Regional Scale Assessment of the Sensitivity of Illawarra Indigenous Heritage Sites to Sea Level Rise and Associated Hazards

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Abstract
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The coastal shoreline was assessed using an adaption of a Coastal Sensitivity Index technique, using Slope, Geology, Shoreline Exposure, Geomorphology, Site Distance to Shoreline, Sea Level Rise, Wave Height and Tidal Range to assess heritage site sensitivity to sea level rise. Indigenous heritage sites on the shoreline around Lake Illawarra estuary were assessed using an adaption of modelling designed to investigate biophysical vulnerability to erosion and flooding hazards using estuarine geomorphic units. The relative effectiveness of the desk based modelling approach was also examined by ground-truthing of a number of sites analysed in the coastal site sensitivity index.

The results of the coastal analysis highlighted several sites located near beaches in the region that were estimated to have ‘Very High’ sensitivity to sea level rise and the associated hazards. In the Lake Illawarra estuary heritage sites were estimated to generally have higher sensitivity when located on the coastal barrier. Results of both methods indicated that sites on resilient bedrock landforms were considerably less sensitive than sites on Quaternary sediment. However, ground-truthing at Bass Point suggested in some locations sites may be sensitive to coastal hazards despite being associated with resilient landforms.

The study was able to identify Indigenous heritage sites within the coastal Illawarra region that were most sensitive to climatic and sea level rise driven hazards. The ground-truthing of sites identified areas for future research to improve the desk based approach, particularly in regards to including the sensitivity of individual site types to erosion and inundation hazards. Desk based regional modelling was shown to be a useful tool for planning and conservation management, particularly in directing resources to sites of the highest risk, and informing the direction of more in depth studies into the hazards faced by coastal Indigenous heritage sites.

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Regional Scale Assessment of the Sensitivity of Illawarra Indigenous Heritage Sites to Sea Level Rise and Associated Hazards

By

Samuel Mathew Knott

A thesis submitted in part fulfilment of the requirements of the Honours degree of Bachelor of Science Advanced

School of Earth and Environmental Sciences,
Faculty of Science Medicine and Health
University of Wollongong (2016)
The information in this thesis is entirely the result of investigations conducted by the author, unless otherwise acknowledged, and has not been submitted in part, or otherwise, for any other degree or qualification.

Samuel Mathew Knott

6th June 2016
This thesis is dedicated to my father Peter John Knott, who died unexpectedly during the course of my studies

1956-2015
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Abstract

Climate change and sea level rise are expected to exacerbate existing coastal hazards such as erosion and inundation. As a result many coastal heritage sites around the world are expected to be put at potential risk of damage or destruction. The likely susceptibility of Australia’s Indigenous coastal heritage sites to these hazards is widely recognised but the sensitivity has not been quantified or analysed in detail. In order to assess the sensitivity of Indigenous coastal heritage sites, both coastal and estuarine indices of sensitivity and vulnerability were adapted to be used in a heritage context. The study focused on the coastal Illawarra region of southern NSW. Desk based regional models were produced within the ArcGIS program for both Coastal and Estuarine shorelines in the region with underlying landform sensitivity used as a proxy for heritage site sensitivity.

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The results of the coastal analysis highlighted several sites located near beaches in the region that were estimated to have ‘Very High’ sensitivity to sea level rise and the associated hazards. In the Lake Illawarra estuary heritage sites were estimated to generally have higher sensitivity when located on the coastal barrier. Results of both methods indicated that sites on resilient bedrock landforms were considerably less sensitive than sites on Quaternary sediment. However, ground-truthing at Bass Point suggested in some locations sites may be sensitive to coastal hazards despite being associated with resilient landforms.

The study was able to identify Indigenous heritage sites within the coastal Illawarra region that were most sensitive to climatic and sea level rise driven hazards. The ground-truthing of sites identified areas for future research to improve the desk based approach, particularly in regards to including the sensitivity of individual site types to erosion and inundation hazards. Desk based regional modelling was shown to be a useful tool for planning and conservation management, particularly in directing resources to sites of the highest risk, and informing the direction of more in depth studies into the hazards faced by coastal Indigenous heritage sites.
1 Introduction

The warming of the earth’s climate system is now considered unequivocal, and is widely accepted by the scientific community (Pachauri et al. 2014, Cook et al. 2013). Climate change is expected to drive an increase in global mean sea level that will lead in many cases to the likely exacerbation of various coastal hazards, such as erosion and inundation (Church et al. 2013, Solomon et al. 2007, Gornitz et al. 2001). Coastlines around the world will be affected on varying scales by these coastal hazards (Gornitz 1991). As a result, coastal planners and academics have undertaken extensive investigations into how these hazards will affect coastlines, as well as their associated human populations and infrastructure (Gornitz et al. 2001, Zhang et al. 2011, Woodroffe et al. 2012).

Coastal hazards exacerbated by sea level rise have the potential to damage or destroy many archaeological and heritage sites (Reeder et al. 2012). However, according to Erlandson (2012) “little has generally been done to plan for or mitigate the effects of human-induced sea level rise and marine erosion on archaeological and historical resources in coastal zones around the world”. There are of course exceptions, in North-western Europe several countries such as Scotland, England and France have schemes in place to physically survey heritage assets by pooling research and resources in large-scale community driven projects (Daire et al. 2012, Westley et al. 2011). However, for countries with large coastlines such as the United States and Canada, the application of similar intensive physical surveys to the entire coast is not feasible. Due to the need for coastal heritage site assessment despite this challenge, the use of desk based modelling has arisen as a method to prioritise resources for conservation in these nations (Westley et al. 2011, Reeder-Myers 2015, Reeder et al. 2012).

Australia, much like the United States and Canada has a relatively large coastline making comprehensive intensive physical-survey initiatives a difficult task. However, unlike the United States and Canada, desk based models such as Coastal Vulnerability Indices have not been widely applied to heritage concerns. In fact, in NSW Indigenous heritage conservation and assessment is largely undertaken through individual Environmental Impact Assessments in areas outside of National Parks, in what Wesson (2005) describes as a “piecemeal fashion”. By taking a regional approach to investigate the climate and sea level driven hazards faced by heritage sites in the Illawarra, this study will provide a more complete picture of the likely scale of the issues faced in terms of heritage assets, and potentially highlight the areas of most pressing concern.
1.1 Aims and Objectives

The aim of this study is to evaluate the sensitivity of Indigenous heritage sites in the Illawarra coastal region to hazards driven by climate change, primarily sea level rise. The project will take a regional approach, and aims to assess the viability of broad-scale modelling for the direction of resources and management. This will be achieved through the adaption of existing hazard assessment techniques, and the application of these in a heritage context. These aims will be accomplished through achieving the following objectives:

i. Coastal Assessment – Analyse the sensitivity of heritage sites located on the coastline of the Illawarra region to hazards associated with sea level rise.

ii. Estuarine Assessment – Analyse the sensitivity of heritage sites located in the Lake Illawarra estuary to coastal and terrestrial hazards associated with sea level rise and climate change.

iii. Site Study – Assess the effectiveness and accuracy of regional scale analysis for heritage concerns by investigating individual sites within the study area.

iv. Assessment of Outcome – Review the findings of the analyses undertaken, in order to consider the viability of applying regional sensitivity analyses to heritage sites for planning and conservation management.
1.2 Study Area

Figure 1.1, Study Area in context of Australian East Coast. The studied section of the coast is shown in red on the image to the right of the figure.

The study area for this project is the coastline of the Illawarra region in southern NSW, Australia, including the shoreline of Lake Illawarra (Figure 1.1). The northern extent of the study area is at Otford approximately 151°01'14"E, 34°12'11"S. The southern extent of the study area is in Killalea State Park at 150°51'39"E, 34°36'39"S. Analysis took place of the land within 500m of the shoreline, as defined by the Bureau of Meteorology’s Australian Hydrological Geospatial Fabric (AHGF).

The Illawarra coastline is wave dominated with an average Spring tide range of 1.2m (Short 2007). The predominant swell direction that influences the coast is from the south south-east (Kulmar et al. 2013). Sandy beaches of Quaternary sediment occur along the coast, often separated by prominent rocky headlands (Short 2007). Headlands and points are formed from resilient geological units, such as those of the Gerringong Volcanics and the Shoalhaven Group (Abuodha 2009). The northern reaches of the study area intersect with the steep slopes associated with the Illawarra escarpment. Both the Narrabeen Group and the Illawarra Coal
measures have been described as ‘weak’ by Young (1979) due to their low resistance to erosion.

The study area includes the shoreline around Lake Illawarra. Up until 2007 Lake Illawarra was an example of an ICOLL (Intermittently Closed and Open Lakes and Lagoons). However in 2007 the entrance to the lake was permanently opened by dredging, and the construction of training walls (Young et al. 2014). Lake Illawarra is a wave-dominated, barrier estuary (Roy et al. 2001), with a catchment area of 238km² (Office of Environment & Heritage 2016b).
2 Background

2.1 Introduction

As governments and planners around the world are beginning to face the reality of climate change and the potential impacts that will be brought on as a result, archaeologists too are coming to grips with the implications that this will have on their discipline, field data and heritage studies generally. Sea levels are expected to continue rising, and place historic and archaeological sites in the path of associated impacts, such as erosion and inundation. Coastal vulnerability and sensitivity models have been around for decades and have paved the way for applying similar techniques to heritage sites. The application to heritage sites is based on the assumption that heritage sites are inherently linked to the land on or in which they are situated.

2.2 Sea Level

There has been significant research on the potential for sea levels to rise in the foreseeable future due to climate change, and one of the most cited supporting documents is the Intergovernmental Panel on Climate Change’s 2007 report (Solomon et al. 2007). This report bases potential sea-level rise on process-based modelling and predicts sea levels to rise between 18-59cm by 2100 (Solomon et al. 2007). Process-based modelling techniques project sea levels by modelling the inputs from the various contributing processes. As well as process-based models, semi-empirical models have also been used to predict future sea-level rise, previous sea level data and measured relationships with temperature are used to project future changes. Notably Rahmstorf (2007) used this method to project sea levels rising by 50-140cm by 2100. The more recent 2013 IPCC report uses a process-based model similar to the 2007 report. However, updated information has led to a higher projected sea level rise between 26-82cm (Church et al. 2013).

There is a substantial gap between many process-based and semi-empirical sea-level projections, with the latter generally projecting higher values (Moore et al. 2013). However according to Moore et al. (2013), there has been significant convergence in projections from both types of models in the more recent publications, often due to larger values for process based models with the inclusion of more robust ice sheet data. The original 2007 IPCC Report (Solomon et al. 2007), showed much lower projections than the subsequent 2013 report (Church et al. 2013). However many experts still agree that under a situation of
continuing global temperature increase, sea levels will rise much higher than the 2013 report suggests, with the average projections of 90 surveyed experts being 70-120cm by 2100 (Horton et al. 2014).

In terms of the study area, the Illawarra coast in NSW, there is a slight variation on the effects of sea level rise locally. The 2009 NSW government sea level benchmarks of 40cm by 2050 and 90cm by 2100 were based on the 2007 IPCC report. Taking the highest figure of 59cm by 2100 and adding 20cm to account for accelerated ice melt, bringing the figure to 79cm (O’Kane 2012). This addition brings the figure much closer to the 2013 report projections of up to 82cm by 2100. In addition to this, the factor of local sea level variation due to higher sea surface temperature and the strengthening of the East Australian Current was derived from McInnes et al. (2007), and adjusted by adding a further 14cm (O’Kane 2012). The figure of 93cm by 2100 was reached, this was rounded to 90cm (O’Kane 2012). Due to the addition of accelerated ice melts this model sits comfortably within the figures of the latest 2013 IPCC report (Church et al. 2013).

The NSW Government has since revoked the sea-level benchmarks in a 2012 change, as part of a broad review on sea level and coastal erosion management (NSW Planning & Environment 2015), however many councils continue to use them to inform their coastal planning and projections. Wollongong City Council released the 2010 Coastal Zone Study report (Cardno Lawson Treloar 2010) based on the NSW 2009 sea level benchmarks. In 2013, the subsequent draft Wollongong Coastal Zone Management Plan indicated that Wollongong City Council would continue to use the now revoked benchmarks (Wollongong City Council 2013). In fact, Lappin (2013) states “A survey conducted by the NSW Office of Environment and Heritage in January 2013, indicates that the majority of coastal councils in the state are continuing to use the previous state-wide sea level rise benchmarks”. Councils associated with the Southern Councils Group, which includes Shellharbour Council immediately to the south of Wollongong, are continuing to use the previous benchmarks in line with legal advice given to NSW coastal councils by Statewide Mutual. The advice recommending that councils, “not move away from the benchmarks, until further advice is given by OEH as to a new approach for sea level rise planning” (Statewide Mutual 2013). While the rescinded state benchmarks are legally the best basis for councils, the close agreement of the figures to the most recent IPCC report maximum projections, suggest that the benchmarks still provide a valid scientific basis for planning as well (Church et al. 2013).
2.3 Local Indigenous History

The Illawarra region is the traditional home of the Dharawal people, and there is evidence of Aboriginal presence in the area for close to 20,000 years before present (Organ and Speechley 1997, Bowdler 1976). The region is rich in natural resources and has been described as the ‘garden of NSW’ (Organ and Speechley 1997). High availability of natural resources in the area meant that the region had an Aboriginal population density of around 2-4 people per square kilometre in pre-European times, which was likely among the highest on the continent (Organ and Speechley 1997). Dharawal people have long been incredibly well connected with this lush landscape, with utilisation of resources in all of the major environmental zones: marine, intertidal and estuarine environments as well as the forested escarpment and woodland plains above and below it (Wesson 2005). It is estimated that the region had a population of 2000-3000 people by 1788 (Organ and Speechley 1997).

From about 20-17,000 years ago during the Last Glacial Maxim, sea levels were around 120-130m lower than Present Mean Sea Level for much of eastern Australia (Lewis et al. 2013). This suggests shorelines for the Illawarra region would have likely been several kilometres east of the present coast. The rise and movement of the sea inland towards the present day coastline would potentially have drowned many older Indigenous sites that were situated on the palaeoshoreline (Rowland and Ulm 2012). In fact Organ and Speechley (1997) suggest that Aboriginal migration into Australia some 50,000+ years ago followed a coastal trend, moving south from Asia and spreading inland only during recent times (approximately 5000 years ago). If this is the case, the Dharawal people may have been in the region earlier than 20,000 BP as it is entirely possible that much older sites have been lost to sea level rise over successive glacial cycle. There are examples of submerged sites being found on other continental shelves around the world that were occupied during lower sea-level stands, particularly in North-west Europe and the Mediterranean (Bailey and Flemming 2008, Momer 2000, Fitzpatrick et al. 2015).

2.3.1 Bass Point

The archaeological record at Bass Point has evidence of some of the earliest evidence of Indigenous occupation in the Illawarra with uncalibrated radiocarbon ages of up to 17,000 ± 650 BP (Derbyshire and Bowdler 1999). The OEH states that Bass Point is considered to be one of the most significant Aboriginal archaeological sites to be excavated in NSW, and is a rare example of established occupation that continues to be of exceptionally high significance.
to the Aboriginal people of NSW (Office of Environment & Heritage 2016a). The Bass Point sites have been studied since the late 1960’s, and the area is one of the best documented in the Illawarra region. A relatively continuous record of occupation by Indigenous people on the Point has led to considerable evidence of the structure of societal groups and habits within the region compared with other regions in Australia (Bowdler 1976).

