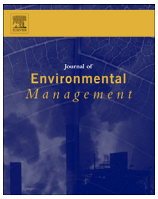
Journal of Environmental Management xxx (2016) 1–9

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman



Research article

The effectiveness of beach mega-nourishment, assessed over three management epochs

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ARTICLE INFO

Article history:
Received 18 July 2016
Received in revised form
9 September 2016
Accepted 30 September 2016
Available online xxx

Keywords:
Beach mega-nourishment
Coastal resilience
Shoreline evolution
Shoreline management planning
Coastal evolution model
Dungeness

ABSTRACT

Resilient coastal protection requires adaptive management strategies that build with nature to maintain long-term sustainability. With increasing pressures on shorelines from urbanisation, industrial growth, sea-level rise and changing storm climates soft approaches to coastal management are implemented to support natural habitats and maintain healthy coastal ecosystems. The impact of a beach mega-nourishment along a frontage of interactive natural and engineered systems that incorporate soft and hard defences is explored. A coastal evolution model is applied to simulate the impact of different hypothetical mega-nourishment interventions to assess their impacts' over 3 shoreline management planning epochs: present-day (0–20 years), medium-term (20–50 years) and long-term (50–100 years). The impacts of the smaller interventions when appropriately positioned are found to be as effective as larger schemes, thus making them more cost-effective for present-day management. Over time the benefit from larger interventions becomes more noticeable, with multi-location schemes requiring a smaller initial nourishment to achieve at least the same benefit as that of a single-location scheme. While the longer-term impact of larger schemes reduces erosion across a frontage the short-term impact down drift of the scheme can lead to an increase in erosion as the natural sediment drift becomes interrupted. This research presents a transferable modelling tool to assess the impact of nourishment schemes for a variety of sedimentary shorelines and highlights both the positive and negative impact of beach mega-nourishment.

1. Introduction

Climate change and the associated rise in sea level are increasing the vulnerability of coastal communities and industries to flood and erosion risk globally (Nicholls et al., 2007). Small scale frequent beach nourishment is a common practise in locations where beach loss is having a negative impact (Cooke et al., 2012). However, management options that adapt with the natural environment are now used to build long-term resilience into new coastal schemes (Kuklicke and Demeritt, 2016). An innovative approach that uses natural processes to redistribute sediment from a mega-nourishment to adjacent beaches is currently being trialled along the Dutch coastline (de Schipper et al., 2016). The approach is intended to create a resilient beach that evolves with changing coastal conditions over a 20-year period. To inform decision makers on the possible consequences of such an intervention in other locations, this research aims to assess the potential benefits and adverse impacts of different approaches to beach mega-nourishment. Management frameworks consider impacts on both the ecology of an environmental system and the socio-economic benefits (Schlacher et al., 2014). This research considers the impacts in terms of erosion reduction and creation of beach width and sheltered water, thus informing management needs in relation to flood and erosion risk in addition to the creation of habitat and recreational space.

The dense population of coastlines worldwide puts people and infrastructure at risk of flooding and erosion over varied time and spatial scales. Population and industrial growth combined with the

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http://dx.doi.org/10.1016/j.jenvman.2016.09.090

Please cite this article in press as: Brown, J.M., et al., The effectiveness of beach mega-nourishment, assessed over three management epochs, Journal of Environmental Management (2016), http://dx.doi.org/10.1016/j.jenvman.2016.09.090

consequence of coastal climate change are increasing pressures on coastal habitats and ecosystems (Villatoro et al., 2014). The use of dredged material is thus used where appropriate within harbours for habitat creation, e.g., within New Jersey Harbor, New York (Yozzo et al., 2004). Such practise has been extended to the open coast, where coastal management strategies now consider new and ambitious 'advance the line' approaches that use marine aggregate to provide softer interventions that work with the natural environment to increase coastal resilience. Such approaches are intended to supplement existing management schemes to prolong their effective life span in addition to increasing protection in their immediate vicinity, providing economic and/or ecosystem benefits. However, their impact can be both positive (beach widening) and negative (inhibited sediment drift), thus modelling and monitoring studies are important to inform decisions associated with intervention design (Capobianco et al., 2002).

Shoreline management strategies often assess three time periods for the purposes of planning and resource allocation: present-day (Epoch 1, 0–20 years), medium-term (Epoch 2, 20–50 years) and long-term (Epoch 3, 50–100 years). Model simulations are used to explore how the size and position of a single- or multi-location mega-nourishment could evolve to support a coastal system comprising natural barriers and embankments, with seawalls in areas of critical infrastructure, over these epochs. The insight gained from this study site will have wider global impact as hard and soft engineered solutions are used in conjunction at many other locations to mitigate coastal erosion and promote healthy coastal environments (Perkins et al., 2015). The varied impact of different mega-nourishment schemes is illustrated in the context of existing management strategies that vary along the frontage, defending to maintaining the shoreline position, as well as allowing for natural retreat.

