Coastal Engineering 96 (2015) 92–99

Contents lists available at ScienceDirect

Coastal Engineering

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

Moving from deterministic towards probabilistic coastal hazard and risk assessment: Development of a modelling framework and application to Narrabeen Beach, New South Wales, Australia

D.J. Wainwright [a,b,*], R. Ranasinghe [c,d], D.P. Callaghan [a], C.D. Woodroffe [e], R. Jongejan [f], A.J. Dougherty [e], K. Rogers [e], P.J. Cowell [g]

[a] School of Civil Engineering, University of Queensland, St Lucia, QLD 4072, Australia
[b] Whitehead and Associates, Cardiff, NSW, Australia
[c] Dept. of Water Science and Engineering, UNESCO-IHE, PO Box 3015, 2610 DA Delft, The Netherlands
[d] Harbour, Coastal and Ocean Engineering, Deltares, PO Box 177, 2600 MH Delft, The Netherlands
[e] University of Wollongong, Australia
[f] Jongejan RMC, Delft, The Netherlands
[g] University of Sydney, Australia

ARTICLE INFO

Article history:
Received 16 June 2014
Received in revised form 22 November 2014
Accepted 24 November 2014
Available online 18 December 2014

Keywords:
Coastal hazard
Probabilistic modelling
Development setback
Economic modelling

ABSTRACT

Traditional methods for assessing coastal hazards have not typically incorporated a rigorous treatment of uncertainty. Such treatment is necessary to enable risk assessments which are now required by emerging risk based coastal zone management/planning frameworks. While unresolved issues remain, relating to the availability of sufficient data for comprehensive uncertainty assessments, this will hopefully improve in coming decades. Here, we present a modelling framework which integrates geological, engineering and economic approaches for assessing the climate change driven economic risk to coastal developments. The framework incorporates means for combining results from models that focus on the decadal to century time scales at which coasts evolve, and those that focus on the short term and seasonal time scales (storm bite and recovery). This paper demonstrates the functionality of the framework in deriving probabilistic coastal hazard lines and their subsequent use to establish an economically optimal setback line for development at a case study site; the Narrabeen–Collaroy embayment in Sydney, New South Wales.

1. Introduction

Intensification of human settlements along coastlines worldwide will mean that many will become increasingly vulnerable to the impact of sea-level rise in the coming century. In the state of New South Wales in eastern Australia, which contains the study site considered by this paper, it has recently been estimated that the contemporary replacement value of some 40,000 to 60,000 residential buildings exposed to storm inundation after a 1.1 m sea-level rise is between 12 and 19 billion dollars (DCC, 2009). Coastal development planning decisions made now have the capacity to either mitigate or exacerbate the severity of sea-level rise consequences to future generations.

Coastal engineers and scientists must use robust methods for assessing the exposure of land to coastal processes and their related hazards in order to provide sound advice relating to the setbacks that should be applied for different types of coastal developments and settings. Due to the considerable uncertainty inherent in our present understanding of coastal processes, it is vital that this uncertainty be acknowledged and incorporated into planning decisions. This paper introduces a framework for incorporating uncertainty associated with environmental forcing into coastal development decision making and demonstrates its application to our primary study site, the Narrabeen/Collaroy embayment on the northern beaches of Sydney, New South Wales, Australia.

2. Framework overview

Risk management approaches to coastal hazards have attracted significant attention for at least the past decade or so (Van Dongeren et al., 2008; Vrijling et al, 2003) and are becoming increasingly common and sophisticated (den Heijer et al, 2012; Penning-Rowsell et al, 2014; Zanuttigh et al., 2014). The present guidelines for Coastal Zone Management Plans in New South Wales (OEH, 2013) advocate a risk management approach. The present standard for formal risk management is contained in International Organisation for Standardisation ISO 31000, which contains features that are common to a wide array of historical

* Corresponding author at: School of Civil Engineering, University of Queensland, St Lucia, QLD 4072, Australia.
E-mail address: d.wainwright2@uq.edu.au (D.J. Wainwright).

http://dx.doi.org/10.1016/j.coastaleng.2014.11.009

risk assessment standards (ECHCPDG, 2000). The formal standard is flexible, allowing for the incorporation of uncertainty in a transparent manner. This is beneficial when balancing quantitative estimates of uncertain coastal hazards against, for example, the potential intangible losses (environmental losses, beach amenity etc.) in the coastal zone.

With reference to the international standard, our framework focuses on using models to quantitatively analyse risks, and deals with the "risk analysis" and "risk evaluation" phases of the overall risk management process. In our application, risk analysis requires determination of the likelihood and consequences of beach erosion reaching a location where it threatens development. Subsequently, our risk evaluation uses an economic model to determine an optimal development setback location, based on whether investment at a particular location is economically viable, given the amount of damage expected to be sustained through damage by coastal processes. The methods applied here are discussed in greater detail in Woodroffe et al. (2012).

3. Components of coastal hazard analysis

Essentially, the coastal *risk analysis* process comprises (i) determination of the extent or severity of identified hazards for a range of exceedance levels (i.e. the *probabilities or likelihoods*); and (ii) determination of the potential losses for the extents and/or severities identified in (i) (i.e. the *consequences*). By quantifying both of these, the overall risk can then be calculated.

