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A coastal vulnerability assessment for planning climate resilient infrastructure

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ABSTRACT

There is a good understanding of past and present coastal processes as a result of coastal monitoring programmes within the UK. However, one of the key challenges for coastal managers in the face of climate change is future coastal change and vulnerability of infrastructure and communities to flooding. Drawing on a vulnerability-led and decision-centric framework (VL-DC) a Decision Support Tool (DST) is developed which, combines new observations and modelling to explore the future vulnerability to sea-level rise and storms for nuclear energy sites in Britain. The combination of these numerical projections within the DST and a Real Options Analysis (ROA) delivers essential support for: (i) improved response to extreme events and (ii) a strategy that builds climate change resilience.

1. Introduction

Energy security is a fundamental requirement for well-functioning modern societies (Morrissey et al., 2018). Due to its prevalent location in coastal areas, climate change, sea-level rise and extreme events represent significant challenges to the global energy infrastructure and supply chain (Reichl et al., 2013; Morrissey et al., 2018; Prime et al., 2018). The UK Energy Networks Association (ENA) identifies the biggest pressure to be from coastal flooding - if an electrical substation is flooded costs in clean up and repair can be high, and on-going costs from disruption and loss of supply have the potential to add to this significantly (Energy Networks Association, 2009). There is already a good understanding of past and present coastal processes, particularly at locations for present and planned nuclear power stations. However, to ensure that coastal populations and the necessary infrastructure required to sustain these populations are resilient in the future, tools that can inform adaptive management are required (Silva et al., 2017; Wadey et al., 2017; Lam et al., 2017). This is a complex problem as shoreline resilience to changes in the physical environment varies spatially and temporally in response to factors such as changing beach volume (Castelle et al., 2015), reduction in sediment supply (Guangwei, 2011), and the degradation of coastal wetlands (Lotzel et al., 2006), as well as to human interventions that are socio-economically, politically and culturally determined (Ratter et al., 2016). To be effective, management tools require the capacity to monitor and project a variety of interlinked physical and societal processes including sea-level rise, storm magnitude/frequency relationships, changing sediment budget (Brown et al., 2016) and population change and economic activity (Prime et al., 2018).

Developed for the UK energy sector as part of the Adaptation and Resilience of Coastal Energy Supply (ARCoES) project, this paper presents a web-based geospatial Decision Support Tool (DST), the ARCoES DST (Fig. 1). Leaflet, an open source Javascript library, is used to construct the DST to enable the end user to interrogate the matrix of model results using slider bars and tick box options to toggle between hazard or inundation maps and overlay different infrastructure or map views (Knight et al., 2015). As described in this paper, the ARCoES DST is used in combination with modelling and monitoring of different coastal environments to better understand future coastal vulnerability. Drawing on the interdisciplinary skills of the ARCoES researchers, the ARCoES DST is combined with an economic framework, Real Options Analysis (ROA), to provide an assessment of when it is most cost-

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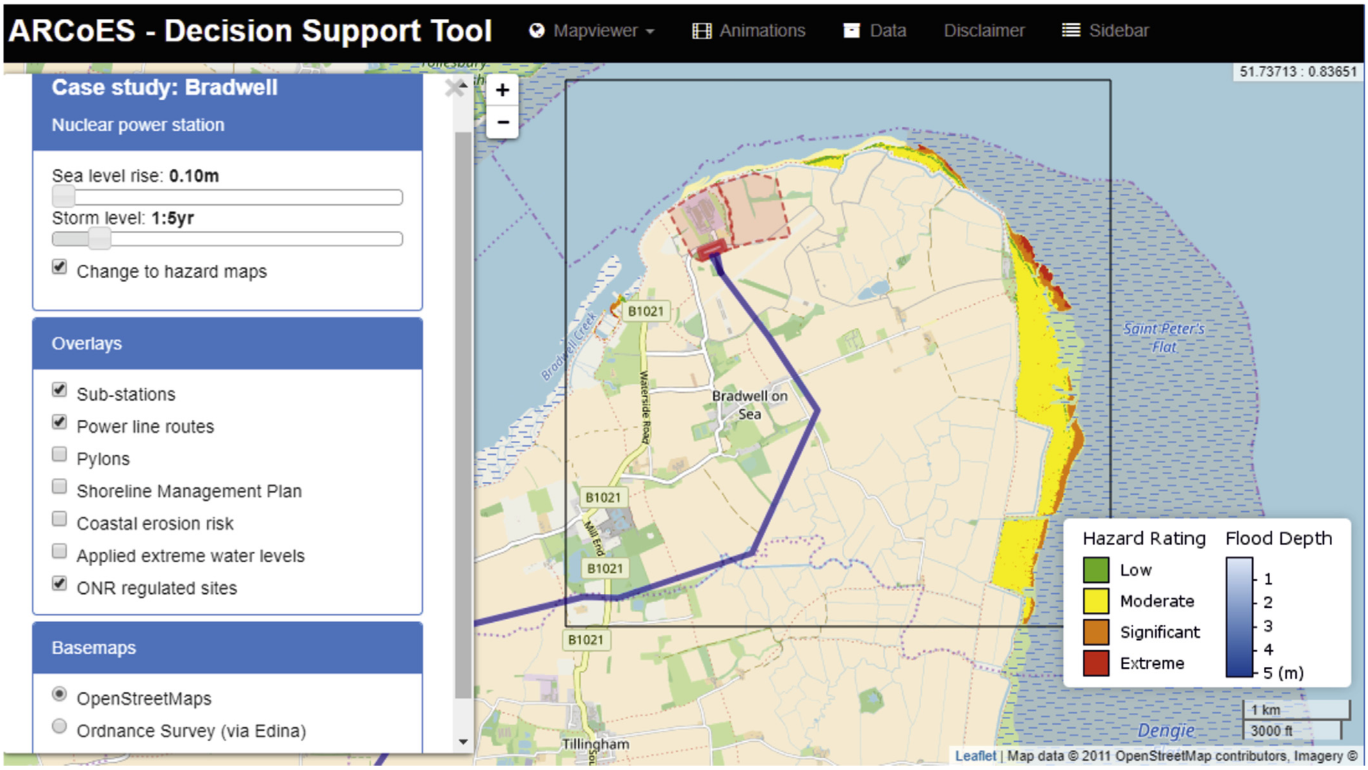

