Coastal hazards of the Dunedin City District

Review of Dunedin City
District Plan—Natural Hazards

Otago Regional Council
Private Bag 1954, Dunedin 9054
70 Stafford Street, Dunedin 9016
Phone 03 474 0827
Fax 03 479 0015
Freephone 0800 474 082
www.orc.govt.nz

ISBN 978-0-478-37678-4

Report writers: Michael Goldsmith, Manager Natural Hazards
Alex Sims, Natural Hazards Analyst

Published June 2014

Cover image: Karitane and Waikouaiti Beach

Contents

List of figures

List of tables

1. Introduction

1.1. Overview

As part of its current review of its District Plan, the Dunedin City Council (DCC) is reviewing the way it manages the use of land, so that the effects of natural hazards (including the effects of climate change) can be avoided, or adequately mitigated. The Otago Regional Council (ORC) is supporting the DCC by collating and presenting natural hazards information to help inform this review, and this report describes the characteristics of natural hazards along the Dunedin City coastline. As well as helping to inform the management of land use through the District Plan review, this report will assist with other activities such as the development of local emergency management response plans, building consents, and infrastructure planning, renewal and maintenance.

This report identifies areas where natural hazards may affect public safety, buildings and the infrastructure which supports coastal communities. It is part of a series of technical reports which have been prepared by the ORC and DCC to inform the review of Dunedin City District Plan:

1. Project Overview (ORC, 2014a)
2. **Coastal Hazards of the Dunedin City District**
3. Flood Hazard on the Taieri Plain and Strath Taieri (ORC, 2014b)
4. Flood Hazard of Dunedin's urban streams (ORC, 2014c)
5. The hazard significance of landslides in and around Dunedin City (GNS, 2014a)
6. Assessment of liquefaction hazards in the Dunedin City District (GNS, 2014b)

The focus of this report is on coastal hazards such as storm surge and tsunami; inundation from river flooding and surface runoff; and the effects of climate change and sea-level rise. The effects of other hazards are also described where these are significant. Ideally, the reader should view the description of natural hazards contained in this report alongside the information contained in the other reports, particularly the project overview and the assessment of landslide and liquefaction hazard (listed above as numbers 1, 5 and 6 respectively).

1.2. Scope

The geographical scope of this report is the coastline of the Dunedin City District. This extends approximately 200km from the mouth of the Pleasant River in the north, to Taieri Mouth in the south, and includes the Otago Harbour. This report describes the natural hazards of the 15 communities which are located on, or in close proximity to this coastline (Figure 1). The combined population of these communities was approximately 22,500 at the time of the 2013 census, which is 19% of the total population of the Dunedin District.

The communities identified in Figure 1 are existing settlements, located on relatively low-lying land, near the coast. This report describes the characteristics of the natural hazards which can affect these settlements, and identifies areas where those hazards are present.

Other low-lying areas where no settlement currently exists, but where demand for future development may possibly occur in the future are also identified in this report, and the nature of the hazards which can affect those areas is also described, based on current knowledge. These include the lower reaches of the Pleasant River, Whareakeake (or Murdering), Kaikai, Smaill's, Boulder, Allan's and Victory beaches, Hoopers and Papanui inlets, and Sandfly Bay.

More elevated communities such as Seacliff, Doctors Point, Waverley, and parts of St Clair have not been included in this study, as they are elevated above the influence of the Pacific Ocean.

1.3. Describing natural hazards in coastal communities

The natural hazards which affect the settlements shown in Figure 1 have been described by bringing together existing information about:

1. The nature and extent of inundation due to coastal hazards (storm surge, tsunami and erosion) and heavy rainfall (river flooding, surface ponding),

2. The potential effects of sea-level rise, and possible changes to the morphology of the shoreline over the next 100 years,

3. The nature of other hazards present in that area.

The description of the 'hazardscape' of each community has been informed by a range of information, including previous investigations of natural hazards (eg, ORC 2012a, NIWA 2007, NIWA 2008), observations and local knowledge, historical shoreline mapping, and national guidance on sea-level rise and climate change (eg, Bell 2013, MfE 2008a, 2008b). Where possible, natural hazards have been described in terms of their effect on the health and safety of people and communities – i.e. how they may affect public safety, buildings and other infrastructure supporting communities.

The assessment has also considered the cumulative effects of single or multiple hazards on a community, in particular:

1. The likelihood of an area being affected by *any* hazard. For example, land which is susceptible to coastal storm surge may also be prone to river flooding and liquefaction due to seismic shaking.

2. The likelihood of an area being affected over the *longer term*. For example, the chance of a coastal community being affected by a high magnitude tsunami event in any given year may be relatively small, but the likelihood of such an event occurring at least once during the time a person may live in such an area (10 – 50+ years) is much higher. It is noted that as sea level rises, the likelihood that an elevated sea level event will reach a level where it can affect people and assets will increase.

3. The cumulative effects of *repetitive events* on people and assets. An example is where a series of extreme sea level and/or flood events occur over a short space of time, affecting a particular community or area several times in quick succession.

4. The likelihood of a *combination* of hazards occurring at the same time. For example, a coastal community at the mouth of a river, where the effects of flooding may be exacerbated by elevated sea levels.

Within each community, areas which have a similar vulnerability to natural hazards have been identified and mapped. The Otago Natural Hazards Database (www.orc.govt.nz) provides access to additional information about the natural hazards which can affect coastal communities.

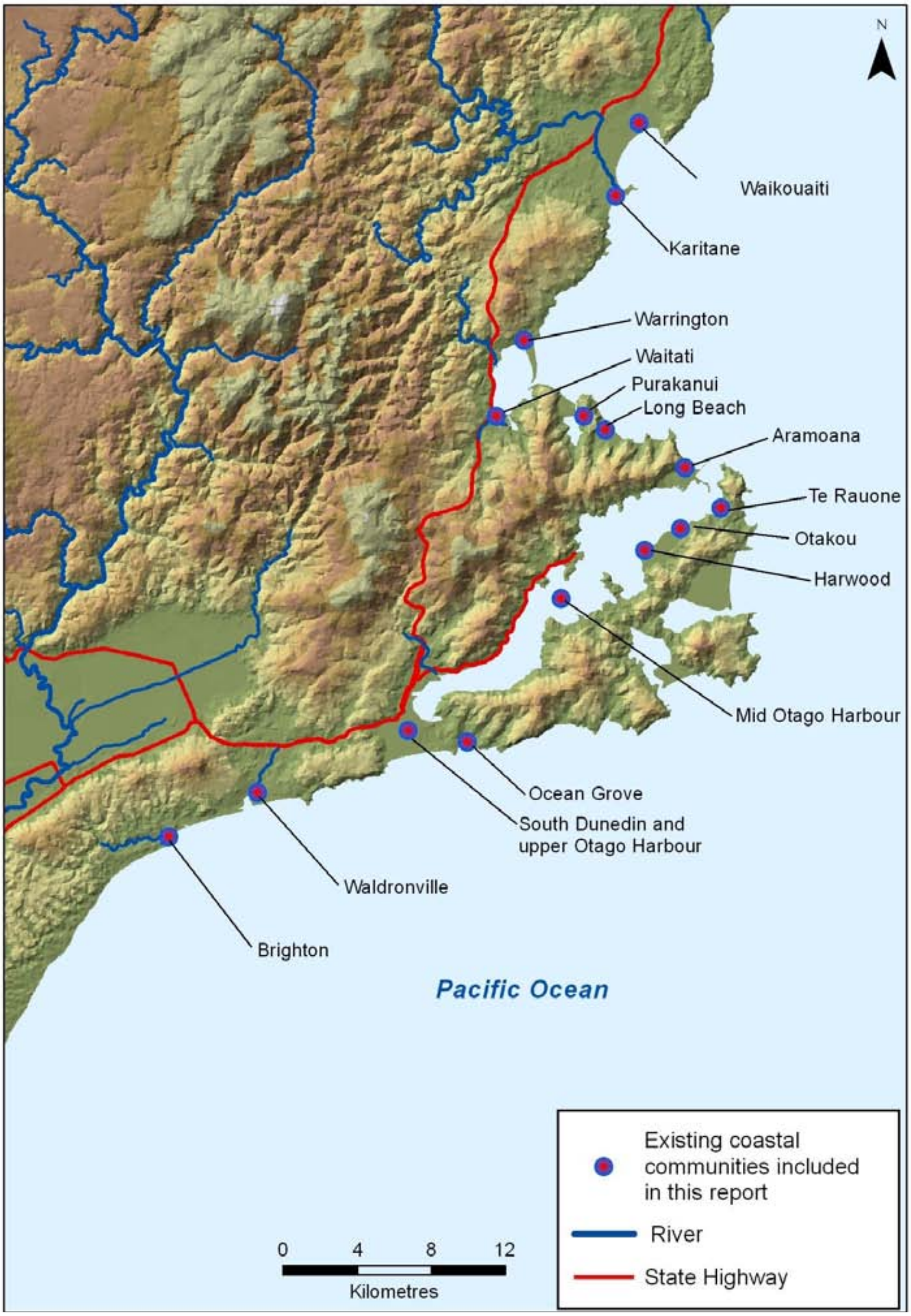

Figure 1 Dunedin City coastal communities included in this report

1.4. Mapping Natural Hazard Areas

This section describes how natural hazard areas have been mapped for existing low-lying communities along Dunedin's coastline, as well as for adjacent low-lying areas where no settlement currently exists, but where demand for development may occur in the future. These mapped areas are intended to provide a general indication of the land which is potentially subject to one or more hazards – they are not land-use management 'zones'. Appendix 2 provides a series of maps and cross-section profiles for each of the communities discussed in this report. These images help to show the height of the land, relative to mean sea level, and to the water levels associated with selected storm surge and tsunami events (Table 1 and Table 2).

1.5. Coastal hazard areas

The lowest-lying land in each community which is particularly vulnerable to coastal hazards has been defined using the following method:

Area A: Land which is below the height identified as the 1:100 year storm surge level by NIWA (2008). These heights are reproduced in Table 1.[1] A 1:100 year event is one that has a 1% chance of occurring in any given year, and a 63% chance of occurring in the next 100 years. Such an event is therefore 'likely' (but not certain) to occur over any 100 year period. Additional justification for using the 1:100 year level is that the New Zealand Coastal Policy Statement (NZCPS, 2010 – Policy 24) states that 'Hazard risks, over at least 100 years, are to be assessed', with regard to factors that include 'the potential for inundation of the coastal environment'.

It is noted that more elevated land may act as a buffer to restrict direct inundation of Area A from the sea. Area A therefore identifies land which would be affected by inundation if there was direct connection to the sea during a 1:100 year storm surge event, or if surface runoff / floodwater were to reach the same height as the sea during such an event.

Area B: The most recently available guidance to local government in New Zealand regarding sea-level rise over the next 100 years is from NIWA (Bell, 2013), which advises that "A sea-level rise of 1.0m by 2115 relative to 1990 mean sea level is the most credible estimate of sea-level rise for New Zealand regions at this stage…" As a result of this guidance, 1m has been added to the 1:100 year storm surge level identified by NIWA (2008). This level is also shown in Table 1, and the land within each community which lies below this level is mapped as Area B.[2]

---

[1] Note that these levels have been adjusted by +0.11m to account for the increase in sea level that has occurred since 1958, when the msl datum (Dunedin Vertical Datum 1958, or DVD-58) was established, and are the same as those used in ORC (2012a). The values in Table 1 have also been rounded to the nearest 0.05m (5cm).

[2] The Ministry for the Environment (MfE, 2008a) recommends that all assessments should consider the consequences of a mean sea-level rise of at least 0.8 metres relative to the 1980–1999 average. However, the most recent report compiled by the IPCC (2013) considers sea-level rise of up to 0.98m likely by the year 2100 (relative to the 1986 – 2005 baseline). The report 'Climate Change Impacts on Dunedin' (Fitzharris, 2010) recommended that Dunedin City should plan for up to 1.6m sea-level rise by 2090. Therefore the DCC has decided to plan for a minimum of 0.8m and a maximum of 1.6m sea-level rise by 2090 considering the recommendations from both central government and more recently the scientific community (DCC, 2011a). The additional 1m used to map Area B lies within this range.

Table 1 Predicted storm surge levels for an event with a return period of 100 years (relative to DVD-58), sourced from NIWA (2008). Other communities are included in this report for which NIWA (2008) did not model storm surge levels. Where this is the case, the level for the closest relevant community modelled by NIWA is used (see Appendix 1).

Location	At current sea level (Area A)	With 1m of sea-level rise (Area B)
Brighton	2.10	3.1
Kaikorai	2.05	3.05
St Kilda / St Clair	2.05	3.05
Upper Otago Harbour	1.90	2.90
Long Beach	1.80	2.80
Purakanui	1.80	2.80
Warrington	1.75	2.75
Karitane	1.85	2.85

1.6. Uncertainty of mapped coastal hazard areas

There is some uncertainty associated with the levels used to map coastal hazard areas A and B for each community. These include:

1. Inaccuracies or limitations in the modelling and topographic data used to determine the levels shown in Table 1
2. The combined effects of large flood events in rivers, coinciding with storm surge events along the coast,
3. The additional effects of storm surge events interacting with buildings or water-borne debris.

More information about these limitations is contained in ORC (2012a) and NIWA (2008). The levels shown in Table 1 are considered to be the lower bound. Consideration should therefore be given to specific situations around the margins of Areas A and B, particularly where the land is gently sloping, as a relatively small increase in water level could significantly increase the area affected.

1.7. Other coastal hazards

The land mapped in this report as Area A only takes account of the inundation which could occur if water reached the level of a 1:100 year storm surge event, while Area B shows land which could be affected under this same scenario, if sea-level were 1m higher. Storm surge events of a higher magnitude, tsunami and coastal erosion can also present a hazard for the coastal areas of the Dunedin City District.

NIWA (2008) also identified the water level for a storm surge event with a return period of 500 years, and this is shown in Table 2. GNS (2013) provides the latest assessment of all sources of tsunami that could affect the New Zealand coast, and gives the expected wave heights (at the coast) for return periods of 500, 1,000 and 2,500 years. These are also shown in Table 2. The peak tsunami wave heights specified by GNS were restricted to the open coast, rather than for estuaries and other inlets such as the Otago Harbour.

Table 2 Predicted heights for a 1:500 year storm surge event, and for high magnitude tsunami events (source report in brackets). Note that the heights shown in this table relate to current mean sea level.

Location	1:500 storm surge (ORC, 2012a)	1:500 year tsunami (GNS, 2013)	1:1000 year tsunami (GNS, 2013)	1:2500 year tsunami (GNS,2013)
Brighton	2.20	5.3	6.5	7.9
Kaikorai	2.15	3.6	4.5	5.5
St Kilda / St Clair	2.15	3.6	4.5	5.5
Upper Otago Harbour	2.00	N/A	N/A	N/A
Long Beach	1.90	4.8	5.7	6.9
Purakanui	1.90	4.8	5.7	6.9
Warrington	1.90	5.0	5.9	7.0
Karitane	1.95	5.0	5.9	7.0

The levels shown in Table 2 have not been used directly to map coastal hazard areas for the following reasons:

- The levels associated with the 1:500 year storm surge event are not significantly higher than those identified for a 1:100 year event.
- The actual extent and depth of inundation from tsunami events will vary according to a number of factors, including the direction from which the tsunami approaches, and the influence of headlands, sand dunes, embankments and onshore topography on waves as they move towards the coastline and then onto the land.
- High magnitude storm surge and tsunami events may have a significant impact on the morphology and height of the land, which in turn will affect the extent and depth of inundation (eg, vertical or horizontal displacement of land due to movement on a nearby fault line during an earthquake).

As stated, this report does not specifically map areas which may be vulnerable to high magnitude, low frequency events, such as those listed in Table 2. However, the residual risk associated with such events is accounted for by describing the areas which are more likely to be affected in general terms (eg, coastal terraces which are still relatively low-lying, but above the levels listed for Area B in Table 1).

1.8. Other hazard areas

This report also maps the parts of each community which have some vulnerability to other natural hazards, or which currently act as a buffer to protect communities against the effects of erosion and direct inundation from the sea. These include:

1. Coastal erosion (by analysing observed changes in shoreline position since the mid-20th century, and describing locations where further coastal erosion could have a significant impact on communities).

2. Flood hazard

3. Rockfall hazard

4. Alluvial fan hazard

5. Sand dunes, sand spits and raised coastal terraces.

Other natural hazards have been mapped to help provide a broad understanding of the hazards in each community. Where these have been mapped, they are labelled with the predominant hazard type(s) or characteristic of the land. Part 2 of this report provides some explanation as to the characteristics of each of these areas.

Hazards associated with landslides, liquefaction and lateral spread are not mapped in this report, although they are referred to where these are significant. Instead, reference is made to two recent reports by GNS Science (2014a, 2014b), where these contain more detailed information on these hazards for particular communities.

The absence of information on a certain type of hazard or for a certain property or area does not necessarily mean that there is not a hazard of that type that affects that community. It may mean that the ORC does not have any information, possibly because that particular area has not been studied, due to it having a low priority or demand for that sort of information.

2. Coastal communities in the Dunedin City District

2.1. Brighton and Ocean View

Figure 2 Topography of Brighton and the surrounding area

Setting

Brighton and Ocean View are located on the south coast of the Dunedin District, approximately 16 km south-west of the Dunedin CBD (Figure 1 and Figure 2). Parts of the township lie at low elevation, less than 5m above msl (Figure 3). The settlement is spread out along the coast and lies between coastal hills to the north, which rise to elevations of 350m, and the Pacific Ocean. Otokia Creek flows through the centre of Brighton, while Taylors and another un-named ephemeral creek pass through Ocean View. All three creeks flow directly into the sea.

Brighton and Ocean View had a combined population of 1,419 at the time of the 2013 Census, a decrease of 3% compared with the population in 2001. More than 90% of the dwellings are permanently occupied, with many residents commuting to Dunedin for work or school. The settlement contains a small convenience store and other commercial premises, a camping ground, sports fields and facilities, a primary school and a surf lifesaving club.

Assessment of Risk

The current level of development in Brighton is reasonably intensive residential, with rural land (including 'lifestyle' blocks) on the outskirts. Although it is one of the larger settlements situated along the coastline of the Dunedin district, much of the township is sufficiently elevated, and/or set back from the shoreline, so as to have a relatively low vulnerability to coastal and flood hazard. The stable population also means that there has been limited demand for intensive development on hazard-prone land, although sub-division of lifestyle sections on the adjacent hills has continued to occur. DCC (2009) identified that considerable infill (or subdivision) development could occur within the boundaries of Brighton Township however, should there be sufficient demand.

Parts of the town are vulnerable to a range of natural hazards, and are also vulnerable to the effects of climate change, through increasing sea level and the potential for larger, more frequent rainfall events. Any increase in the level of development in these areas will add to the risk associated with natural hazards.

Figure 3 The mouth of Otokia Creek at Brighton, with low-lying residential land at centre-right (August 2011)

Characteristics of mapped hazard areas in Brighton

Brighton's location and topography expose it to two broad types of hazard; inundation (either from the sea, or from heavy rainfall / flood events), and land instability (including coastal erosion, landslides, and the effects of seismic shaking). The characteristics and effects of these hazards are described broadly below. Mapped hazard areas are shown in Figure 4 to Figure 6, along with other areas which play an important role in protecting these coastal communities.

- Direct Inundation from the Pacific Ocean

Two categories of lower-lying land have been identified using the methods outlined in Part 1 of this report. These are described below, and shown in Figure 4 and Figure 5. The overall effects of direct inundation from the Pacific Ocean (including velocity, depth and duration) may create a threat to life/safety, could result in damage to buildings, and create difficulties when evacuating people. These effects are likely to be greatest in areas which are low-lying, and/or immediately adjacent to the ocean.

Area A: Land which is below the height identified as the 1:100 year storm surge level (Table 1). This area is also vulnerable to other coastal hazards such as tsunami and coastal erosion, and inundation resulting from heavy rainfall events and high flows in Otokia Creek, Taylors Creek and the un-named creek. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Area B: Land which is below the combined height of the 1:100 year storm surge level, and an additional 1m (as described in the introduction, and listed in Table 1). Although higher than Area A, this area currently has some vulnerability to high magnitude, low frequency tsunami, storm surge, and flood events. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Beyond Area B: High magnitude, low frequency events (as described in Table 2) may affect land which is higher than that mapped as Area B, irrespective of sea-level rise. Although such events may occur rarely, they could affect much of the coastal terrace that lies between Brighton Road and the coast. The actual extent of inundation (along with other characteristics such as velocity and depth) during the largest credible tsunami events are not possible to map accurately, given the current level of information available.

- Other Natural Hazards

Flood hazard: The creeks that flow through Brighton / Ocean View occupy parts of floodwater-dominated alluvial fans and have been subject to active floodwater dominated alluvial fan activity in the past (GNS, 1998). During extreme rainfall events, the velocity and depth of water draining the coastal hills (both as overland flow and floodwaters carried by the local creeks) can carry sediment and debris. The velocity of these flood flows will decrease as they arrive on the flatter, low-lying creek-beds within the Brighton Township, causing entrained sediment and debris to be deposited. The deposition of sediment (usually fine silts and sands) can alter the form of the fan surface, and may affect roads and buildings. Material entrained in floodwaters can cause additional damage to buildings and other assets (i.e. beyond that of flooding due to water only.

As well as being vulnerable to river flooding, these low-lying areas are susceptible to extreme tide, storm surge or tsunami events, or a combination of these hazards.

A separate flood hazard area is also mapped on Figure 5, near the intersection of McColl Road and Brighton Road. Although not connected to a waterway, surface runoff can pond in this low-lying area at the base of the coastal hills (Figure 8).

Seismic hazard: Ground shaking at Brighton with a return period of 100 years is likely to displace objects and crack large windows (Opus 2005). The maximum intensity ground shaking modelled by Opus (2005) for Brighton is associated with a magnitude 7 earthquake on the Akatore Fault. This would make it very difficult for people to stand and cause substantial damage to chimneys and un-reinforced stone and brick walls.

In addition to the effects of ground shaking, unconsolidated sediment (silts and sands) and a shallow water table mean the land in and around Brighton is susceptible to subsidence, lateral spreading around the margins of creek beds and liquefaction during earthquakes. Ground subsidence, lateral spread or liquefaction has the potential to damage roads, power lines, underground pipes and building foundations. GNS (2014b) describes the hazard associated with liquefaction in the Brighton area.

Land instability: A prominent hazard affecting the Brighton area is land instability, in the form of landslides, which have the potential to damage buildings, roads, power-lines and pose a threat to life/safety. Many landslides are located on the slopes surrounding the volcanic necks of Saddle Hill, Jaffrays Hill and Scroggs Hill. These include both large bedrock landslides that are seated in relatively unstable sedimentary rocks, and smaller surficial landslides which often occur within the regolith that overlies the bedrock. The old Brighton Road Slide underwent a major movement in 1939, severing the original road to Brighton and leading to its abandonment. Landslides in this area are considered to have high sensitivity to small modifications in stability factors such as erosion and human modification (GNS, 2014a). A recent report by GNS (2014a) describes the hazard associated with mapped landslides in the vicinity of Brighton.

- Other Coastal Areas

Raised coastal terrace: A raised coastal terrace and dune system is mapped on Figure 4, Figure 5 andFigure 6. This acts as a buffer to protect the communities of Brighton, Ocean View and also Westwood to the northeast against the effects of erosion and direct inundation from the sea. Activities that disturb the form of this foreshore area and its vegetation cover (such as excavation or the removal of vegetation) may compromise its stability. This buffer area may be affected by future changes in sea level or large storm events. Figure 7 shows that the shoreline generally accreted (moved seaward) or remained stable in the Brighton area between 1947 and 2013, although some minor loss of vegetated foredune was noted in recent years near the mouth of Taylors Creek.

Figure 4 Mapped natural hazard areas in Brighton (south)

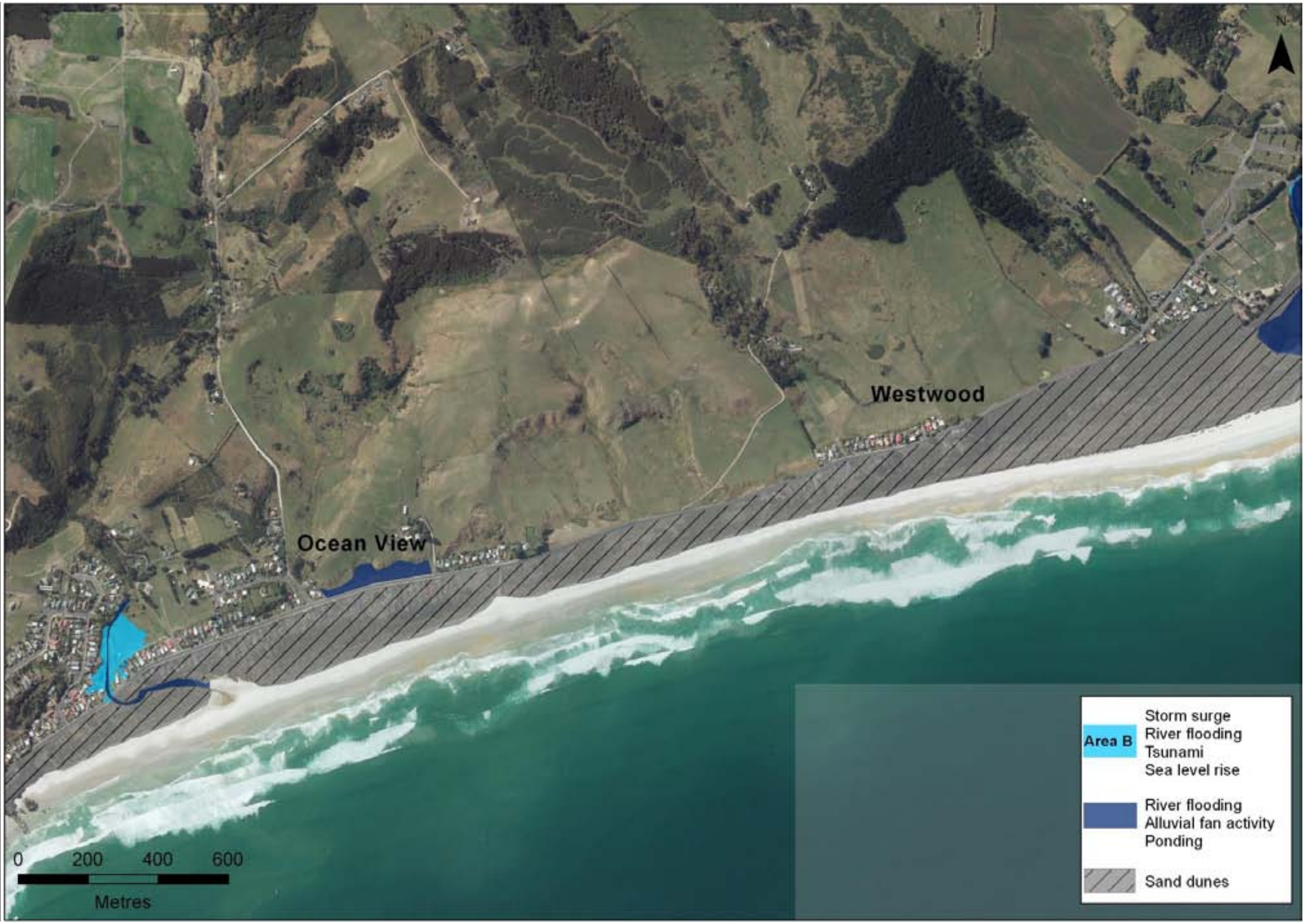

Figure 5 Mapped natural hazard areas in Brighton (north)

Figure 6 Land mapped as 'Raised Coastal Terrace', on the seaward side of Taieri Mouth Road, between Brighton and Taieri Mouth. In places this area is narrow (<50m), as shown in the inset.