Our study was limited to hazards associated with the location of a dune scarp on a sandy beach. Hazard definition becomes more complicated when it is applied to planning over long time frames with non-stationary boundary conditions, such as the expected sea-level rise over coming centuries. The discrimination of mean trend (e.g. recession) from fluctuating components (erosion and recovery) of shoreline location and their analysis can be summarised as:

$$d(t) = \overline{R}_V - \overline{R}_{SL} - E \quad (1)$$

where $d(t)$ is the distance from the present day scarp location at time t; $\overline{R}_V$ is the ongoing recession resulting from the time averaged sediment budget ($+ve =$ accretion); $\overline{R}_{SL}$ is the recession resulting from a rising sea level; and E is an allowance for storm erosion, representing movement of the shoreline from its pre-storm location to the base of the storm cut erosion scarp.

A further allowance can be made for post-storm slumping and/or reduced foundation capacity although, with adequate site investigation, this component can be treated deterministically and has been set aside for the purposes of this paper. All three components on the right side of Eq. (1) are subject to significant uncertainty and here we address and incorporate an understanding of that uncertainty into our analysis.

4. Study site: Narrabeen Beach

At 3.6 km, the Narrabeen–Collaroy embayment is the longest sandy system in the Sydney region. It is located 20 km north of Sydney CBD (Fig. 1). The embayment fronts a prograded coastal barrier with a tidal inlet at the northern end that maintains a well-developed flood tide delta (Fig. 1). This inlet leads to a back barrier estuary (Narrabeen Lagoon) behind the northern portion of the barrier. The Narrabeen–Collaroy compartment is a relatively closed system bound in the north by Narrabeen Headland and in the south by the prominent headland known as Long Reef Point. Rip cells, with their type and spacing varying

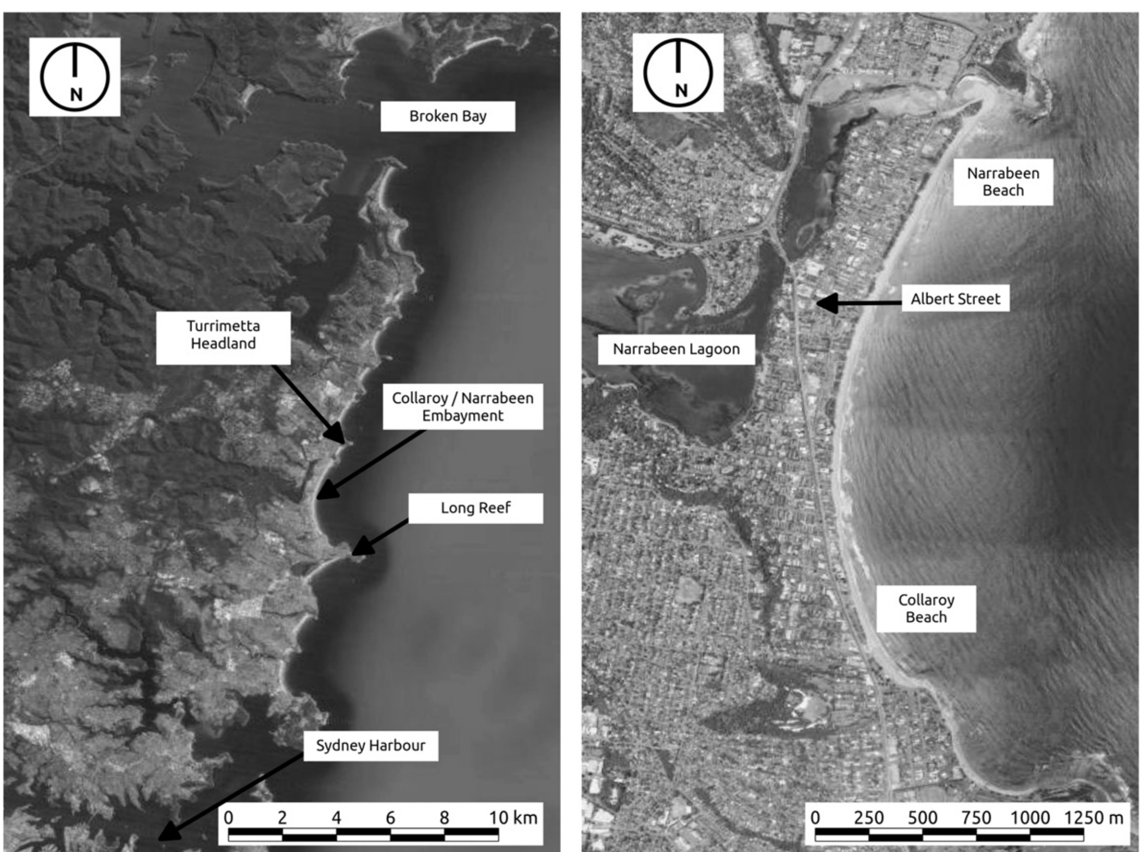

Fig. 1. Left frame shows Narrabeen–Collaroy Beach with respect to the Sydney coastline. Right frame shows Narrabeen Beach and Collaroy Beach. Imagery © 2014 CNES/SPOT Image, Digital Globe, Sinclair Knight Merz, Terrametrics, Map Data © 2014 Google.