2.4 History at Risk

While sea levels have been rising for much of the last ~18,000 years they peaked at about 7,000 BP slightly above Present Mean Sea Level, before gradually falling to current levels from 2,000 years ago (Sloss et al. 2007). Due to anthropogenic climate change sea level rise has been shown to be accelerating (Erlandson 2012, Rahmstorf 2007, Church et al. 2013). Rising sea levels have the potential to put many coastal archaeological and heritage sites at risk. In fact, the United Nations have listed sea level rise and coastal erosion as one of seven key processes resulting from anthropogenic climate change that will have a negative impact on World Heritage (Daire et al. 2012). Coastal sites have long been at risk from threats such as coastal modifications, destruction of wetlands, marine erosion as well as population growth and development. The increase in the rates of sea level rise will add to these risks considerably through erosion, increased storm cycles and intensity as well as inundation (Erlandson 2012). More than half of the world’s population live on the coast, and with these populations and infrastructure coming under increased pressure from sea level and climate factors, secondary impacts (such as changed settlement patterns and construction of coastal defences) will surely impact sites (Bickler et al. 2013).

Many sites have already been lost in recent times. For example, Hurricane Katrina destroyed over 1000 heritage sites along the deltaic coastlines of the Gulf of Mexico (Erlandson 2012). Aside from extreme events, an increase in the rate of mean sea level rise leads to millions of sites being damaged or lost to marine erosion around the world each year (Erlandson 2012). Hundreds of archaeological and other heritage sites are already suffering damage from marine forces or at present are perilously close to the water’s edge along the English Channel and Atlantic coasts of Europe, these sites may disappear in very short time scales of several months or years (Daire et al. 2012). The urgency of documenting these sites has led to charity-driven operations in Scotland, England and France aimed at quickly recording as much of the endangered history as possible (Reeder-Myers 2015). As sea levels continue to
rise more and more, sites not currently considered vulnerable will surely be in danger. The question is which sites, and at what point.

The Australian coastline is significantly longer than those of the northwest Europe, thus documenting heritage sites across the entire coastline would be a much larger, more logistically-complicated and resource intensive task. Nevertheless, it is safe to assume that many heritage sites both documented and undocumented would also be at risk to the impacts of sea level rise along the expansive Australian continental shelf. In fact, sites in the Illawarra region show distinct evidence of having been modified by marine forces, especially in the last few decades. Hughes & Sullivan (1974) demonstrated that multiple coastal sites in the Illawarra, and elsewhere in NSW, contained evidence of being reworked by marine forces in the past, including four individual sites studied on Bass Point (Hughes and Sullivan 1974). This evidence would suggest that heritage sites in the Illawarra have been influenced by coastal forces in the past, and sea level rise will likely have similar effects on these sites into the future.

The increase in mean sea level will certainly have geomorphological effects on the coastline, although individual coastal areas will likely respond differently and over differing time scales. Geomorphological changes to the coast will likely lead to the transformation and/or vulnerability of heritage sites. Broadly, the major change to the coast usually associated with sea level rise is erosion, but sediment accretion and burial of heritage sites is also possible (Daire et al. 2012, Lewis 2000). In some cases, such as low energy coastlines, burial of sites often leaves them intact and may not necessarily destroy the site (Lewis 2000). High energy areas of coasts differ significantly. In these circumstances, sites may suffer damage, and remains become scattered, and in some cases sites may be completely lost due to dynamic erosion processes (Westley et al. 2011, Erlandson 2012). While some sites may appear to be relatively undamaged even small disturbances may limit research potential and methods of analysis (such as accurate dating), and adversely affect scientific investigation generally.

While erosion is not the only issue facing heritage sites, it is generally of the greatest significance, as the potential for damage and change to sites is tied heavily to the landscape in which they are situated. In the 2009 report by the Australian National University (Australian National University 2009) regarding the implications of climate change for Australia’s world heritage areas, it is highlighted that many Indigenous midden sites, sea cave deposits and other archaeological sites are highly dependent on the protection and maintenance of their
underlying and/or encompassing landforms. It was also acknowledged that due to spiritual values, which appear to be atemporal, the loss of sacred sites can be devastating to the community (Australian National University 2009).

There are hundreds of Indigenous significant sites in the Illawarra region that are currently registered with the OEH (Cardno Lawson Treloar 2010). Of these sites, many are located near the coastline. However, the significance of the area for Indigenous people does not solely rest upon registered heritage sites. Culture and history are often linked to landscapes as a whole rather than tied to specific sites independently of one another, while heritage sites are important they are part of a larger narrative (Ross and "Members of the Quandamooka Aboriginal Land Council" 1996). Songlines are a classic example of this notion. In some Indigenous cultures, songlines are used to bring together all living and non-living things, material objects, people’s names as well as those of the land, winds and seasonal events are all given a place in these songs (Bradley 2008). The western idea of history and culture is not necessarily applicable to Indigenous cultural heritage. The interlinked nature of things within songlines, however, reframes the significance of the seemingly insignificant. A site or feature of the landscape may play a role in terms of a larger cultural narrative of the area, giving it more significance than may appear when viewed in isolation (Bradley 2008).

2.5 Coastal Models

With nearly half of the world’s population living within 100km of the coast, and 100 million living in coastal areas that are less than a metre above sea level (Erlandson 2012), considerable work has been done over the last few decades in terms of modelling the vulnerability of particular coastal areas as well as assessing potential impacts to coasts in the event of sea level change. Many of these studies have assessed the potential impacts of sea level change on coastal populations and infrastructure. New York is an example of a coastal megacity which has been the focus of several studies on sea level rise and the related potential impacts to population and infrastructure (Shepard et al. 2012, Gornitz et al. 2001). The models created for New York, like many similar studies utilise data from Digital Elevation Models (DEM) as well as socioeconomic data, erosion rates and infrastructure and building information. These models based in areas of high population are primarily concerned with the effects of sea level rise on people and the built environment. The focus on the current anthropic landscape and infrastructure means that impacts on natural habitats of other species, or impacts to things such as heritage sites may be missed. There are many other
studies, however, that do focus on the natural environmental impacts instead of the human and infrastructure impacts, such as changes to habitats and geomorphology (Kane et al. 2015), or water salinity and sediment changes (Wong et al. 2015). It is difficult to create any model that gives the ‘full picture’ as the complexity and varying rates of change in each affected parameter make combining every type of change and its outcomes virtually impossible. Models of sea level rise and its impacts on the coast are therefore related to the specific question of the research and may not give accurate results for other questions within the same study area.

Coastal models are heavily dependent on the quality of the data that are used to create the model, and this is particularly apparent in the case of DEMs which are regularly used in sea level rise modelling scenarios. In most cases, LiDAR DEMs are significantly more vertically and horizontally precise than older methods (Poulter and Halpin 2008). However there can be variation in the resolution of different LiDAR datasets, often due to differing data-gathering foci, or constraints on data collection. In the case of coastal sea level rise models, horizontal resolution has been shown to be very important due to the importance of hydrological connectivity in modelling inundation rates and extent (Poulter and Halpin 2008), with larger grid sizes often obscuring the nature of hydrological connectivity and overestimating inundation extents (Poulter and Halpin 2008). Vertical resolution can be fairly precise in modern DEMs, although the margin of error is often larger than the relative rates of yearly sea-level rise, by an order of magnitude, making yearly projections difficult (Poulter and Halpin 2008). This is part of the reason that it is more common to use multi-decadal time scales in models of sea level projections—precise yearly changes are not possible due to high margins of error in these temporal ranges.

In the Illawarra region, there have been examples of sea level rise scenarios modelled, notably by Cardno Lawson Treloar Pty Ltd (2010), who completed a model on behalf of Wollongong City Council, investigating the potential extent of impacts of sea-level rise under the former NSW state government benchmarks on the Wollongong coast. The sensitivity of the Wollongong coast to the impacts of rising sea levels has also been investigated outside of the council and government framework (Abuodha and Woodroffe 2010). These studies, however, are not directly comparable, with one study focusing on the potential extent of specific impacts such as erosion, while the other is a sensitivity model and not designed to forecast the extent of possible beach recession (Abuodha and Woodroffe 2010). The studies
mentioned do both highlight that the Illawarra coastline is susceptible to pressures and potential impacts caused by a rise in sea levels in the area.

2.6 Estuarine Models

Estuaries have been defined by Boyd et al (1992 p. 142), “as the seaward portion of a drowned valley which receives sediment from both fluvial and marine sources, and which contains facies influenced by tide, wave and fluvial processes”. In South East Australia, most estuaries formed in drowned coastal valleys that were cut by rivers during sea level low stands of the Quaternary glacial periods (Roy et al. 2001). In the context of climate change and sea level rise vulnerability, estuaries have not been assessed to the same extent as coastlines. Rogers and Woodroffe (2016 p. 128) suggest that this “may relate to the complexity of estuarine environments that occur in a range of geomorphological settings and are exposed to a variety of climate-change drivers”.

Modelling of estuarine landscapes in the context of sea level rise has often developed from the framework of coastal vulnerability. Studies have examined estuarine vulnerability using an index approach, similar to those developed for coastal vulnerability assessments (Denner et al. 2015). However, coastal vulnerability index based approaches often omit terrestrial hazards. Alternative approaches have utilised hydrodynamic modelling techniques, both with, and without input from terrestrial hazards (Monbaliu et al. 2014, Morris et al. 2013, Wolanski and Chappell 1996). Rogers & Woodroffe (2016) developed a method of assessment which was applied to the NSW south coast. The approach utilised geomorphology as an indicator of the biophysical vulnerability of estuaries to both coastal and terrestrial hazards. The model incorporated inundation and erosion hazards from fluvial and coastal sources (Rogers and Woodroffe 2016).

2.7 Archaeological Models

The risks posed by sea level rise to many coastal archaeological sites have driven a number of investigations and projects over the last decade. In the United Kingdom and France for example charity driven initiatives have been implemented to investigate rising sea levels and their impacts on heritage sites. In Scotland there is Scottish Coastal Archaeology and the Problem of Erosion (SCAPE), in England the Rapid Coastal Zone Assessment Survey (RCZAS) and in France there is Archéologie Littorale et Réchauffement Terrestre (ALERT) (Reeder-Myers 2015). These national initiatives usually focus on surveying the entire
coastline and any nearby heritage sites, helping to identify the sites most at risk to the impacts of erosion and sea-level rise. Countries with much larger coastlines, such as the United States and Australia are at a disadvantage when it comes to this approach of studying the entire coast, because of the much larger areas and longer coastlines (Reeder-Myers 2015).

Regional scale projects can still cover large areas, but can lack the detail of finer local scale studies. Reeder-Myers (2015) uses a larger regional scale in a Cultural Resource Vulnerability study in California, where three distinct areas were studied each spanning 1000-1700km² in area and having coastlines of between 418-1500km in length. The method is similar to many coastal vulnerability studies with important factors (such as geology of the coast, slope, elevation and distance of the heritage site to the shoreline) all given a value and used in a vulnerability equation (Reeder-Myers 2015). This approach is very useful for large scale studies, and, with quality high resolution data, large areas can be investigated. One area where error could occur is in how precisely heritage sites can be positioned, with the author acknowledging that these data have come from many different archaeologists and are therefore susceptible to multiple errors (Reeder-Myers 2015). This approach can highlight vulnerability of cultural resources, but is not intended to predict when sites will be affected or the specific ways in which this may happen at a given site. The large scale of some coastlines also means subtle small scale changes in local geomorphology and coastal erosion risk are difficult to determine.

Studies on a regional to local scale can be more precise, particularly if the region is already well studied in the context of coastal processes and hazards. Vulnerability models can incorporate results of previous studies, especially in areas such as ground stability risks or flood hazard, to create models which not only flag potential vulnerability but also can highlight the types of impact that are likely to affect individual sites (Bickler et al. 2013, Reeder et al. 2012). Incorporating projected changes with current data also allows for the projection of impacts over longer timescales in the study area. In the study of climate change on the archaeology of New Zealand’s Whangarei district, the benefits of incorporating previous studies that had been conducted in the area where substantial, allow a broader investigation of potential hazards to sites (Bickler et al. 2013). Using pre-existing coastal erosion risk data was useful for examining the current risks to sites in the region, and a 10m buffer was created to determine sites that are close to these hazard areas. In terms of predicting future impacts, the data are still useful, although potentially less accurate as the method for projection was to increase the buffer zone to 50m (Bickler et al. 2013). While it is
useful to identify sites at potential future risk, this approach may not necessarily reflect the changes in coastal erosion process and extent over a larger timescale. Smaller scale studies also benefit from being able to incorporate more precise or localised data. Coastal erosion risk, for example, is highly variable and may change over scales of 10s of metres, and multi kilometre models can miss these subtle changes (Reeder et al. 2012).

Some areas have other individual risks that may not be present elsewhere. Urbanisation for example, has also been included in cultural resource vulnerability studies as a local risk to sites (Reeder et al. 2012). These types of model have a large advantage in that they can often be desk based in nature, allowing for relatively quick and cost effective analysis of the potential impacts for heritage sites in a given area (Westley et al. 2011).

Individual site models are generally the most accurate in predicting specific changes that may affect a site. In a study of several sites in Georgia, USA, Robinson et al. (2010) investigated the changes in shorelines over time using historical aerial photographs and analysing the differences over time to gather a trend of shoreline recession. This type of approach is extremely useful in determining the potential for impact to a particular site, but relies on the availability of high quality historical data. Few sites will have adequate available data for this type of approach. Individual site vulnerability has also been assessed in France by Shi et al. (2012) in a study that used individual site surveys to assess impacts on sites and proximity of the site to potential hazards. These data were then used to create a resource vulnerability index to determine sites at the most risk (Shi et al. 2012). In both examples, it is clear that individualised investigations of site vulnerability can be very precise, but they are also very time and resource intensive. The major drawback is that the intensive nature of these studies makes it difficult to efficiently analyse very large numbers of sites in a reasonable timeframe or resource efficient manner. Localised or individual investigations can be useful for gathering information on the potential for impacts on a site at small analytical scales; and as in the case of Shi et al. (2012) the development of a Vulnerability Evaluation Form may mean that assessing sites could be done efficiently by many individuals simultaneously, making information gathering much more effective.

Other types of modelling exist for investigating future impacts of sea level rise. For example Johnson, Marrack and Dolan (2015) examined the impacts on Hawai’i’s archaeology of the 2011 tsunami, which was measured as 1.06m above mean high water. This information was compared with DEM data driven extents of sea water inundation under several sea level rise
scenarios to give an indication of future impacts on sites. The results allowed a representation of the potential for damage under sea level rise scenarios, but the models could not take into account other damage that would be a result of wave dynamics changing and the added effect of this (Johnson et al. 2015). A caveat to this modelling strategy is the need for a tsunami to take place in the study area, an occurrence that is fairly unlikely in most settings. The study does highlight, however, that models can be created in a range of ways, and that local events and influences can be highly effective when incorporated well into studies.
3 Coastal Site Study

3.1 Coastal Site Sensitivity Index

The basis for the coastal approach taken in this thesis is the notion that the sensitivity of a heritage site is inherently linked to the sensitivity of the location, or of the landscape on which it lies or is a part of. There have been several previous archaeological studies into the potential effects of sea level change on heritage sites, conducted primarily in North America and Europe. These studies assess site vulnerability through the use of established coastal vulnerability index techniques, and infer vulnerability of the sites according to their position on the landscape (Westley et al. 2011, Reeder-Myers 2015). The Illawarra coastal shoreline has previously been examined using an index approach, with a sensitivity index developed by Abuodha & Woodroffe (2010). The sensitivity index included additional variables that differed from the classic North American developed Vulnerability Index, such as Barrier Type and Shoreline Exposure. These additional variables were intended for the South-East Australian context. The Coastal Sensitivity Index developed by Abuodha and Woodroffe (2010), focused on the Illawarra region of NSW, and is thus highly appropriate for use in the current study area to assess coastal heritage site sensitivity. This model was adapted for the current study to create a Coastal Site Sensitivity Index (CSSI).