Figure 7 Changes in the Brighton coastline between 1947 and 2013, overlaid on an aerial photograph collected in 2013 (source: DCC)

Figure 8 Surface ponding on low-lying land near the intersection of Brighton Road and McColl Road (May 2013)

2.2. Waldronville and Westwood

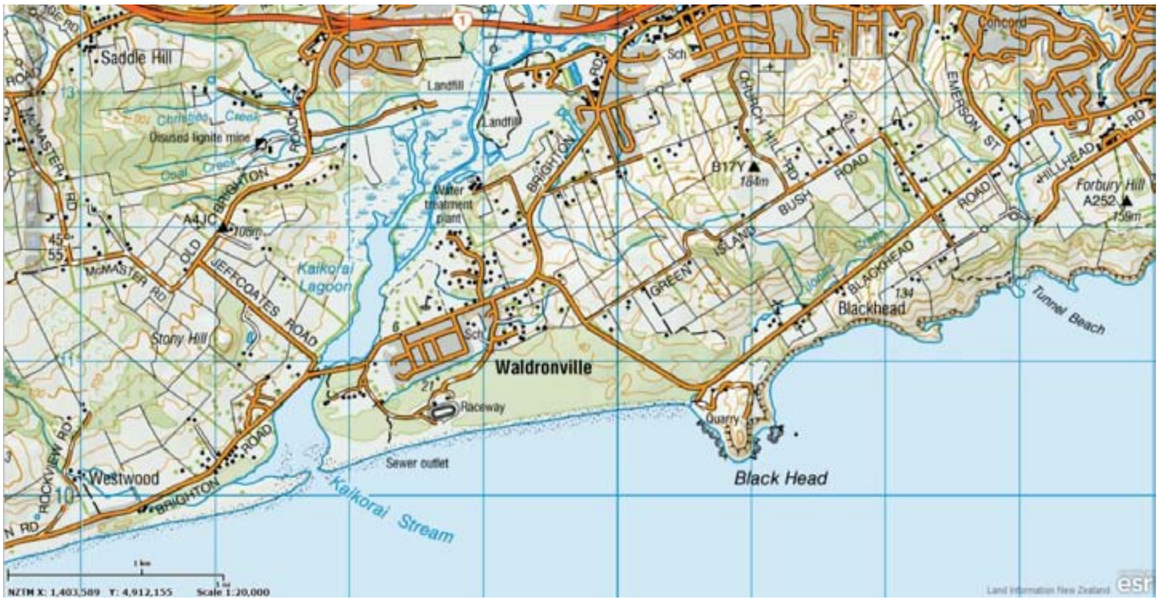

Figure 9 Topography of Waldronville and surrounding areas

Setting

The community of Waldronville has a population of approximately 500, while the surrounding semi-rural area (including Forbury Hill, Blackhead, Kaikorai Estuary and Westwood) had a rapidly growing population of 960 at the time of the 2013 census, up from 504 in 2001. Most of the residential development within this area has occurred on land which is either sufficiently elevated or set back from the coast to not be affected by coastal hazards.

The flood hazard of the Kaikorai Estuary (upstream of the Brighton Road Bridge), including the effects of elevated sea levels and the temporary formation of a sand bar across the mouth, are described in the report 'Flood Hazard of Dunedin's urban streams'.

Characteristics of mapped hazard areas in Waldronville and Westwood

This section summarises the characteristics and effects of natural hazards, for the areas mapped in Figure 10.

- Direct Inundation from the Pacific Ocean

The overall effects of direct inundation from the Pacific Ocean (including frequency, velocity, depth and duration) may create a threat to life/safety, and could result in damage to buildings. These effects are likely to be greatest in areas which are low-lying, and/or immediately adjacent to the ocean.

Area A: Land which is below the height identified as the 1:100 year storm surge level (Table 1). This area is also vulnerable to other coastal hazards such as tsunami and coastal erosion, and inundation resulting from heavy rainfall events and high flows in Kaikorai Stream. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Otago Regional Council

Area B: Land which is below the combined height of the 1:100 year storm surge level, and an additional 1m (as described in the introduction, and listed in Table 1). Although higher than Area A, this area currently has some vulnerability to high magnitude, low frequency tsunami, storm surge, and flood events. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Beyond Area B: High magnitude, low frequency events (as described in Table 2) may affect land which is higher than that mapped as Area B, irrespective of sea-level rise. Although such events may occur rarely, they could affect much of the coastal terrace and the margins of the Kaikorai estuary. The actual extent of inundation (along with other characteristics such as velocity and depth) during the largest credible tsunami events are not possible to map accurately, given the current level of information available.

- Other Natural Hazards

Flood hazard: The area marked as flood hazard on Figure 10 shows the current extent of the Kaikorai Stream channel and estuary, downstream of the Brighton Road Bridge. Changes in the form of the channel and estuary can occur, either gradually, or as a result of storm / flood events.

- Other Coastal Areas

Raised coastal terrace: A raised coastal terrace and dune system is mapped on Figure 10. This acts as a buffer to protect Waldronville against the effects of erosion and direct inundation from the sea. Activities that disturb the form of this foreshore area and its vegetation cover (such as excavation or the removal of vegetation) may compromise its stability. This buffer area may be affected by future changes in sea level or large storm events. Figure 11 shows that the extent of the vegetated foredune generally accreted (moved seaward) or remained stable in the Waldronville area between 1947 and 2013.

Figure 10 Mapped coastal hazards areas in Waldronville and Westwood

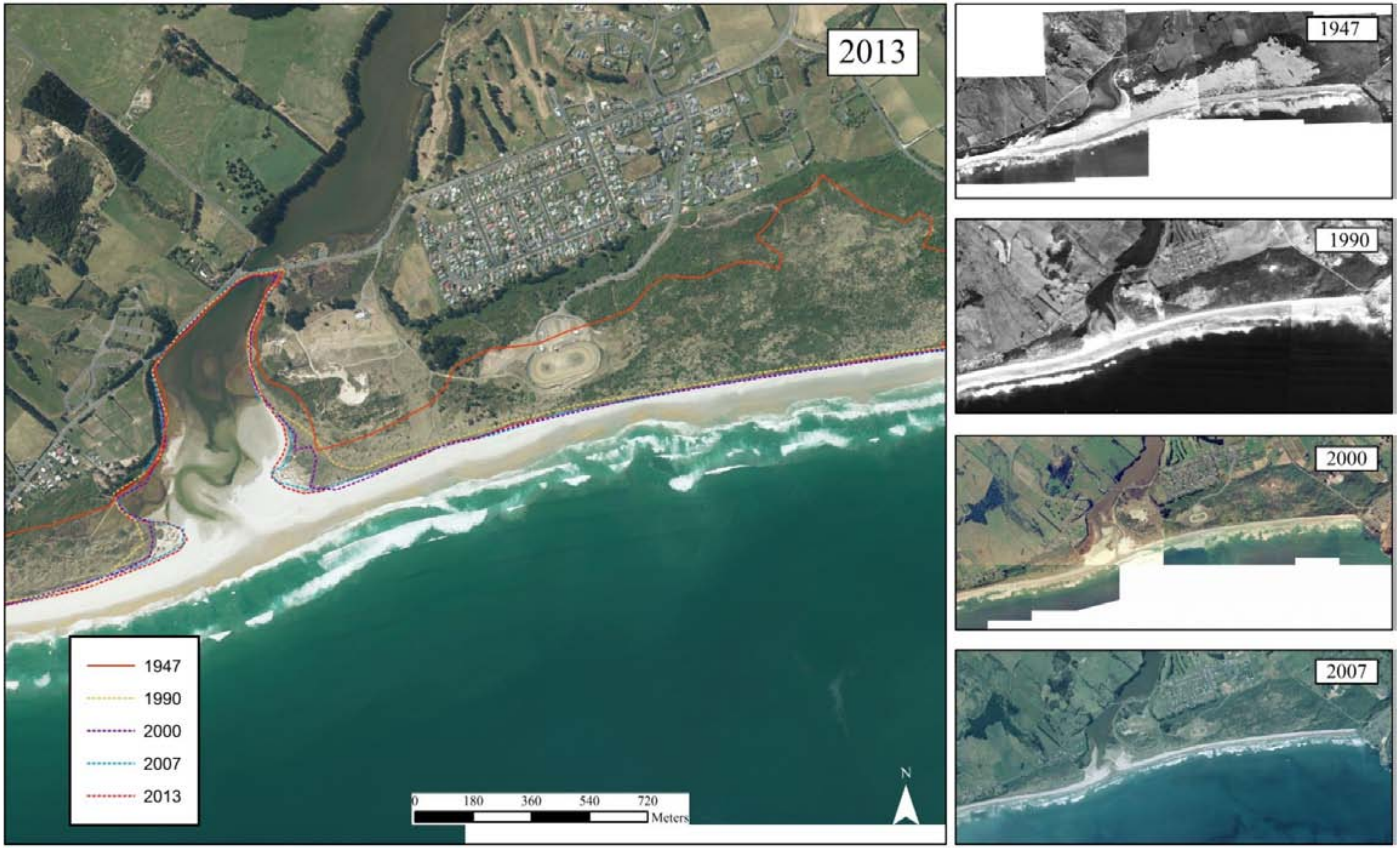

Figure 11 Main image: changes in the extent of the vegetated foredune near Waldronville between 1947 and 2013, overlaid on an aerial photograph collected in 2013. Smaller images: the historical aerial photos used to determine changes in the location of the vegetated foredune. (source: DCC).

2.3. South Dunedin and the upper Otago Harbour

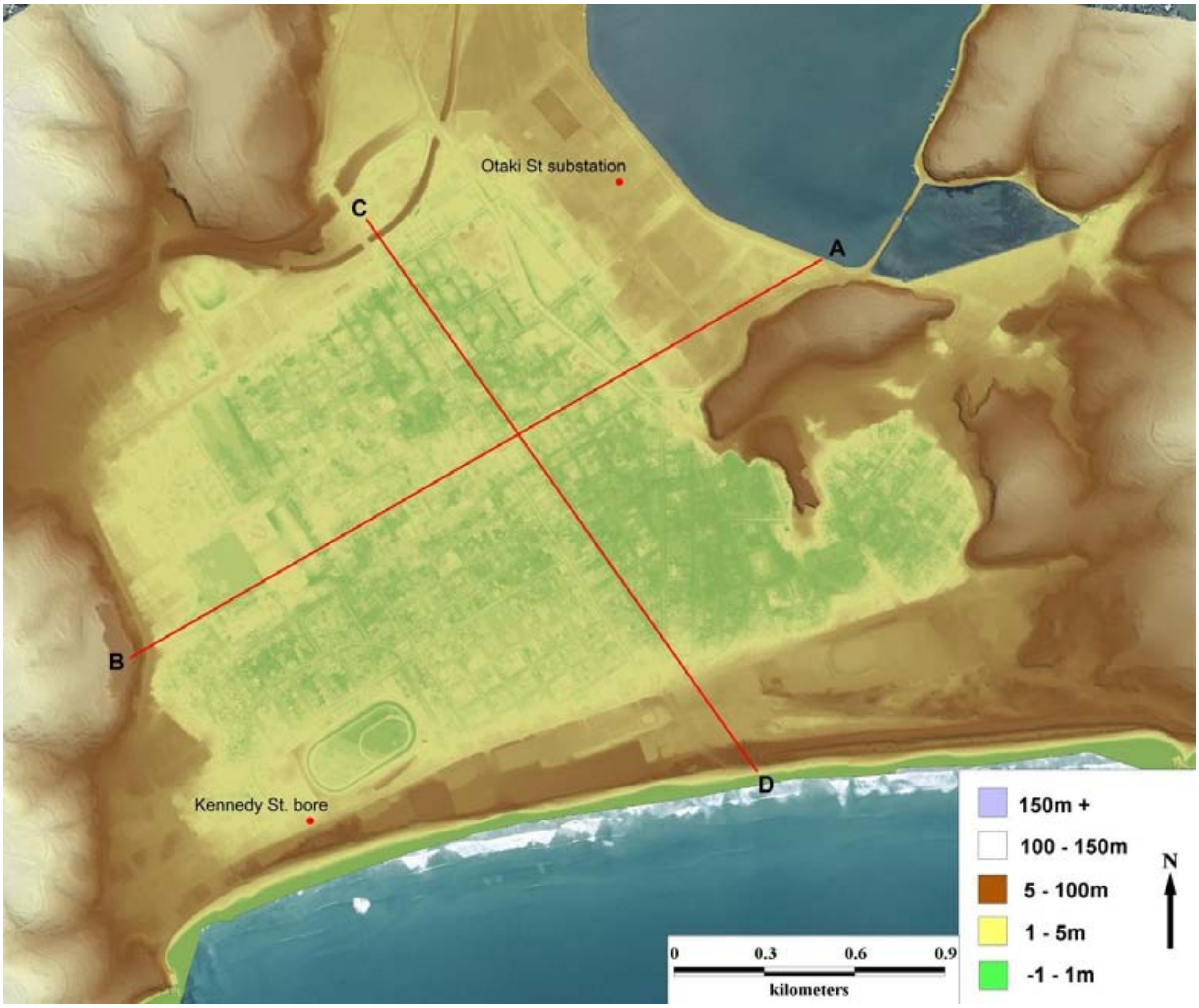

Figure 12 Elevation map of the South Dunedin and upper Otago Harbour area. Height is relative to mean sea level.

Setting

This section describes the natural hazards of South Dunedin and the margins of the upper Otago Harbour (from Ravensbourne to Andersons Bay Inlet). This area has a population of approximately 10,000 (Statistics NZ, 2013 Census data) spread over a highly urbanised and densely populated area of approximately 600 hectares. Land located adjacent to the Otago harbour, and in the South City area is mainly commercial and industrial while land to the south and west consists of private residential dwellings, a racecourse and a number of sports fields.

Some important infrastructure (including the Otaki Street electricity substation) and transport links are situated near the harbour. Much of the shoreline area is used regularly for recreation, including playing fields, cycle and walkways, boating and surf clubs, and the beaches of St Kilda / St Clair.

Topography: This area comprises flat, low-lying land which is bounded by the hills of Otago Peninsula and Dunedin City, the harbour, and the Pacific Ocean (Figure 12 and Figure 15).

Sea-level rise since the peak of the last ice age led to the progressive infilling of what is now South Dunedin with alluvial and coastal sediments.[3] Extensive artificial reclamation occurred between the 1850's and 1970's, transforming the area from coastal dunes, salt marshes and intertidal deposits to its current form. Figure 12 shows that much of the land in South Dunedin is less than 1m above mean sea level, and is therefore within the current tidal range (approximately 1m above and below the msl datum, shaded green on Figure 12). Reclaimed land around the upper harbour is slightly higher, up to 4m above msl.

The low-lying nature of this area is further illustrated in Figure 13, which shows two cross sections through South Dunedin. Cross-section A-B shows that the South Dunedin residential area lies at a lower elevation than the commercial land closer to Portsmouth Drive. Cross-section C-D shows that almost all the land between the South Island Main Trunk Line railway embankment and Hancock Park is less than 2m above mean sea level.

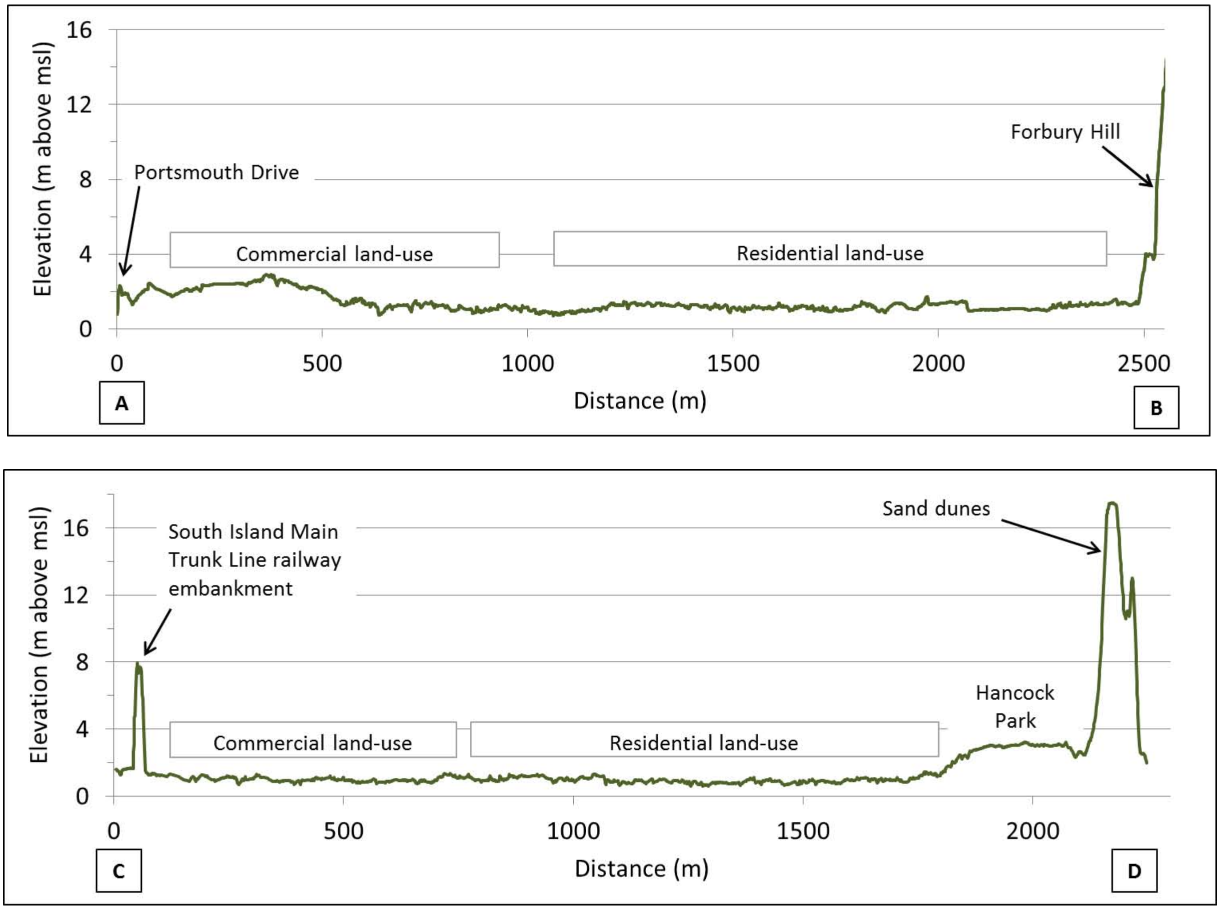

Figure 13 Cross-sections A-B and C-D (as shown on Figure 12) through South Dunedin

Groundwater: The shallow groundwater aquifer which lies beneath South Dunedin is an important part of the natural setting of this area (ORC, 2012d). Seawater intrudes into the South Dunedin aquifer around its coastal fringes, inhibiting the drainage of groundwater derived from surrounding hill catchments and internal runoff. Normal tidal cycles influence the water table below South Dunedin on a day-to-day basis, particularly those areas closer to the sea. The strong relationship between these two parameters is shown in Figure 14. This shows changes in sea level at Green Island due to normal astronomical tides, and changes

[3] Global melting of ice sheets caused sea level to begin rising 20,000 years before present, quickening about 14,000 years ago. Sea levels have been nominally stable for the last 2,000 years

in the water table at the Kennedy Street bore during February 2014. The largest fluctuations in groundwater occur when the tidal range is greater, and higher (spring) tides result in higher peaks in groundwater. The location of the Kennedy Street bore is shown in Figure 12, and the site is located approximately 115m back from St Clair Beach. The typical ground level at that location is 1.4m above msl.

The strong connectivity between sea and groundwater levels and the unconsolidated sandy nature of the ground means that the water table may rise rapidly during storm surge or prolonged / heavy rainfall events. Sea level and rainfall are therefore crucial controls on flood hazard in the South Dunedin area.

The minimal gradient of South Dunedin means stormwater must be pumped to the Portsmouth Drive pumping station and discharged to the Otago Harbour (OPUS, 2012). The stormwater network that serves South Dunedin is aged and pervasively cracked. Fortuitously, infiltration of groundwater into the stormwater network suppresses the water table, preventing surface ponding under normal conditions (ORC, 2012d). While the stormwater network aids the drainage of south Dunedin's groundwater under dry conditions, its ability to drain groundwater rapidly diminishes during heavy rainfall events or times of elevated sea level, meaning the groundwater table rises and water may pond on the surface (ORC, 2009b). The velocity of ponded water is generally very low, although ponding may persist for several days.

Modelling (ORC, 2012d) shows that an increase in mean sea level (of up to 0.4m) would likely exacerbate flood hazard and instances of groundwater ponding across South Dunedin. The areas which would initially be affected include Forbury Raceway, Tonga Park, Bathgate Park, and parts of Tainui.

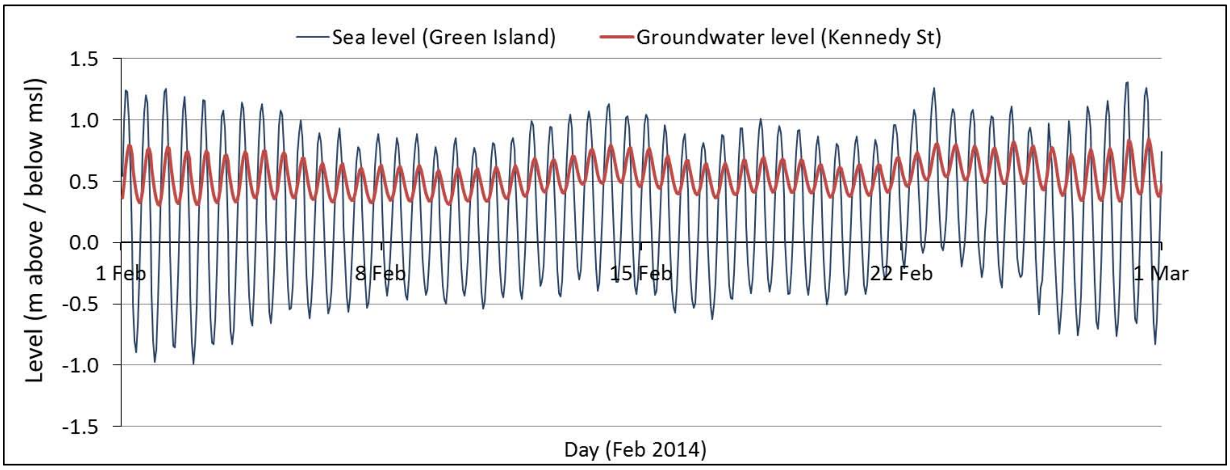

Figure 14 Graph showing sea level at Green Island and groundwater level at Kennedy Street, during February 2014. The typical ground level at the Kennedy Street bore is 1.4m above msl (Figure 12).

Assessment of Risk

Unlike most other coastal communities in the Dunedin City District, the South Dunedin / upper Otago Harbour area has a large number of permanent residents and a high population density, along with commercial / industrial buildings and important infrastructure. As a result, overall exposure of the community to natural hazards is much higher than in smaller coastal communities which have a similar low-lying topography and are also underlain by loose, unconsolidated sediments (eg, Harwood, Aramoana). Small changes in the characteristics of the natural hazards which affect South Dunedin may therefore affect large numbers of people and a significant amount of infrastructure and other valuable assets.

Characteristics of mapped natural hazard areas in South Dunedin and the upper Otago Harbour

As discussed above, elevated sea level and heavy rainfall events both contribute to flood hazard in this area. Under present conditions (i.e. the existing land topography and current sea level) the most extensive flooding will occur in the lowest-lying areas, and where the water table is particularly shallow. The same method used to identify low-lying land in other coastal communities has been used to identify the most flood-prone land in South Dunedin and around the upper harbour. The characteristics of these areas are described below, along with the importance of the dune system and the more elevated reclaimed land which provides a level of protection against coastal hazards such as tsunami and storm surge.

- Low-lying land

Two categories of lower-lying land in South Dunedin and around the upper Otago Harbour have been identified using the methods outlined in Part 1 of this report, and these are shown in Figure 15.

