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Assessing the vulnerability of coastal infrastructure to sea level rise using multi-criteria analysis in Scarborough, Maine (USA)

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ABSTRACT

Sea level rise and climate change will have widespread impacts on coastal towns and cities, many of which have seen dramatic increases in development over recent decades. In addition to potential private property damage, the critical public infrastructure that supports these regions will become increasingly vulnerable to coastal flooding. This paper describes a straightforward, structured methodology for identifying and prioritizing critical infrastructure vulnerabilities in the coastal community of Scarborough, Maine, USA. The study uses GIS mapping and analysis techniques to identify infrastructure vulnerabilities in a coastal town under three different potential future flooding scenarios. A simple multi-criteria analysis matrix is used to explore the often hard to quantify, multifaceted consequences of infrastructure loss. Numerical scores are attributed to represent the economic, social, health and safety and environmental impacts of coastal flooding, allowing vulnerable locations to be ranked in order of overall importance. The results are summarized in a series of tables, maps and data sheets that convey data in readily accessible formats. High traffic roads, including evacuation routes, and major utility corridors are identified as the most critical vulnerable infrastructure assets in the town. Targeted improvements are recommended in these critical areas to improve system and community resilience to climate change and sea level rise. Our approach makes use of standard techniques, requires limited data and is therefore readily transferable for use in infrastructure planning in other similar communities. The methodology encourages public engagement and education, and the results can be used by the local authorities to pursue external funding opportunities to support investment in proactive infrastructure adaptation. The identification of key system weaknesses will allow future infrastructure investment to be targeted to the most critical areas, and assist in improving emergency response plans.

1. Introduction

Climate change and sea level rise present the greatest challenge facing most coastal communities at the present time. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPC, 2007) projected that global sea level will rise by up to 60 cm by 2 100. These projections were recently revised in the Fifth Assessment Report (IPCC, 2013), based on an improved understanding of glacial and ice sheet inputs, with potential sea level rise ranging from 0.3 m to almost 1 m by 2 100. Other recent studies have identified acceleration of polar ice sheet melts (Rignot et al., 2008) that raise the possibility of a global rise of 1 m or more by 2 100 (Pfeffer et al., 2008; Lowe et al., 2009). Multiple studies have shown that climate change will also increase the vulnerability of coastal communities to extreme coastal storms (Bender et al., 2010; Lin et al., 2012). The combination of rising static water levels and an increase in the severity and frequency of storm events will lead to increasing submergence and flooding of coastal areas and accelerated rates of coastal erosion. These physical impacts have both direct and indirect socio economic impacts, which appear overwhelmingly negative (Nicholls and Cazenave, 2010), and have the potential to threaten the long-term viability of many coastal towns and cities.

Recent intense development of the coastal zone has significantly raised the overall economic, social and environmental risks associated with coastal flooding. A detailed understanding of the potential impacts of climate change and sea level rise will be essential to formulating efficient, proactive and transferable response strategies. In many cases the high value of coastal properties and the essential

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contribution of these to local tax revenues will favor implementation of adaptation and protection measures. However, funding for this work will not be easily available given the current pressure on public financing. Vulnerability assessments and decision matrices will be needed to identify specific target areas where mitigation efforts should be focused. Structured methods for prioritizing investment will be necessary to maximize the efficiency of expenditure and hence the overall benefit to the community.

Infrastructure systems, such as transportation networks and utilities play a critical role in supporting coastal communities. Many of these systems are already vulnerable to coastal storms. Climate change and sea level rise will further increase the vulnerability of these systems to coastal flooding and erosion, with both short-term and long-term consequences. Damage to essential infrastructure will hamper emergency response teams during coastal flooding events, and compromise recovery efforts in the immediate aftermath. In the long term it will also become increasingly difficult to manage, maintain and operate essential services, threatening the long-term viability of entire coastal communities.

Adaptation planning efforts from around the world, developed in response to the threat of future sea level rise, offer insights into universally applicable paradigms. These include the need for structured approaches with clearly defined planning stages (Mukheibir and Ziervogel, 2007), and for institutional capacity building and greater vertical integration of government agencies (Storbjork and Hedren, 2011). The importance of connecting scientists, coastal managers, and regional and local stakeholders to form collaborative teams equipped to tackle the key issues is also central to effective adaptation planning (McGinnis and McGinnis, 2011). Whilst scoping studies at the national or state level usually provide sufficient basic information for policy makers on the overall risk situation, specific adaptation has to be planned mostly at the community level (Sterr, 2008). Therefore, there is a need for coastal communities to use a structured framework to rank the importance and assess the vulnerability of their infrastructure. This will facilitate proactive, efficient and transparent decisions on where to invest in mitigation and adaptation measures.