The regional sensitivity analysis adapted some parts of the Abuodha & Woodroffe (2010) study to better suit current datasets. The regional sensitivity analysis was performed within the ArcGIS program, utilising the Spatial Analyst extension. Digital Elevation Model (DEM) data was used primarily to calculate slope. This dataset was updated to the Shuttle Radar Topography Mission (SRTM) DEM developed by Geoscience Australia, as opposed to the 25m DEM provided by the NSW Department of Lands and Property that was used by Abuodha & Woodroffe (2010). The analysis also used a raster-based approach with ~28m cells based off the SRTM DEM. This approach differed to the large cells used by Abuodha and Woodroffe (2010), which were over a kilometre in length. The increased spatial resolution allowed analysis of specific landscape points as opposed to broader regional cells, which is important for determining local site sensitivity. The current analysis also excluded estuarine areas to focus on the open coastal segment, primarily due to the differing effects of tides in estuarine settings which may be amplified or diminished due to the specific estuarine morphology (Rogers and Woodroffe 2016), as well as differences in wave action and effects.
Due to these issues, it was deemed best to exclude estuarine heritage sites so as to instead focus on the open coast.

The data used to create the Coastal Site Sensitivity Index included both Process and Structural variables. The variables consisted of Wave Height, Tidal Range, Relative Sea Level Rise, Coastal Slope, Rock type, Shoreline Exposure, Distance to Shoreline and Geomorphology (Table 3.1). Additional variables used in the Abuodha & Woodroffe study (2010) included Shoreline Change and Barrier Type, however, these variables were excluded.

The basis for excluding Shoreline Change from the current study was due to the assertion by Abuodha & Woodroffe (2010) that when this variable was excluded, the pattern of sensitivity in the model did not markedly change. This is likely due to the “complex erosional and accretionary behaviour along this coast which precludes forecasting the direction or rate of shoreline change” (Abuodha and Woodroffe 2010). The further exclusion of Barrier Type, was due to the complexities of analysing the coast with a smaller cell size. The use of smaller cell sizes, of tens of metres as opposed to greater than a kilometre, means that many of the cells are rocky coast segments. Barriers are described as ‘elongated, shore-parallel sand bodies that extend above sea-level’ (Abuodha and Woodroffe 2010). The fact that many cells would not have a sand barrier presents a problem, as a consistent dataset cannot be created to compare sites across the region. It was for this reason that the variable Barrier Type was omitted.

Distance to Shoreline was added to the already existing variables utilised by Abuodha and Woodroffe (2010), as a means of more accurately representing site-specific sensitivity. For example, a site 500m from the shore will have a different level of sensitivity to coastal processes compared to one that is 2m from the shore, even with all other variable conditions remaining the same. The use of Distance to Shoreline as a variable is common in this type of study, with regards to assessing individual site sensitivity (Reeder-Myers 2015, Reeder et al. 2012, Bickler et al. 2013).

The equation for the CSSI was adapted directly from Abuodha & Woodroffe (2010). The individual variables were each applied with an equal weighting as shown in Figure 3.1.
CSSI = \sqrt{\frac{a \times b \times c \times d \times e \times f \times g \times h}{8}}

(Figure 3.1, CSSI equation adapted from Abuodha & Woodroffe (2010). $a =$ Geology, $b =$ Coastal Slope, $c =$ Geomorphology, $d =$ Shoreline Exposure, $e =$ Distance to Shoreline, $f =$ Tidal Range, $g =$ Wave Height and $h =$ Sea Level Rise)

Table 3.1, Site Sensitivity Value Criteria (Adapted from Abuodha & Woodroffe (2010))
3.1.1 Study Area

The study area was determined as a 500m buffer inland from the shoreline of the Illawarra region in southern NSW (Figure 1.1), however the CSSI excluded the shoreline of Lake Illawarra. The study area for the CSSI can be seen in Figure 3.2. The Northern boundary of the study area was at Otford, and the study area then encompassed a 500m ribbon which terminated at Killalea State Park, just South of Bass Point. A polygon representing this area was created to allow clipping of relevant data to the defined area.

3.1.2 Site Data

The data for the Indigenous heritage sites came from the Aboriginal Heritage Information Management System (AHIMS), which was obtained through the New South Wales Office of Environment and Heritage (OEH). The locations are represented as points, with additional attributes attached such as the type of site present e.g. (Artefact, Shell, Burial, Potential Archaeological Deposit (PAD), Scarred Tree, Aboriginal Resource Gathering, Aboriginal Ceremony and Dreaming), source of location data e.g. (1:250,000 Imperial, 1:25/50/100k conversion, Differential GPS, non-Differential GPS) and contribution to primary importance.

3.1.3 DEM & Slope

The DEM used for the regional analysis was part of the SRTM data released by Geoscience Australia. Elevation data is represented in cells of 1 arc second, which is equivalent to just under 28m. These data were used to create a slope dataset in raster format (Figure 3.2). Coastal slope was calculated in degrees. Degrees of slope were then classified into 5 sensitivity categories, to give each raster cell a value according to the CSSI.

3.1.4 Geology

The underlying geological data for the study area was sourced from the NSW seamless geology package, produced by NSW Department of Trade & Investment. Polygon layers that intersected the study area were exported and clipped. A raster dataset was created by converting these layers into the raster format to align with the SRTM DEM cell position and sizing. The raster was then classified with values for each cell determined by the sensitivity category of each rock type according to the CSSI (Figure 3.3).
Figure 3.2, Slope values of the CSSI study area represented in categories according to the CSSI (Table 3.1). (© Commonwealth of Australia (Geoscience Australia) 2011)
Figure 3.3, Geology of the Illawarra coast derived from NSW Seamless Geology Package, represented according to CSSI values. (© State of New South Wales (Department of Trade and Investment, Regional Infrastructure and Services) 2015)
3.1.5 Shoreline Exposure

The exposure of the shoreline with regards to the predominant swell direction was determined by creating a polyline layer, capturing the orientation of the shore. Polylines were digitised according to NSW aerial imagery and 1m Light Detection and Ranging (LiDAR) derived DEM datasets. These datasets were produced by NSW Land and Property Information. The SRTM DEM was also used to cross-reference elevation data. The shoreline was determined as between -0.5 and 0.5m elevation, and then crosschecked with the NSW Land and Property Aerial Imagery. The polyline was separated at the vertices; the orientation of each individual line was then able to be determined from North. This made it possible to obtain comprehensive data on the orientation of individual beaches and shoreline sections in relation to predominant swell. The predominant swell direction in the region was found to be South South-East. This has been shown in the study of NSW waverider buoys over a multi-decadal time scale (Kulmar et al. 2013). The shoreline orientation data were used to create buffer zones, to determine areas that were within 500m of the various orientation categories (Figure 3.4). Areas that were influenced from more than one category of exposure due to the shoreline orientation were assigned the highest applicable value.

3.1.6 Geomorphology

Geomorphology of the study area was classified into four categories based on the CSSI value table. The geomorphology was derived using 1m LiDAR DEMs to establish elevation and slope, in conjunction with NSW Aerial Imagery and NSW Seamless Geology data layers. The Geomorphology for each section of coast was created using polyline classification of the shoreline, which then enabled the application of a buffer. The buffered areas were converted to raster format (Figure 3.5), assigning values to the study area according to the CSSI Table 3.1.
Figure 3.4, Values for shoreline exposure of the Illawarra coastline to south south-east swell, represented by coloured categories determined by the CSSI.
Figure 3.5, Geomorphology of the Illawarra coastline, represented in categories determined from the CSSI (Table 3.1).
3.1.7 Distance to Shore

The distance of sites from the shoreline was included into the index calculation. The shoreline was defined by the Bureau of Meteorology AHGF Shoreline Hydroline. A raster dataset was created using a Euclidean distance calculation. This dataset was used to assign values to cells based on their distance to the shoreline. The distance measurements were then used to group cells into sensitivity classes. Areas 0-50m from the shore were given a value of 5 (Very High), 51-100m were valued at 4 (High), 101-200m were 3 (Moderate), 201-300m were 2 (Low) and 301-500m were 1 (Very Low) (Figure 3.6). Euclidean distance calculations are based on the raster cell size. The cell size for this raster was ~28m, as it was made to fit the template of the SRTM DEM. Due to the size of each cell, and the method of measurement, it was not suitable to class sites according to distances less than 50m.

3.1.8 Tidal range

The tidal range for the NSW beaches is given in Short (2007) as uniform across all relevant beaches in the study area. The Spring tide average range is 1.2m with a 0.8m Neap tide. Therefore, for the purpose of the current study, the tidal range was taken as 1.2m and applied uniformly across the coast, and buffered to apply to the study area. The raster for the study area was given the value of 3 according to the CSSI sensitivity category Table 3.1.

3.1.9 Wave Height

Wave height data were also obtained from Short (2007), with a mean wave height of 1.6m. This mean wave height is listed for the entire NSW coast, therefore is applicable to the Illawarra region. Data from waverider buoys analysed by Manly Hydraulics also supports this with the mean $H_{\text{sig}}$ recorded at 1.6m at Botany Bay and 1.58m at Port Kembla (Shand et al. 2011). Therefore the value of 1.6m was used for the study area and the value of each cell was determined to be 4 for this variable.
Figure 3.6, Distance to shoreline values determined for the Illawarra study area. Distance values were placed in categories from the CSSI shown in Table 3.1.
3.1.10 Sea Level Rise

Sea level rise has been observed over the past few decades to have been increasing. Satellite altimeter readings have suggested Global Mean Sea Level (GMSL) rise up to 3.2mm ± 0.4mm/year over the last few decades (Church et al. 2013). However, recently work has shown that this increase is slightly overestimated due to instrumental drift. The more accurate estimation is between 2.6mm ± 0.4mm and 2.9mm ±0.4mm per year (Watson et al. 2015). The figures produced by Watson et al. (2015) refer to Global Mean Sea Level (GMSL) rise; they do not necessarily fit exactly with the Illawarra region of NSW. However, McInnes et al. (2015) do suggest that the increase in Southern Australia is likely to be very close to that of GMSL, with local variation taken into account. IPCC projections of GMSL over the next century suggest a significant increase in sea level rise rates is likely (Church et al. 2013, Solomon et al. 2007). In the Wollongong region planning for the future impacts of sea level rise has taken place based on the former NSW government benchmarks (Wollongong City Council 2013, Lappin 2013). Many councils have been directed to continue using these projections until further advice is provided (Statewide Mutual 2013). The former NSW benchmarks were set at a rise of 40cm above 1990 levels by the year 2050 and 90cm by 2100, and to reach these marks yearly sea level rise would have to average 6.7mm/year and 8.2mm/year respectively. Taking into account both current and projected rates of sea level rise the value of 5 was given to the study area. This was to keep in line with current planning strategies of local councils, and the significant increases projected for sea level rise rates over the coming decades. The raster could also have been set at the value of 4, according to the figures given by Watson et al. (2015). However, the given margin for error extends into the higher category to result in a value of 5, and in light of the significant increase in projected rates of sea level rise, the value of 5 was settled upon for the CSSI.
3.2 Results

The Coastal Site Sensitivity Index was applied to 126 sites in the Illawarra regions coastal strip, from Otford in the North to Killalea State Park, just South of Bass Point. Each of the 126 sites was assigned a value derived from the CSSI. The index produced 34 unique sensitivity values ranging from 18 to 153. These values were divided into Quintiles and labelled as ‘Very Low’ to ‘Very High’ sensitivity. The distribution of the sensitivity values across the region is represented in Figure 3.7. To further examine the sensitivity of sites, the region was divided into five areas: north-most Sandon point (Figure 3.8), Wollongong (Figure 3.9), Port Kembla (Figure 3.10), Barrack Point (Figure 3.11) and furthest south Bass Point (Figure 3.12).

Figure 3.7, CSSI MAP. The map shows the heritage sites from the AHIMS database in the Illawarra coastal study area. Sites are coloured according to sensitivity categories determined by the CSSI. (© NSW Office of Environment and Heritage 2015)
Figure 3.8, Sandon Point. The northern section of the CSSI study area around Sandon Point, heritage sites are shown with colours determined by site sensitivity categories. (© NSW Office of Environment and Heritage 2015)
3.2.1 Sandon Point

The Northern section of the coast around Sandon Point predominately contained ‘Moderate’ to ‘High’ sensitivity ranked sites (Figure 3.8). There were two exceptions, the first being the northernmost site at Scarborough water reservoir. This site ranked ‘Very Low’ due to high slopes, a cliffed coastline, Narrabeen group geology and a large distance to the shoreline. The other exception was the Sturdee Avenue site which ranked ‘Low’ largely due to distance from the shore. The remaining sites were influenced by the primary geological presence, which was a combination of the Illawarra coal measures and Quaternary sediment. Additionally, CSSI values of the remaining sites were influenced by low slopes and high shoreline exposure of the area, and relatively sensitive geomorphology. The main differentiation of sites in the area around Sandon point site was distance to shoreline, with the exception of the Scarborough site which had a large slope and cliffed coast influence.

3.2.2 Wollongong

The Wollongong section consisted of the area spanning from Bellambi point in the north, southwards to Wollongong Harbour. Wollongong had sites classed from ‘Low’ to ‘Very High’ sensitivity present (Figure 3.9). The area north of Wollongong Harbour was almost entirely Quaternary sediment, with fully exposed beaches backed by plains and very low slope values. These factors led to a significant number of sites being classed as ‘High’ sensitivity. The area was similar to Sandon Point (Figure 3.8), with the addition of higher ranked shoreline exposure, and less prominence of the Illawarra coal measures. One particular site ‘Marine Parade’ was particularly noteworthy, having a sensitivity value of ‘Very High'. The index value of 153.09 recorded for this site was also the highest individual value of the entire coastal study area from Otford to Killalea. Further south around Wollongong Harbour, there were several ‘Low’ classed sites. The primary difference in categories between the Wollongong Harbour sites and those further north, was the relative protection from south south-east wave action and the outcrop of Shoalhaven group sandstone. The Shoalhaven group sandstone in particular provided a more stable geological base.
Figure 3.9, Wollongong. The section of the CSSI study area between Wollongong and Bellambi Point, sites in the figure are shown coloured according to sensitivity categories determined by the CSSI. (© NSW Office of Environment and Heritage 2015)
Figure 3.10. Port Kembla. The Port Kembla section of the CSSI study area, sites are represented as coloured points. Colours are determined by the CSSI sensitivity categories. (© NSW Office of Environment and Heritage 2015)
3.2.3 Port Kembla

The Port Kembla area had a significant spread of sensitivity classes between sites. Sites on Hill 60 were shown to be much less sensitive than those either side of the point, on the low flat beaches (Figure 3.10). The ‘Very Low’ category sites on Hill 60 were influenced by high slopes, outcrops of Shoalhaven group siltstone and low exposure to wave action. Sites were also protected from wave action by the cliffs to the south. The sites that are located both north and south of Hill 60 were located on low, flat, sandy beaches, this is largely the reason for the ‘High’ and ‘Very High’ rankings of these sites. Distance to shoreline was the main variable that determined the difference in sensitivity category of sites to the south of Hill 60, and their resulting ‘Low’ classifications.