Area A: Land which is below the height identified as the 1:100 year storm surge level (Table 1). For the St Kilda / St Clair area, this level is identified as 2.05m above msl, while for the upper harbour, it is 1.9m above msl.[4] The St Kilda / St Clair level has been used to define the part of Area A which lies to the southwest of Andersons Bay Road, while the upper harbour level has been used to define Area A around the margins of the Otago Harbour. This reflects the most likely source of direct inundation from the ocean for each part of Area A. Parts of Area A are already affected by inundation, due to the limited capacity for storm water to drain away during heavy rainfall events (Figure 19), and direct inundation from the harbour during king tide events (Figure 16).

The dune system that separates South Dunedin from the Pacific Ocean buffers the low-lying land behind against direct inundation from the sea, during normal astronomical tides and also during more elevated sea level events (such as storm surge or tsunami). The dune system is heavily modified in parts, including the St Clair esplanade and the Kettle Park / Hancock Park playing fields. The approximate extent of the dune system, including where it has been artificially modified, is shown in Figure 15.

While the crest of the dunes is up to 20 metres above msl towards the Chisholm Park Golf Club, in some places it is as low as 5 metres above msl (ORC, 2012a). The level of the Pacific Ocean and within the harbour does influence groundwater level in Area A however, and this is discussed above. If changes to the dune system resulted in it being breached or overtopped during a 1:100 year storm surge event, much of South Dunedin could be inundated, to an extent similar to that shown in Figure 15. The lowest suburbs in South Dunedin are Tainui and eastern St Kilda, and these lie as much as 1.5 metres below the 1:100 year storm surge level.

[4] Due to the more sheltered nature of the Otago Harbour the water level for a given return period is lower than for the open coast to the south, which, due to its orientation, is exposed to elevated sea levels of a greater height (ORC, 2012a).

Area A is also vulnerable to other coastal hazards. The Otago Harbour is sheltered from the open sea, and so the effects of a tsunami around the margins of the harbour would likely be minor. However, if changes to the St Kilda / St Clair dune system meant it was unable to provide a buffering effect against tsunami waves, the velocity of those waves could result in significant damage to buildings, infrastructure and pose a risk to safety in the South Dunedin part of Area A.

Changes in the St Kilda / St Clair shoreline between 1947 and 2013 are shown in Figure 17. During this period there was minimal change at the heavily modified western end of the beach (St Clair Esplanade), shoreline erosion occurred in the vicinity of Moana Rua Road, while the shoreline accreted (moved seaward) at the eastern end of the beach. Figure 18 shows erosion of the fore-dune which occurred as a result of storm events in the winter of 2007. Tonkin & Taylor (2011) describe the 2007 storms as being 'the most potentially damaging single event on record since 1997'.

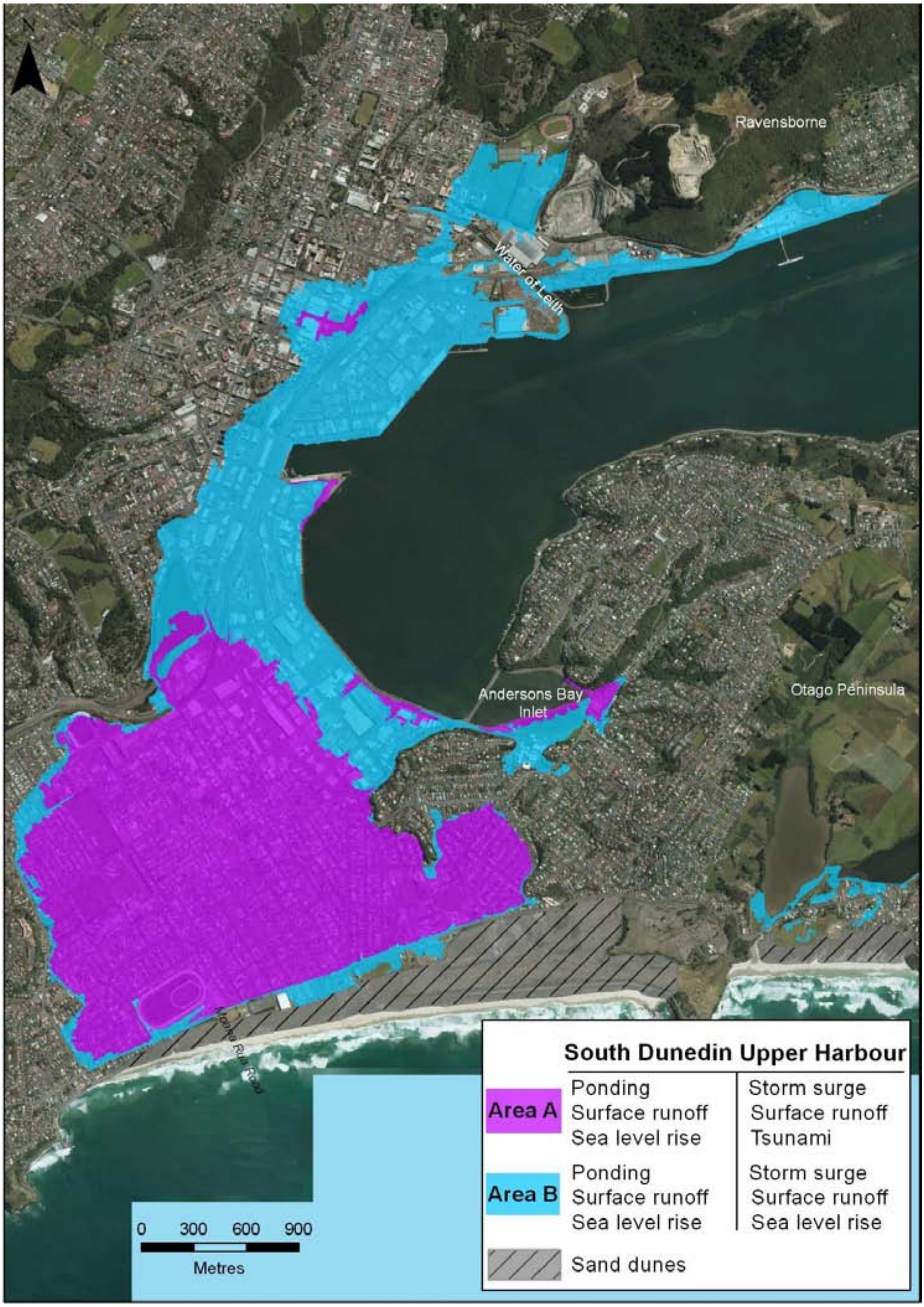

Figure 15 Mapped natural hazard areas in South Dunedin and around the upper Otago Harbour

Figure 16 Surface ponding on Teviot Street, June 2013 (source: ODT)

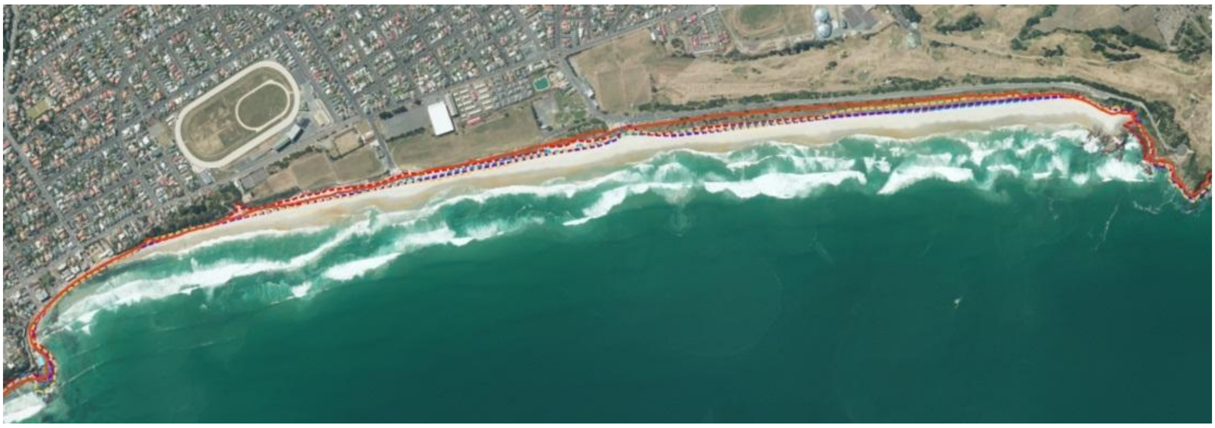

Figure 17. Changes in the St Kilda / St Clair coastline between 1947 and 2013, overlaid on an aerial photograph collected in 2013 (source: DCC)

Area B: Land which is below the combined height of the 1:100 year storm surge level (at St Kilda / St Clair), plus an additional 1m (i.e. land which is less than 3.05m above msl). This land would potentially be inundated if sea level was 1m higher than at present, and a 1:100 year storm surge event occurred. As for Area A, the extent of inundation under this scenario would depend in part on the 'connectivity' between the ocean or harbour and the land. The South Dunedin dune system (or other engineered structures) could help to mitigate the effects of storm surge, if these features were to remain in place throughout the event.

Figure 18 Erosion of the fore-dune at St Kilda Beach in July 2007 (left), and September 2007 (right)

- Other Natural Hazards

Flood hazard: Much of the central city and North Dunedin is vulnerable to flood hazard associated with the Water of Leith, and from stormwater. Inundation from these sources could occur independently, or in combination with elevated sea levels. The likelihood of inundation occurring due to one, or a combination of these sources has not been determined, but will be higher than that assigned to the two areas identified in Figure 15. Flood and stormwater hazard are described in the 'Flood hazard of Dunedin's urban streams' report (ORC, 2014c), and DCC Stormwater Integrated Catchment Management Plans (DCC, 2011b) respectively.

Seismic hazard: Ground shaking in South Dunedin with a return period of 100 years is likely to displace objects and crack large windows (Opus 2005). The maximum intensity ground shaking modelled by Opus (2005) for South Dunedin is associated with a magnitude 7 earthquake on the Akatore Fault. This would make it difficult for people to stand, and cause moderate damage to chimneys and un-reinforced stone and brick walls. The 1974 magnitude 4.9 Dunedin earthquake toppled chimneys and caused minor damage to roof tiles and other masonry across Dunedin City, but damage was concentrated on the alluvial flats of South Dunedin.

Ground subsidence or liquefaction as a result of seismic shaking has the potential to damage roads, power poles, under-ground pipes and building foundations. GNS (2014b) describes the hazard associated with liquefaction and lateral spread in the South Dunedin and upper Otago Harbour area further. Almost all of the land mapped as Area A or B in Figure 15 was identified as being composed of materials which have a moderate to high likelihood of being susceptible to liquefaction by GNS (2014b).

Figure 19 Left: surface flooding on the corner of Forbury Road and Albert Street in August 2007 (source: DCC). Right: flooding in Normanby Street in April 1923 (source: http://caversham.otago.ac.nz/resource/community/hard_times.html.)

2.4. Ocean Grove

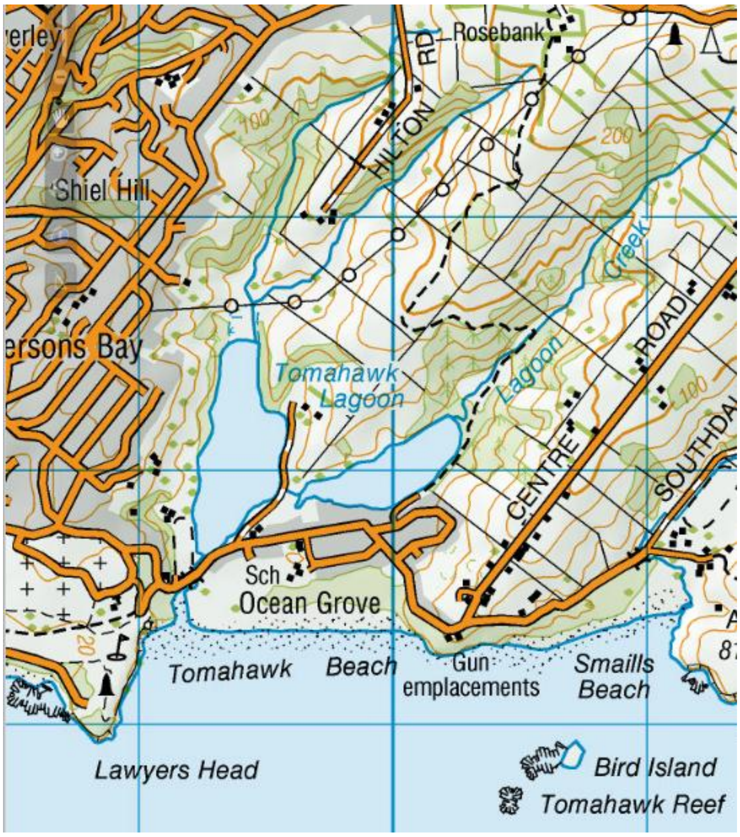

Figure 20 Topography of Ocean Grove and the surrounding area

Setting

The community of Ocean Grove had a population of 480 at the time of the 2013 census. The suburb is located at the base of the Otago Peninsula, on a raised platform of Holocene beach deposits which is generally elevated by 3-5m above msl (Figure 20). The community is set back at least 200m from the shoreline, and is buffered against direct inundation from the sea by dunes which are elevated up to 14m above msl. Lower-lying land, including around the margins of the Tomahawk Lagoon, lies to the north of Ocean Grove.

Characteristics of mapped hazard areas in Ocean Grove

The location and topography of Ocean Grove expose it to two broad types of hazard; inundation (either from the sea, or from heavy rainfall / flood events), and land instability (including shoreline change and the effects of seismic shaking). The characteristics and effects of these hazards are described broadly below, and these have been used to map the hazard areas shown in Figure 21.

- Direct inundation from the Pacific Ocean

Lower-lying land in Ocean Grove has been identified using the methods outlined in Part 1 of this report, and this is described below and shown in Figure 21. Under current conditions, the elevated dune system which separates Ocean Grove from the Pacific Ocean provides a level of protection against direct inundation from the sea. Lower-lying land on the margins of Tomahawk Lagoon could be affected by inundation, if sea level was sufficiently elevated to allow 'backflow' (to the north) through the lagoon outlet, or if floodwater was unable to drain through the outlet for an extended period.

Area B: Land which is below the combined height of the 1:100 year storm surge level, plus an additional 1m (as listed in Table 1). Although higher than the current 1:100 year storm surge level, this area still has some vulnerability to high magnitude, low frequency tsunami and flood events. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Beyond Area B: High magnitude, low frequency events (as described in Table 2) may affect land which is higher than that mapped as Area B, irrespective of sea-level rise. Although such events may occur rarely, they could affect much of the raised platform of beach deposits upon which Ocean Grove lies. The actual extent of inundation (along with other characteristics such as velocity and depth) during the largest credible tsunami events are not possible to map accurately, given the current level of information available.

- Other Natural Hazards

Flood Hazard: As discussed above, low-lying land flanking the Tomahawk Lagoon can be inundated during times of heavy rainfall, although this is generally caused by surface ponding rather than the level of the lagoon. The Tomahawk lagoon drains to the Pacific Ocean through a narrow channel (Figure 23). Managing the form of the channel is important as it allows runoff to drain to the ocean, and it also provides a degree of protection against coastal inundation.

Seismic shaking: Ground shaking at Ocean Grove with a return period of 100 years is likely to displace objects and crack large windows (Opus 2005). The maximum intensity ground shaking modelled by Opus (2005) for this area is associated with a magnitude 7 earthquake on the Akatore Fault. This would likely make it very difficult for people to stand and would cause substantial damage to chimneys and un-reinforced stone and brick walls.

In addition to the effects of ground shaking, unconsolidated sediment (silts and sands) and a shallow water table mean the land in and around Ocean Grove is susceptible to subsidence and liquefaction during earthquakes. These processes have the potential to damage roads, power lines, underground pipes and building foundations.

GNS (2014b) describes the hazard associated with liquefaction in the Ocean Grove area further, and identifies most of the suburb as being underlain by materials which have a moderate to high likelihood of being susceptible to liquefaction.

- Other Coastal Areas

Raised coastal terrace: A raised coastal terrace and dune system is mapped on Figure 21. This acts as a buffer to protect lower-lying areas further inland against the effects of erosion and direct inundation from the sea. Activities that disturb the form of this foreshore area and its vegetation cover (such as excavation or the removal of vegetation) may compromise its stability. This buffer area may be affected by future changes in sea level or large storm events. Changes to the coastline between 1947 and 2007 are illustrated in Figure 22, and this shows that the seaward limit of vegetation on these dunes moved south (i.e. towards the coast) during this period.

Figure 21 Mapped coastal hazard areas in Ocean Grove

Figure 22 Changes in the Ocean Grove coastline between 1947 and 2007, overlaid on an aerial photograph collected in 2013 (source: DCC)

Figure 23 View from Tomahawk Road Bridge looking upstream toward the lower lagoon, during a period of prolonged rainfall in June 2013

2.5. South coast of the Otago Peninsula – Smaill's Beach to Victory Beach

The margins of the bays and inlets along the south coast of the Otago Peninsula are, in some cases, relatively low-lying. These areas are generally un-developed at present, but demand for development may possibly occur in the future.

A number of raised coastal terraces and dunes are located within these bays and inlets, and these are shown on the following pages. These can act as a buffer to protect lower-lying areas further inland against the effects of erosion and direct inundation from the sea. Activities that disturb the form of this foreshore area and its vegetation cover (such as excavation or the removal of vegetation) may compromise its stability. These buffer areas may be affected by large storm events, tsunami or land instability. As sea level rises, the likelihood that these areas will be affected by erosion or inundation (due to storm surge or tsunami) will increase.

Within these sand dunes and coastal terraces, there are sections of land which lie below the height identified as the 1:100 year storm surge level, and the 1:100 year storm surge level plus an additional 1m (as described in Part 1). However, these categories of low-lying land were not mapped separately, as the elevation and surface form of coastal dunes changes over time, and the characteristics of these areas means they are generally unsuitable for development.

Beyond sand dunes/ coastal terraces: High magnitude, low frequency events (as described in Table 2) may still affect land which is higher than that mapped as sand dunes/ coastal terrace, irrespective of sea-level rise.

Figure 24 Mapped coastal hazard area at Smaill's Beach

Figure 25 Mapped coastal hazard area at Boulder Beach and Sandfly Bay

Figure 26 Mapped coastal hazard area at Allan's Beach and Hoopers Inlet

Figure 27 Mapped coastal hazard area at Victory Beach and Papanui Inlet

2.6. Mid Otago Harbour – St Leonards to Deborah Bay (West Harbour), and Macandrew Bay to Lower Portobello (Peninsula)

Figure 28 Coastal communities located within the central part of the Otago Harbour, and the topography of surrounding areas

Setting

A number of settlements are spread along the margins of the central part of the Otago Harbour (Figure 28 – natural hazards affecting the Harwood area are described in the following chapter). At the time of the 2013 census, the total population of these communities was approximately 5,900, which is 5% of the total population of the Dunedin City District.

Although these communities are vulnerable to a range of natural hazards, the geography of this area means that the influence of coastal processes (such as storm surge, tsunami and coastal erosion) is generally limited. The shoreline is relatively stable, and defined either by rock walls originally constructed in the 1860's and 70's or by rocky headlands, and by important road links (SH88 on the West Harbour, and by Portobello Road on the Peninsula).

Otago Regional Council

The area is sheltered from the Pacific Ocean, limiting the effect of large ocean swell and tsunami events. However inundation of low-lying areas may still occur, due to spring tides and/ or additional storm surge resulting from persistent strong winds. There are relatively few urban areas subject to inundation from the sea however, as the Otago Peninsula and West Harbour hills generally rise steeply from the harbour edge.

GNS (2014b) describes the hazard associated with landslides, and the effects of seismic shaking (liquefaction and lateral spread) in the Otago Peninsula area further.

Mapped coastal hazard areas in the mid Otago Harbour

- Low-lying land

Two categories of lower-lying land have been identified using the methods outlined in Part 1 of this report. The only extensive areas of low-lying land are shown in Figure 30. As a 1:100 year storm surge level was not specified for the mid harbour area by NIWA (2008), the estimate for the upper harbour has been used as a substitute (Appendix 1).

Area A: Land which is below the height identified as the 1:100 year storm surge level for the Upper Otago Harbour (Table 1). This area is generally restricted to the shoreline, although Figure 30 shows parts of Careys Bay and Sawyers Bay would be affected at this level. As sea level rises, the likelihood that inundation resulting from these hazards will affect this area will increase.

Area B: Land which is below the combined height of the 1:100 year storm surge level (as described in Part 1 of this report, and listed in Table 1), plus an additional 1m. Reclaimed land at Port Chalmers (including the school and the surrounding residential area; and the wharf area) are included in this area. There are other small pockets of land around the margins of the mid-harbour which lie below this level, but development within these areas is generally limited to fairly robust assets and infrastructure, such as roads and bus shelters, and occasionally 1 or 2 residential or commercial premises. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Areas A and B may also be vulnerable to tsunami (NIWA, 2007), or inundation resulting from storm water run-off (DCC, 2011b).

Figure 29 View to the south, showing reclaimed residential land at Port Chalmers

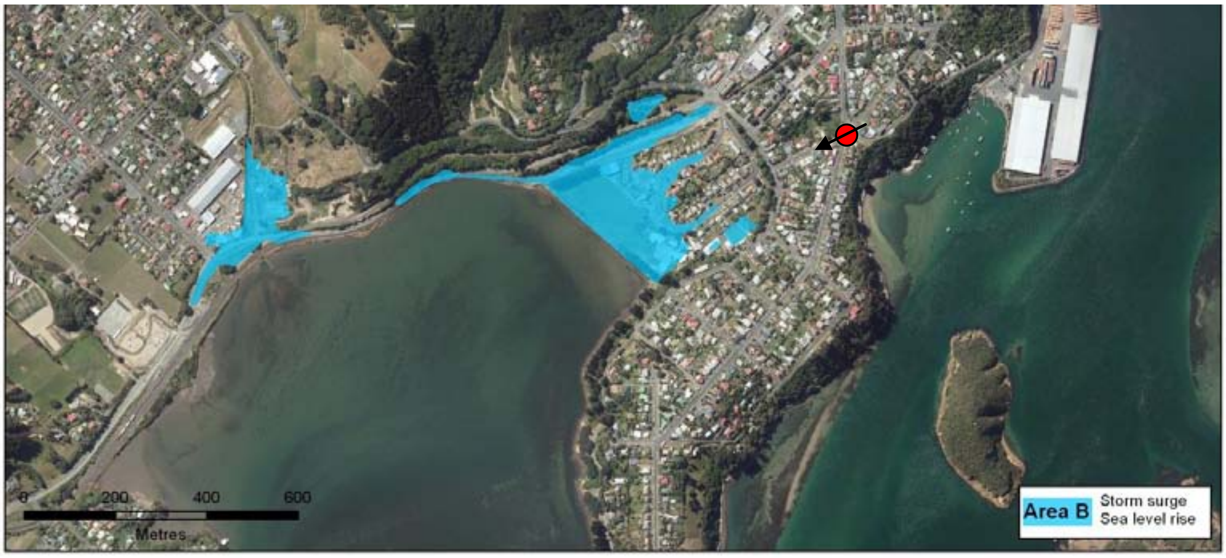

Figure 30 Mapped coastal hazards areas in Sawyers Bay and Port Chalmers. The approximate direction and location of the photo in Figure 29 is also shown.

2.7. Harwood, Otakou and TeRauone

Figure 31 Topography of Harwood, Te Rauone and the surrounding area

Setting

The settlements of Harwood, Otakou and Te Rauone are located inside the entrance to Otago Harbour, on loose, well sorted Holocene sand and silt deposits (GNS, 1996). They are located on flat, low-lying ground, less than 5m above msl (Figure 32 and Figure 33), and are flanked by the coastal hills of Otago Peninsula to the south and east (Figure 31).

The northern tip of the Otago Peninsula (which also includes the small settlement of Lower Portobello) had a population of 471 at the time of the 2013 census, declining from 495 in 2006 and 522 in 2001. Approximately 62% of the 396 dwellings in this area are permanently occupied (Statistics NZ, 2013).

Assessment of risk

The current level of development within Harwood and Te Rauone is generally low density residential, with a mix of older and more recent buildings. There is limited commercial activity. Much of the surrounding area and vacant lots are used for rural and recreational purposes. As a result, the overall exposure of the community to natural hazards is lower than if there was a larger and more permanent population, as the number of people exposed to natural hazards is generally small. The population can increase significantly during weekends and the summer months however, due to the number of cribs in the area, and day visitors.

The permanent population of this area has decreased in recent times. If a significant increase in the level of development were to occur, it may add to the risk associated with natural hazards, particularly if it were to occur on land that is low-lying or close to the shoreline. It is noted that there is potential for significant infill (subdivision) of larger properties on land between Harington Point and Harwood that is less than 5m above msl (DCC, 2009, ORC, 2012a).