Case study: Bradwell

Nuclear power station

Sea level rise: **0.10m**

Storm level: **1:5yr**

☑ Change to hazard maps

Overlays

☑ Sub-stations
☑ Power line routes
☐ Pylons
☐ Shoreline Management Plan
☐ Coastal erosion risk
☐ Applied extreme water levels
☑ ONR regulated sites

Basemaps

● OpenStreetMaps
○ Ordnance Survey (via Edina)

Hazard Rating	
🟩	Low
🟨	Moderate
🟧	Significant
🟥	Extreme

Flood Depth: 1, 2, 3, 4, 5 (m)

Fig. 1. The ARCoES DST, available at http://arcoes-dst.liverpool.ac.uk/. Flood risk assessments for ONR regulated sites (shaded) are covered by existing pre-operational and operational safety cases.

effective to implement a new management approach. From a policy perspective, the data produced by the DST, when combined with a Real Options Framework can be used to initiate discussions with coastal practitioners to identify how future vulnerability to coastal flooding may be mitigated through appropriate and timely intervention and adaptation. Importantly, although the methodology is designed for the nuclear energy sector, the DST could also be applied for other coastal management needs.

Within this context, the aim of this paper is to demonstrate the usefulness of the ARCoES DST in understanding the physical and economic impact of sea-level rise and storms across 4 nuclear energy sites located along the coast of the UK. These sites include Seascale (representing Sellafield in the northwest), Lilstock (representing Hinkley Point in the southwest), Sizewell (in the east), and Bradwell (in the southeast). We also focus on Fleetwood (in the northwest) as an example of its application to a coastal community. The paper continues as follows: the methods used to deliver this holistic assessment are presented in Section 2. In Section 3 a selection of results to demonstrate the application and capabilities of the resulting DST at different sites is provided. The way in which this DST can be used to conceptualize shoreline management requirements to pose questions at a high level for specialized studies to address is discussed in Section 4, before the conclusions about the future resilience of UK coastal energy are drawn in Section 5.

2. Site descriptions

Although applied to a number of locations, here we focus on five study sites with different coastal geomorphology and hazard exposure. This national application demonstrates the development of a DST for the management needs of an industry with infrastructure in multiple locations rather than in response to site-specific coastal conditions. Each site requires a slightly different model configuration (see Section 3) but uses the same approach.

The coastline at Seascale/Sellafield faces the Irish Sea, the actual location is quite exposed (offshore 10% exceedance $H_s = 2$ m; max $H_s = 5.7$ m; data from British Oceanographic Data Centre (BODC) wave buoy MCMBE-OFF 1974–1976), with a maximum tide range and 1% storm surge height during winter of 7 m and 1 m, respectively. However, the beach morphology fronting the facility is characterised by a reflective high tide gravel/cobble beach with an extremely dissipative sandy intertidal zone. A storm monitored in January 2013 that more or less coincided with spring high tide had therefore insignificant impact on the beach (Almeida et al., 2014).

At Lilstock/Hinkley Point, located in the Bristol Channel, the site is not fully exposed to the Atlantic waves, but wave conditions can be relatively energetic (offshore 10% exceedance $H_s = 1.8$ m; max $H_s = 3.7$ m; data from BODC wave buoy SEVERNEST A 1979–1981). This is a mega-tidal environment with a maximum tide range of 10.7 m and a 1% storm surge height during winter of 0.8 m. However, in common with Sellafield, the wide and low gradient intertidal zone, here a rocky platform instead of a sandy beach, is extremely dissipative, limiting the wave energy levels impacting the high tide gravel/cobble beach. A storm monitored in December 2013 had therefore very limited morphological impact.

The gravel beach at Sizewell faces the North Sea. Wave conditions are relatively mild (offshore 10% exceedance $H_s = 0.6$ m; max $H_s = 2.2$ m; data from BODC wave buoy ALDEBURG 1975–1977) and the maximum tide range and 1% storm surge height during winter are 2.4 m and 1 m, respectively. During the 5-year duration of the ARCoES project, not a single extreme wave event occurred at Sizewell, but some measurements were made during a relatively modest storm event in March 2013. These revealed that the subtidal bar morphology at this site provides significant protection to the high tide gravel beach from large waves and that the main morphological changes occurred due to longshore sediment transport processes. The most significant wave events along the North Sea coast are from the northeast quadrant, but Sizewell is partly sheltered from such storms because the coastline aligns south-southwest to north-northeast, and potentially the most damaging waves for Sizewell are extremely rare storm waves from the