3.2.4 Barrack Point

‘Barrack Point’ included both Barrack point and the lake entrance (Figure 3.11). The sites in the region were classed from ‘Low’ to ‘Very High’ sensitivity. The entrance to Lake Illawarra was flanked by several sites, ranging from ‘Low’ to ‘Moderate’ sensitivity, according to the CSSI. These sites were on low sloping, sandy beaches and barriers, composed of Quaternary sediment. The distance to the shore and relatively protected shoreline mitigated some of the higher values recorded for the other variables at these sites, accounting for the ‘Low’ and ‘Moderate’ categories. A few of these sites around the lake entrance were very close to the edge of the channel that connects Lake Illawarra to the ocean. Due to the exclusion of estuaries from the CSSI this section of water in the channel was not defined as ‘shoreline’. This exclusion will certainly have an effect on the sensitivity classes of the sites directly adjacent to this channel, and the results for these sites are likely erroneous.

Barrack Point has sites classed as ‘Moderate’, ‘High’ and ‘Very High’ sensitivity. The difference between the ‘High’ and ‘Very High’ ranked sites in terms of the model was the distance to shore. The sites located either side of the channel just North of Barrack Point were similar to those at the Lake Illawarra entrance. With the channel not recorded as ‘shoreline’, true sensitivity of these sites will likely differ from the values of the model. The remaining ‘Moderate’ classed site was located directly in the centre of Barrack Point. This site had a lower value than the nearby channel sites due to being further from the shore, and location upon the outcrop of Shoalhaven Group sandstone that forms the point itself.
Figure 3.11, Barrack point, Barrack Point and Lake Illawarra entrance. Heritage sites in this section are represented by coloured points, colours are determined by sensitivity categories determined by the CSSI. (© NSW Office of Environment and Heritage 2015)
3.2.5 Bass Point

The Bass Point section (Figure 3.12) represents the southern limit of the study area. Site sensitivity categories ranged from ‘Very Low’ to ‘High’. The ‘Moderate’ and ‘High’ sensitivity sites were all situated on Quaternary sediment layers. This included the sites along Shellharbour Beach and the ‘Moderate’ classed sites along the middle of the Bass Point headland. The ‘Low’ and ‘Very Low’ classed sites were situated upon Bumbo Latite. Bumbo Latite is a member of the Gerringong Volcanics, and was given a value of 2, or ‘Low’ in the CSSI. This geological influence in part explains the difference in ranking of sites that were geographically close, yet defy the general trend whereby sensitivity is lowered as distance from the shore increases (Figure 3.13). Shoreline exposure to predominant swell direction also had a substantial effect in differentiating sensitivity of closely located sites, particularly around Bass Point. This was due to the multiple small bays and points that provide varying extents of protection to the sites along the coastal strip.
Figure 3.12, Bass Point. Bass Point and Shellharbour section of CSSI study area. Heritage sites are represented as points, each coloured according to sensitivity determined by the CSSI. (© NSW Office of Environment and Heritage 2015)
Figure 3.13, Bass Point and Shellharbour section of the CSSI study area. Sites are represented as coloured points, with colours determined by the CSSI sensitivity categories. Geology is represented by coloured raster layers over the area. Green coverage indicates Gerringong Volcanics, while Red coverage is used to show areas of Quaternary Sediments. (© NSW Office of Environment and Heritage 2015) © State of New South Wales (Department of Trade and Investment, Regional Infrastructure and Services) 2015)
3.2.6 Sites by CSSI Category

Overall the results for the 126 sites examined showed that only 4.8% (n=6) of sites were classed as ‘Very High’ sensitivity, and 12.7% (n=16) were classed as ‘Very Low’ (Table 3.2). The majority of sites were within the three remaining categories of sensitivity: ‘Low’, ‘Moderate’ and ‘High’. The largest individual class of sites was the ‘Low’ sensitivity group, representing 32.5% (n=41) of all sites. ‘Moderate’ classed sites made up 28.6% (n=36) of the overall 126, with the remaining 21.4% (n=27) in the ‘High’ sensitivity category. Important to note is that while there were 126 sites individually listed in the study area, in many cases there were multiple sites located at the same point. The effect of this is that some points represent more than one site, and this must be taken into account when viewing statistics regarding sites. This can effectively create clusters of site categories, which means the frequencies of each sensitivity category may not be similarly represented in a spatial sense.

<table>
<thead>
<tr>
<th>CSSI Category</th>
<th>Frequency</th>
<th>Percent</th>
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</thead>
<tbody>
<tr>
<td>Very Low</td>
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<td>12.7</td>
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<tr>
<td>Low</td>
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<td>32.5</td>
</tr>
<tr>
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<td>36</td>
<td>28.6</td>
</tr>
<tr>
<td>High</td>
<td>27</td>
<td>21.4</td>
</tr>
<tr>
<td>Very High</td>
<td>6</td>
<td>4.8</td>
</tr>
<tr>
<td>Total</td>
<td>126</td>
<td>100.0</td>
</tr>
</tbody>
</table>

The results suggest that 33 sites, or roughly one-quarter of the 126 sites were classed as ‘High’ or ‘Very High’ sensitivity to sea level rise within the study area. Twenty of these 33 sites were listed in the register as ‘Artefact’. Within the ‘High’ and ‘Very High’ categories, six sites were recorded as ‘Shell’ and five sites were recorded as ‘Burial’ (Table 3.3). The remaining two sites of the 33 were a single ‘PAD’ site and a site classed as ‘Non-Human Bone and Organic material’. The high occurrence of ‘Artefact’ sites in the higher sensitivity categories is in line with the regional total, with 52.4% (n=66) of the 126 sites being listed as ‘Artefact’. Similarly ‘Shell’ sites make up 31.7% (n=40) of the regional total.
Table 3.3, CSSI sensitivity categories compared to heritage site type.

<table>
<thead>
<tr>
<th>Site Type in OEH Data</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aboriginal Ceremony and Dreaming</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Aboriginal Resource and Gathering</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Artefact</td>
<td>8</td>
<td>20</td>
<td>18</td>
<td>16</td>
<td>4</td>
<td>66</td>
</tr>
<tr>
<td>Burial</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Modified Tree (Carved or Scarred)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Non-Human Bone and Organic Material</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Potential Archaeological Deposit (PAD)</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Shell</td>
<td>8</td>
<td>17</td>
<td>9</td>
<td>4</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>16</td>
<td>41</td>
<td>36</td>
<td>27</td>
<td>6</td>
<td>126</td>
</tr>
</tbody>
</table>

Sixteen sites in the region were listed by the OEH data as ‘Contributes to Primary Importance’; four of these listed sites were within the ‘High’ sensitivity rankings (Table 3.4). These ‘High’ sensitivity sites that are regarded as contributing to primary importance include the Burial at McCauley’s Beach midden, an Artefact at Barrack Point, and a PAD site and Shell site from Wombarra Beach Midden.

Table 3.4, CSSI sensitivity categories compared to Primary Importance

<table>
<thead>
<tr>
<th>Importance</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contributes to Primary Importance</td>
<td>1</td>
<td>2</td>
<td>9</td>
<td>4</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Not Determined</td>
<td>15</td>
<td>39</td>
<td>27</td>
<td>23</td>
<td>6</td>
<td>110</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>16</td>
<td>41</td>
<td>36</td>
<td>27</td>
<td>6</td>
<td>126</td>
</tr>
</tbody>
</table>
4 Estuarine Site Study

The impacts of sea level rise and climate change often differ in an estuarine setting when compared to an open coast. This is largely due to estuarine morphology influencing tidal variations, and a greater exposure of estuaries to terrestrial hazards (Morris et al. 2013, Monbaliu et al. 2014, Wolanski and Chappell 1996). Estuarine morphology plays a significant role in influencing tidal variations, such as attenuation and amplification (Roy et al. 2001). While the impacts of fluvial inundation and erosion add complexity to modelling hazards related to sea level rise. Unique tidal variations and fluvial processes can exert differing severities of impact for each individual estuary. Both geology and geomorphology exert marked influence on the way an individual estuary is affected by sea level changes (Wolanski and Chappell 1996).

In order to effectively examine heritage sites in the context of sea level change, it was necessary to separate those influenced by estuarine landscape controls from those in a coastal setting. AHIMS registered sites within 500m of the Lake Illawarra shoreline were extracted to determine vulnerability to estuarine processes. To examine estuarine sites, the underlying landscape, as with coastal sites, was used as a proxy to determine the sensitivity or vulnerability of the sites by their location on the landscape. Estuarine vulnerability in the South East Australian context has been examined by Rogers & Woodroffe (2016), using geomorphology and elevation as indicators to assess estuarine exposure, sensitivity and adaptive capacity. This approach was adapted and applied to heritage sites in the Lake Illawarra estuary. The approach utilised the ArcGIS program and Spatial Analyst extension. Due to the development of this model by Rogers and Woodroffe (2016) for the broad region that encapsulates the estuarine study area, it represented the best fit for the determination of heritage site sensitivity and vulnerability within the Lake Illawarra estuarine area.

4.1 Estuarine Methodology

The modelling technique described by Rogers & Woodroffe (2016), was applied to the Lake Illawarra Estuary. The analysis utilised a raster-based approach within the ArcGIS program and Spatial Analyst extension. The input data included the Geoscience Australia SRTM DEM with a cell size of ~28m. This dataset was used to determine the elevation and slope of cells within the estuary, as well as act as a template for cell position and size. The Geology data
were sourced from the NSW Department of Industry, Resources & Energy. The Coastal Quaternary Geology package released in 2015 was utilised for the base geology data. The Quaternary Geology and Basement Geology layers from the package were used to inform the structural and geomorphological classification of the estuary. The NSW Coastal Quaternary Geology package released in 2015, superseded the previous package produced in 2008 (Troedson et al. 2015). The most recent dataset was chosen over the 2008 package used by Rogers & Woodroffe (2016), as the previous dataset only covered half of Lake Illawarra (Rogers and Woodroffe 2016).

4.1.1 Estuarine Site Vulnerability Index

The raster cells surrounding the lake were classified into the categories of ‘Low’, ‘Medium’, and ‘High’ vulnerability for each of the defined drivers of change. Coastal Erosion, Coastal Inundation, Fluvial Erosion and Fluvial Inundation were all modelled individually for the estuary. The output values of these separate analyses were then combined to produce total vulnerability values for the area. The classification of exposure, sensitivity and adaptability for each analysis was determined by assigning cell values according to the criteria defined by Rogers & Woodroffe (2016)(Tables 4.2 & 4.3).

The total values for each cell in the combined map were then classified according to the vulnerability categories outlined in Rogers & Woodroffe (2016)(Table 4.1). Heritage sites were then able to be examined by location vulnerability. This was achieved by extracting raster cell values by points representing heritage sites listed in the OEH AHIMS database. Sites were then displayed and analysed according to the categories of vulnerability used for the underlying cells.

In addition the categorised sites that were below 1m in elevation were extracted and displayed. The purpose of this step was to analyse the possibility of site specific inundation occurring anticipated sea level rise scenarios of ~90cm by 2100.

<table>
<thead>
<tr>
<th>Vulnerability Category</th>
<th>Cell Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>24 - 30</td>
</tr>
<tr>
<td>Moderately High</td>
<td>19 - 23</td>
</tr>
<tr>
<td>Moderate</td>
<td>14 - 18</td>
</tr>
<tr>
<td>Moderately low</td>
<td>9 - 13</td>
</tr>
<tr>
<td>Low</td>
<td>5 - 8</td>
</tr>
<tr>
<td>Negligible</td>
<td>0 - 4</td>
</tr>
</tbody>
</table>
## Table 4.2, Estuarine Coastal Drivers and Effects (Adapted from Rogers & Woodroffe (2016))

<table>
<thead>
<tr>
<th>Drivers &amp; Effect</th>
<th>Component</th>
<th>Indicator</th>
<th>Input data set</th>
<th>Explanation</th>
<th>Cell Label (Score)</th>
<th>Cell score and description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erosion Exposure</td>
<td>Deposit type; Slope; Elevation</td>
<td>Deposit; Quaternary geology; DEM</td>
<td>Lower elevations exhibit greater exposure to wave action; Greater exposure to wave action closer to shoreline; Steep slopes limit wave run-up; Marine drivers exhibit history of operating near coastal and estuarine Quaternary deposits.</td>
<td>Low (1)</td>
<td>Coastal barrier/Estuarine plain + Elevation &gt;5 m; or Alluvial plain + elevation &lt;5 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Moderate (2)</td>
<td>Estuarine plain + Elevation &lt;5 m; or Coastal barrier + Elevation &lt;5 m + Slope &gt;10°</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High (3)</td>
<td>Coastal barrier + Elevation &lt;5 m + Slope &lt;10°</td>
<td></td>
</tr>
<tr>
<td>Sensitivity Geology</td>
<td>Bedrock &amp; Quaternary geology</td>
<td>Hard bedrock geology less sensitive to erosion than Quaternary deposits.</td>
<td>Low (1)</td>
<td>Bedrock geology</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High (3)</td>
<td>Quaternary deposits</td>
<td></td>
</tr>
<tr>
<td>Adaptive capacity Maturity</td>
<td>Deposit type; Elevation</td>
<td>Deposits; Quaternary geology; DEM</td>
<td>Marine deposits (lesser extent estuarine deposits) exhibit greater exposure to marine drivers than estuarine and alluvial units, sequentially; Low elevations exhibit greater exposure to marine drivers.</td>
<td>Low (1)</td>
<td>Coastal barrier/Estuarine plain +Elevation &gt;5 m; or Alluvial plain + elevation &lt;5 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Moderate (2)</td>
<td>Estuarine plain + Elevation &lt;5 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High (3)</td>
<td>Coastal barrier + Elevation &lt;5 m</td>
<td></td>
</tr>
<tr>
<td>Inundation Sensitivity</td>
<td>Bedrock &amp; Quaternary geology</td>
<td></td>
<td>All cells are equally sensitive to inundation and assigned a score of 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adaptive capacity Maturity</td>
<td>Deposit type; Elevation</td>
<td>Deposits; Quaternary geology; DEM</td>
<td>Supratidal areas (2-5 m elevation), and to a lesser extent intertidal areas (&lt; 2 m), exhibit past capacity to resist erosion and build elevation; Higher elevations (5-10 m) unlikely to be exposed to marine and terrestrial hydrological processes that build elevation.</td>
<td>High (1)</td>
<td>Elevation &gt;2 m and Elevation &lt;5 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Moderate (2)</td>
<td>Elevation &lt;2 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Low (3)</td>
<td>Elevation &gt;5 m and Elevation &lt;10 m</td>
<td></td>
</tr>
<tr>
<td>Drivers &amp; Effect</td>
<td>Component</td>
<td>Indicator</td>
<td>Input data set</td>
<td>Explanation</td>
<td>Cell Label (Score)</td>
<td>Cell score and description</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------</td>
<td>-----------</td>
<td>----------------</td>
<td>-------------</td>
<td>-------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Exposure</td>
<td>Deposit type; Slope; Elevation; Quaternary geology; DEM</td>
<td>Fluvial deposits (lesser extent estuarine deposits) exhibit greater exposure to terrestrial drivers. Steep slopes exhibit greater runoff. Low elevations exhibit greater exposure to terrestrial drivers.</td>
<td>Low (1)</td>
<td>Alluvial plain/Estuarine plain + Elevation &gt;5 m; or Coastal barrier + Elevation &lt;5 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosion</td>
<td>Sensitivity</td>
<td>Geology</td>
<td>Bedrock &amp; Quaternary geology</td>
<td>Hard bedrock geology less sensitive to erosion than quaternary deposits</td>
<td>Low (1)</td>
<td>Bedrock geology</td>
</tr>
<tr>
<td>Adaptive capacity</td>
<td>Maturity</td>
<td>Quaternary geology; DEM</td>
<td>Supratidal areas (2-5 m elevation), and to a lesser extent intertidal areas (&lt; 2 m), exhibit past capacity to resist erosion and build elevation. Higher elevations (5-10 m) unlikely to be exposed to marine and terrestrial hydrological processes that build elevation.</td>
<td>High (1)</td>
<td>Elevation &gt;2 m and Elevation &lt;5 m</td>
<td></td>
</tr>
<tr>
<td>Fluid</td>
<td>Exposure</td>
<td>Deposit type; Slope; Elevation; Quaternary geology; DEM</td>
<td>Marine and estuarine deposits exhibit greater exposure to wave activity and storm surge. Steep slopes exhibit less run-up. Low elevations exhibit greater exposure to wave activity and storm surge.</td>
<td>Low (1)</td>
<td>Alluvial plain/Estuarine plain + Elevation &gt;5 m Coastal barrier + Elevation &lt;5 m</td>
<td></td>
</tr>
<tr>
<td>Inundation</td>
<td>Sensitivity</td>
<td>Maturity</td>
<td>Quaternary geology; DEM</td>
<td>Supratidal areas (2-5 m elevation), and to a lesser extent intertidal areas (&lt; 2 m), exhibit past capacity to resist erosion and build elevation. Higher elevations (5-10 m) unlikely to be exposed to marine and terrestrial hydrological processes that build elevation.</td>
<td>High (1)</td>
<td>Elevation &gt;2 m and Elevation &lt;5 m</td>
</tr>
</tbody>
</table>