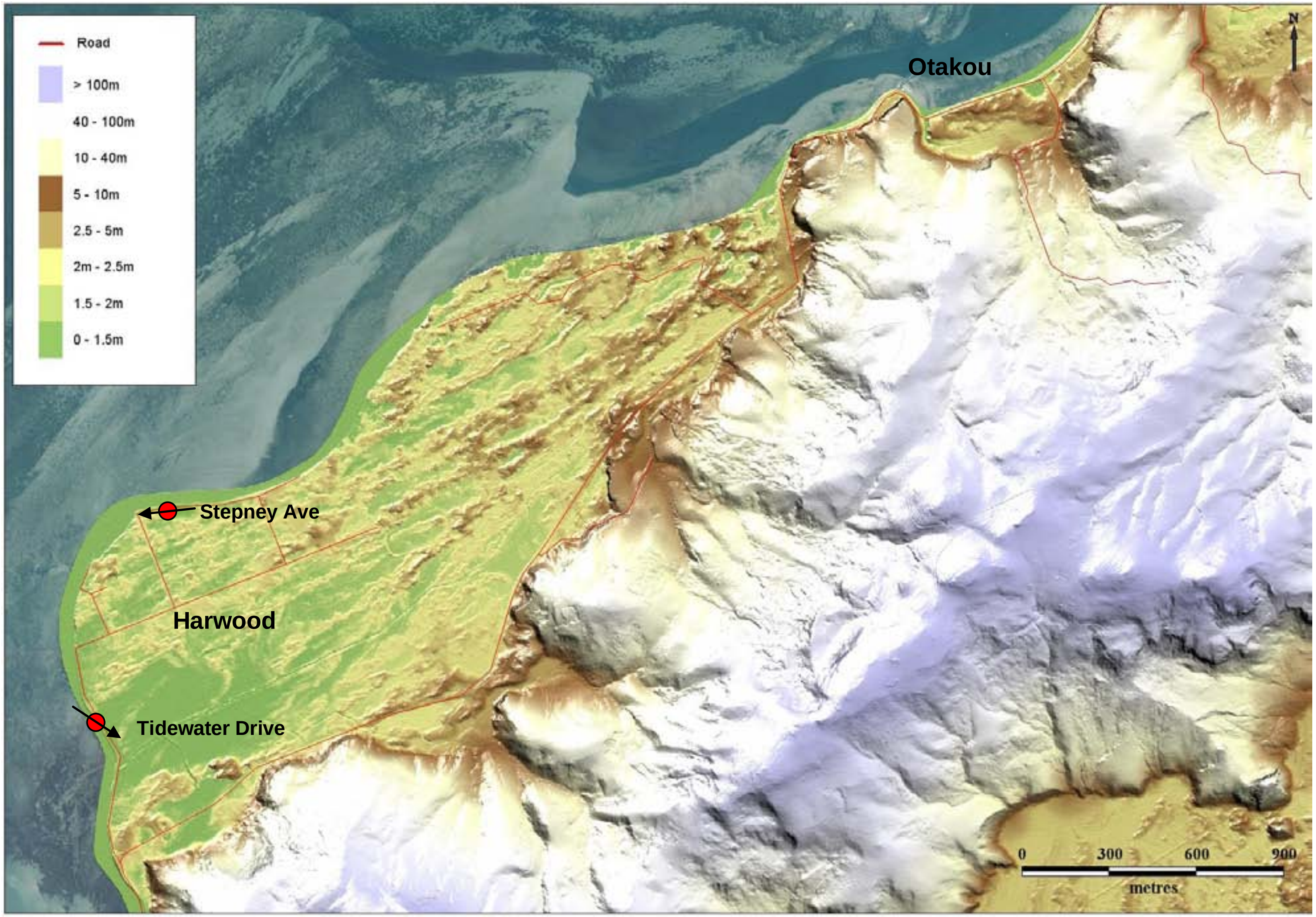

Figure 32 Elevation map of Harwood and Otakou, with the approximate direction and location of the photos shown in Figure 34

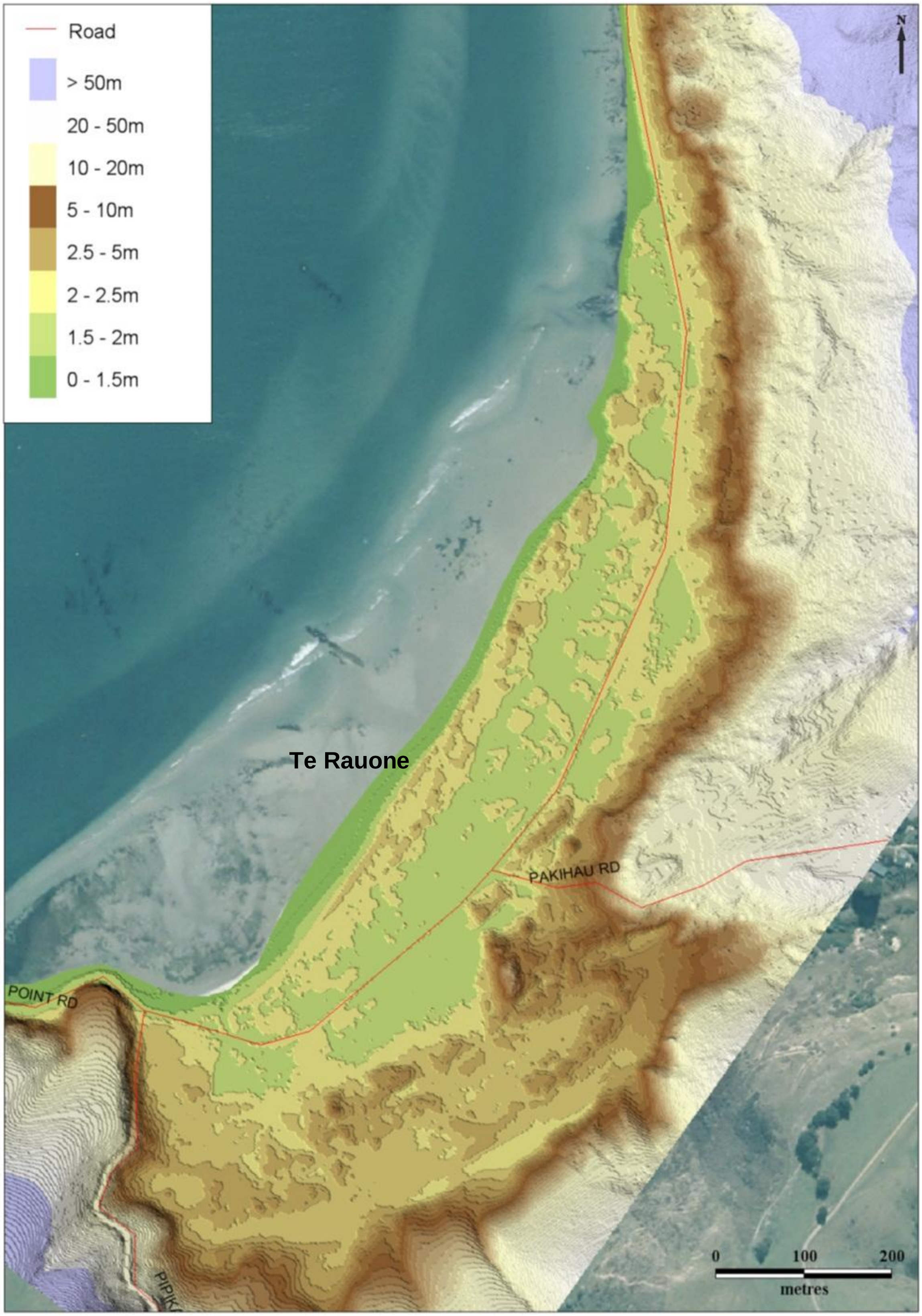

Figure 33 Elevation map of the Te Rauone area

Characteristics of mapped natural hazards that affect Harwood, Otakou and Te Rauone

Two categories of lower-lying land in Harwood, Otakou and Te Rauone have been identified using the methods outlined in Part 1 of this report. The low elevation of these three settlements, their location between Otago Harbour and the hills of Otago Peninsula, and the unconsolidated, sandy substrate mean that these areas are vulnerable to two main types of hazard; inundation from the sea and land instability (including coastal erosion, landslides, and the effects of seismic shaking). The characteristics and effects of these hazards are described below. Mapped hazard areas are shown in Figure 35.

- Direct Inundation from the Otago Harbour

The lack of any topographic barrier (eg, sand dunes, elevated road embankment) between these settlements and the Otago Harbour to act as a protective 'buffer' means that normal astronomical tides can inundate the lowest-lying parts of these communities (Figure 34). The depth and extent of inundation associated with storm surge and tsunami events was not modelled by NIWA (2007, 2008), but is likely to be significant due to the low elevation of these two areas, and the lack of any protective buffer (ORC (2012a). The overall effects of inundation (including frequency, velocity, depth and duration) create a potential threat to life/safety, could result in damage to buildings, and would create difficulties when evacuating people

Figure 34 Effects of high tide and/or storm surge conditions at Harwood (left: May 2013, Stepney Ave); (right: July 2011, Tidewater Drive)

Area A: Land which is below the height identified as the 1:100 year storm surge level for Long Beach and Purakanui (Table 1).[5] If water was to reach this height, most properties along Tidewater Drive and Stepney Ave in Harwood would be affected in some way, while the effect at

[5] As a 1:100 year storm surge level was not specified for this area by NIWA (2008), the estimate for the nearest communities have been used as a substitute. As the three communities are located within the Otago Harbour, they may have a different level of exposure to events that may affect towns located on the open coast. However, Table 1 shows that there is only a 0.1m difference in the level of a 1:100 year storm surge for the Upper Harbour, and the communities of Long Beach / Purakanui.

Otakou and Te Rauone would be more limited. However, breaking waves may cause additional damage to the shoreline, buildings and other assets, beyond that of direct inundation by slow-moving waters only.

This area may also be vulnerable to other coastal hazards such as tsunami, and ponding due to heavy rainfall events. The likelihood of coastal hazards affecting this area will increase due to predicted sea-level rise, with the consequences of those hazards also likely to be more severe.

Low-lying land on the margins of this area has been affected by coastal hazards in recent times (Figure 34).

Area B: Land which is below the combined height of the 1:100 year storm surge level and an additional 1m (as described in Part 1 of this report, and listed in Table 1). If water was to reach this height, much of the coastal terraces upon which Harwood, Otakou and Te Rauone lie would be inundated, with depths ranging from 0.5 to 2m.

As for Area A, this area currently has some vulnerability to high magnitude, low frequency tsunami and storm surge events. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Beyond Area B: High magnitude, low frequency events (as described in Table 2) may affect land which is higher than that mapped as Area B, irrespective of sea-level rise. Although such events may occur rarely, they could affect other, more elevated parts of raised coastal terraces around the margins of the lower Otago Harbour. The actual extent of inundation (along with other characteristics such as velocity and depth) during the largest credible tsunami events are not possible to map accurately, given the current level of information available.

In general, areas of higher elevation are more suitable for development as they are less susceptible to surface ponding during times of heavy rainfall, and are less likely to be inundated by seawater during a storm surge or tsunami event. It is noted that the coastal terraces upon which the three settlements sit are generally low-lying, and consist of unconsolidated sediment (silts and sand) which are vulnerable to erosion and seismic shaking (see below).

- Other Natural Hazards

Seismic hazard: Ground shaking at Harwood with a return period of 100 years is likely to displace objects and crack large windows (Opus 2005). The maximum intensity ground shaking modelled by Opus (2005) for this area is associated with a magnitude 7 earthquake on the Akatore Fault. This would make it difficult for people to stand, and cause moderate damage to chimneys and un-reinforced stone and brick walls.

In addition to the effects of ground shaking, unconsolidated sediment (silts and sands) and a shallow water table mean the land in and around Harwood, Otakou and Te Rauone is susceptible to subsidence and liquefaction during earthquakes. Ground subsidence or liquefaction has the potential to damage roads, power poles, underground pipes and building foundations.

Landslide hazard: The Otago Peninsula is also susceptible to shallow landslides and rock-fall hazard and the ORC holds some records of landslides, particularly on slopes to the south of Harwood and Otakou. These features can be reactivated, or new slides occur as a result of extreme rainfall events, or given sufficient seismic shaking. Landslides that are considered to be very sensitive to stability factors and moderately to steeply sloping land needs to be subject to thorough geomorphic and geotechnical investigations prior to development. There are few, effective and affordable, long term solutions to large slow landslide movement (GNS, 2014a).

GNS (2014a and 2014b) provide more detail on the hazard associated with mapped landslides and liquefaction respectively.

Coastal erosion: Erosion of sand has been noted at Te Rauone beach over many decades (ORC, 2008a), and a range of private coastal protection works have been installed at the northern end of the beach (closest to Harington Point) as a result. Changes in the coastline at Te Rauone between 1956 and 2013 are shown in Figure 36. The northern end of the beach did not change significantly over this time. Erosion (retreat) of up to about 60m has occurred in the centre of the bay, while the vegetated shoreline has moved seaward by a similar amount in the south. An analysis of shoreline change revealed no significant changes at Harwood or Otakou during this period.

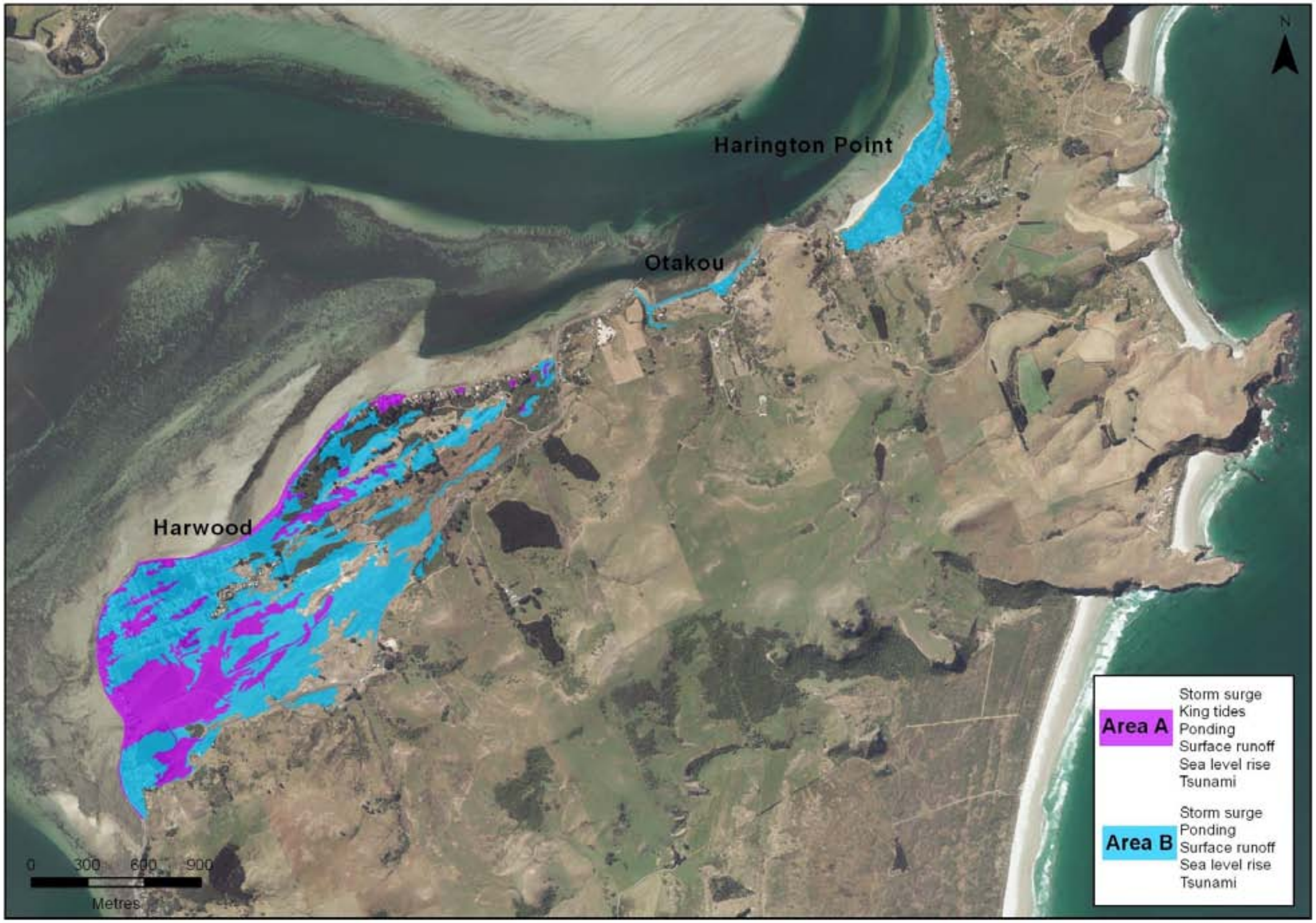

Figure 35 Mapped natural hazard areas in Harwood, Otakou and Te Rauone

Figure 36 Changes to the shoreline at Te Rauone between 1956 and 2013, overlaid on an aerial photograph collected in 2013 (source: DCC)

2.8. Aramoana and Te Ngaru

Figure 37 View of Aramoana and the coastal dunes which separate it from the Pacific Ocean (December 2013)

Setting

The settlement of Aramoana is located on flat, low-lying ground which is generally less than 3m above msl (Figure 37). It is flanked by a range of coastal hills to the west which rise to about 200m. Low coastal dunes to the north, which are elevated up to 4m above msl, separate the settlement from the Pacific Ocean. Tidal sand-flats lie immediately to the south and east of the township.

Te Ngaru is located 2km to the south-west of Aramoana, and sits on an old beach ridge, between the coastal hills and Otago Harbour. The permanent population of these two settlements was 147 at the time of the 2013 census, up slightly from 138 in 2001. The only road access is via Aramoana Road which, although sealed, is narrow and winding and can be affected by the current range of astronomical tides and wave action within the harbour.

Assessment of Risk

Many of Te Ngaru and Aramoana's residential dwellings are holiday houses and therefore not occupied permanently (Statistics NZ, 2013), and many permanent residents commute to Port Chalmers or Dunedin during the working week. As a result, the overall exposure of the community to natural hazards is lower than if there was a larger and more permanent population, as the number of people exposed to natural hazards is generally small. The township is a popular holiday and weekend destination however, particularly during the summer months.

Characteristics of natural hazards affecting Aramoana and Te Ngaru

The location and topography of Aramoana expose it to two broad categories of natural hazard: inundation (either from the sea or as a result of heavy rainfall events), and land instability (including coastal erosion, rock-fall and the effects of seismic shaking). The characteristics and effects of these hazards are described below, and these have been used to map the hazard areas shown in Figure 38.

- Direct inundation from the Pacific Ocean

Two categories of lower-lying land in Long Beach have been identified using the methods outlined in Part 1 of this report. These are described below, and shown in Figure 38.

It is noted that the coastal dunes and the Moana Street and Aramoana Road embankments provide some protection against direct inundation from the Pacific Ocean and/or the Otago Harbour during elevated sea level events (Figure 38). However, water could enter these communities if these features were eroded or overtopped, or infiltration (piping) occurred during storm surge or tsunami events. Any increase in sea-level will increase the likelihood of the Moana Street / Aramoana Road embankments being overtopped due to elevated sea level events, or the normal range of astronomical tides.

The overall effects of direct inundation from the Pacific Ocean (including velocity, depth and duration) could result in damage to buildings and create difficulties when evacuating people, along with the stress this may create for affected residents. These effects are likely to be greatest in areas which are low-lying, and/or immediately adjacent to the ocean.

Area A: Land which is below the height identified as the 1:100 year storm surge level (Table 1). If water was to reach this height, approximately 70 residential properties in Aramoana and Te Ngaru would be inundated to a depth of up to 0.5m, with some deeper inundation at the southern end of Te Ngaru. This area is also vulnerable to other coastal hazards such as tsunami and surface ponding due to heavy rainfall. Low-lying land in this area has been affected by surface ponding (i.e. not direct inundation from the sea) in recent times, (Figure 40).

Area B: Land which is below the combined height of the 1:100 year storm surge level and an additional 1m (as described in Part 1 of this report, and listed in Table 1). Although higher than Area A, this area may still be affected by high magnitude, low frequency tsunami and storm surge events, where these have the ability to overtop or penetrate the dunes or road embankments which separate Area B from the coast. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase. At current sea level, surface ponding is less likely to affect this area than lower-lying land in Area A.

Beyond Area B: High magnitude, low frequency tsunami events (as described in Table 2) may affect land which is higher than that mapped as Area B, irrespective of sea-level rise. Although such events may occur rarely, they could affect much of the coastal terrace upon which Aramoana and Te Ngaru are situated. The actual extent of inundation (along with other characteristics such as velocity and depth) during the largest credible tsunami events are not possible to map accurately, given the current level of information available.

- Other Natural Hazards

Surface ponding: The relatively low elevation of the Aramoana and Te Ngaru settlements, a shallow water table,[6] and normal astronomical tides can combine to impede the natural drainage of water during prolonged or heavy rainfall events. This can contribute to extensive surface ponding in low-lying parts of the settlement. Prolonged inundation can occur under current conditions (Figure 40), and this can damage buildings and vehicles, and cause major inconvenience to residents.

An additional source of inundation is overland flow from the adjacent hills, which, combined with a high water table, can also result in surface ponding. The limited ability of water to drain away means runoff can pond in shallow surface depressions in, and to the south of the township (Figure 42).

Any increase in mean sea level and the upper range of the normal tidal cycle will likely exacerbate the problems associated with surface ponding, and may influence the depth, frequency the duration of ponding. Changes in climate may also lead to increases in the intensity and frequency of storm events (MfE, 2008). The combined effects of more frequent and intense heavy rainfall events and a higher base sea-level may further exacerbate the effects of ponding.

Surface ponding hazard has not been mapped as part this investigation, and the extent of inundation will depend on the duration and intensity of each rainfall event, and the ability of water to drain away (which is partly controlled by sea level). Lower-lying land which will be more prone to this hazard will generally lie within Area A.

Rockfall hazard: Land to the west of Aramoana between the base of the coastal cliffs and Pari / Paloona Streets is subject to rockfall. Rockfall could cause localised but severe damage to buildings and roads in this area, and present a risk to safety.

Seismic shaking: Ground shaking at Aramoana with a return period of 100 years is likely to displace objects and crack large windows (Opus 2005). The maximum intensity ground shaking modelled by Opus (2005) for Aramoana is associated with a magnitude 7 earthquake on the Akatore Fault. This would make it difficult for people to stand, and cause moderate damage to chimneys and un-reinforced stone and brick walls.

Ground subsidence or liquefaction as a result of seismic shaking has the potential to damage roads, power lines, underground pipes and building foundations. GNS (2014b) describes the hazard associated with liquefaction in the Aramoana area further. The coastal terrace upon which Aramoana and Te Ngaru are situated are identified as being composed of materials which

[6] Groundwater is generally shallow at the coast, as this is where groundwater discharges to the sea. Heavy rainfall events will cause the water table to rise resulting in ponding in low lying areas/depressions (R. Morris, ORC, pers. comm., 10 December 2013).

have a moderate to high likelihood of being susceptible to liquefaction by GNS (2014b). Rockfall or landslide activity on the cliffs to the west of Aramoana may also occur due to seismic shaking.

- Other Coastal Areas

Sand dunes / sand spits: A number of these features are located on the margins of Aramoana, and these are described below, and mapped on Figure 38.

- The sand dunes to the north of Aramoana act as a buffer to help protect it against the effects of erosion and direct inundation from the sea during tsunami and storm surge events. Activities that disturb the form of the dunes (such as excavation or the placement of structures) or its vegetation cover may compromise their stability. Any increase in mean sea level may mean that wave action would increasingly affect the stability of these sand dunes. However, there would need to be sustained erosion of the dunes before residential properties were directly affected by the Pacific Ocean (either from direct inundation or coastal erosion).
- The Aramoana sand spit which extends to the southeast, and acts as a buffer between elevated sea levels / wave action from the Pacific Ocean, and the inner harbour. As above, activities that disturb the form of the dunes and sand spit (such as excavation or the placement of structures) or its vegetation cover may compromise their stability. The seaward edge of the sand spit retreated by approximately 75m between 1956 and 2013.
- The sand dunes and tidal flats which lie to the south of the Moana Street road embankment, and to the east of Aramoana Road, which are currently subject to inundation from the sea and/or surface ponding (Figure 42). This area is generally undeveloped, and lies less than 3m above msl.

Figure 38 Mapped natural hazard areas in the Aramoana / Te Ngaru area

Figure 39 Evidence of rock fall from adjacent cliffs at Aramoana (December 2013)

Figure 40 Surface Ponding on Paloona Street, 22 June 2013. 171 mm of rain fell in the preceding 7 days at the nearest rain gauge site (Long Beach). The high tide peaked at 1.18m above msl at Green Island at 1.15 pm on this day. This is within the normal high tide range at this site, where water levels of up to 1.7m have been observed since May 2003 (when records began). Several attempts by the local Fire Brigade were made to pump water away from inundated properties, with limited success (source: ODT).

Figure 41 Changes in the Aramoana coastline between 1956 and 2013, overlaid on an aerial photograph collected in 2013 (source: DCC)

Figure 42 Surface flooding between the base of the hill catchments and Aramoana Road on 17 June 2013

2.9. Heyward Point to Long Beach

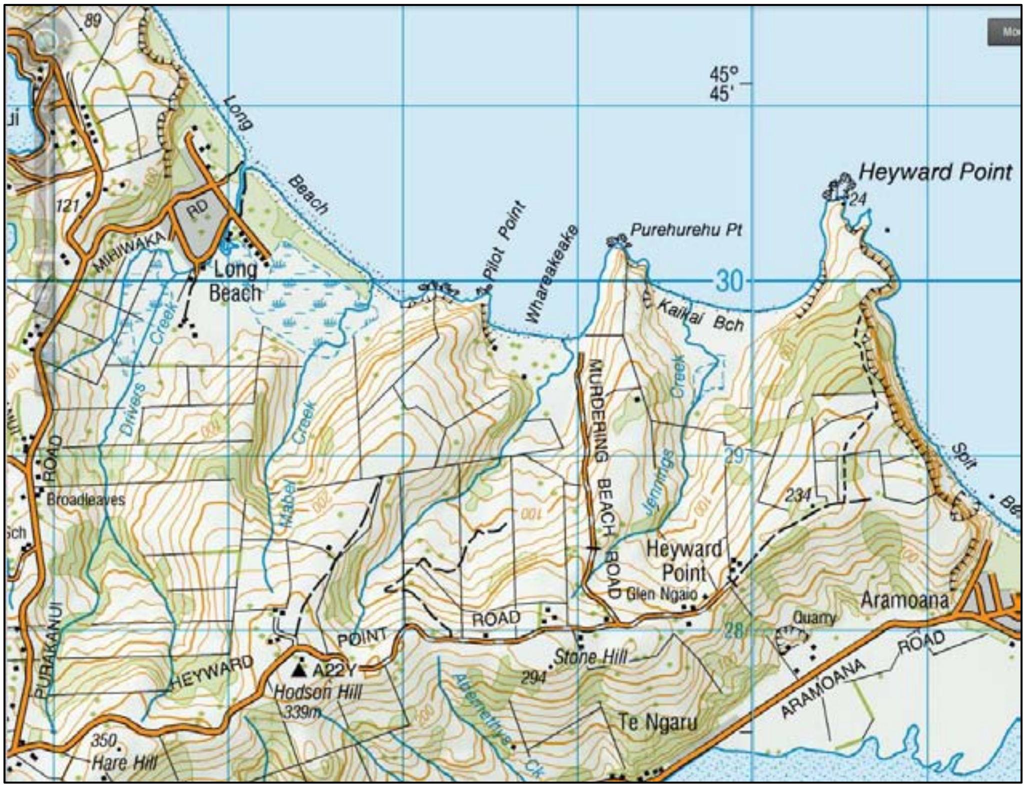

Figure 43 Topography of the Heyward Point to Long Beach area

Setting

The only permanent settlement along this stretch of coastline is Long Beach, which is located on flat, low-lying ground which is generally less than 3m above msl. Long Beach is bordered by coastal hills to the east, west and south which rise to between 200 and 350m (Figure 43). A series of low dune ridges, up to 5m in elevation, separate the northern edge of the settlement from the Pacific Ocean. Drivers and Mabel Creeks cross swampland before incising the coastal dunes as they convey runoff from the upstream catchment to the coast. The permanent population of Long Beach was 108 at the time of the 2013 census, up from 93 in 2006. Access is via Purakanui Road which connects to Port Chalmers and Waitati. Low-lying (but currently undeveloped) land is also located at Kaikai and Murdering (or Whareakeake) Beaches, as shown in Figure 48.

