwashing or overtopping, driven by the coincidental wave conditions. A storm surge occurs when high winds and low atmospheric pressure act on the sea surface to cause a temporary increase in water level (Wells, 2011). If this occurs in conjunction with a high tide, particularly a spring tide, an extreme still water level (EWL) event arises. EWLs will have an increased impact (McInnes et al., 2003) and increased probability of occurrence (Prime et al., 2015) in the future due to rising mean sea level. Wind waves, generated locally, or swell waves, generated by an offshore storm, impacting a coastline at the same time as the EWL, will increase the observed water level at the shoreline above the EWL alone due to wave run-up and set-up (Longuet-Higgins, 1970), further increasing the impact of the extreme event (Chini and Stansby, 2012).

This paper demonstrates the uncertainty in flood hazard due to variability within the combined forcing of extreme events. The UK design standard for sea defences varies depending on asset being protected, for example, nuclear power stations are designed to be resilient to a 1 in 10,000 year event but a typical design tolerance for urban areas is a 1 in 200 year event, or a 0.5% annual probability of occurrence (Wyse, 2015). This design standard can be applied using one variable such as EWL, which has been calculated at a national scale for 16 return periods of extreme water levels (McMillan et al., 2011). A more comprehensive standard is one that considers both water level (WL) and significant wave height (*Hs*) occurring together. This can then be used to understand further contributions to coastal flooding such as wave run-up. Combining two variables in this way is known as multivariate probability analysis or joint probability analysis (Coles and Tawn, 1990). In the context of WL and *Hs*, joint probability methods were rare until the 1980's rare due to the lack of long-term wave data and suitable

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[*] Corresponding author.
E-mail address: tprime@liv.ac.uk (T. Prime).

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statistical tools. Therefore, the standard process was to consider the wave and water levels separately (Hames and Reeve, 2007). As it became clear that there was a need for better understanding of joint probability, research was undertaken to overcome these barriers (Hawkes and Svensson, 2006) resulting in the development of specialist joint probability analysis software, JOIN-SEA; used by industry as well as academic researchers and also for the research in this paper (Hawkes and Gouldby, 1998).

Using the joint probability of WL and *Hs* is more representative of an extreme event than combining the *Hs* and EWL of a given return period calculated in isolation. Classifying the joint conditions as well as their probability of occurrence provides a better understanding of how resilient current defences are to extreme events (Wadey et al., 2015). However, different combinations of *Hs* and WL can have the same joint probability of occurrence. The varying impacts from these different combinations of a given return period have not been examined before.

For this study we selected the annual probability of 0.5%, or 1 in 200 years in return period (RP) terminology, representative of a typical UK standard of defence. This is consistent with the UK Environment Agency flood mapping service that shows areas benefiting from flood defences at this annual probability of

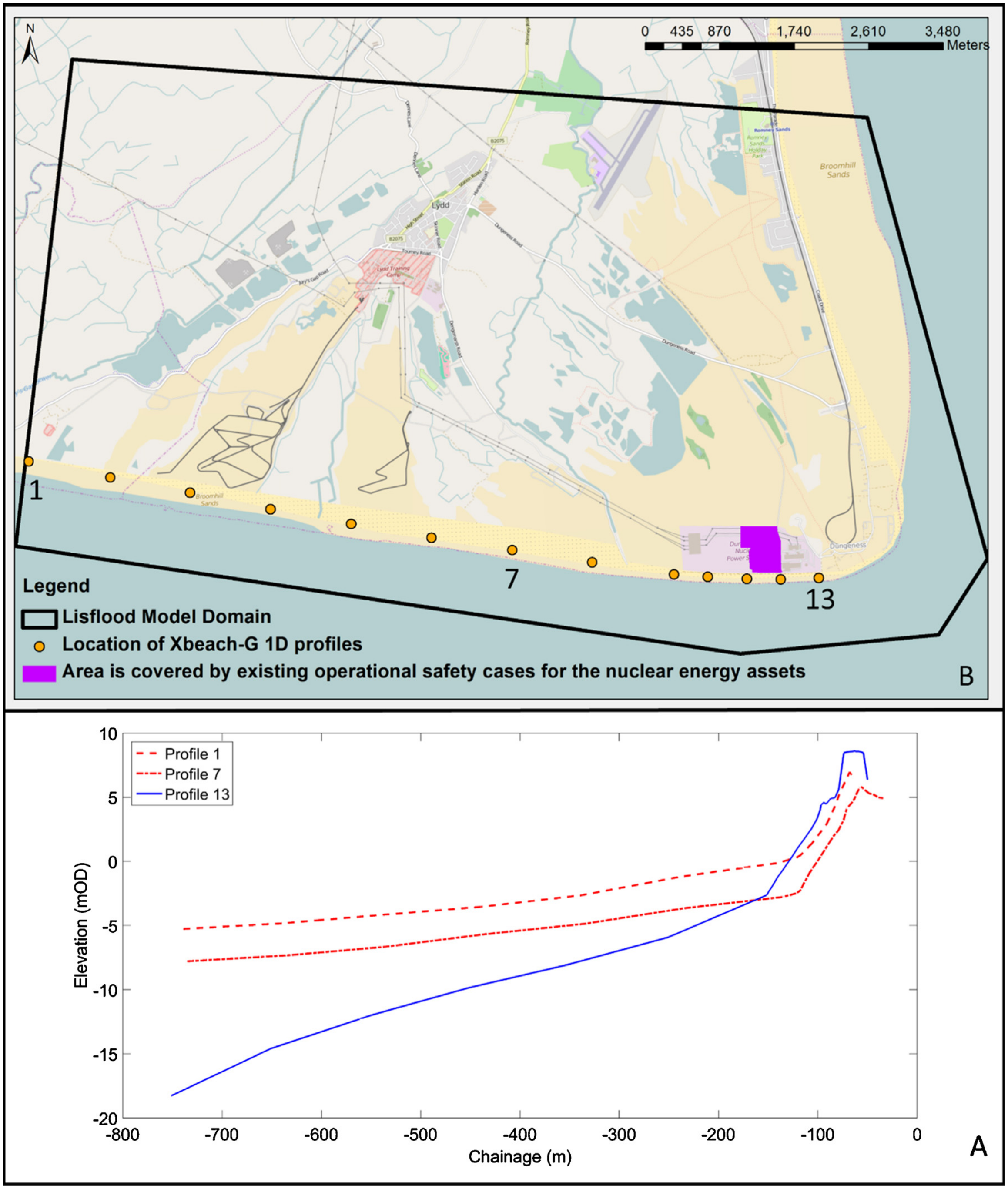

Fig. 1. (A) Beach profiles showing the shoreline variability, the red lines (profile 1 and 7) represent the natural defences and the blue line (profile 13) represents the engineered defences fronting the power stations.**1B**: Dungeness and Romney Marsh; the black line shows the model boundary. The orange dots denote the beach profiles used within the storm impact model. The area shaded in purple is covered by existing operational safety cases for the nuclear energy assets. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)