All cells are equally sensitive to inundation and assigned a score of 1.
4.1.2  Estuarine Site Exposure & Sensitivity Index

The determination of site vulnerability based on the modelling technique adapted from Rogers & Woodroffe (2016), presents some difficulties. The vulnerability of the estuarine landscape is determined by exposure, sensitivity and adaptability. While heritage sites are linked to the landscape that they are located on, they may not necessarily adapt in the same fashion as the underlying landform. The determination of natural adaption in the estuarine vulnerability study refers to “the building of land elevation through natural processes such as accretion or plant productivity” (Rogers and Woodroffe 2016 p. 130). These natural processes of adaption may afford some protection to the biophysical system in an estuary, but do not necessarily do the same for the heritage sites. Some sites may be significantly disturbed due to these natural processes, while others may benefit from accretionary processes increasing protection. In either scenario, landscape adaption is not necessarily equal to site adaption, and therefore may not be a directly applicable proxy for use in estimating site vulnerability. Due to the potential differences in adaptability for estuarine landscapes and the sites that are within them, the sensitivity and exposure of sites was examined by removing the adaptive capacity values from the model produced by Rogers & Woodroffe (2016).

The process for producing an Estuarine Site Exposure and Sensitivity Index (ESESI) was similar to the Estuarine Site Vulnerability Index, with the omission of adaptive capacity values. Values for both sensitivity and exposure were determined from the classification in Tables 4.2 and 4.3. developed by Rogers and Woodroffe (2016). Coastal Erosion, Coastal Inundation, Fluvial Erosion and Fluvial Inundation models were all produced excluding adaptive capacity. The cell values of each analysis were then combined by adding all values in raster calculator. A final estuarine sensitivity and exposure map was produced and all cells classified into Sensitivity and Exposure categories (Table 4.4). Heritage site points were then used to extract values from the cells at the site locations.

<table>
<thead>
<tr>
<th>Sensitivity &amp; Exposure Category</th>
<th>Cell Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>18 – 20</td>
</tr>
<tr>
<td>Moderately High</td>
<td>15 – 17</td>
</tr>
<tr>
<td>Moderate</td>
<td>12 – 14</td>
</tr>
<tr>
<td>Moderately low</td>
<td>9 – 11</td>
</tr>
<tr>
<td>Low</td>
<td>5 - 8</td>
</tr>
<tr>
<td>Negligible</td>
<td>0 - 4</td>
</tr>
</tbody>
</table>
## 4.2 Results

### 4.2.1 Estuarine Site Vulnerability Index

The ESVI was applied to 91 Indigenous heritage sites within 500m of the Lake Illawarra shoreline. The values for each site were derived by extracting cell values from the vulnerability model, according to the location of sites. The total vulnerability values were determined by the four individual drivers of change modelled for the Lake Illawarra estuary. Coastal Erosion (Figure 4.1), Coastal Inundation (Figure 4.2), Fluvial Erosion (Figure 4.3) and Fluvial Inundation (Figure 4.4) were individually modelled, and then combined. The resulting cell values of total vulnerability for the estuary are shown in Figure 4.5.

The sites were found in the categories ‘Negligible’ to ‘Moderately High’, with no sites deemed to be ‘High’ vulnerability (Table 4.5). The largest individual category was ‘Moderate’ vulnerability with 33% of the 91 sites (n=30). Both ‘Negligible’ and ‘Moderately High’ categories were also significantly represented. Sites classed as ‘Negligible’ vulnerability made up 31.9% (n=29) of the total. ‘Moderately High’ vulnerability sites were determined to make up 27.5% with 25 individual sites being placed in this category. Only one site was determined to be ‘Moderately Low’ vulnerability. The ‘Low’ vulnerability category had 6 sites represented according to the ESVI analysis, only accounting for 6.6% of the overall sites.

<table>
<thead>
<tr>
<th>Vulnerability Category</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible</td>
<td>29</td>
<td>31.9</td>
</tr>
<tr>
<td>Low</td>
<td>6</td>
<td>6.6</td>
</tr>
<tr>
<td>Moderately Low</td>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>Moderate</td>
<td>30</td>
<td>33.3</td>
</tr>
<tr>
<td>Moderately High</td>
<td>25</td>
<td>27.5</td>
</tr>
<tr>
<td>High</td>
<td>6</td>
<td>6.6</td>
</tr>
<tr>
<td>Total</td>
<td>91</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Figure 4.1, Coastal Erosion Vulnerability Map. The Values for each cell are displayed in categories ranking them from ‘Low’ to ‘High’ Vulnerability. Cells with a value of 1 or less have been excluded. Values from 2-3 are classed as ‘Low’ Vulnerability, values from 4-6 are classed as ‘Moderate’ Vulnerability, values from 7-9 are classed as ‘High’ Vulnerability.

Figure 4.2, Coastal Inundation Vulnerability Map. The values for each cell are displayed in categories ranking them from ‘Low’ to ‘High’ Vulnerability. Cells with a value of 1 or less have been excluded. Values of 2 are classed as ‘Low’ Vulnerability, values of 3-4 are classed as ‘Moderate’ Vulnerability, values from 5-6 are classed as ‘High’ Vulnerability.
Figure 4.3, Fluvial Erosion Vulnerability Map. The values for each cell in this map are displayed in categories ranking them from ‘Low’ to ‘High’ Vulnerability. Cells with a value of 1 or less have been excluded. Values from 2-3 are classed as ‘Low’ Vulnerability, values from 4-6 are classed as ‘Moderate’ Vulnerability, values from 7-9 are classed as ‘High’ Vulnerability.

Figure 4.4, Fluvial Inundation Vulnerability Map. The values for each cell are displayed in categories ranking them from ‘Low’ to ‘High’ Vulnerability. Cells with a value of 1 or less have been excluded. Values of 2 are classed as ‘Low’ Vulnerability, values of 3-4 are classed as ‘Moderate’ Vulnerability, and values of 5-6 are classed as ‘High’ Vulnerability.
Figure 4.5, Estuarine Vulnerability Map. The map shows the relative vulnerability of cells in the estuary determined by the vulnerability of each cell to Coastal Erosion and Inundation as well as Fluvial Erosion and Inundation. The values are a sum of the Coastal and Fluvial vulnerability maps. The cells have been categorised as Low, Moderately Low, Moderate, Moderately High and High Vulnerability. All cells with a value of 4 or below have been excluded and are considered to be of negligible vulnerability. Values of 5-8 have been classed as Low Vulnerability, values of 9-13 have been classed as Moderately Low Vulnerability, values of 14-18 have been classed as Moderate Vulnerability, values of 19-23 have been classed as Moderately High Vulnerability and values of 24-30 have been classed as High Vulnerability.
The sites were represented by points, each coloured to display extracted vulnerability value. The points display the overall vulnerability for each site location to the coastal and fluvial drivers of change. Sites that are located in areas that were classed as negligible vulnerability were also displayed on the Site Vulnerability map (Figure 4.6).

Figure 4.6, Site Vulnerability Map. The map displays the sites that lie within 500m of the shore of Lake Illawarra. Sites are represented in colours that define which vulnerability class they have been placed into. Sites were classed by extracting the value of the cell at the location of the site. Sites that are classed Negligible Vulnerability have a value of 0-4, sites that are classed Low Vulnerability have a value of 5-8, sites that are classed as Moderately Low Vulnerability have a value of 9-13, values of 14-18 have been classed as Moderately High Vulnerability. There were no sites found to be in a location of High Vulnerability which would have been values of 24-30.
Sites of ‘Negligible’ vulnerability were located on areas of bedrock outcrop. Bedrock was determined to be significantly less vulnerable than the sedimentary landforms within the analysis. The distribution of ‘Negligible’ vulnerability sites and the relationship to bedrock control can be seen in Figure 4.7.

Figure 4.7, Bedrock in relation to estuarine site vulnerability. The figure has bedrock outcrops around the estuary displayed in blue. Site vulnerability classes are also displayed by points coloured for the respective vulnerability class. (© NSW Office of Environment and Heritage 2015)(© NSW Department of Industry 2015)
Sites on the eastern side of the lake had predominately ‘Moderate’ to ‘Moderately High’ vulnerability values. There was a significant proportion of sites located along the edge of the coastal barrier of the lake (Figure 4.8). The sites on the coastal barrier were quite close to the shoreline and most were below 2m in elevation, contributing to ‘Moderately High’ vulnerability values. ‘Moderate’ vulnerability sites were found near the lake entrance, the difference in value largely due to increased elevation in this area. The ‘Moderate’ vulnerability site on the north-east was on an area of ‘Anthropogenic’ sediment. The value for this site may be compromised due to the exclusion of this sedimentary unit from a large part of the analysis. This stems from difficulties in inferring process due to extensive modification by human activity. One ‘Negligible’ vulnerability site was present in the eastern zone, which was located on resilient bedrock.

The single ‘Low’ vulnerability site on the barrier to the North of the lake’s entrance, was ranked ‘Low’ due to error. The error was caused by converting polygon datasets to raster. The site occurs along the contact of the estuarine and coastal barrier sedimentary units. Due to the conversion of both units to raster format with ~28m cell size, the cell that the site is located on was not classified as either unit. This can occur on polygon boundaries during raster conversion, the result from this analysis was an anomalously low score for the cell. Similarly, the ‘Low’ vulnerability site just south of the lake’s inlet returned a low score also due to error. The cell that the site is located on was less than zero in elevation, and was therefore wrongfully excluded from further analysis when removing cells on the lake. With the 2 erroneously classified sites excluded, there is a clear ‘Moderate’ to ‘Moderately High’ trend along the Eastern side of the lake, particularly along the coastal barrier.
Figure 4.8, Estuarine site vulnerability in the east of Lake Illawarra. Site vulnerability is represented by colours at each site relating to each vulnerability category. (© NSW Office of Environment and Heritage 2015)
Figure 4.9, Estuarine site vulnerability for the western side of Lake Illawarra. Sites are represented by points displaying colours according to the vulnerability rank of each site. (© NSW Office of Environment and Heritage 2015)
The Western side of Lake Illawarra (Figure 4.9) has a significant number of sites that are categorised as ‘Negligible’ vulnerability. This is primarily due to the geology of the area, with bedrock presence leading to negligible vulnerability values in the analysis. The sites located around the deltas were on alluvial sedimentary units. The exception to this was the ‘Moderately Low’ ranked site near the southern end of the lake. The ‘Moderately Low’ site was situated on estuarine sediment, which may explain the difference in value to the nearby sites. The ‘Low’ ranked site at the north-east corner of the figure was ranked as ‘Low’ vulnerability due to an error. This was caused by the conversion of polygon geology data to raster format, as the site occurs along the margin of Estuarine and Bedrock units.

The sites were further examined by extracting the sites that were below 1m in elevation (Figure 4.10). The presence of the ‘Low’ category site points was due to error in the ranking of these sites. Sites of ‘Negligible’ vulnerability were shown to be present in the extracted map. The bedrock landscape of the sites may not be particularly vulnerable. However, if lake levels rise in line with projected sea level by 2100, these sites may well be inundated. Many of the ‘Moderately High’ vulnerability sites located on the coastal barrier on the east of the lake also appeared to be below 1m in elevation.
Figure 4.10, Estuarine site vulnerability of sites below 1 m in elevation. Sites that have elevations of less than 1 m are shown. Sites are coloured according to the vulnerability of each site determined by the CSSI. (© NSW Office of Environment and Heritage 2015)
The ESVI categorised 91 heritage sites around the Lake Illawarra shoreline. 52.7% of these sites were listed as ‘Artefact’ (n=48), and 36.3% as ‘Shell’, representing the large portion of the sites examined (Table 4.6). The remaining sites present in the analysis were ‘PAD’ at 6.6% (n=6), ‘Burial’ sites at 2.2% (n=2) and ‘Aboriginal Ceremony and Dreaming’ and ‘Modified Tree’ sites with one example each.

Table 4.6, Site types in relation to ESVI categories.

<table>
<thead>
<tr>
<th>Site Type</th>
<th>Negligible</th>
<th>Low</th>
<th>Moderately Low</th>
<th>Moderate</th>
<th>Moderately High</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aboriginal Ceremony and Dreaming</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Artefact</td>
<td>19</td>
<td>4</td>
<td>0</td>
<td>13</td>
<td>12</td>
<td>48</td>
</tr>
<tr>
<td>Burial</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Modified Tree (Carved or Scarred)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Potential Archaeological Deposit (PAD)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Shell</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>11</td>
<td>11</td>
<td>33</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>29</strong></td>
<td><strong>6</strong></td>
<td><strong>1</strong></td>
<td><strong>30</strong></td>
<td><strong>25</strong></td>
<td><strong>91</strong></td>
</tr>
</tbody>
</table>

From the ESVI model, it was determined that eleven of the total 91 sites were listed as contributing to primary importance (Table 4.7). Of the eleven sites, six of these were represented in the ‘Moderate’ vulnerability category. One site was determined to be ‘Low’ vulnerability. The remaining four sites listed by the OEH as ‘Contributes to Primary Importance’ were in the ‘Moderately High’ vulnerability category, the highest recorded category from estuarine site vulnerability study.
4.2.2 Estuarine Site Exposure & Sensitivity Index

The results of the ESESI provided an alternative method for assessing heritage sites in an estuarine setting. The exclusion of the adaptive capacity values was necessary to account for differences in the way these adaption processes may affect sites, in comparison to the broader biophysical estuarine system.