Assessment of Risk

A number of residential dwellings in Long Beach are holiday houses and are therefore not occupied permanently (Statistics NZ, 2013). As a result, the overall exposure of the community to natural hazards is lower than if there was a larger and more permanent population, as the number of people exposed to natural hazards is generally small. The township is a popular holiday and weekend destination however, particularly during the summer months.

Characteristics of mapped hazard area affecting Long Beach

The location and topography of Long Beach expose it to two broad categories of natural hazards: inundation (either from the sea, or heavy rainfall events), and land instability (including coastal erosion, rock-fall, and the effects of seismic shaking):

- Direct Inundation from the Pacific Ocean

Two categories of lower-lying land in Long Beach have been identified using the methodology outlined in Part 1 of this report. These are described below, and shown in Figure 44.

It is noted that the coastal dunes to the north of Long Beach currently provide some protection against direct inundation from the Pacific Ocean during periods of elevated sea level (Figure 44 and

Figure 47). However, water could enter the township if the dunes were eroded or overtopped, or infiltration (piping) occurred during storm surge or tsunami events. The buffering effect is more limited where Drivers and Mabel Creeks cut through the coastal dunes, providing a more direct passage between the ocean and the Long Beach community.

Area A: Land which is below the height identified as the 1:100 year storm surge level (Table 1). If water was to reach this height, a number of residential properties in Long Beach would be inundated to a depth of up to 0.5m, particularly on Beach Road, and the lower (eastern) end of Mihawaka Road. This area is also vulnerable to other coastal hazards such as tsunami and surface ponding due to heavy rainfall. Low-lying land in this area has been affected by surface ponding (i.e. not direct inundation from the sea) in recent times (Figure 45).

Area B: Land which is below the combined height of the 1:100 year storm surge level and an additional 1m (as described in Part 1 of this report, and listed in Table 1). Although higher than Area A, this area may still be affected by high magnitude, low frequency tsunami and storm surge events, where these have the ability to overtop or penetrate the dunes or road embankments which separate Area B from the coast. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase. At current sea level, surface ponding is less likely to affect this area than lower-lying land in Area A.

Beyond Area B: High magnitude, low frequency tsunami events (as described in Table 2) may affect land which is higher than that mapped as Area B, irrespective of sea-level rise. Although such events may occur rarely, they could affect much of the coastal terrace upon which Long Beach is situated. The actual extent of inundation (along with other characteristics such as velocity and depth) during the largest credible tsunami events are not possible to map accurately, given the current level of information available.

- Other Natural Hazards

Surface ponding: The relatively low elevation and flat topography of the Long Beach settlement, a shallow water table,[7] and normal astronomical tides can combine to impede the natural drainage of water during prolonged or heavy rainfall events. This can contribute to extensive surface ponding in low-lying parts of the settlement. Prolonged inundation can occur under current conditions (Figure 45), and this can damage buildings and vehicles, and cause major inconvenience to residents.

Any increase in mean sea level and the upper range of the normal tidal cycle will likely exacerbate the problems associated with surface ponding, and may influence the depth of inundation, the frequency of events, and the duration of ponding. Changes in climate may also lead to increases in the intensity and frequency of storm events (MfE, 2008). The combined effects of more frequent and intense heavy rainfall events and a higher base sea-level may further exacerbate the effects of ponding.

Surface ponding hazard has not been mapped as part this investigation, and the extent of inundation will depend on the duration and intensity of each rainfall event, and the ability of water to drain away (which is partly controlled by sea level). Lower-lying land which will be more prone to this hazard will generally lie within Area A.

Flood hazard: The channel and margins of Drivers and Mabel Creeks are mapped on Figure 44 as a flood hazard area, as they are regularly affected by inundation during heavy rainfall events, and may be affected by fast-moving water and debris during storm surge or tsunami events. Low-lying land to the south of Long Beach can also be affected by flooding for extended periods, due to runoff from the surrounding hill catchments being unable to drain rapidly to the Pacific Ocean (Figure 46).

Rockfall and landslide: Land immediately below the steep coastal cliffs to the west of Long Beach can be affected by falling boulders and debris. Rockfall and cliff collapse may be initiated during extreme rainfall or seismic events. Rockfall could cause localised but severe damage to buildings and roads in this area, and present a risk to safety.

The coastal hills near Long Beach are susceptible to shallow landslides, and although no larger landslides have been mapped on the surrounding slopes (GNS, 2012), they remain a possibility, especially during extreme rainfall events. A small (15m) landslip blocked Mihiwaka Rd in April 2010, cutting off access to the Long beach community (ODT, 2010)

Seismic shaking: Ground shaking at Long Beach with a return period of 100 years is likely to displace objects and crack large windows (Opus 2005). The maximum intensity ground shaking modelled by Opus (2005) for Long Beach is associated with a magnitude 7 earthquake on the Akatore Fault. This would make it difficult for people to stand, and cause moderate damage to chimneys and un-reinforced stone and brick walls.

[7] Groundwater is generally shallow at the coast, as this is where groundwater discharges to the sea. Heavy rainfall events will cause the water table to rise resulting in ponding in low lying areas/depressions (R. Morris, ORC, pers. comm., 10 December 2013).

Ground subsidence or liquefaction as a result of seismic shaking has the potential to damage roads, power lines, underground pipes and building foundations. GNS (2014b) describes the hazard associated with liquefaction in the Long Beach area further, and describes the coastal terrace upon which the township is situated as being composed of materials which have a moderate to high likelihood of being susceptible to liquefaction.

- Other Coastal Areas

Sand dunes: The sand dunes to the north of Long Beach act as a buffer to help protect it against the effects of erosion and direct inundation from the sea during tsunami and storm surge events. Activities that disturb the form of the dunes (such as excavation or the placement of structures) or its vegetation cover may compromise their stability. Any increase in mean sea level may mean that wave action would increasingly affect the stability of these sand dunes. However, there would need to be sustained erosion of the dunes before residential properties were directly affected by the Pacific Ocean (either from direct inundation or coastal erosion).

Several areas were also mapped as sand dunes/ coastal terrace at Murdering and Kaikai Beaches (Figure 48). Within these sand dunes and coastal terraces, there are sections of land which lie below the height identified as the 1:100 year storm surge level, and the 1:100 year storm surge level plus an additional 1m (as described in Part 1). However, these categories of low-lying land were not mapped separately, as the elevation and surface form of coastal dunes changes over time, and the characteristics of these areas mean they are generally unsuitable for development.

Figure 47 shows that the vegetated foredune accreted (moved seaward) between 1956 and 2013. This aggradation is likely to have increased the ‘buffering’ ability of the dune system against coastal hazards.

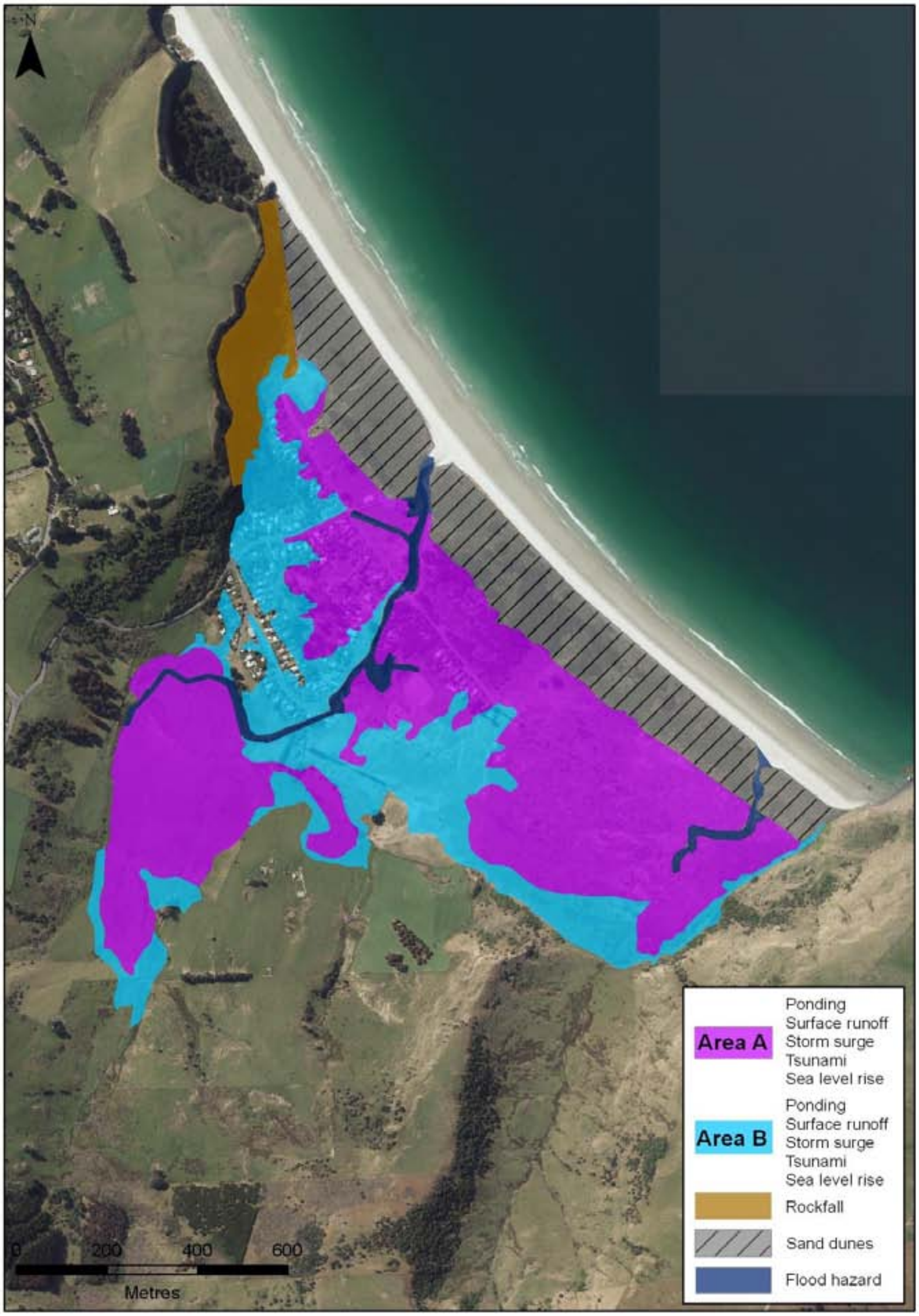

Figure 44 Mapped natural hazards areas in Long Beach

Figure 45 Water ponding on a property at Long Beach after heavy rainfall in May 2010 (source: ODT)

Figure 46 Long Beach during a heavy rainfall event in June 2013. The steep cliffs to the west of the settlement, and the low-lying, flood-prone area to the south can both be seen in this image.

Figure 47 Changes in the location of the vegetated foredune at Long Beach between 1956 and 2013, overlaid on an aerial photograph collected in 2013 (source: DCC)

Figure 48 Mapped natural hazards areas in Murdering Beach (left) and Kaikai Beach (right)

2.10. Purakanui

Figure 49 View of Purakanui from Bay Road (source: Google Street View)

Setting

The settlement of Purakanui is located on the eastern margin of Purakanui Inlet. Most residential sections are located on more elevated slopes, although some development does exist close to the margins of the inlet. The margins of the inlet are clearly defined by roads, or rocky headlands (Figure 49). As such, the effects of coastal hazards such as storm surge, tsunami and coastal erosion on existing development is limited.

The permanent population of Purakanui was 66 at the time of the 2013 census, down from 75 in 2006. Access is via Purakanui Road which connects to Port Chalmers and Waitati (Figure 43).

Low-lying land

Lower-lying land around the margins of Purakanui Inlet has been identified using the methodology outlined in Part 1 of this report. This includes roads, boat ramps and boat sheds (Figure 49), some low-lying land on the western side of the inlet, and the raised coastal terrace which lies between the estuary outlet and Osborne Road.

Area A: Land which is below the height identified as the 1:100 year storm surge level (Table 1). This area may also be vulnerable to inundation during tsunami events (ORC, 2012a). As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Area B: Land which is below the combined height of the 1:100 year storm surge level, and an additional 1m (as described in the introduction, and listed in Table 1). Although higher than Area

A, this area currently has some vulnerability to high magnitude, low frequency storm surge and tsunami events. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Flood hazard*:* Several steep gullies and ephemeral streams pass through the residential part of Purakanui. The location of the thalweg (or deepest part) of these waterways is shown on Figure 50, although the area which could be affected by flooding during a heavy rainfall event has not been mapped.

Figure 50 Mapped natural hazard areas in Purakanui

2.11. Waitati

Figure 51 Topography of Waitati and the surrounding area

Setting

Waitati is located in the south-west corner of Blueskin Bay (Figure 51) and much of the settlement lies at low elevation, less than 5m above msl. The township is flanked by coastal hills to the west, south and east, with several peaks over 600m. The Waitati River flows through Waitati from west to east, and Orokonui Creek borders the eastern edge of the township. Both rivers discharge into Blueskin Bay estuary at the east of the settlement.

The Waitati settlement (including Orokonui and south to Donald's Hill / Shortcut Roads) had a population of 315 at the time of the 2013 Census, compared to 303 in 2006. Most dwellings are permanently occupied with many residents commuting to Dunedin for work or school. The small settlement boasts a community hall, library, primary school and volunteer fire brigade, and has a number of small businesses. In addition to local roads, some key links in the lower South Island transport network pass through Waitati, including State Highway 1 and the South Island Main Trunk Railway Line. The railway embankment which separates Waitati from Blueskin Bay acts as a buffer against the force of breaking waves, but can also inhibit the drainage of floodwater from the Waitati River.

Previous flood events in Waitati

The Waitati River catchment is short and steep, dropping from 739m at Swampy Summit to sea level over a distance of just 9km. Heavy rainfall in the headwaters drains rapidly and with little warning to the lowland river flats that surround the Waitati Township (ORC, 1993). Natural drainage to the Pacific Ocean is via the Blueskin Bay estuary, and can therefore be restricted when water level in the estuary is high, due to normal astronomical tides, or any additional storm surge component.

Parts of Waitati were affected by high flows in the Waitati River in May 1957, March 1968, June 1980, February 1991 and in April 2006 (ORC, 2013). The largest event since European settlement is likely to have occurred in the 1920's, when "the meandering Waitati became one sheet of water from one side of the valley to the other" (ORC, 1993). The main channel of the Waitati River changed its course below the Harvey Street Bridge during a large flood in the 1880's.

Figure 52 Waitati River close to overtopping the true left bank, downstream of the Harvey Street Bridge, April 2006

Figure 53 Waitati River overtopping at Killarney Street, Waitati, Feb 1991

Assessment of Risk

The current level of development within the Waitati settlement is generally low density residential with relatively old housing stock, and some small-scale commercial activity. The township is exposed to a range of natural hazards, and, like many coastal communities, is vulnerable to the effects of climate change, through increasing sea level and the potential for larger, and more frequent heavy rainfall events and floods. Although the town's population has only increased slowly in recent years, any increase in the level of development will add to the risk associated with natural hazards.

Characteristics of mapped hazard areas in Waitati

The location and topography of Waitati expose it to two broad types of natural hazard: land instability (such as the effects of seismic shaking, including liquefaction), and inundation (either from the sea, or flooding during heavy rainfall events). The interaction of different processes (e.g. coastal storm surge coinciding with high river flows and surface runoff) can also increase the level of hazard faced by the Waitati community. Buildings and other structures may exacerbate the hazard associated with flood or coastal hazard events, by contributing debris, or by restricting, amplifying or re-directing the flow of water. The characteristics and effects of natural hazards in Waitati are described below, and these have been used to map the hazard areas shown in Figure 54.

- Direct Inundation from the Pacific Ocean

Two categories of lower-lying land have been identified using the methodology outlined in Part 1 of this report. These are described below, and shown in Figure 54. Elevated sea levels may result in water entering the township from Blueskin Bay, as backflow up the Waitati River and/or by overtopping the railway embankment (Figure 54). The overall effects of direct inundation from the Pacific Ocean may create a threat life/safety, could result in damage to buildings and create difficulties when evacuating people. These effects are likely to be greatest in areas which are low-lying, and/or immediately adjacent to the ocean.

Area A: Land which is below the height identified as the 1:100 year storm surge level (Table 1). This area is also vulnerable to other coastal hazards such as tsunami, and inundation resulting from heavy rainfall events and high flows in the Waitati River or Orokonui Creek. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Area B: Land which is below the combined height of the 1:100 year storm surge level, and an additional 1m (as described in the introduction, and listed in Table 1). Although higher than Area A, this area currently has some vulnerability to high magnitude, low frequency tsunami, storm surge, and flood events (as described in ORC (2012a), and shown in Figure 53). As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Beyond Area B: High magnitude, low frequency tsunami events (as described in Table 2) may affect land which is higher than that mapped as Area B, irrespective of sea-level rise. Although such events may occur rarely, they could affect much of the low-lying area in and around Waitati. The actual extent of inundation (along with other characteristics such as velocity and depth) during the largest credible tsunami events are not possible to map accurately, given the current level of information available.

- Other Natural Hazards

Flood and alluvial hazard: The lower Waitati River floodplain is prone to flood hazard (i.e. high river flows) and alluvial fan activity (water-borne sediment). The overall effects of inundation due to river flooding (including duration, depth and velocity) could create a risk to public safety, result in damage to buildings, and create stress for residents who were required to evacuate. There is potential for the river to create a different course in its lower reaches due to lateral migration of the active channel (caused either by the erosive power of floodwaters, or the accumulation of sediment in the channel). Both the current channel and the channel that existed prior to a flood event in the 1880's are shown in Figure 54.

The Waitati River and its tributary streams also convey entrained sediment (generally fine silts and sands) from the surrounding hills to the low-lying floodplain during times of intense rainfall. The deposition of this sediment on the floodplain may influence runoff patterns, and affect assets such as roads and buildings. Material entrained in floodwaters can cause additional damage to buildings and other assets (i.e. beyond that of flooding due to water only). The deposition of sediment within the main channel of the Waitati River can reduce its capacity, causing the river to avulse and overflow onto adjacent areas.

The lower reaches of the Orokonui Stream catchment have been mapped as an alluvial fan (Barrell et.al 1998, Opus 2009), which have been subject to active floodwater-dominated alluvial fan activity in the past.

Seismic hazard: Ground shaking at Waitati with a return period of 100 years is likely to displace objects and crack large windows (Opus 2005). The maximum intensity ground shaking modelled by Opus (2005) for Waitati is associated with a magnitude 7 earthquake on the Akatore Fault. This level of shaking would make it difficult for people to stand, and cause moderate damage to chimneys and un-reinforced stone and brick walls.

Ground subsidence or liquefaction as a result of seismic shaking has the potential to damage roads, power lines, underground pipes and building foundations. GNS (2014b) describes the hazard associated with liquefaction in the Waitati area further. The lower part of the Waitati River floodplain (including the Waitati township) is identified as being composed of materials which have a moderate to high likelihood of being susceptible to liquefaction.

Landslide hazard: Although approximately 34% of the Waitati River catchment has been mapped as comprising landslide features, none have been identified within or directly above the Waitati Township.

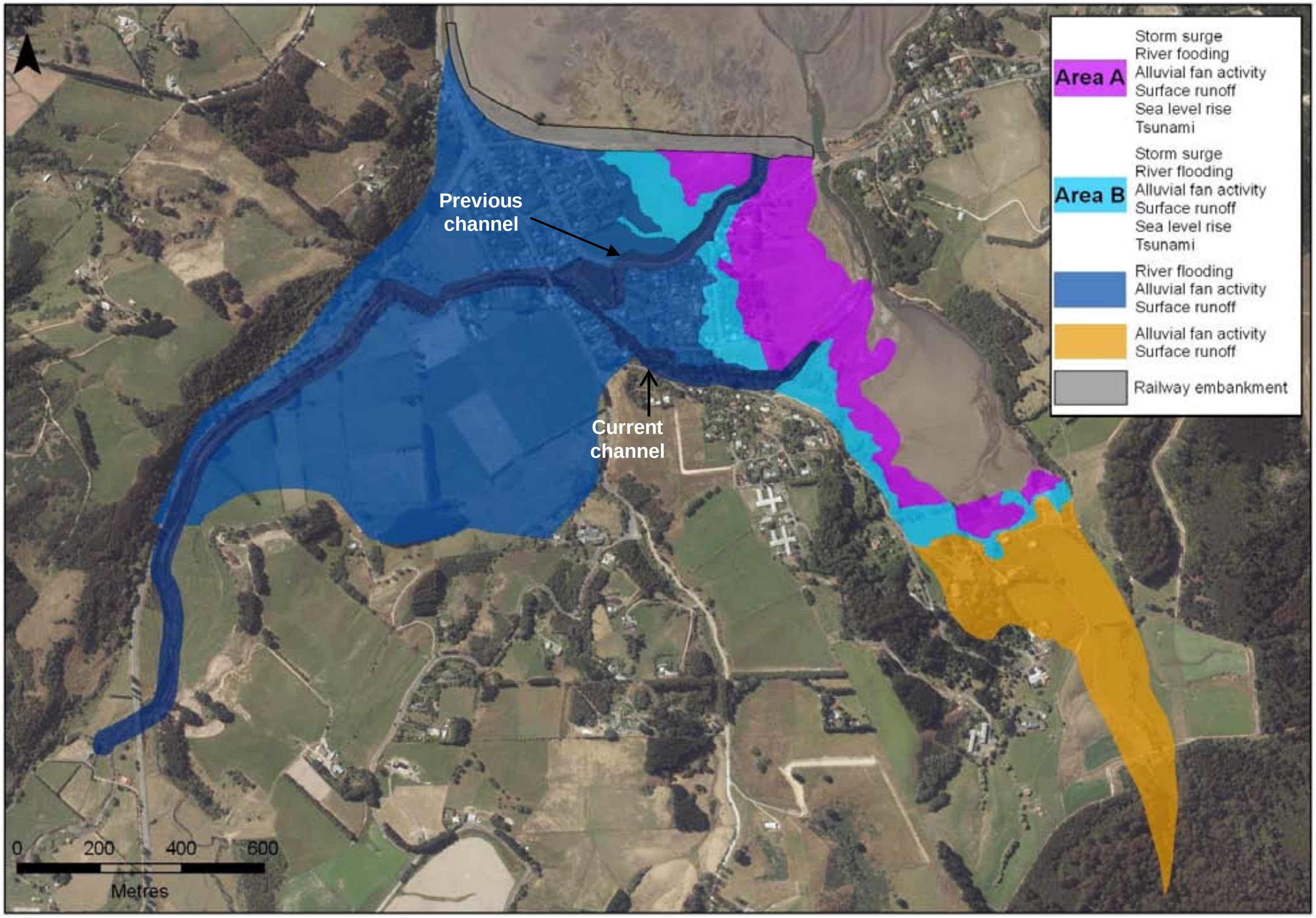

Figure 54 Mapped natural hazard areas in Waitati. The current channel of the Waitati River and the channel that existed prior to a flood event in the 1880's are shown as a darker blue.

2.12. Warrington and Evansdale

Figure 55 Topography of Warrington, Evansdale and the surrounding area

Setting

The settlement of Warrington is situated on land which is elevated 8m or more above msl, in the north-east corner of Blueskin Bay (Figure 55). Coastal hills rise to an elevation of 400m to the north and west of the township, and a sand-spit extends approximately 2.2km to the south, separating Blueskin Bay from the open coast. Warrington had a population of 450 at the time of the 2013 census, increasing from 426 in 2006 and 399 in 2001(Statistics NZ, 2013).

Evansdale is located 1.5km to the west, at the base of the Kilmog Hill on State Highway 1, with a population of approximately 45 people. Although the wider Evansdale area is low-lying, most of the residential activity is centred on areas of slightly higher elevation (Figure 56).

Figure 56 View of Evansdale from SH1, looking south (source: Google Maps)

Assessment of risk

The overall exposure of the Warrington and Evansdale communities to natural hazards is currently relatively low, due to the small population, and because most development has occurred on land which is moderately elevated - beyond the normal influence of the sea, and outside the area most affected by land instability. The risk to the community could increase however, if additional development occurred in lower-lying areas or on steeper slopes to the north of Warrington.

Characteristics of mapped natural hazard areas in Warrington and Evansdale

The location and topography of these communities expose them to two broad types of hazard; inundation (either from the sea, or from heavy rainfall / flood events), and land instability (including coastal erosion, landslides, and the effects of seismic shaking). The characteristics and effects of these hazards are described below. Mapped hazard areas are shown in Figure 57, along with other areas which play an important role in protecting these coastal communities.

- Direct Inundation from the Pacific Ocean

The elevation of Warrington means that storm surge is unlikely to affect residential parts of the township (there are only 2-3 houses situated on land which is less than 6m above msl). Although Evansdale is protected to some extent by the Warrington sand spit, parts of the community are low-lying, and are vulnerable to extreme tides, storm surge and tsunami. The effects of these events (including velocity, depth and duration) could create a threat to life/safety, result in damage to buildings, and would create difficulties when evacuating people. These effects are likely to be greatest in areas which are low-lying, and/or immediately adjacent to the ocean.