The 'advance the line' management strategy termed 'mega-nourishment' or 'sandscaping', largely stems from the Dutch initiative 'De Zandmotor'; a 21.5 M m^3 sand mega-nourishment implemented so that natural wave energy and circulation will redistribute the sand, widening beaches over a 10–20 km stretch over a 20-year period (Stive et al., 2013). The concomitant reduction in the frequency of beach nourishment from typical 3- to 5-year cycles, and the limitation of human intervention to a 128 ha (~1 km^2) area of shoreline, reduces the disturbance to the local ecosystem while providing benefits in addition to reduced flood and erosion risk, such as habitat creation and increased amenity for shoreline recreation. This approach has been successful along part of the southern Dutch coast, where a uniform sandy shoreline exists. Implementing a similar strategy for coastlines where the intrinsic dynamics and geomorphology are more complex (e.g., interacting systems of rock coastline, estuaries, sand dune systems, etc.) will require different designs and aggregate sizes (or combinations of aggregates) according to the environmental challenge being addressed (Bishop et al., 2006). To explore the feasibility of mega-nourishment for a complex coast, such as in the UK (French et al., 2016), the Coastal Evolution Model (CEM, Ashton and Murray, 2006a,b) is used calibrated to historic recession rates. The CEM is an exploratory model simulating alongshore sediment transport that can include engineered structures, allowing the exploration of shoreline change in response to alternative management strategies (Barkwith et al., 2014b).

Numerical models can be used as tools to provide scientific evidence in support of coastal flood and erosion risk management (Brown et al., 2016). Ensembles of simulations provide a data base of potential impacts capturing the uncertainties of softer management approaches to inform the decisions associated with the design of new coastal schemes. Examples include simulating the influence of vegetated foreshores on the wave loading of defences (Vuik et al., 2016) and of wetlands on reducing storm tide elevations (Smolders et al., 2015). Here, exploratory modelling of a case study situated in the English Channel (Fig. 1) is used to identify the generic down-drift impact of 'mega-nourishment' due to wave driven gravel transport. The site is designated a Site of Scientific Special Interest (SSSI) for international geological and ecological interests, and also supports valuable infrastructure and assets (Maddrell, 1996). This macrotidal location, with an approximately 6.7 m semidiurnal tidal range (Stupples, 2002), experiences large storm surge conditions (Wadey et al., 2015) and a bimodal, bidirectional wave climate (Mason et al., 2009) (Fig. 1). The largest waves exceed 5 m significant wave height with approximately 18 s peak period and come from the southwest (Figs. 1 and 2). Coastal defences comprise a natural gravel barrier and earthen embankments (Prime et al., 2016), supplemented with a seawall in areas of urban infrastructure (Fig. 1). Despite the coastal protection, there is continuous threat of coastal flooding by extreme events (Long et al., 2006). Since the 1960s periodic shingle recycling has been carried out to retain shingle along the frontage. However, the current policy option is 'no active intervention' where the natural barrier has formed. The potential erosion reduction offered by a range of hypothetical 'Gravel Engines' (Table 1) is explored and the increased coastal protection provided by these mega-nourishments across this frontage over the three shoreline management planning epochs evaluated.

The effectiveness of beach mega-nourishment options ranging in size, number and location (Table 1) are modelled over a 100-year period. The schemes represent novel management approaches to soft intervention that will have time-varying impact over the long-term. By using a simple coastline with multiple management strategies, which interact, this model application aims to identify the possible consequences (both positive and negative) of such an approach to coastal management to inform management decisions. The simulations suggest that a multi-location nourishment scheme provides greater reduction in erosion than a single mega-nourishment of larger size, although the combined impact is less than the sum of the impacts from each component when modelled in isolation. Over 20 years, consistent with the design life of De Zandmotor, smaller scale interventions are as efficient at reducing erosion as a mega-nourishment scheme, making them more cost-effective over shorter management timeframes due to the lower implementation costs. Designing a nourishment scheme such that it works with the natural environment to maintain a high level of resilience ensures long-term costs associated with the intervention are minimised (Stive et al., 2002). The value of larger mega-nourishments is thus more likely to be appreciated beyond a 20-year timeframe.

In Section 2 details of the behavioural modelling approach are provided. The results are described in Section 3 and discussed in Section 4. The concluding remarks stating the benefits of varied approaches to beach mega-nourishment are given in Section 5.

2. Methods

A one-line coastal evolution model (CEM, Ashton and Murray, 2006a,b) has been adapted to investigate the potential evolution of a hypothetical gravel intervention along the Dungeness headland (Fig. 1). The land-sea mask used to represent the headland was obtained from Lidar data collected in August 2014. The model, applied at a 100 m horizontal resolution, can be driven by the observed offshore wave climate (Ashton and Murray, 2006a,b) or a long-term offshore wave climatology to evolve the coastline. In Rye Bay (the southern shore of Dungeness, Fig. 1) a 1.8 km wave model of the English Channel and Southern North Sea was used to provide the local wave climate. The model applied was the 3rd generation

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