The ESESI was run in the same way as the ESVI by combining the values of cells from Coastal Erosion (Figure 4.11), Coastal Inundation (Figure 4.12), Fluvial Erosion (Figure 4.13) and Fluvial Inundation (Figure 4.14). The only change to the process was the removal of the adaptive capacity values from each of the input models. The result of combining the four respective analyses, was the production of a single map with cell values defined by the exposure and sensitivity of each cell to the coastal and fluvial drivers of change (Figure 4.15).

Heritage site points within 500m of the shoreline of Lake Illawarra were used to extract the value of the categorised cells from the overall exposure and sensitivity analysis. The resulting ESESI values for these sites were then displayed in coloured categories. Site points were classed ‘Low’, ‘Moderately Low’, ‘Moderate’, ‘Moderately High’ or ‘High’ sensitivity to Sensitivity and Exposure to Coastal and Fluvial drivers of change (Figure 4.16).
Figure 4.11, Coastal Erosion Sensitivity & Exposure Map. The values for each cell in this map are ranked as ‘Low’, ‘Moderate’ or ‘High’ for sensitivity and exposure to coastal erosion. Values of 1 were excluded from the map. Cell values of 2 were classed as ‘Low’ sensitivity and exposure, values of 3-4 were classed as ‘Moderate’ sensitivity and exposure and values of 5-6 were classed as ‘High’ sensitivity and exposure to coastal erosion.

Figure 4.12, Coastal Inundation Sensitivity & Exposure Map. The values for each cell were categorised as ‘Low’, ‘Moderate’ or ‘High’ for sensitivity and exposure to coastal inundation. Cells were determined to have values ranging from 1-4, with all cells being equally sensitive to Inundation and values of 1 being excluded. Values of 2 were classed as ‘Low’ sensitivity and exposure, values of 3 were classed as ‘Moderate’ sensitivity and exposure and values of 4 were classed as ‘High’ sensitivity and exposure to coastal inundation.
Figure 4.13, Fluvial Erosion Sensitivity & Exposure Map. The values for each cell in this map are ranked as ‘Low’, ‘Moderate’ or ‘High’ for sensitivity and exposure to fluvial erosion. Values of 1 were excluded from the map. Cell values of 2 were classed as ‘Low’ sensitivity and exposure, values of 3-4 were classed as ‘Moderate’ sensitivity and exposure and values of 5-6 were classed as ‘High’ sensitivity and exposure to fluvial erosion.

Figure 4.14, Fluvial Inundation Sensitivity & Exposure Map. The values for each cell were categorised as ‘Low’, ‘Moderate’ or ‘High’ for sensitivity and exposure to fluvial inundation. Cells were determined to have values between ranging from 1-4, with all cells being equally sensitive to inundation and values of 1 being excluded. Values of 2 were classed as ‘Low’ sensitivity and exposure, values of 3 were classed as ‘Moderate’ sensitivity and exposure and values of 4 were classed as ‘High’ sensitivity and exposure to fluvial inundation.
Figure 4.15, Total Estuarine Sensitivity and Exposure Map. The map shows all cells in the estuary categorised in to ‘Low’, ‘Moderately Low’, ‘Moderate’, ‘Moderately High’ and ‘High’ sensitivity and exposure to coastal and fluvial drivers of change. The cell values ranged from 0-20. Values of 0-4 were excluded from the final display map as they were classed as having ‘Negligible’ sensitivity and exposure. Values of 5-8 were classed as ‘Low’, values of 9-11 were classed as ‘Moderately Low’, values of 12-14 were classed as ‘Moderate’, values of 15-17 were classed as ‘Moderately High’ and values of 18-20 were classed as ‘High’ sensitivity and exposure.
Figure 4.16. Site Exposure and Sensitivity Map. The map displays heritage sites within 500m of the Lake Illawarra shoreline, the sites have been coloured according to the category of exposure and sensitivity that they have been assigned from the Total Estuarine Sensitivity and Exposure Map. Sites with extracted values of 0-4 have been classed as ‘Negligible’ exposure and sensitivity, Sites assigned the values of 5-8 were classed as ‘Low’, sites with values of 9-11 were classed as ‘Moderately Low’, sites with values of 12-14 were classed as ‘Moderate’ and sites with values of 15-17 were classed as ‘Moderately High’ sensitivity and exposure. No sites had values that would be classed as ‘High’ sensitivity and exposure, which are values of 18-20.
Sites on the eastern side of the lake were predominately classed as ‘Moderately High’ (Figure 4.17). There were three points classed as ‘Low’ sensitivity and exposure. The two ‘Low’ ranked points to the south were classed in this category due to error. This was consistent with the classification in the ESVI model. The northernmost ‘Low’ ranked site on the eastern side of the Lake was located on ‘Anthropogenic’ sediment which was not included in assessment by geomorphic unit. Therefore, the value for this site may not represent true exposure and sensitivity. The remaining sites on the coastal barrier were consistently classed as ‘Moderately High’ sensitivity and exposure. There was one ‘Negligible’ classed site on the northern shore of the lake. This site was ‘Negligible’ in both models due to being situated on resilient bedrock. There was one ‘Moderate’ site point present. This site on the northern shore had moved down one category from ‘Moderately High’ in the ESVI to ‘Moderate’ in the ESES1.

The western side of the lake had a significant number of sites classed as ‘Negligible’ exposure and sensitivity (Figure 4.18). These rankings were unchanged from the previous ESVI, and were a result of bedrock geology underlying the sites. Site points located around the deltas, appeared to be classed as ‘Moderately High’ exposure and sensitivity, with some having been moved up a class from ‘Moderate’ in the ESVI. There was one exception, the lone ‘Low’ ranked site on the south-western shore, was lowered in rank from ‘Moderate’ in the ESVI. The remaining ‘Low’ ranked site in the north was affected by error during the analysis and returned a similar value to the ESVI model.
Figure 4.17. Estuarine Site Exposure & Sensitivity of the Eastern Section of Lake Illawarra. The eastern section of the lake is shown, with sites represented as points. Each point is coloured according to the exposure and sensitivity of the site determined by the EESI. (© NSW Office of Environment and Heritage 2015)
Figure 4.18, Estuarine Site Exposure & Sensitivity of the Western Section of Lake Illawarra. The western section of the lake with sites represented as points. Points are coloured according to the exposure and sensitivity value determined for each site by the EESLI. (© NSW Office of Environment and Heritage 2015)
The sites examined in ESESI that were below 1m in elevation were extracted (Figure 4.19). The sites with ‘Low’ exposure and sensitivity values were previously determined to have erroneous values. The remaining sites in the low elevation extraction were ‘Moderately High’ according to the ESESI. The exceptions were the two site points that were categorised as having ‘Negligible’ exposure and sensitivity. The bedrock base that the sites are located on is the primary contributor to the ‘Negligible’ values found at these sites points. However, the extraction of sites below 1m shows that in a bathtub style model, assuming up to 1m water level rise within the lake, these sites would likely be effected.

Figure 4.19, Estuarine Exposure & Sensitivity of Sites Under 1m. Sites under 1m of elevation are shown, with colours indicating the category of exposure and sensitivity as determined by the ESESI. (© NSW Office of Environment and Heritage 2015)
The ESESI examined the same sites as the ESVI. Of the 91 sites examined in both models the ESESI showed an increase in ‘Moderately High’ classed points (Table 4.8). 54.9% (n=50) of all sites were classed ‘Moderately High’ by the ESESI. The second largest category was ‘Negligible’ with 31.9% (n=29), showing no change from the ESVI. The change in category was from the ‘Moderate’ class, which decreased from 30 sites in the ESVI to just two in the ESESI. An additional three sites were also categorised as ‘Low’ in the ESESI when compared to the ESVI.

<table>
<thead>
<tr>
<th>Category</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible</td>
<td>29</td>
<td>31.9</td>
</tr>
<tr>
<td>Low</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Moderately Low</td>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>Moderate</td>
<td>2</td>
<td>2.2</td>
</tr>
<tr>
<td>Moderately High</td>
<td>50</td>
<td>54.9</td>
</tr>
<tr>
<td>Total</td>
<td>91</td>
<td>100.0</td>
</tr>
</tbody>
</table>

The ESVI categorised 91 heritage sites around the Lake Illawarra shoreline. 52.7% of these sites were listed as ‘Artefact’ (n=48), and 36.3% as ‘Shell’, representing the large portion of the sites examined (Table 4.9). The remaining sites present in the analysis were ‘PAD’ at 6.6% (n=6), ‘Burial’ sites at 2.2% (n=2) and ‘Aboriginal Ceremony and Dreaming’ and ‘Modified Tree’ sites with one example each.
From the ESESI model, it was determined that eleven of the total 91 sites were listed as contributing to primary importance by the OEH (Table 4.10). Of the eleven sites, ten of these were represented in the ‘Moderately High’ vulnerability category, the highest recorded category from estuarine site vulnerability study. One site was determined to be ‘Low’ vulnerability, the only other category represented.

Table 4.9, Site types by ESESI category

<table>
<thead>
<tr>
<th>Site Type</th>
<th>ESESI Category</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Negligible</td>
<td>Low</td>
</tr>
<tr>
<td>Aboriginal Ceremony and Dreaming</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Artefact</td>
<td>19</td>
<td>5</td>
</tr>
<tr>
<td>Burial</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Modified Tree (Carved or Scarred)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Potential Archaeological Deposit (PAD)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Shell</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 4.10, ESESI categories and site importance

<table>
<thead>
<tr>
<th>Importance</th>
<th>ESESI Category</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Negligible</td>
<td>Low</td>
</tr>
<tr>
<td>Contributes to Primary Importance</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Not Determined</td>
<td>29</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>9</td>
</tr>
</tbody>
</table>
5 Bass Point

5.1 Site Locations

Six individual site points analysed in the CSSI were visited, to evaluate the effectiveness of the study. Sites were investigated to determine their location accuracy, and the CSSI estimated site sensitivity categories were compared to the observable characteristics of the recorded site points. Site locations were determined from AHIMS point data. The sites were classed as being of ‘Very Low’, ‘Low’ and ‘Moderate’ sensitivity by the CSSI. Sites were present on both the northern and southern shorelines of the Point, as well as one site located in the protected Bushrangers Bay (Figure 5.1). Each site point represented at least two site types within the AHIMS register. All points recorded both ‘Shell’ and ‘Artefact’ site types.

There has been extensive archaeological study done in the Bass Point region over several decades, particularly on shell middens (Bowdler 1976, Hughes and Sullivan 1974, Office of Environment & Heritage 2016a). Sites were expected to be shell midden, based on previous published work, and designation of ‘Shell’ as site type for all relevant points.

Bass Point was visited on Thursday the 26th of May 2016. The sites were located at around the time of the occurrence of high tide. The Bureau of Meteorology determined high tide as 1.27m peaking at 11:25 AM (Table 5.1). A handheld GPS was used to locate sites according to WGS1984 UTM Zone 56S. The site data and locations were originally defined in the Geographic Coordinates System GDA 1994. The points were converted to a Projected Coordinate System (WGS1984 UTM) using the Project tool within the Data Management extension of the ArcGIS program. The projected coordinates were then used to locate the sites.
Figure 5.1, Bass Point Sites. Sites that were present on Bass Point are shown on the map, with colours of CSSI ranking applied to each point. Sites that were investigated in the field study are numbered accordingly. (© NSW Office of Environment and Heritage 2015)

Table 5.1, Bureau of Meteorology Tide Chart (Bureau of Meteorology 2016)

**Tide Predictions – Bureau of Meteorology**

**Port Kembla, NSW – May 2016**

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>THU 26 MAY</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOW</td>
<td>5:22 am</td>
<td>0.41 m</td>
<td></td>
</tr>
<tr>
<td>HIGH</td>
<td>11:25 am</td>
<td>1.27 m</td>
<td></td>
</tr>
<tr>
<td>LOW</td>
<td>4:50 pm</td>
<td>0.85 m</td>
<td></td>
</tr>
<tr>
<td>HIGH</td>
<td>11:16 pm</td>
<td>1.67 m</td>
<td></td>
</tr>
</tbody>
</table>
5.2 Results

5.2.1 Site 1

![Site Sensitivity Map]

Figure 5.2, Site 1 Location. The site is shown as a point on the shore near the gravel loader. (© NSW Office of Environment and Heritage 2015)

Site 1 was recorded as being adjacent to the Gravel Loader on the northern shore of Bass Point (Figure 5.2). The site was determined by the CSSI to have ‘Very Low’ site sensitivity. The location of the site was found to be close to the water, according to GPS coordinates. GPS accuracy was recorded as 6m. Photographs of the indicated coordinate point were taken at 10:05 AM (Figure 5.3 & 5.4). It was noted that the high water mark was approximately 2m inland of the specified point. This was determined by the presence of a strandline composed of washed up seaweed (Figure 5.5). It was also noted that there was no surficial evidence of archaeological artefact or shell midden. To account for spatial error the surrounding area was examined in a radius of approximately 30m, no surficial evidence of archaeological material was encountered.
Figure 5.3, Site 1 Facing East. The image shows the location of Site 1 on Bass Point. The GPS location is marked with a yellow north arrow in the centre of the image.

Figure 5.4, Site 1 Facing South-East. The image shows the landscape behind the site. The site location is indicated by a yellow north arrow placed on the ground.
Figure 5.5, Site 1 High Water Mark. The image shows the strandline approximately 2 m south of site location. Yellow north arrow is used as a scale bar and not the location of Site 1 point.
The second site point (Site 2) was located on the northern shore of the Point (Figure 5.6). The CSSI value for this site was ‘Low’. Photographs for the specified point were taken at around 10:40 AM. GPS accuracy was recorded as 5m, the site coordinates indicated the point to be on a rock platform (Figure 5.7 & 5.8). The located point showed no surficial signs of artefact or shell archaeological material.
Figure 5.7, Site 2 on Rock Platform. The site location is indicated by a yellow north arrow visible on the rock platform.

Figure 5.8, Site 2 Surrounding Areas. The landscape behind site 2 is shown in this image. The location is represented by a yellow north arrow visible on the rock platform.
Approximately 60m from the Site 2 coordinates, photographs were taken of mollusc species associated with documented midden sites at Bass Point (Bowdler 1976) (Figures 5.9 & 5.10). The species represented were *Cabestana spengleri*, *Lunella torquata*, *Lunella undulata* and *Dicathais orbita*. The shells showed signs of bio-erosion processes, including evidence of the boring into shell by clionid sponges, and small adhering mineralised tubes created by worms. The evidence of bio-erosion suggests these shells have been submerged in water for some time after the death of the organism (Vermeij 1993).

The shells were located with pumice stones, a few metres inland of the strandline (Figure 5.11). Coordinates of these shells were recorded to compare to site locations (Figure 5.12). Several other photographed shells were found grouped next to a footpath several metres from the beach, however these were likely relocated from the original source by fossickers and coordinates were not recorded (Figure 5.13).
Figure 5.9, Shell with Pumice. Shell was found with pumice approximately 2-3 m inland of the strandline on the beach 60 m from Site 2. Yellow north arrow acts as scale bar.

Figure 5.10, Examples of Shell with Pumice. Shell species associated with midden deposits visible amongst pumice on the beach 60 m from Site 2. Yellow north arrow acts as a scale bar.
Figure 5.11, Beach Near Site 2. Image of the beach found 60 m from Site 2 with camera facing to the east. The strandline is visible in the centre of the photograph. A yellow north arrow to the right of centre indicates shell examples found with pumice and the position of the GPS coordinates taken with photographs.