Area A: Land which is below the height identified as the 1:100 year storm surge level (Table 1). This area is also vulnerable to tsunami, and inundation resulting from high flows in Careys Creek. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Area B: Land which is below the combined height of the 1:100 year storm surge level, and an additional 1m (as described in Part 1 and listed in Table 1). Although higher than Area A, this area currently still has some vulnerability to high magnitude, low frequency tsunami, storm surge, and flood events. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Beyond Area B: High magnitude, low frequency events (as described in Table 2) may affect land which is higher than that mapped as Area B, irrespective of sea-level rise. Although such events may occur rarely, they could affect much of the alluvial fan area which forms the floodplain of Careys Creek, and much of the Warrington sand spit. The actual extent of inundation (along with other characteristics such as velocity and depth) during the largest credible tsunami events are not possible to map accurately, given the current level of information available.

- Other Natural Hazards

Flood and alluvial fan hazard: The low-lying area around Evansdale can be affected by flood events in Careys Creek (ORC, 2009a), and the current channel location is mapped as 'Flood Hazard' in Figure 57. The channel lies within a wider floodplain, which has been mapped as a floodwater-dominated alluvial fan (Barrell et.al 1998, Opus 2009), and has been subject to active floodwater dominated alluvial fan activity in the past. During extreme rainfall events, the velocity and depth of water draining the upper catchment can carry sediment and debris. The velocity of these flood flows will decrease as they arrive on the flatter, low-lying floodplain, causing entrained sediment and debris to be deposited. The deposition of sediment (usually fine silts and sands) can alter the form of the fan surface, and may affect roads and buildings. Material entrained in floodwaters can cause additional damage to buildings and other assets (i.e. beyond that of flooding due to water only).

Seismic hazard: Ground shaking at Warrington with a return period of 100 years would displace objects and crack large windows (Opus 2005). The maximum intensity ground shaking modelled by Opus (2005) for Warrington is associated with a magnitude 7 earthquake on the Akatore Fault. This would likely make it difficult for people to stand, and would cause moderate damage to chimneys and un-reinforced stone and brick walls.

Ground subsidence or liquefaction as a result of seismic shaking has the potential to damage roads, power lines, underground pipes and building foundations. GNS (2014b) describes the hazard associated with liquefaction in the Warrington area further. The lower reaches of Careys Creek and the sand spit to the south of Warrington are identified as being composed of materials which have a moderate to high likelihood of being susceptible to liquefaction. Landslide activity on the hills above Warrington and Evansdale may also be initiated or re-commence due to seismic shaking.

Landslides: The most prominent natural hazard affecting the Warrington area is land instability, in the form of landslides. Like most of the coastal hills of the area, a thin loess cover overlies basalt and alluvial conglomerates that were weathered from the volcanic rock. Even on low-angle slopes (10-20 degrees) these conditions have led to a number of landslides, and mapping by GNS, 2014a shows the slopes of Porteous Hill as far down as Coast Road (Figure 55) being affected. Landslides in the area tend to be triggered by heavy or prolonged rainfall and seismic shaking.

The Coastal Scenic Highway and South Island main trunk line are constantly being displaced at a number of locations and have to be realigned regularly (GNS, 2014a). Future movement is likely to continue to be very slow, and while failure will not have catastrophic effects on infrastructure, ongoing damage is likely. The majority of landslides in this area are considered very sensitive to environmental or human-induced modifications which may result in reactivation.

GNS (2014a) describes the hazard associated with mapped landslides in the Warrington area further.

- Other Coastal Areas

Sand spit: The Warrington sand spit acts as a buffer to protect against the effects of erosion and direct inundation from the sea. Activities that disturb the form of this sand spit and its vegetation cover (such as excavation or the removal of vegetation) may compromise it natural buffering ability. Changes in the morphology of the sand spit may also influence how storm surge and tsunami events affect the Evansdale area in the future. The line of the vegetated foredune at the northern end of the sand spit (closest to Warrington) moved seaward by up to 230m between 1958 and 2013 (Figure 58). This is likely to have increased the buffering effect this feature would have against coastal hazards, for communities on the margins of Blueskin Bay.

Figure 57 Mapped natural hazard areas in Warrington and Evansdale

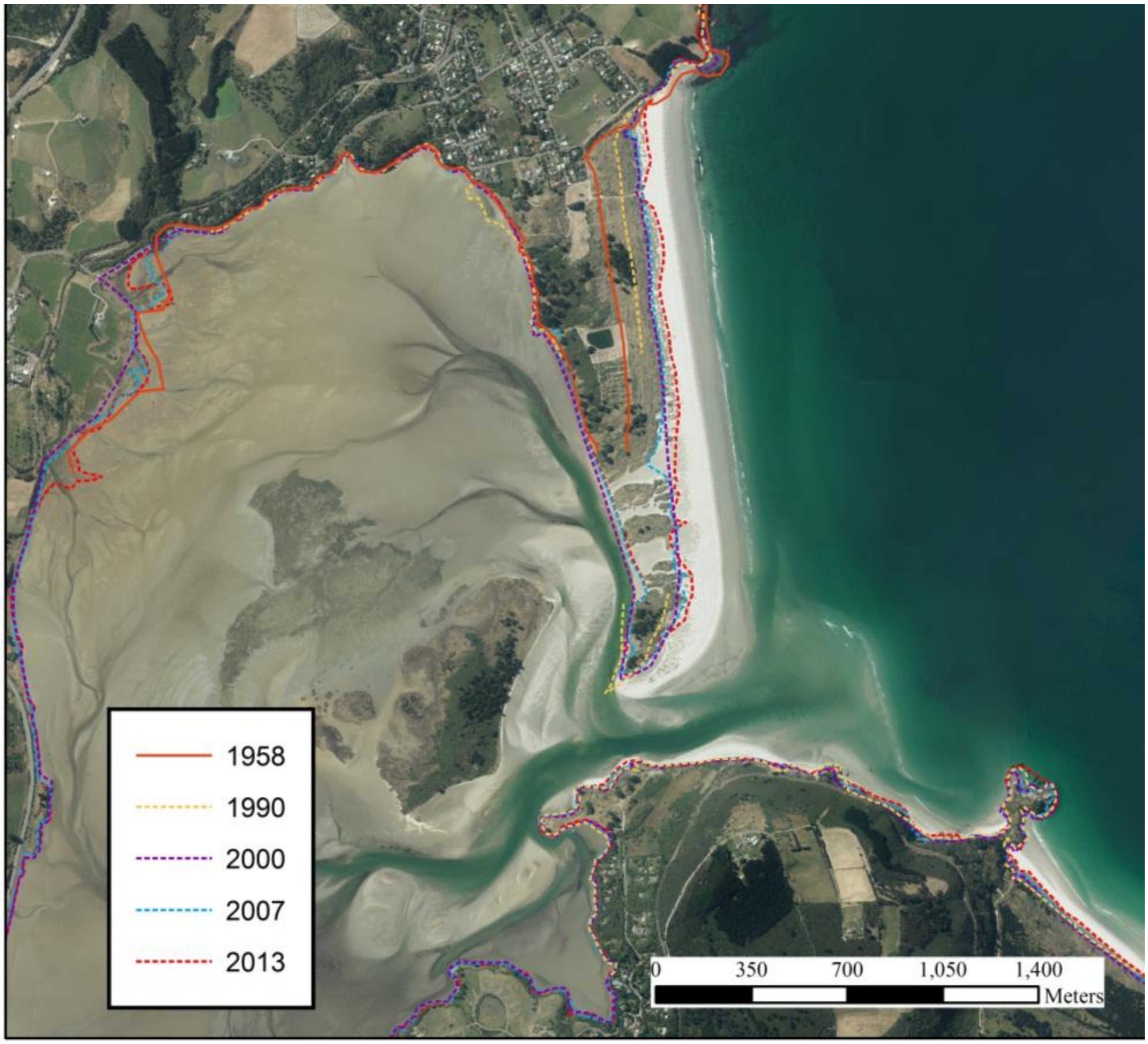

Figure 58 Changes in the northern Blueskin Bay coastline between 1958 and 2013, overlaid on an aerial photograph collected in 2013 (source: DCC)

2.13. Karitane

Figure 59 Aerial photograph of Karitane (dated 2013), showing main features of the town and surrounding area

Setting

Karitane is located on the southern (true right) bank of the Waikouaiti River, stretching from the mouth to 2.5km upstream (Figure 59). A narrow (100 – 200m wide) sand spit separates the lower reaches of the river from the open coast. The southern part of Karitane lies at the base of the Huriawa headland, where the Waikouaiti River is diverted sharply to the east as it enters the Pacific Ocean. The town is exposed to the open coast on its southern side (from Roneval Street, along the coast to the southwest).

Most of Karitane has been built on land which is elevated 8m or more above msl, with the exception of the low-lying isthmus that connects the Huriawa headland to the mainland, and parts of Stornoway Street.

Karitane had a population of 360 at the time of the 2013 Census, compared to 348 in 2006 and 399 in 2001. Approximately half of the dwellings are permanently occupied, and the town is a popular holiday retreat (Statistics NZ, 2013). The settlement has a primary school and a number of small businesses.

Previous flood events in the Waikouaiti River:

The Waikouaiti catchment covers an area of $425km^2$ and surrounding peaks range in elevation from 400-700m (ORC, 2008b). Large flood events in this catchment are relatively infrequent, but when they do occur, can have a significant effect on development located on the lower floodplain, including parts of Karitane. The low gradient of the river and the minimal elevation of the floodplain area cause floodwater to spill across a wide area, inundating farmland, residential dwellings and parts of SH1.

The largest flood in recent history was that in June 1980 and Figure 60 shows the extent of floodwaters during this event. The depth, velocity and duration of inundation across this flood hazard area will vary, but floodwaters have the potential to damage buildings and pose a risk to life/safety (Figure 61). Localised effects due to surface runoff from the hills to the south, including re-mobilisation and deposition of sediment, can also occur.

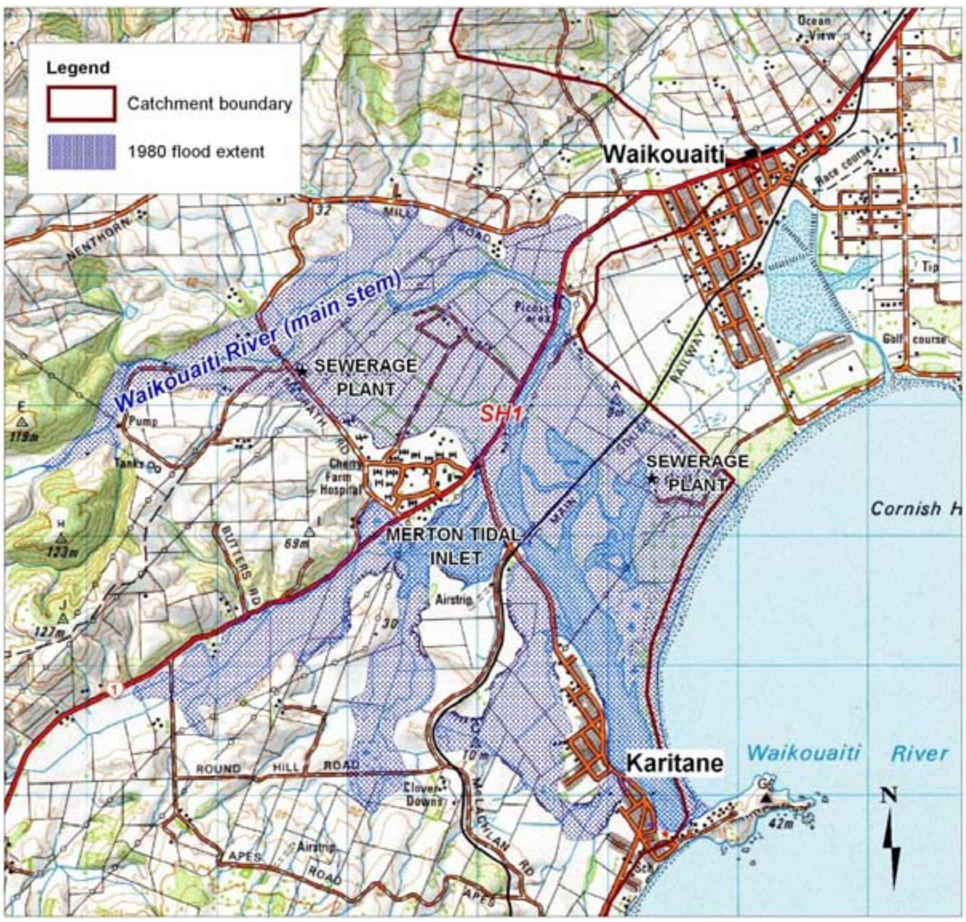

Figure 60 Extent of flooding on the Waikouaiti River during the largest event in recent history, in June 1980 (source: ORC, 2008b)

Figure 61 Images taken during the June 1980 flood. Karitane church and adjacent house on Stornoway Street (right), and Coast Road (left).

A secondary flow path of the Waikouaiti River carries flow to the west of Karitane during flood events, re-entering the main channel at Stornoway Street and creating a temporary ‘island’ upon which the northern half of the settlement has been built (Figure 62).

The lower 5 km of the Waikouaiti River is influenced by the tide under low-flow conditions, and when high water levels in the river coincide with elevated sea levels at the coast, the extent, depth and duration of inundation in Karitane may be exacerbated (Figure 62).

Figure 62 View of Karitane, Waikouaiti Beach and the lower Waikouaiti River floodplain, at a flow of approximately 450m^3/s at 11am on 17 July 2013. The river peaked at 512m^3/s earlier in the day, a flow which has an estimated return period of between 10 and 15 years (ORC, 2008b). Stornoway Street (where a secondary flow path re-enters the Waikouaiti River) is at centre-left of the image.

Assessment of risk

The overall exposure of the Karitane community to natural hazards is currently relatively low, as most development has occurred on land which is moderately elevated - beyond the normal influence of the sea or the Waikouaiti River, and outside the area most likely to be affected by land instability. The risk to the community could increase however, if additional development occurred in lower-lying areas.

Characteristics of mapped natural hazards areas in Karitane

Karitane and the surrounding area is subject to natural coastal and river processes, and the interaction of these during storm events can influence the depth and extent of inundation, water velocity and sedimentation. The settlement is predominantly built on Late Pleistocene shoreline deposits, consisting of weathered sand with pebbles and shells overlain by loess (GNS, 2001). The lower-lying land (which has generally not been settled, and forms the wider floodplain) consists of more recent Holocene river deposits of gravel, sand and mud. The area is therefore subject to land instability (including coastal erosion, sedimentation during flood events, and the effects of seismic shaking, including liquefaction and subsidence). The characteristics and effects of these hazards are described broadly below, and have been used to map the hazard areas in Figure 63.

- Direct Inundation from the Pacific Ocean

Two categories of lower-lying land have been identified using the methodology outlined in Part 1 of this report. These are described below, and shown in Figure 63. The overall effects of direct inundation from the Pacific Ocean (including velocity, depth and duration) may create a threat to life/safety, could result in damage to buildings, and would create difficulties when evacuating people. These effects are likely to be greatest in areas which are low-lying, and/or immediately adjacent to the ocean. It is noted that the Waikouaiti River mouth provides a passage through which storm waves and elevated sea levels can move into the lower reaches of the estuary.

Area A: Land which is below the height identified as the 1:100 year storm surge level (Table 1). This area is also vulnerable to other coastal hazards such as tsunami and coastal erosion, and inundation resulting from heavy rainfall events and high flows in the Waikouaiti River. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Area B: Land which is below the combined height of the 1:100 year storm surge level, and an additional 1m (as described in the introduction, and listed in Table 1). Although higher than Area A, this area currently has some vulnerability to high magnitude, low frequency tsunami, storm surge, and flood events. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Beyond Area B: High magnitude, low frequency storm surge and tsunami events (as described in Table 2) may affect land which is higher than that mapped as Area B, irrespective of sea-level rise. Events such as these would affect much of the lower Waikouaiti River floodplain, and could also affect land adjacent to Karitane's south beach. The actual extent of inundation (along with other characteristics such as velocity and depth) during the largest credible tsunami events are not possible to map accurately, given the current level of information available.

Apart from a small number of houses located on the isthmus connecting the Huriawa headland to the mainland, most residential properties within Karitane are outside of Areas A and B. However, the northern part of the town would likely become isolated during a 1:100 year storm surge event (particularly if the Waikouaiti River was also high), and access to the north would be affected by inundation and erosion of local roads and bridges.

- Other Natural Hazards

Flood hazard: Land which is vulnerable to river flooding, as well as storm surge and tsunami, or a combination of these hazards. The flood hazard area shown in Figure 63 is derived from ORC (2008b). The depth, velocity and duration of inundation across this area will vary, but floodwaters have the potential to damage buildings, pose a risk to life/safety (Figure 61), and create difficulties when evacuating people. Localised effects due to surface runoff from the hills to the south, including re-mobilisation and deposition of sediment, can also occur.

Some of the land mapped within the ‘Flood Hazard’ area on Figure 63 is also vulnerable to direct inundation from the Pacific Ocean, as it lies below the 1:100 year storm surge level. The effects of inundation are likely to be exacerbated by sea-level rise. Any buildings in this area may exacerbate the hazard associated with flood or coastal hazard events, by contributing debris, or by restricting, amplifying or re-directing the flow of water.

Alluvial fan hazard: The southern part of Karitane is exposed to alluvial fan hazard, as mapped by Barrell *et al.* (1998), and shown in Figure 63. During extreme rainfall events, this active alluvial fan can convey sediment from the hill catchments to the south towards Karitane. The velocity of these flood flows will decrease as they approach the Waikouaiti River floodplain, causing entrained sediment and debris to be deposited. The deposition of large volumes of sediment can alter the form of the fan surface, affect roads and buildings, and may interact with high flows in the Waikouaiti River.

Land instability: A landslide feature to the south of Karitane at Puketeraki has a history of ongoing movement, and is considered very sensitive to environmental or human-induced modifications which may result in reactivation. GNS (2014a) describes the hazard associated with landslides in the Karitane area further.

Seismic hazard: Ground shaking at Karitane with a return period of 100 years is likely to result in ground shaking which would displace objects and crack large windows (Opus 2005). The maximum intensity ground shaking modelled by Opus (2005) for Karitane is associated with a magnitude 7 earthquake on the Akatore Fault. This would likely make it difficult for people to stand, and would cause moderate damage to chimneys and un-reinforced stone and brick walls.

In addition to the effects of ground shaking, the presence of unconsolidated sediment (silts and sands) mean the land in and around Karitane is susceptible to subsidence and liquefaction during earthquakes. Ground subsidence or liquefaction has the potential to damage roads, power lines, underground pipes and building foundations.

GNS (2014b) describes the hazard associated with liquefaction in the Karitane area.

- Other Coastal Areas

Sand spit: The narrow sand spit to the east of the Waikouaiti River currently provides some protection for Karitane from the effects of breaking waves (Figure 62 and Figure 64). However the low elevation and unconsolidated sand which makes up this barrier means seawater may erode or overtop the spit during storm surge or tsunami events, increasing the potential for storm waves to affect the shoreline on the southern margin of the estuary. Changes to the coastline between 1958 and 2013 are illustrated in Figure 65. The most significant changes during this time occurred at the mouth of Waikouaiti River, with erosion occurring at the southern tip of the sand spit. Activities that disturb the natural form of the spit (such as excavation or the placement of structures) or its vegetation cover may compromise its stability.

Figure 63 Mapped natural hazard areas in the vicinity of Karitane, and at the mouth of the Waikouaiti River (inset)

Figure 64 Mouth of the Waikouaiti River, showing the sand spit which separates the river and town from the coast (December 2013)

Figure 65 Changes in the Karitane coastline between 1958 and 2013, overlaid on an aerial photograph collected in 2013 (source: DCC)

2.14. Waikouaiti

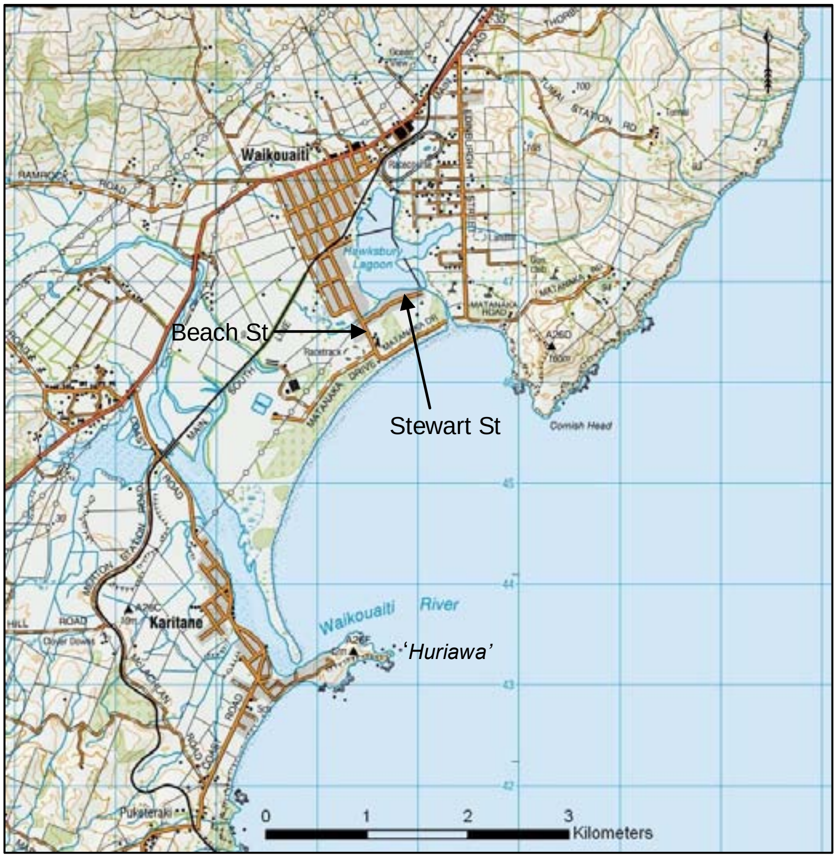

Figure 66. Topography of Waikouaiti, Karitane and the surrounding area

Setting

The town of Waikouaiti is located at the northern end of the unnamed bay which lies between Cornish Head and the Huriawa headland, and approximately 3km north of the Waikouaiti River Mouth (Figure 66).[8] The town is bordered by a flat, relatively low-lying terrace and the Waikouaiti River to the west, and the Hawksbury Lagoon to the east. A causeway and a series of culverts separate the western part of this lagoon from the uncontrolled eastern portion (which has a direct connection to the Pacific Ocean via the outlet) (Wildland Consultants, 2009). These structures may influence the effects of storm surge, tsunami or flood events, although this has not been modelled as part of this report.

A 300-400m wide strip of raised Holocene sand deposits, 2-5m high, separate the town from the coastline, with a narrow outlet linking the south-east corner of the Hawksbury lagoon to the open coast.

[8] The town is sufficiently elevated not to be affected by flood flows in the Waikouaiti River (ORC, 1993).

At the time of the 2013 census, about 1,122 people lived in Waikouaiti (up slightly from 1,095 in 2006), and roughly a third of those live within 1.2km of the coast (ORC, 2012a). Most of the dwellings (approximately 85%) are permanently occupied (Statistics NZ, 2013).

The dwellings situated closest to the shoreline are located at the southern end of Beach Street, and also on Stewart Street, some 350m back from the beach. Stewart Street is the lowest-lying part of the town, with residential properties situated on land that is less than 2m above msl. The rest of Waikouaiti lies further back from the ocean on land that is at least 5m above msl.

Assessment of risk

Although Waikouaiti is one of the larger settlements situated along the coastline of the Dunedin district, most of the township is sufficiently elevated, and set back from the current shoreline, so as to have a relatively low vulnerability to natural hazards. The relatively slow rate of population growth also means that there has been limited demand for intensive development on more hazard-prone land.

However, parts of the town are vulnerable to a range of hazards (as described below), and are vulnerable to the effects of climate change, through increasing sea level and the potential for larger, and more frequent heavy rainfall events. Any increase in the level of development in these areas will add to the risk associated with natural hazards.

Characteristics of mapped hazard areas in Waikouaiti

The location and topography of Waikouaiti expose it to two broad types of hazards: inundation (either from the sea or as a result of heavy rainfall events), and land instability (including coastal erosion and the effects of seismic shaking, including liquefaction). Changes in climate and sea-level rise over the next 100 years will likely accentuate the effects of inundation and coastal erosion. The characteristics and effects of these hazards are described below, and these have been used to map the hazard areas shown in Figure 67.

- Direct Inundation from the Pacific Ocean

Two categories of lower-lying land have been identified using the methodology outlined in Part 1 of this report. These are described below, and shown in Figure 67. The overall effects of direct inundation from the Pacific Ocean (including velocity, depth and duration) may create a threat to life/safety, could result in damage to buildings, and would create difficulties when evacuating people. These effects are likely to be greatest in areas which are low-lying, and/or immediately adjacent to the ocean.

Area A: Land which is below the height identified as the 1:100 year storm surge level (Table 1). This area may also be vulnerable to other coastal hazards such as tsunami, and inundation resulting from heavy rainfall events and high water levels in the Hawksbury Lagoon. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Area B: Land which is below the combined height of the 1:100 year storm surge level, and an additional 1m (as described in Part 1 of this report, and listed in Table 1). Although higher than

Area A, this area currently has some vulnerability to high magnitude, low frequency tsunami, storm surge, and flood events. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Beyond Area B: High magnitude, low frequency events (as described in Table 2) may affect land which is higher than that mapped as Area B, irrespective of sea-level rise. Although such events may occur rarely, they could affect much of the raised coastal terrace that lies between Waikouaiti and the coast, and the margins of the Hawksbury Lagoon. The actual extent of inundation (along with other characteristics such as velocity and depth) during the largest credible tsunami events are not possible to map accurately, given the current level of information available.