The primary objective of this study was to develop and test such a method for identifying and prioritizing key infrastructure vulnerabilities. This will enable infrastructure investment to be effectively targeted to improve system resilience, reduce long-term overall costs and minimize significant irreversible flooding impacts. It will also assist in emergency management planning through the identification of key system weaknesses, and facilitate access to external funding sources by the development of adaptation solutions. The structured approach described in this paper aims to be easily transferable so that it can be readily adopted and adapted as a model for use by other similar communities.

2. Study site

With nearly eight miles of ocean shorefront on Saco Bay and the largest contiguous tidal salt marsh in the State of Maine, Scarborough presents a good example of the challenges facing many coastal communities as they prepare for future sea level rise, see Fig. 1 for location map.

Scarborough is located at the northern end of Saco Bay, a long cuspate shoreline that extends southwest through the towns of Old Orchard Beach and Saco and terminates at Fletcher Neck in Biddeford. The bay shoreline forms the longest unbroken sand beach in Maine. The mouth of the Scarborough River is located at the north end of Saco Bay and opens inland to Scarborough Marsh, an extensive low-lying salt marsh system that extends approximately 6 km inland and covers an area of more than 2 000 ha. The low, rocky headland of Prouts Neck forms the northern end of Saco Bay, and the Scarborough shoreline continues northeast from this feature along Scarborough Beach, and a short section of rocky bluffs to Higgins Beach, and the mouth of the Spurwink River.

Prevailing winds in Maine are from the southwest, but major offshore storm systems produce strong winds and the associated high waves from the more damaging directions between southeast and northeast as they pass up the coastline from south to north. The sandy sections of ocean shoreline in Scarborough are low and vulnerable to storm waves, particularly from the southeast. The areas surrounding the marsh are generally low lying, with numerous road and utility crossings of tributary rivers and inlets. The topography of the area and key features are shown on Fig. 2.

The mean tidal range in the study area, as measured at the Portland tide gauging station is 3 m (9.8 ft) with spring tide ranges of up to 4.2 m (13.8 ft). The large tide range has historically

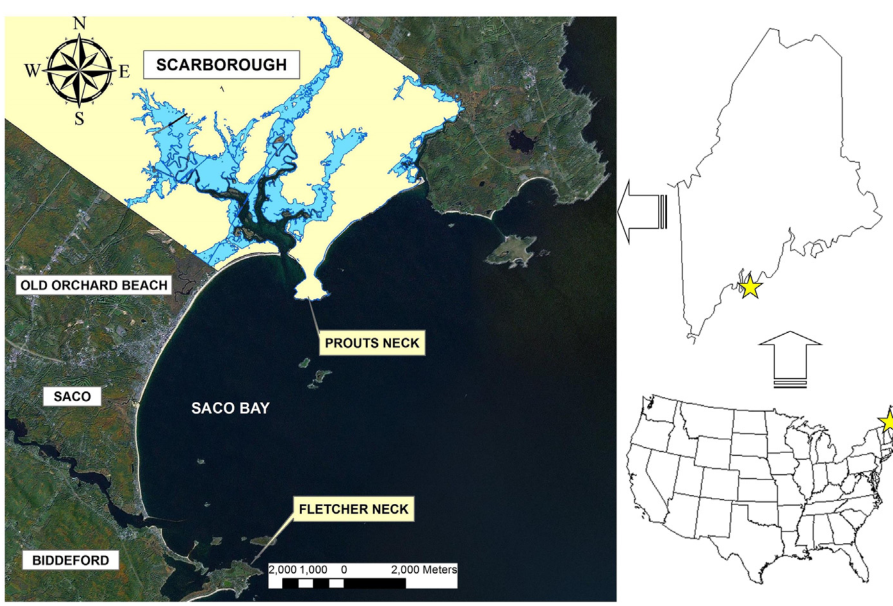

Fig. 1. –Location Map of Scarborough, State of Maine, USA. Areas of tidal influence are shaded in blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)