Figure 5.12, Shell Examples. Shells found near a footpath, several metres from the beach.
Figure 5.13, Site 2 and Beach Coordinates. Site 2 is shown in the image with a green point indicating 'Low' sensitivity. The coordinate location of shell found with pumice is represented by a pink coloured point. Also present in the image is a 'Moderate' sensitivity site that was not investigated; it is visible as a yellow coloured point. (© NSW Office of Environment and Heritage 2015)
Site 3 was located near the sheltered Bushrangers Bay (Figure 5.14). The site was assigned a ‘Moderate’ sensitivity value, according to the CSSI. Coordinates indicated the site was on the Northern edge of the bay, attempts were made to reach the site from the bay shoreline. There was no evidence of archaeological material at the foot of the cliff. The site point was located above the cliff, which was able to be reached by passing through a vegetated area from the road. GPS accuracy was limited due to dense vegetation cover; the accuracy was recorded as 12m. The coordinate location showed no surficial evidence of archaeological material (Figure 5.15). The surrounding area was investigated in an approximately 20m radius. Further investigation was limited due to dense vegetation.
Figure 5.15, Location of Site 3. The location of site 3 is indicated by the yellow north arrow. Images of the broader landscape were difficult to capture due to dense vegetation cover.
5.2.4 Site 4

![Site 4 Location Map](image)

Site 4 was located on the Southern shore of the Point as seen in Figure 5.16. The site was determined to be ‘Very Low’ sensitivity by the CSSI. The location of the site point was found to be on a rock platform. The platform was partially inundated due to high tide. Photographs were taken at approximately 12:10 PM (Figure 5.17). GPS accuracy was within 6m when locating this point. The site point and surrounding area showed no surficial evidence of archaeological material. The nature of the location, with Southern exposure and observed wave action, did not suggest it was a location that a shell midden or other archaeological material could survive without being quickly destroyed.
Figure 5.17, Site 4 Location. Site 4 is indicated by a yellow north arrow in the centre of the image above the water.
5.2.5 Site 5

Site 5 was located on the Southern coastline of Bass Point (Figure 5.18). The point was reached by 12:30 PM. GPS accuracy was 6m on approach to this location. As with Site 4 this point was located on a rock platform. The site was located at the base of a depression in the rock. It was deemed unsafe to go directly to the coordinate location due to high tide. A photograph was taken of the location (Figure 5.19). There were no surficial signs of archaeological material. Similarly to Site 4, wave action and exposure of this location would likely prevent any archaeological material surviving intact for any significant length of time.
Figure 5.19, Site 5 Location. Site 5 was located at the base of the depression visible in the image. Due to high tide it was not possible to place a marker at the site location.
Figure 5.20, Site 6 Location Map. The map indicates the location of Site 6. Site six is displayed as a green point. The map suggests that the site is located off the southern shore of the point in the ocean. (© NSW Office of Environment and Heritage 2015)
The final site is shown in Figure 5.20. It was not possible to reach this point. The coordinates for this site were indicating a location at least 20m off the coast (Figure 5.21). GPS accuracy was noted as within 5m. The time was 12:45 PM, indicating that the tide was close to high of 1.27m. With an average Spring tide range of 1.2m in the region (Short 2007), it is unlikely that this point would be on land even at low tide. The shoreline within 50m of the location was examined, with no surficial evidence of archaeological material.

While no firm evidence of archaeological material was located at the recorded locations for the six chosen sites at Bass Point, some equivocal evidence was recorded in the shells near Site 2 (Figures 5.9 & 5.10). There was no unequivocal evidence that these shells were derived from a midden in the immediate vicinity, and it is possible that these shells were moved to the back beach by storm action. This would explain the considerable amounts of pumice found in association with the shells. There has been evidence of sites at Bass Point being reworked by storm action in the past (Hughes and Sullivan 1974), which means that the possibility that these shells were midden-derived cannot be excluded. Three of four sites on the northern shore of Bass Point were determined to have experienced wave action by Hughes and Sullivan (1974). These sites were reasonably close to the beach near Site 2 and could be a potential source for the shell material (Figure 5.22).
Figure 5.21, Site 6 Location. The image shows the estimated location of Site 6 according to GPS coordinates.

Figure 5.22, Bass Point Site Comparison. Site points from the AHIMS database are displayed on the map, including colours indicating sensitivity categories determined from the CSSI. On the figure to the right of the map, sites studied in Hughes and Sullivan (1974) are shown on a drawing of Bass Point. (Adapted from (Hughes and Sullivan 1974)). (© NSW Office of Environment and Heritage 2015)
6 Discussion

6.1 Coastal Site Sensitivity

The CSSI provided an estimate of sensitivity for the registered heritage sites along the Illawarra coastline. The sensitivity of sites, with regards to impacts associated with sea level rise, was based on underlying landform sensitivity. Using landform sensitivity as a proxy is consistent with the assessment made by ANU (2009 p. xi) that states that, “the preservation of unique cultural values—including Aboriginal middens, sea cave deposits, archaeological sites, rock art and cave art sites— is highly dependent on the maintenance and protection of their underlying landforms from climate change impacts”.

The analysis found that higher sensitivity ranked sites tended to be on flat, sandy beaches and plains made up of Quaternary sediment. This is evident among the ‘High’ sensitivity sites found on Wollongong’s Northern Beaches, which are also fully exposed to the predominant south south-east swell. With all variables weighted equally across the study area, there was no prevailing process that exhibited the most control on sensitivity.

The combination of multiple variables with relatively high spatial resolution allowed for individual site sensitivity values to be estimated. The Port Kembla headland (Hill 60) was a useful example in demonstrating the strength of the relatively high spatial resolution used for the CSSI. On this coastal segment, there were examples of the highest and lowest categories of sensitivity present within a few hundred metres (Figure 6.1). The top of the headland had sites classed as ‘Very Low’ sensitivity, while the flat beaches either side of the headland had sites ranked as having ‘Very High’ sensitivity.
Figure 6.1, Port Kembla CSSI Site Points. Sites are represented by points coloured to indicate sensitivity categories determined by the CSSI. (© NSW Office of Environment and Heritage 2015)
Out of the 126 sites analysed in the CSSI, six sites were found to be ‘Very High’ sensitivity. The ‘Very High’ sensitivity sites were found to be relatively spread out over the study area. However, ‘Very High’ sensitivity classed sites generally had many similar attributes. All were found to be very close to the shore, on Quaternary sediment, with low slopes and high exposure to predominant swell direction. The ability to identify heritage sites in a relatively large area with the highest estimated sensitivity, is an extremely useful tool for conservation. These sites which are likely facing the most pressing conservation concerns can therefore be prioritised for further research or protection.

The information held by AHIMS regarding the contribution of a particular site to overall importance, allows sites with high importance to be extracted from the CSSI results. With four sites regarded as contributing to primary importance classed as ‘High’ sensitivity within the study area, the value of regional assessment is evident. Once the sensitivity estimation of sites is completed, sensitivity values can be attached to the sites attribute table. Enquiries into important sites, or particular sites of interest may then yield information on individual sensitivity to sea level impacts. With site type recorded, further research on differential impacts to particular site types could allow further prioritisation based on relative sensitivity. The CSSI can be integrated with other data on coastal characteristics or hazards. Integration of multiple datasets to increase the estimation capability of models investigating heritage sites has taken place before on coasts in Newfoundland, Canada (Westley et al. 2011) and the Whangarei District of New Zealand (Bickler et al. 2013). The ability to easily integrate additional data, as well as the quick and relatively simple application of the CSSI make it a powerful tool for stakeholders in heritage site conservation and management.

6.1.1 Issues with model

There were some issues identified that had the capacity to affect accuracy of the model in some cases. Possible sources for error came from the methods of the model itself, as well as techniques used to create particular datasets and how they were applied.

One key issue was that the analysis assumes all variables have an equal impact on site sensitivity. Weighting of variables accounts for differential impacts of some processes over others. A number of previous coastal heritage studies have been completed without weighting variables (Shi et al. 2012, Westley et al. 2011), while others have applied weighting to variables, to assess vulnerability in a more intensive analysis (Reeder et al. 2012, Reeder-Myers 2015). These weighted models rely on high quality data for the entire study region,
with the benefit of sensitivity estimations that more closely reflect complex shoreline responses to sea level rise.

The analysis had some issues with coverage of the entire study area. Some data such as shoreline exposure and geomorphology left small gaps in the coverage area. This was due to the angles of polyline data, which created a separation when the buffer when applied (Figure 6.2). When these data are included into the CSSI equation, it can create gaps where no data are present. The presence of no data in the calculation leads values of -9999 for some small areas. The model produced coverage that was sufficient to cover all sites, so small gaps in the final model did not have an effect on the results for individual sites. To counter this issue, shoreline exposure and geomorphology values could have been determined using different techniques.

Figure 6.2, Buffer Separation. The image shows an example of gaps in coverage of buffer polygons. The areas not covered by the buffer would not be assigned a value.
The shoreline was derived from the AHGF Hydroline Shoreline. This polyline layer does not follow shoreline into channels, such as Lake Illawarra inlet and other small channels along the coast (Figure 6.3). The effect this has is the classification of these channels as land. In some cases sites that are on the edge of a channel, but some distance back from the channel mouth, will be given a distance weighting derived from the distance to the mouth of the channel. Error is then introduced to the analysis as the site sensitivity value will be lower than the true sensitivity of the site. The sites around the Lake Illawarra channel were impacted by this effect. This problem was compounded by the exclusion of estuarine bodies from the coastal study. However, this was accounted for in the estuarine focused site studies.

Figure 6.3, Shoreline at Channels. The image shows the AHGF shoreline, the line cuts across some channels effectively leading to the channel to be treated as land in the CSSI (© Commonwealth of Australia (Bureau of Meteorology) 2014) (© NSW Office of Environment and Heritage 2015)
Heritage site points may represent an object or place that is less than a metre in size. A regional scale analysis does not have the spatial resolution to operate at this scale. In fact, with spatial resolution based on ~28m grid cells the CSSI is likely stretching or even exceeding the capability of many of the datasets used already. Regional analysis also simplifies many processes and variables acting on sites. However, while a regional analysis lacks precision in some areas, the approach has many positive qualities. The primary advantage of regional scale analysis is it’s the quick application, allowing the estimation of site sensitivity over a large area in a relatively time effective fashion. In this sense the CSSI was effective in providing an estimation of site specific sensitivity over the Illawarra coastal region.

6.2 Estuarine Site Vulnerability

The ESVI allowed estimation of heritage site vulnerability to hazards driven by climate change and sea-level rise for the Lake Illawarra estuary. The ESVI was based on the estuarine biophysical vulnerability analysis technique developed by Rogers and Woodroffe (2016). The analysis followed the technique outlined in Rogers & Woodroffe (2016), and extracted values according to heritage site locations. The biophysical vulnerability of each cell was used as a proxy for site vulnerability.

The analysis indicated that sites on the eastern side of the lake tended to have slightly higher values for vulnerability. ‘Moderately High’ vulnerability was recorded across most of the coastal barrier, it was clear that coastal hazards exhibited a significant effect on vulnerability in the east of the estuary. Many of the sites in the eastern section of the estuary were located on this coastal barrier. The western side of the lake had significantly more ‘Negligible’ vulnerability sites. This was due to many of the sites being located on bedrock around the lake fringes, such as the Broughton Formation and Berry Siltstone of the Shoalhaven Group, and the Dapto Latite a member of the Gerringong Volcanics (Young 1976).

Bedrock presence limited the vulnerability values of the cells significantly within the ESVI. However, while hard rock landforms may be resistant to erosion, sites on these locations are unlikely to be so resilient. Extracting sites that were less than a metre above sea level determined two individual site points that were classed as ‘Negligible’ vulnerability but below a metre in elevation. If the former NSW benchmark of 90cm of sea level rise by the year 2100 was achieved, these sites would face the possibility of being drowned and potentially damaged in that timespan. This is not to say that the ESVI was incorrect, it simply
shows that the model is suitable as a first pass. Insights gained from applying the ESVI can
direct future investigations in this area. The inclusion of heritage site specific values for
sensitivity and exposure (such as individual site type susceptibility to erosion) would allow
sites on resilient bedrock to be evaluated more precisely.

The ESVI was a quick and relatively easy to use tool for examining heritage site vulnerability
in an estuarine setting. The addition of terrestrial hazards as well as coastal erosion and
inundation make this a powerful technique for estimating site vulnerability based on the
biophysical vulnerability of the underlying terrain. The relatively precise spatial resolution
built into the original model allows sites to be assessed on an individual basis using cells of
approximately 28m in size, and capturing variations over 10s of metres. The analysis that was
adapted for the ESVI, was created as a tool that makes it possible to direct and prioritise
higher level assessment (Rogers and Woodroffe 2016). The same can be said for the ESVI,
the analysis allows an estuary wide estimation of heritage site vulnerability that can be used
to direct and prioritise heritage concerns.

6.2.1 Issues with the model and process

Error was encountered in the ESVI analysis due to data conversion methods. Geology data
was in the form of GIS polygon layers released by the NSW Department of Industry,
Resources and Energy. The conversion of these datasets to raster format created some
misclassification along polygon boundaries. The Polygon to Raster tool was used in ArcGIS.
The default method for conversion is the CELL_CENTER method. If the centre of a cell falls
within the boundary of the polygon it is classified correctly. If part of the cell is within the
boundary, but the centre is not, this can cause a classification error (figure 6.4). The error
contributed to several sites along geological boundaries being incorrectly classified. This type
of error does not have much effect on large catchment wide or regional analysis with only a
few cells affected. However, when adapting the Rogers & Woodroffe (2016) technique for
individual points, conversion of data accounted for some localised error.
The analysis outlined by Rogers and Woodroffe (2016) uses geomorphological units as an indicator of biophysical vulnerability. This presents some unique issues in the Lake Illawarra estuary. The estuary is in a highly populated area and has been influenced by human impacts and modifications over several decades. The northern section of the Windang barrier was extensively excavated for sand behind Perkin’s beach (figure 6.5). This was later infilled with sediment dredged from the central lake (Lake Illawarra Authority 2016). As a result, there are large areas determined to be anthropogenic derived sediment in the north-east of the lake. These sedimentary units were not included in the criteria of the study, and therefore not given values in the index. This is also true for the undifferentiated sedimentary units, also present in the estuary and not included in the geomorphic classification (Figure 6.6).
Figure 6.5, Sand Excavation Behind Perkin's Beach. The image shows sand excavation works taking place behind Perkin's beach in the middle of the 20th century. Image taken from Lake Illawarra Authority (2016).

Figure 6.6, Anthropogenic and Undifferentiated Sedimentary Units. Anthropogenic and Undifferentiated Quaternary sedimentary units from the NSW Coastal Quaternary Geology Package are shown around Lake Illawarra. Heritage sites are also shown represented as coloured points. Point colour was determined by exposure and sensitivity category from the ESES1. (© NSW Office of Environment and Heritage 2015)(© NSW Department of Industry 2015)
In addition to modelling issues, some overall approaches to the process could be improved. Heritage sites within the Lake Illawarra catchment were only examined if they were within 500m of the shoreline. This is acknowledged to be an oversight, where examination of the broader estuarine system would have been more appropriate. In the ESVI total vulnerability map (Figure 4.5), it is apparent that some areas on the alluvial plains to the west of the lake have ‘Moderately High’ vulnerability. Excluding sites that may occur in these areas due to distance to shoreline does not give a full account of vulnerability for sites in the estuarine catchment area. Climate change hazards particularly in estuaries may impact areas relatively far from shorelines. This is particularly apparent in the case of fluvial erosion impacts seen in Figure 6.7.