- Other Natural Hazards

Flood hazard: The Office Creek catchment upstream of SH1 and the area around the racecourse is low-lying relative to the surrounding area, and is therefore vulnerable to the effects of flooding and sedimentation (Figure 67 and Figure 69). The velocity of flood water in this area would generally not be high. However, the overall effects of inundation (including frequency, duration and depth) would result in damage to buildings, and create difficulties and stress when evacuating people.

The outlet of the Hawksbury Lagoon is also mapped as a flood hazard area, and the ability of floodwaters to drain through this outlet can be affected by conditions at the mouth. The morphology of this outlet also plays a role in determining the level of inundation further inland, due to coastal storm surge and tsunami events.

Alluvial fan hazard: During times of very heavy rainfall, ephemeral streams and overland flow may convey entrained sediment (generally fine silts and sands) from the surrounding hills to the low-lying floodplain beside Waikouaiti. A number of composite alluvial fans are mapped to the north and east of Waikouaiti (Opus, 2009). The deposition of this sediment on the lower slopes may influence runoff patterns, and affect assets such as roads and buildings

Landslide hazard: A report by GNS (2014a) shows that much of Waikouaiti is located on a feature which is a possible landslide. Any landslide activity which may have occurred in this location is thought to be old (more than 12,000 years ago), and the likelihood of this feature moving further as a result of environmental and/or human induced modifications is also thought to be very low.

Seismic hazard: Ground shaking at Waikouaiti with a return period of 100 years is likely to displace objects and crack large windows (Opus 2005). The maximum intensity ground shaking modelled by Opus (2005) for Waikouaiti is associated with a magnitude 7 earthquake on the Akatore Fault. This would likely make it difficult for people to stand, and would cause moderate damage to chimneys and un-reinforced stone and brick walls.

In addition to the effects of ground shaking, unconsolidated sediment (silts and sands) and a shallow water table means that some land on the margins of Waikouaiti is susceptible to subsidence, liquefaction and lateral spreading during earthquakes. These processes have the potential to damage roads, power lines, underground pipes and building foundations.

GNS (2014b) describes the hazard associated with liquefaction in the Waikouaiti area further. The low-lying area to the north-east corner of the town, and the coastal terrace to the south are identified as being composed of materials which have a moderate to high likelihood of being susceptible to liquefaction.

- Other Coastal Areas

Raised coastal terrace: A raised coastal terrace and dune system is mapped on Figure 67. This acts as a buffer to protect lower-lying areas further inland against the effects of erosion and direct inundation from the sea. Activities that disturb the form of this foreshore area and its vegetation cover (such as excavation or the removal of vegetation) may compromise its stability. This buffer area may be affected by future changes in sea level or large storm events. Changes to the coastline between 1958 and 2013 are illustrated in Figure 70, and this shows limited (but consistent) erosion of the vegetation line, by up to 34m, at the north-eastern end of the beach over this time. Evidence of recent erosion at this location is shown in Figure 68.

In addition, the erosive power of breaking waves (generated by either a storm surge or tsunami event), combined with long-term shoreline retreat and sea-level rise, may mean that the 'buffering' capacity of the raised coastal terrace is reduced over time.

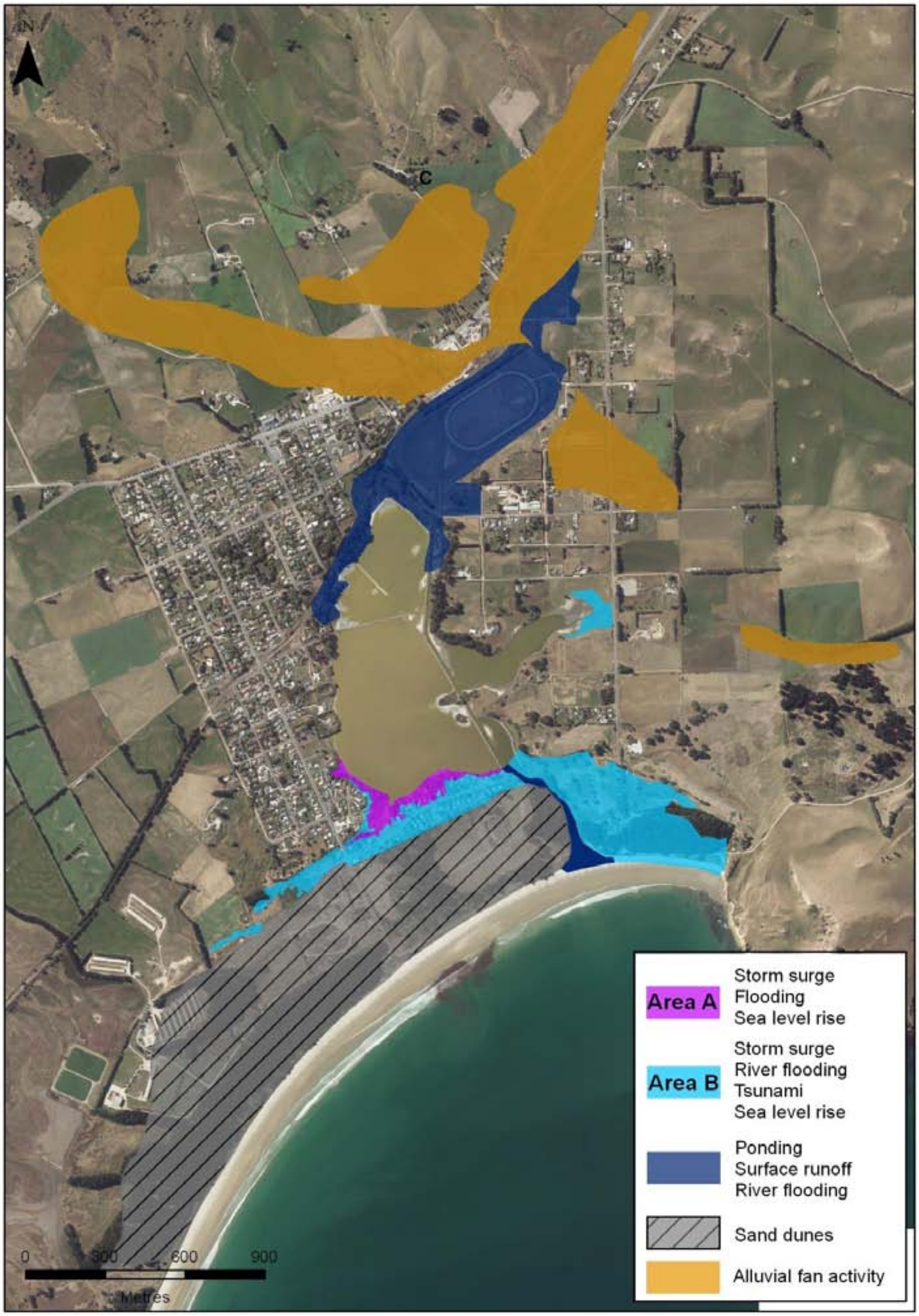

Figure 67. Mapped natural hazard areas in the Waikouaiti area

Figure 68 Evidence of recent erosion of Holocene beach deposits at the north-eastern end of Waikouaiti Beach, alongside Matanaka Drive (December 2013)

Figure 69 Surface flooding at the north-eastern corner of Waikouaiti, following a prolonged rainfall event in August 2012. The Hawksbury Lagoon can be seen to the right of the image, and the Waikouaiti racecourse is to the left.

Figure 70. Changes in the Waikouaiti coastline between 1958 and 2013, overlaid on an aerial photograph collected in 2013 (source: DCC)

2.15. Pleasant River mouth

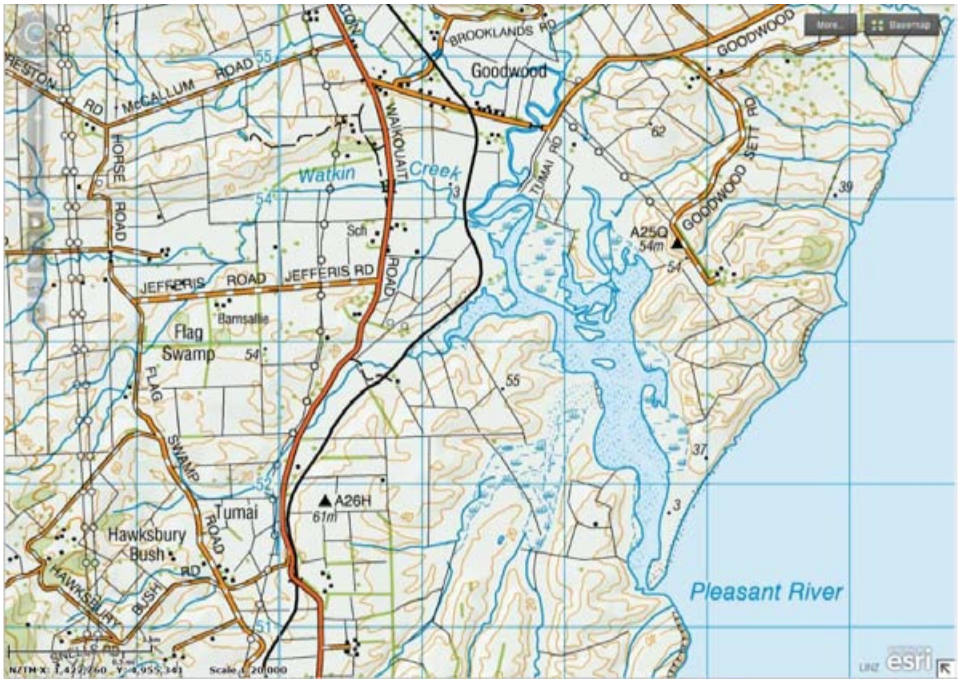

Figure 71 Topography of the lower Pleasant River catchment, including Goodwood

Setting

The Pleasant River catchment has an area of 130km^2 and varies in altitude from 616m above msl (Mt Watkin) to sea level (ORC, 1993). Below Goodwood and State Highway 1 the channel opens out onto tidal estuarine mudflats which extend for about 3km along the river for a width of 300m (Figure 71).

Only the lower part of the Pleasant River catchment lies within the Dunedin City District, with the remainder lying within the Waitaki District. Currently there is no development on the mapped hazard areas shown on Figure 72.

Characteristics of mapped hazard areas in the lower reaches of the Pleasant River

- Low-lying land

Lower-lying land around the margins of the Pleasant River estuary has been mapped and is shown in Figure 72.

Area A: Land which is below the height identified as the 1:100 year storm surge level for Waikouaiti (Table 1). This area may also be vulnerable to inundation during tsunami events (GNS, 2013). As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Area B: Land which is below the combined height of the 1:100 year storm surge level for Waikouaiti, and an additional 1m (as described in the introduction, and listed in Table 1).

Although higher than Area A, this area currently has some vulnerability to high magnitude, low frequency storm surge and tsunami events. As sea level rises, the likelihood that inundation resulting from these hazards will reach a level where it can affect people and assets in this area will increase.

Floodplain: The accurate topographic data (LiDAR) used to map Areas A and B only extends 2km upstream of the mouth, and low-lying land upstream of this point could therefore not be mapped using the method outlined in Part 1. Instead, the approximate extent of the low-lying land which may be affected by flooding or storm surge has been mapped using aerial photos collected in 2013, and verified using historical flood photos and field observations. This is mapped on Figure 72 as 'Floodplain', and has been extended for approximately 300m upstream of the Waitaki District / Dunedin City boundary.

- Other Natural Hazards

Seismic hazard: Ground shaking due to remote or nearby earthquake activity could result in subsidence, liquefaction and lateral spreading during earthquakes. These processes have the potential to damage roads, power lines, underground pipes and building foundations. These effects are may be larger where the land is underlain by unconsolidated sediment (silts and sands) and a shallow water table. Opus (2005) identified that the Pleasant River floodplain is 'possibly susceptible' to liquefaction.

- Other Coastal Areas

Sand Spit: A sand spit / dune system is mapped on Figure 72. This acts as a buffer to protect lower-lying areas within the estuary against the effects of direct inundation from the sea. Activities that disturb the form of this foreshore area and its vegetation cover (such as excavation or the removal of vegetation) may compromise its stability. This buffer area may be affected by future changes in sea level or large storm events.

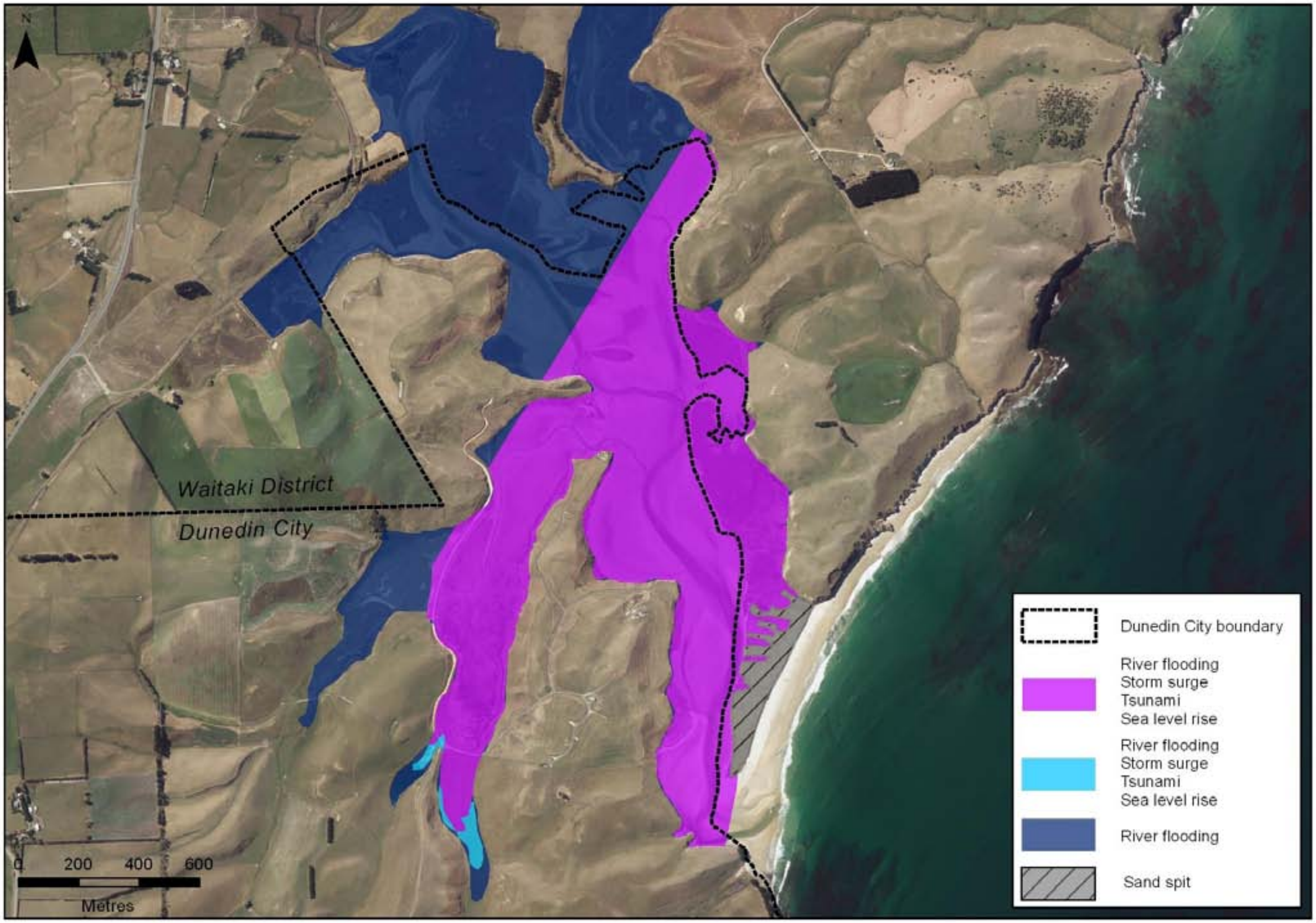

Figure 72. Mapped natural hazard areas in the lower Pleasant River

Figure 73 Inundation of low-lying land adjacent to the lower reaches of the Pleasant River, following a period of heavy rainfall in August 2012

Glossary

Alluvial Fan: Landforms that develop where a steep gully emerges from its confines onto a flatter valley floor, or at other sites where sediment accumulates in response to changes in stream gradient and/or width.

Avulsion: The abandonment of a river channel and the establishment of a new channel at a lower elevation on its floodplain as a result of floodplain / channel aggradation.

Erosion: The wearing away of land-surface materials, especially rocks, sediments, and soils by the action of water, wind or a glacier (GNS, 2009).

Holocene: A geological epoch which began at the end of the Pleistocene (at about 11,700 calendar years ago) and continues to the present. The Holocene is part of the Quaternary period.

Inundation: Complete coverage of an area of land by water sourced from the sea, rivers, streams, lakes or surface runoff.

King tide: An especially high tide event occurring twice a year, when there is alignment of the gravitational pull between sun and moon.

Liquefaction: When saturated fine grained sediments (such as sand and silt) are subjected to high intensity shaking and lose their ability to stay cohesive. As sediments are shaken, they act like a fluid, causing deformation, settlement, and sometimes lateral spread towards rivers or lakes.

Mean sea level (msl): The sum of average tides: the middle level between high and low tides. Current msl is relative to Dunedin Vertical Datum 1958 (DVD-58) + 12cm to account for sea-level rise since 1958 (DVD-58 is based on tide data collected in 1918, 1923-27, 1929, 1935 and 1937, with a mid-point year of approximately 1928).

Modified Mercalli Intensity: A measure of earthquake intensity by providing a descriptive list of effects based on the Richter scale of earthquake magnitude (Appendix 3).

Pleistocene: The geological epoch which lasted from about 2,588,000 to 11,700 years ago, spanning the world's recent period of repeated glaciations.

Regolith: A layer of loose, heterogeneous material covering solid rock. It includes dust, soil, broken rock, and other related materials.

Sea level rise: Long term changes in relative sea level caused by either eustatic changes, e.g. brought about by thermal expansion, or changes in vertical land movements (IPCC, 2013)

Seismic hazard: Hazards derived from effects of an earthquake.

Sedimentation: The deposition of sediment.

Storm surge: A state of elevated sea level due to a combination of tides, wind-stress, atmospheric pressure and waves.

Tidal range: The difference in height between consecutive high and low waters. The tidal range varies from a maximum during spring tides to a minimum during neap tides.

Tsunami: A series of waves generated when a large volume of water in the sea, or in a lake, is rapidly displaced. The principal sources of tsunami are large submarine or coastal earthquakes, underwater landslides and large landslides from coastal or lakeside cliffs (Power, 2013).

Vulnerability: Liability or exposure to a hazard or disaster.

References

Australian Geographic, March 8, 2012. Floods: 10 of the deadliest in Australian history.

Barrell, D. J. A., McIntosh, P. D., Forsyth, P. J., Litchfield, N. J., Eden, D. N., Glassey, P. J., Brown, L. J., Froggatt, P. C., Morrison, B., Smith Lyttle, B., Turnbull. I. M. 1998. 'Quaternary fans and terraces of coastal Otago, New Zealand' Institute of Geological and Nuclear Sciences science report 98/11.

Bell, 2013. A submission on the proposed Northland Regional Policy Statement. Evidence of Dr. Robert Gordon Bell for Director-General of Conservation.

Dunedin City Council 2011a. Climate Change Predictions Policy 201, Corporate Policy, DCC, 6 September 2011

Dunedin City Council, 2011b. Integrated Catchment Management Plan documents. Accessed online at http://www.dunedin.govt.nz/your-council/council-projects/3waters/icmpdocuments

Dunedin City Council 2009. Dunedin City Residential Capacity Study.

Fitzharris, B. 2010. Climate change impacts on Dunedin. Climate Management Ltd. Unpublished report for Dunedin City Council. March 2010.

GNS Science 2014a. The hazard significance of landslides in and around Dunedin City. Report prepared for the Otago Regional Council.

GNS Science 2014b. Assessment of liquefaction hazards in the Dunedin City District. Report prepared for the Otago Regional Council.

GNS Science, 2013. Review of tsunami hazard in New Zealand.

GNS Science, 2012. Attributing and reconciling source of landslide data within the Dunedin City Council area. Report prepared for the Otago Regional Council.

GNS Science, 2001. Geology of the Waitaki Area.

GNS Science, 1996. Geology of the Dunedin Area.

Hannah, J. and Bell, R.G. 2012 'Regional sea level trends in New Zealand' Journal of Geophysical Research, vol. 117.

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

[Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Ministry for the Environment, 2008a. Coastal Hazards and Climate Change. A Guidance Manual for Local Government in New Zealand. 2nd edition. Revised by Ramsay, D, and Bell R. (NIWA). Prepared for Ministry for the Environment.

Ministry for the Environment, 2008b. Preparing for climate change. A guide for local government in New Zealand.

New Zealand Coastal Policy Statement, 2010. Published by the Department of Conservation, P.O. Box 10420, The Terrace, Wellington 6143.

NIWA, 2008. Client Report CHC 2008-047. Otago Regional Council Storm Surge Modelling Study.

NIWA, 2007. Client Report CHC 2007-030. Otago region hazards management investigation: tsunami modelling study.

New Zealand Standard 9401: 2008. Managing Flood Risk – A Process Standard. Standards New Zealand.

Otago Regional Council, 2014a. Review of Dunedin City District Plan – Natural Hazards. Project Overview

Otago Regional Council, 2014b. Flood Hazard of the Taieri Plain and Strath Taieri.

Otago Regional Council, 2014c. Flood Hazard of Dunedin's urban streams.

Otago Regional Council 2013. Natural hazards information for mediation session Nov 15, 2013. File Note prepared for resource consent application SUB 2012-104 and LUC 2012-571.

Otago Regional Council 2012a. Community vulnerability to elevated sea level and coastal tsunami events in Otago.

Otago Regional Council 2012b. 100 year ARI levels for DCC communities. Memorandum prepared in response to a request from Dunedin City Council.

Otago Regional Council 2012c. Milton 2060. Flood Risk Management Strategy for Milton and the Tokomairiro Plain.

Otago Regional Council 2012d. The South Dunedin Coastal Aquifer & Effect of Sea Level Fluctuations.

Otago Regional Council 2009a. The Water Resources of the Waitati River and Careys Creek.

Otago Regional Council 2009b. South Dunedin Groundwater Monitoring – Initial Data November 2009. Report prepared for the Chief Executive ORC.

Otago Regional Council 2008a. Te Rauone Beach – Wave, Tide and Current Monitoring. Report to Council 2008/415.

Otago Regional Council 2008b. The Water Resources of the Waikouaiti River.

Otago Regional Council 2002. Waitaki District Floodplain Report (Draft).

Otago Regional Council 1993. Floodplain Management report: Dunedin District – Rural Areas.

Opus International Consultants 2012. Dunedin 3 Waters Strategy Appendix A: ICMP Summaries, prepared for the Dunedin City Council.

Opus International Consultants 2009. Otago Alluvial Fans Project. Report # 1205 – Version 2, prepared for Otago Regional Council.

Opus International Consultants 2005. Seismic Risk in Otago.

Statistics New Zealand, 2013. 2013 Census population and dwelling map tool. Accessed online January 2013 at http://www.stats.govt.nz/StatsMaps/Home/Maps/2013-census-population-dwelling-map.aspx

Statistics New Zealand, 2006. 2006 Census population and dwelling map tool. Accessed online January 2013 at http://www.stats.govt.nz/StatsMaps/Home/Maps/2006-census-quickstats-about-a-place-map.aspx

Tonkin & Taylor, 2011. Ocean Beach Domain Reserve Management Plan. Coastal issues and options. Report prepared for Dunedin City Council.

Wildland Consultants, 2009. Ecological Management Plan for Hawksbury Lagoon, Waikouaiti.

Appendix 1. Summary of the methods used to map hazard areas for coastal communities

Community	Hazard Area	Methods used to map area
Brighton and Ocean View	A	Land which is below the height identified as the 1:100 year storm surge level for Brighton.
	B	Land which is below the combined height of the 1:100 year storm surge level for Brighton, and an additional 1m.
	Flood	Main channel and floodplain of Otokia and Taylors creeks.
	Raised coastal terrace	Beach platform / dunes that act as a buffer against the effects of erosion and direct inundation from the sea.
Waldronville and Westwood	A	Land which is below the height identified as the 1:100 year storm surge level for Kaikorai.
	B	Land which is below the combined height of the 1:100 year storm surge level for Kaikorai, and an additional 1m.
	Flood	The current extent of the Kaikorai Stream channel and estuary, downstream of the Brighton Road Bridge.
	Raised coastal terrace	Beach platform / dunes that act as a buffer against the effects of erosion and direct inundation from the sea.
South Dunedin and the upper Otago Harbour	A	Land which is below the height identified as the 1:100 year storm surge level for St Kilda / St Clair (South Dunedin). Land which is below the height identified as the 1:100 year storm surge level for the upper Otago Harbour (upper harbour).
	B	Land which is below the combined height of the 1:100 year storm surge level for St Kilda / St Clair, and an additional 1m.
Ocean Grove	A	Land which is below the height identified as the 1:100 year storm surge level for St Kilda / St Clair.
	B	Land which is below the combined height of the 1:100 year storm surge level for St Kilda / St Clair, and an additional 1m.
	Raised coastal terrace	Dunes which act as a buffer against the effects of erosion and direct inundation from the sea
South coast of the Otago Peninsula	A	Land which is below the height identified as the 1:100 year storm surge level for St Kilda / St Clair.
	B	Land which is below the combined height of the 1:100 year storm surge level for St Kilda / St Clair, and an additional 1m.
	Raised coastal terrace	Dunes which act as a buffer against the effects of erosion and direct inundation from the sea.
Mid Harbour	A	Land which is below the height identified as the 1:100 year storm surge level for the upper Otago Harbour.
	B	Land which is below the combined height of the 1:100 year storm surge level for the upper Otago Harbour, and an additional 1m.