![Figure 6.7, Fluvial Erosion Vulnerability. The map displays estimated fluvial erosion vulnerability for the Lake Illawarra estuary, as determined by the ESVI.](image)

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6.3 Estuarine Site Exposure and Sensitivity

The ESESI was similar in methodology to the ESVI. The only difference was the removal of adaptive capacity values. Exposure and sensitivity values were unchanged in the analysis. The intention was to produce a model that more closely represents the extent of hazards faced by heritage sites. The Fourth Assessment Report of Working Group II of the IPCC defined adaptive capacity as ‘The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences’ (Parry et al. 2007 p. 869). Rogers and Woodroffe (2016 p. 130) defined the adaptive capacity of estuaries as ‘largely constitutes building land elevation through natural processes of accretion or plant productivity’. These natural adaptions of landscapes may not contribute to heritage sites abilities to moderate potential damage; in fact the processes may potentially lead to damage.

Using proxy values may not provide a clear enough picture for determining site sensitivity. In the case of directly using the vulnerability analysis developed by Rogers and Woodroffe (2016), there is a danger of misrepresenting the ability of sites to adapt. Certainly, to aid modelling of sites in estuarine environments, adaptive capacity of heritage sites should be included. To do this effectively information regarding the effects that adaption of the estuarine biophysical environment would have on each site type would be necessary. In addition the ability or lack thereof, of each site to adapt independently of the biophysical setting may need to be included. In lieu of this information, sites in the estuarine setting were analysed in the scope of exposure and sensitivity to coastal and flood hazards.

The removal of adaptive capacity led to sites being placed into slightly higher categories than in the ESVI. Over 50% of sites were classed ‘Moderately High’ in relation to exposure and sensitivity in the ESESI. This was largely due to almost all of the sites classed as ‘Moderate’ in the ESVI being put in the higher category for the ESESI after adaptive capacity values were removed. In fact, approximately 85% of sites were classed as either ‘Negligible’ or ‘Moderately High’ in terms of exposure and sensitivity. These values may accurately represent the exposure and sensitivity of heritage sites in this estuarine region, but the results effectively class the sites into two categories making individual site prioritisation difficult.

The ESESI was utilised as a first pass assessment. The intention of this type of analysis is to direct and prioritise higher level assessment. The ESESI was effective on this count, and estimation of exposure and sensitivity of heritage sites around Lake Illawarra indicate that the
majority of sites fall into the category of ‘Moderately High’. This suggests that from a conservation perspective there is a clear need for further assessment. While the analysis does not single out a small number of priority sites for focus, it does signal that there is a case for investigating heritage sites around Lake Illawarra in greater detail.

The issues with applying the model to heritage sites were similar to those encountered in the ESVI, due to the similar methodology used in both analyses. A discussion of issues can be found in section 6.2.1.

6.4 Bass Point

The site investigations of Bass Point allowed a critical evaluation and effective ground-truthing of the CSSI to take place. The CSSI variously categorised sites on the point as ‘Very Low’, ‘Low’ and ‘Moderate’ sensitivity. ‘Moderate’ sensitivity sites, were located on the Quaternary sediment located in the central area of the Point. Sites classed as ‘Low’ and ‘Very Low’ sensitivity were located on Bumbo Latite (a member of the Gerringong Volcanics) which was exposed around the margins of the Point.

Although no archaeological evidence was found at the investigated site points, it was clear that there was a separation in the CSSI values and heritage site sensitivity. Sites 4 and 5 were observed to be experiencing active wave action. This is likely of very little concern for the resistant latite that forms the point, as well as other headlands in the region (Oak 1984). However, an archaeological site such as a shell midden or artefact scatter would likely be at considerable risk from coastal erosion at these locations. These examples demonstrate a potential flaw in the model. Adapting landform sensitivity to use as a proxy for site sensitivity simplifies the relationship between sites and the landforms. While it has been acknowledged that heritage sites rely on the integrity of the underlying landform (Australian National University 2009), it is clear that highly resilient and stable landforms do not entirely negate any risk to heritage sites.

A shell midden on a rock platform such, as those at sites 4 and 5, would not survive for long before being destroyed. The same site may be classed as ‘Low’ sensitivity in the CSSI due to the resilience of the underlying landform. This is the case at sites 4 and 5 with ‘Very Low’ and ‘Low’ sensitivity values respectively. This is not a problem with the original model designed by Abuodha and Woodroffe (2010). In adapting the model to use coastal sensitivity as a proxy for coastal heritage site sensitivity, there is a potential caveat where
landscape sensitivity does not necessarily equal site sensitivity. While unstable and highly sensitive landforms will surely contribute towards higher sensitivity of sites, the same direct relationship may not always be true for lower sensitivity landforms. The very nature of the site itself may render it susceptible to hazards such as erosion. To account for this greater weighting on variables such as distance to shoreline could be applied. Elevation of sites should also be included in the variables and weighted. These additions would help to account for error in sensitivity classification, such as at Sites 1, 2, 4, 5 and 6. These sites were all recorded on relatively low elevations and close to the shoreline, and rising sea levels may lead to these sites being increasingly sensitive to coastal hazards generated by wave action, high tides and storm surges (Bickler et al. 2013).

Equally important to consider in the study is the accuracy of site data. No archaeological evidence was found at any of the site points. In fact the landscape at Sites 2, 4, 5 and 6 would indicate that it is highly unlikely that there was ever surviving archaeological material found there. In particular Site 6 was in the ocean. There was no evidence of any archaeological material found within 30m of any of the sites. With the CSSI, ESVI and the ESESI studies the cell size was ~28m. Therefore, if sites are located more than 30m from the recorded points they will likely be given incorrect sensitivity values, due to being recorded outside of the correct cell. Location inaccuracy can come from a variety of sources. Methods of recording site data have changed over time and some error may have been introduced in the original records (Reeder et al. 2012, ERM 2006). Transfer from original documentation to the AHIMS database may also have introduced some error (ERM 2006). Heritage sites in the database are likely to vary in size and shape and a single point may poorly represent the site, with the boundaries potentially being several metres from the recorded point (Westley et al. 2011).

Close to Site 2 there was some evidence of potential midden-derived material. The shells were located with pumice a few metres inland of the strandline and had evidence of bioerosion processes. The species and sizes found were consistent with middens recorded in the area (Bowdler 1976), but sponge bore holes and worm tubes suggest that the shells spent some time under water after the death of the organism (Vermeij 1993). A significant amount of pumice was found with the shells, with pumice deposition being associated with storms in Australia (Sutherland and Barron 1998). The combination of these factors suggests the possibility that the shells were storm deposited and may have originated from a midden in the
area. There is evidence of midden sites on Bass Point being reworked by storms in the past (Hughes and Sullivan 1974).

The lack of any clear archaeological evidence at any of the investigated Bass Point sites raises questions on the accuracy of site locations throughout the study area. Spatial accuracy of site locations is essential for the GIS-based analysis of heritage site sensitivity. The landforms investigated comply with what would be expected due to the classification of the CSSI, thereby broadly validating the methods of the study. However the ground-truthing highlights that more precise physical investigation must take place. The Bass Point field investigation shows the need for weighting of variables, particularly to account for sites on highly resistant landforms. In addition the need for precise site location data is apparent. Desk based modelling can be a powerful and efficient tool in planning and conservation. However spatial modelling relies on high levels of spatial resolution and accuracy, without which the abilities of the techniques are hindered.
7 Conclusion and Recommendations

Coastal heritage sites around the world are facing the potential of exacerbated coastal hazards driven by sea level rise and climate change (Erlandson 2012). In order to act appropriately all relevant stakeholders need to be able to direct time and resources effectively. Studies into coastal heritage site sensitivity provide a good framework for assessing the priority of needs so that those sites with the highest sensitivity to impacts can leverage the efficiency and power of applied resources. In Australia this approach is particularly useful with the mainland and islands reaching nearly 60,000km of coastline (Geoscience Australia 2016), leading to a large area at potential vulnerable to the hazards associated with sea level rise. In context of scale, it has taken 13 years for the SCAPE program to physically survey only around 5000km of the 15,000km long Scottish coastline (Westley et al. 2011). In NSW outside of the National Parks, ‘assessment and conservation of Aboriginal heritage places and landscapes has taken place in the context of Environmental Impact Assessments (EIA)’ (Wesson 2005 p. 4). Wesson (2005) goes on to describe that assessments have often occurred in a ‘piecemeal fashion’. The issue with conservation studies being applied separately is that they may lack context, or ignore broader narratives. A regional scale investigation into heritage site sensitivity allows the overall picture to be inclusive, rather than individualistic. The significance of a site within the larger cultural narrative may not be apparent when the subject is viewed in isolation (Bradley 2008).

This study utilised the concept of adapting regional coastal vulnerability and sensitivity analysis techniques to heritage concerns, with underlying landscape sensitivity used as a proxy to indicate the potential sensitivity of heritage sites. Adaption of coastal vulnerability indices for heritage sites has been utilised for regional scale studies in the past (Reeder et al. 2012, Reeder-Myers 2015), but this has not yet been applied in an Australian setting. The Illawarra region of NSW has been studied in the context of both coastal sensitivity and estuarine biophysical vulnerability (Abuodha and Woodroffe 2010, Rogers and Woodroffe 2016). Heritage sites on the coastal strip of the Illawarra region were investigated using an adaption of the Coastal Sensitivity Index developed by Abuodha & Woodroffe (2010). To account for differences in impacts of sea level change experienced between open coasts and estuaries, an estuarine specific vulnerability analysis technique was necessary to investigate the sites around the lake. The model developed by Rogers and Woodroffe (2016) for NSW estuarine systems was adapted to fill this gap.
The Coastal Site Sensitivity Index allowed for a quick and effective estimation of sensitivity for 126 sites on the coastline of the Illawarra. Spatial resolution of ~28m cells allowed relatively local changes in variables to be taken into account for a regional approach. The analysis points to sites on exposed beaches, particularly those to the north of Wollongong as having the most significant sensitivity concerns. The Estuarine Site Vulnerability Index and Estuarine Site Exposure and Sensitivity Index similarly allowed for the estimation of vulnerability and sensitivity for 91 sites around Lake Illawarra. The findings of both of these analyses suggested that heritage sites located on the eastern margin of the lake, on the coastal barrier were of the highest concern. Heritage sites that were situated on areas of hard bedrock were found to be the least vulnerable or sensitive to climate and sea level rise driven hazards in all of the models. This was seen in ‘Very Low’ sensitivity sites as well as some ‘Low’ sensitivity sites analysed in the CSSI. In the ESVI and ESESI sits occurring on bedrock margins of Lake Illawarra were classed as ‘Negligible’ for vulnerability and sensitivity respectively.

The Bass Point site study demonstrated that the CSSI was relatively effective for the estimation of landform sensitivity. The site points that were classed as ‘Low’ sensitivity were observed to be tough Bumbo Latite outcrops that are resilient to erosion (Figure 3.13). In terms of site sensitivity however, the Bass Point sites demonstrate the limitations of the analysis. While the landforms at the points were highly resilient due to hard rock, a site on these locations would not be as well protected. The use of coastal sensitivity as a proxy for site sensitivity is useful, as an unstable section of highly sensitive coastline would jeopardise a site that is located on it. However lower sensitivity of a landform does not as readily translate to site sensitivity. This point was also encountered with some ‘Negligible’ sensitivity sites found to be below 1m in elevation in the ESESI and ESVI analyses. The elevation of these sites places them precariously close to the former NSW government benchmark of 90cm of sea level rise by the year 2100. It is clear that sites with ‘Negligible’ sensitivity or vulnerability values should not necessarily be dismissed.

The application of sensitivity indices to heritage sites in the region could be further improved with some changes to the analytical techniques. Weighting of variables to more precisely relate to the specific hazards faced by heritage sites would be useful. This is particularly apparent for sites on hard bedrock classed as ‘Very Low’ or ‘Negligible’ sensitivity. In particular, distance to shoreline and elevation should be weighted higher to more effectively account for heritage sites that may be more susceptible to hazards such as wave action, tidal
range and storm surge but are located on resistant landforms. There are of course other variables that will influence site vulnerability and sensitivity outside of the scope of the study. The input of vegetation cover and land use for example would also be useful variables to take into account for future studies particularly for their influences on erosion. Differences in hazard impacts on particular site types may also be factored into analysis. For example, a grinding groove may have a different capacity to resist the impacts of coastal erosion when compared to a shell midden. Equally in an estuarine setting a scarred tree and an artefact scatter will be differentially affected by inundation. Daire et al. (2012) flagged investigation of differential impacts related to site types as an avenue for future research during work on the ALeRT project in Western France. Variation of hazard effect due to site type would require considerable additional study, but would provide significant information for estimating heritage site vulnerability or sensitivity.

Regional vulnerability and sensitivity analyses of coastal and fluvial drivers can be integrated with other relevant studies, allowing further more complex investigation of hazards potentially affecting heritage sites. In the Whangarei district of New Zealand and the Newfoundland coast of Canada studies have integrated multiple models to assess wider hazards affecting heritage sites (Westley et al. 2011, Bickler et al. 2013). Land use has also been incorporated in heritage site analysis effectively (Reeder et al. 2012, Reeder-Myers 2015).

The CSSI, ESVI and ESESI were all demonstrated to be useful and effective first-pass assessment tools for heritage sites in the region. However, the roles of governance and responsibility for heritage sites also play a role in the assessment of sensitivity to potential hazards. With sites often assessed in a ‘piecemeal’ fashion through individual Environmental Impact Assessments (Wesson 2005). The responsibility of management seems to fall with councils when outside National Parks. However during Wollongong Councils recent Coastal Zone Assessment by Cardno Lawson Treloar (2010), it was noted that the author was not able to obtain site information before publishing. This highlights a relevant issue for heritage site management in NSW. Without assessment of hazards faced by heritage assets, it is incredibly difficult to manage their conservation. The AHIMS register is a powerful tool that is often used for planning, management and conservation of Aboriginal heritage places and objects in NSW (NSW DECCW 2011, NSW ALC 2011). Location accuracy of sites within this dataset is crucial for planning purposes.
The regional analysis techniques used for the CSSI, ESVI and ESESI were demonstrated to be an effective method for assessing site sensitivity to sea level rise and climate change hazards. The analyses were completed as a first-pass approach with the ability to be integrated with further hazard studies. The first-pass approach can be used to target field based studies to heritage sites classified with the highest vulnerability or sensitivity, such as the sites identified as ‘Very High’ sensitivity in the CSSI (Westley et al. 2011). The analyses also identify areas for further more complex second-pass assessments, such as the ‘Low’ sensitivity sites identified in the CSSI and the ‘Negligible’ sensitivity classed sites in the ESESI that were located on resilient landforms that skewed results in the first-pass assessment. However, as with all spatial models, the accuracy and effectiveness of the analysis was shown to be limited by the input data and spatial accuracy of this information. It is for this reason that fine scale studies and physical surveying are still essential to the investigation of heritage site sensitivity to climate change driven hazards. Nevertheless, the power of desk based analysis for prioritisation of resources and energy towards conservation is significant. Effective prioritisation allows for the potential leveraging of resources and management to give the greatest benefit from what is available. In a nation that has vast coasts to cover with relatively limited resources, prioritisation and effective management are key to conservation.
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9 Appendix

Data used in analysis

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