Harwood	A	Land which is below the height identified as the 1:100 year storm surge level for Long Beach and Purakanui.
	B	Land which is below the combined height of the 1:100 year storm surge level for Long Beach and Purakanui, and an additional 1m.
Aramoana	A	Land which is below the height identified as the 1:100 year storm surge level for Long Beach.
	B	Land which is below the combined height of the 1:100 year storm surge level for Long Beach, and an additional 1m.
	Sand Dunes / Sand Spit	Beach platform / dunes / Sand Spits that act as a buffer against the effects of erosion and direct inundation from the sea.
	Rockfall	Land subject to rockfall.
Heyward Point to Long Beach	A	Land which is below the height identified as the 1:100 year storm surge level for Long Beach.
	B	Land which is below the combined height of the 1:100 year storm surge level for Long Beach, and an additional 1m.
	Sand Dunes	Beach platform / dunes that act as a buffer against the effects of erosion and direct inundation from the sea.
	Flood	Main channel and floodplain of Drivers Creek and Mabel Creek.
Purakanui	A	Land which is below the height identified as the 1:100 year storm surge level for Purakanui.
	B	Land which is below the combined height of the 1:100 year storm surge level for Purakanui, and an additional 1m.
Waitati	A	Land which is below the height identified as the 1:100 year storm surge level for Warrington.
	B	Land which is below the combined height of the 1:100 year storm surge level for Warrington, and an additional 1m.
	Flood	The current and former channels of the Waitati River. The lower Waitati River floodplain.
	Alluvial fan	Land mapped as an alluvial fan by Opus, 2009.
Warrington and Evansdale	A	Land which is below the height identified as the 1:100 year storm surge level for Warrington.
	B	Land which is below the combined height of the 1:100 year storm surge level for Warrington, and an additional 1m.
	Flood	Main channel and floodplain of Careys Creek.
	Alluvial fan	Land mapped as an alluvial fan by Opus, 2009.
	Sand spit	Sand spit that acts as a buffer against the effects of erosion and direct inundation from the sea.
Karitane	A	Land which is below the height identified as the 1:100 year storm surge level for Karitane.
	B	Land which is below the combined height of the 1:100 year storm surge level for Karitane, and an additional 1m.
	Floodplain	Waikouaiti River main channel and floodplain.
	Alluvial fan	Land mapped as an alluvial fan by Opus, 2009.
	Sand Spit	Sand spit that acts as a buffer against the effects of erosion and direct inundation from the sea.

Waikouaiti	A	Land which is below the height identified as the 1:100 year storm surge level for Karitane.
	B	Land which is below the combined height of the 1:100 year storm surge level for Karitane, and an additional 1m.
	Flood hazard	Outlet of the Hawksbury Lagoon.
	Alluvial fan	Lower-lying area, prone to flooding and sedimentation.
	Raised coastal terrace	Beach platform / dunes that act as a buffer against the effects of erosion and direct inundation from the sea.
Pleasant River mouth	A	Land which is below the height identified as the 1:100 year storm surge level for Karitane.
	B	Land which is below the combined height of the 1:100 year storm surge level for Karitane, and an additional 1m.

Appendix 2. Cross-section maps

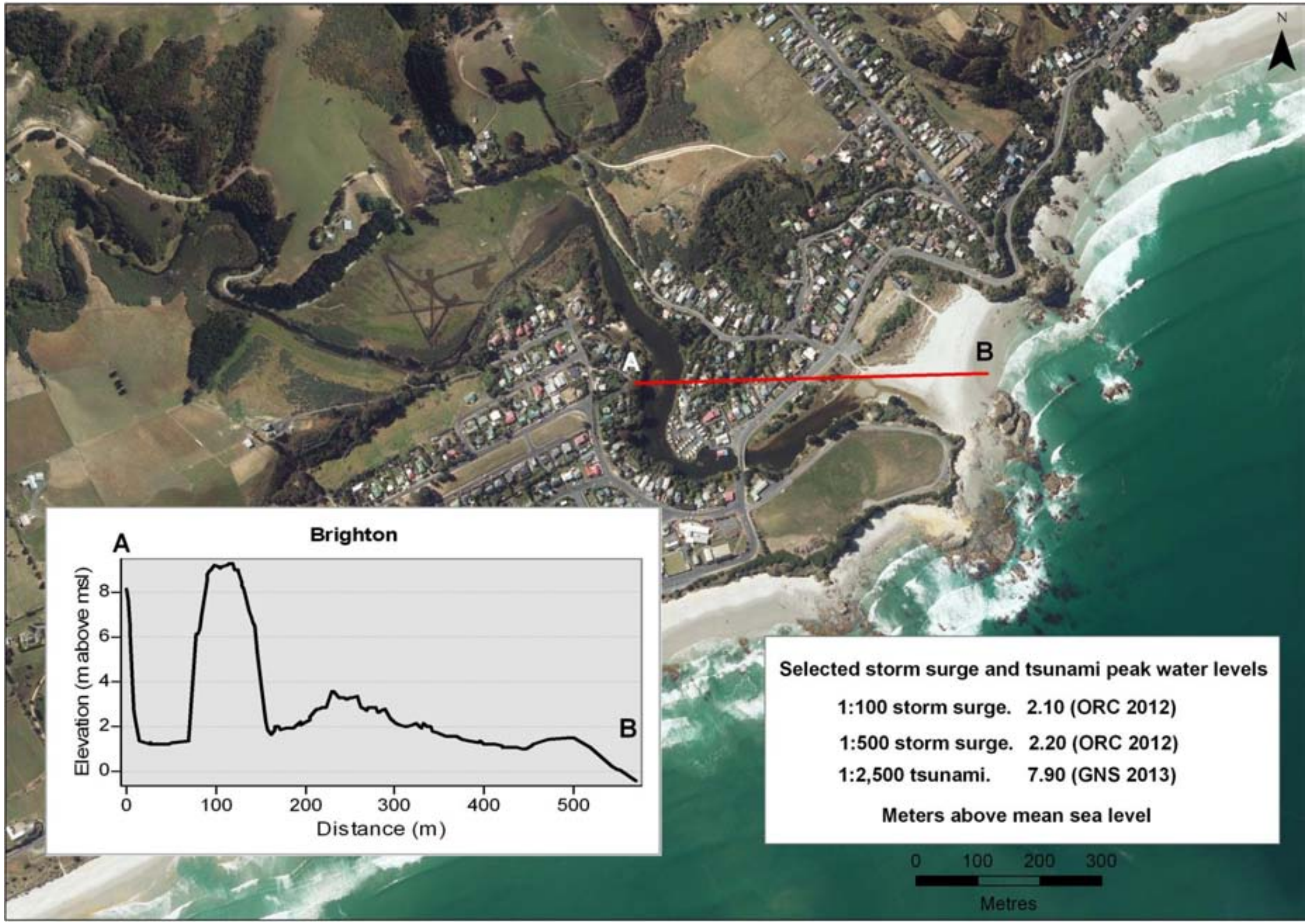

Figure 74 Cross section A-B through Brighton, and peak water levels associated with selected high magnitude storm surge and tsunami events

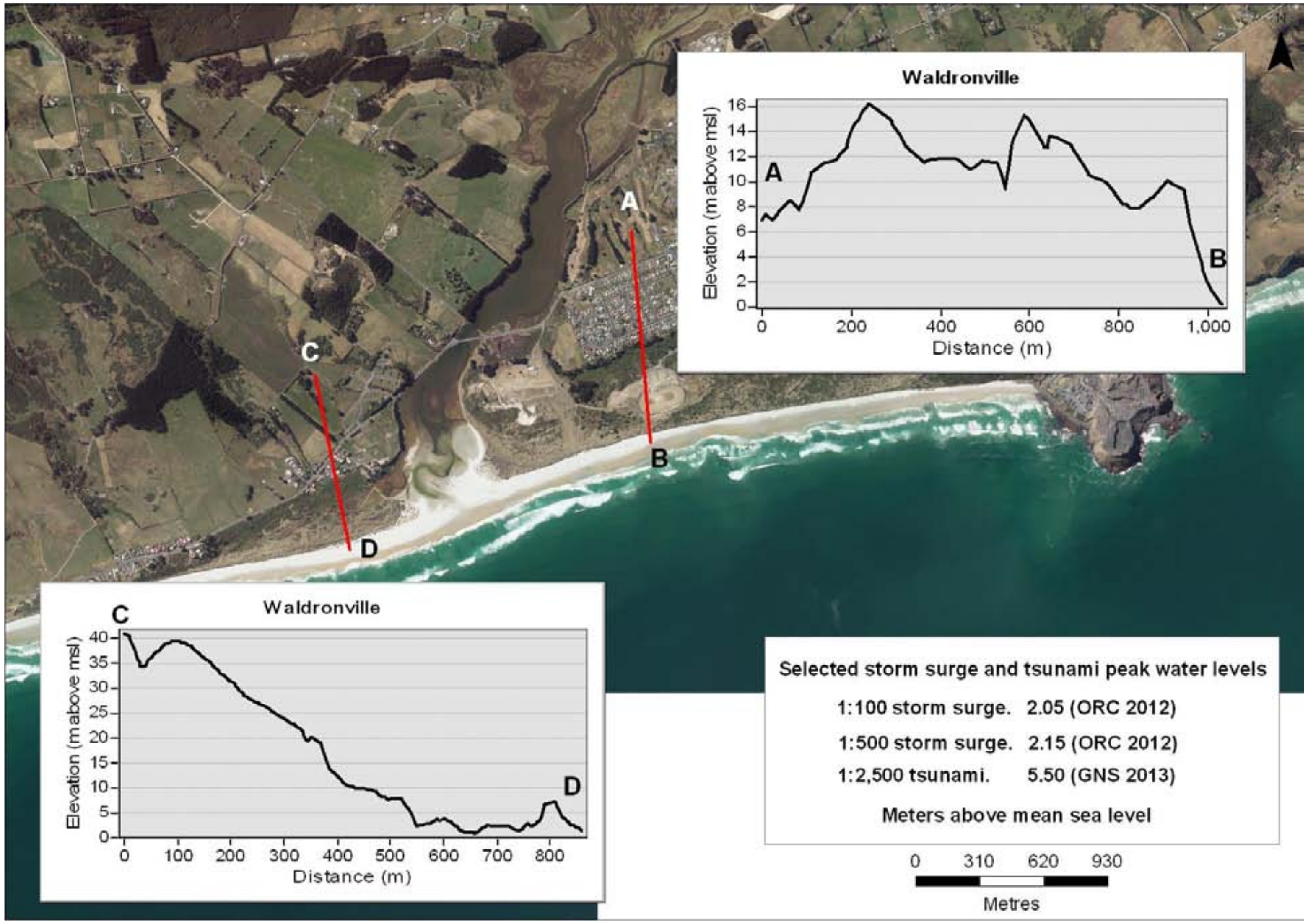

Figure 75 Cross section A-B and C-D through Waldronville, and peak water levels associated with selected high magnitude storm surge and tsunami events

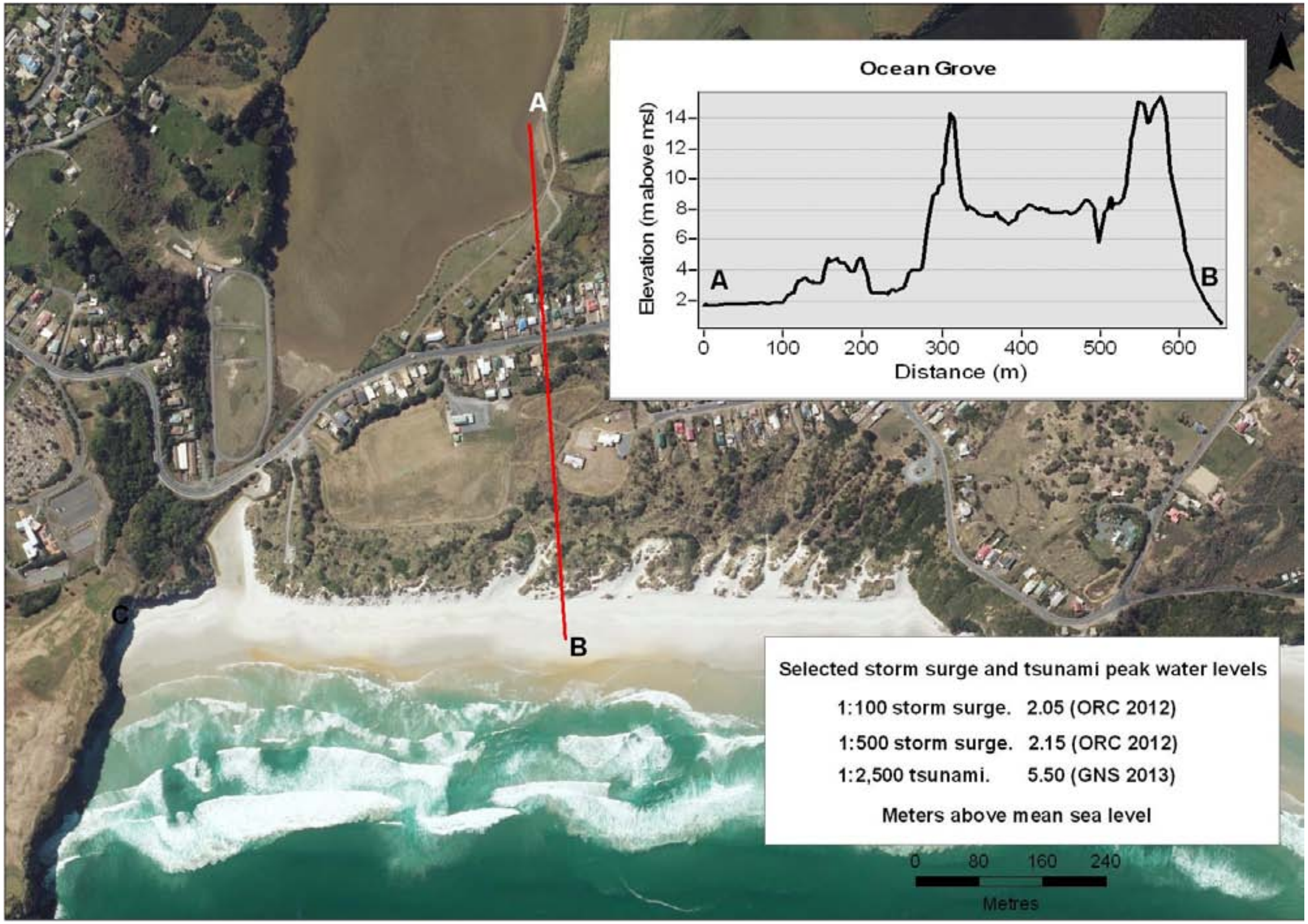

Figure 76 Cross section A-B through Ocean Grove, and peak water levels associated with selected high magnitude storm surge and tsunami events

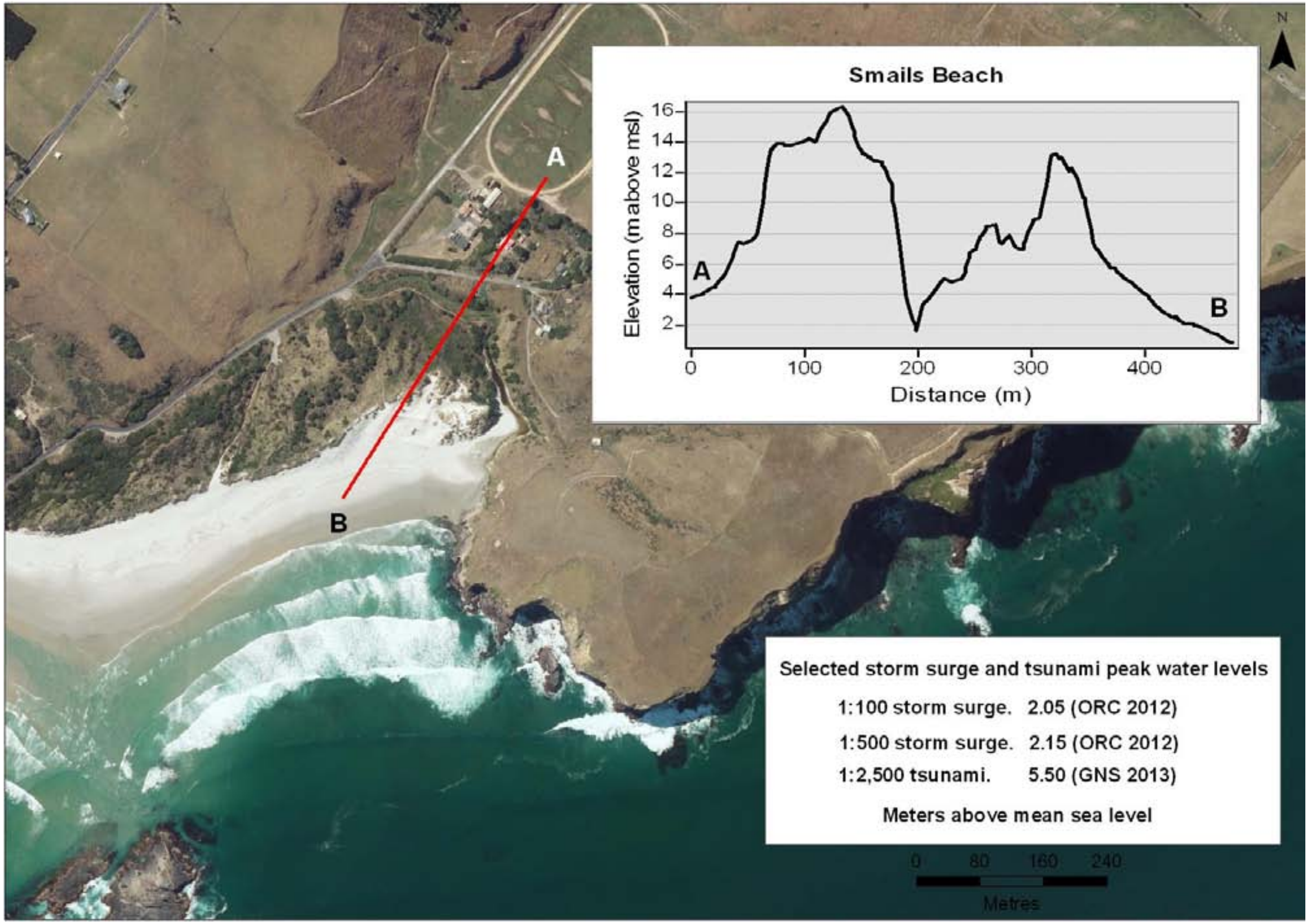

Figure 77 Cross section A-B through Smails Beach, and peak water levels associated with selected high magnitude storm surge and tsunami events

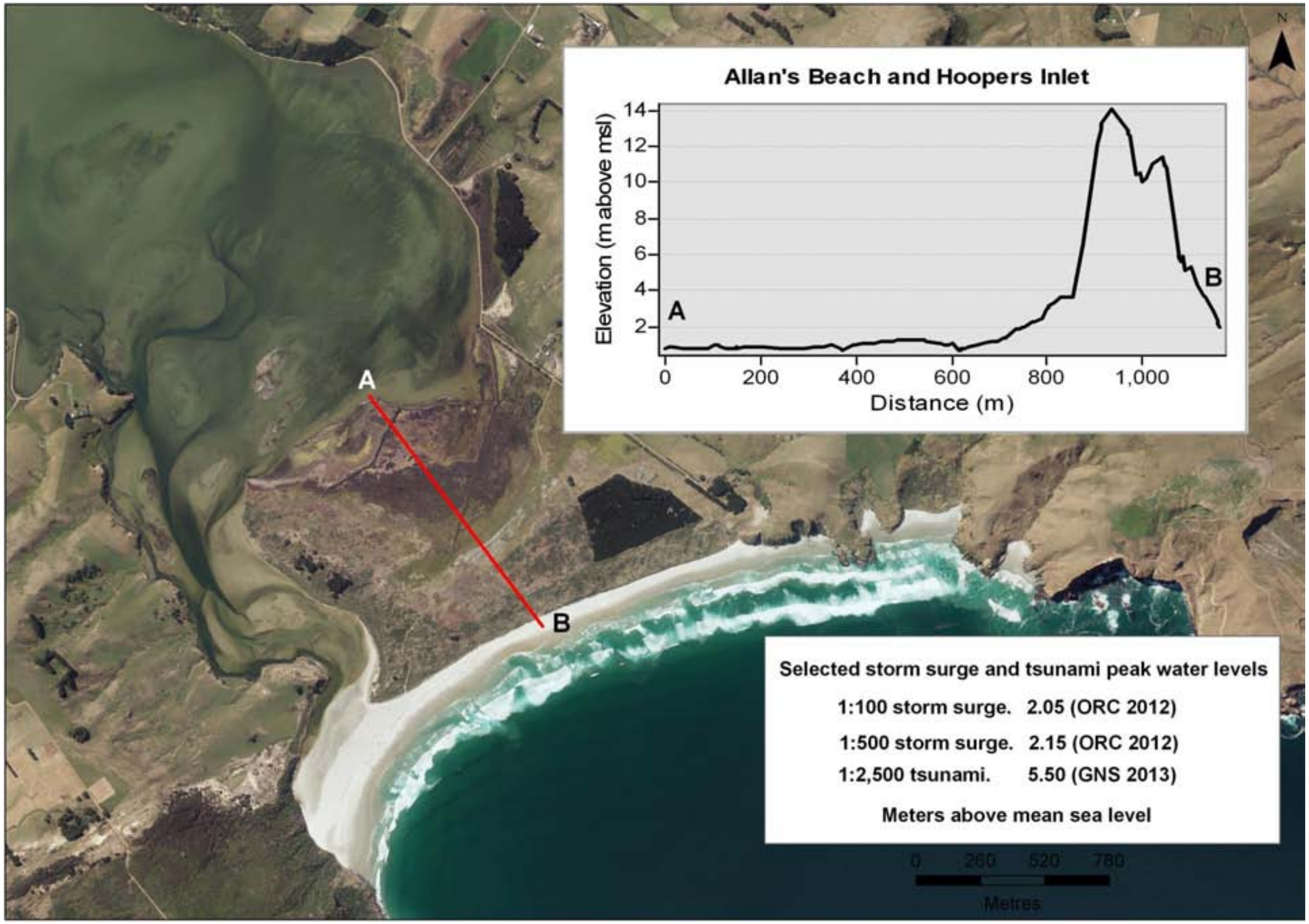

Figure 78 Cross section A-B through Allan's beach and Hoopers Inlet, and peak water levels associated with selected high magnitude storm surge and tsunami events

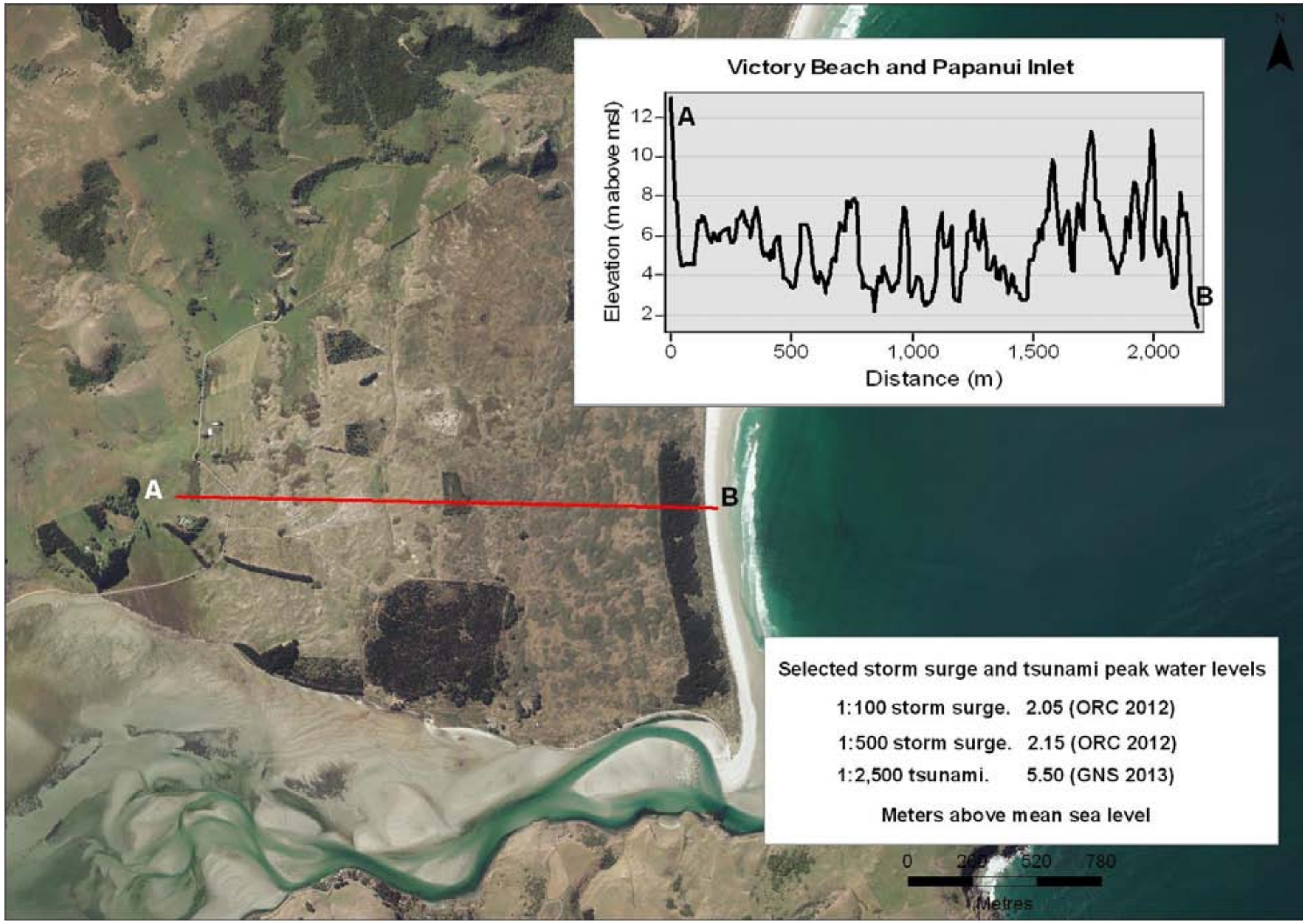

Figure 79 Cross section A-B through Victory Beach and Papanui Inlet, and peak water levels associated with selected high magnitude storm surge and tsunami events

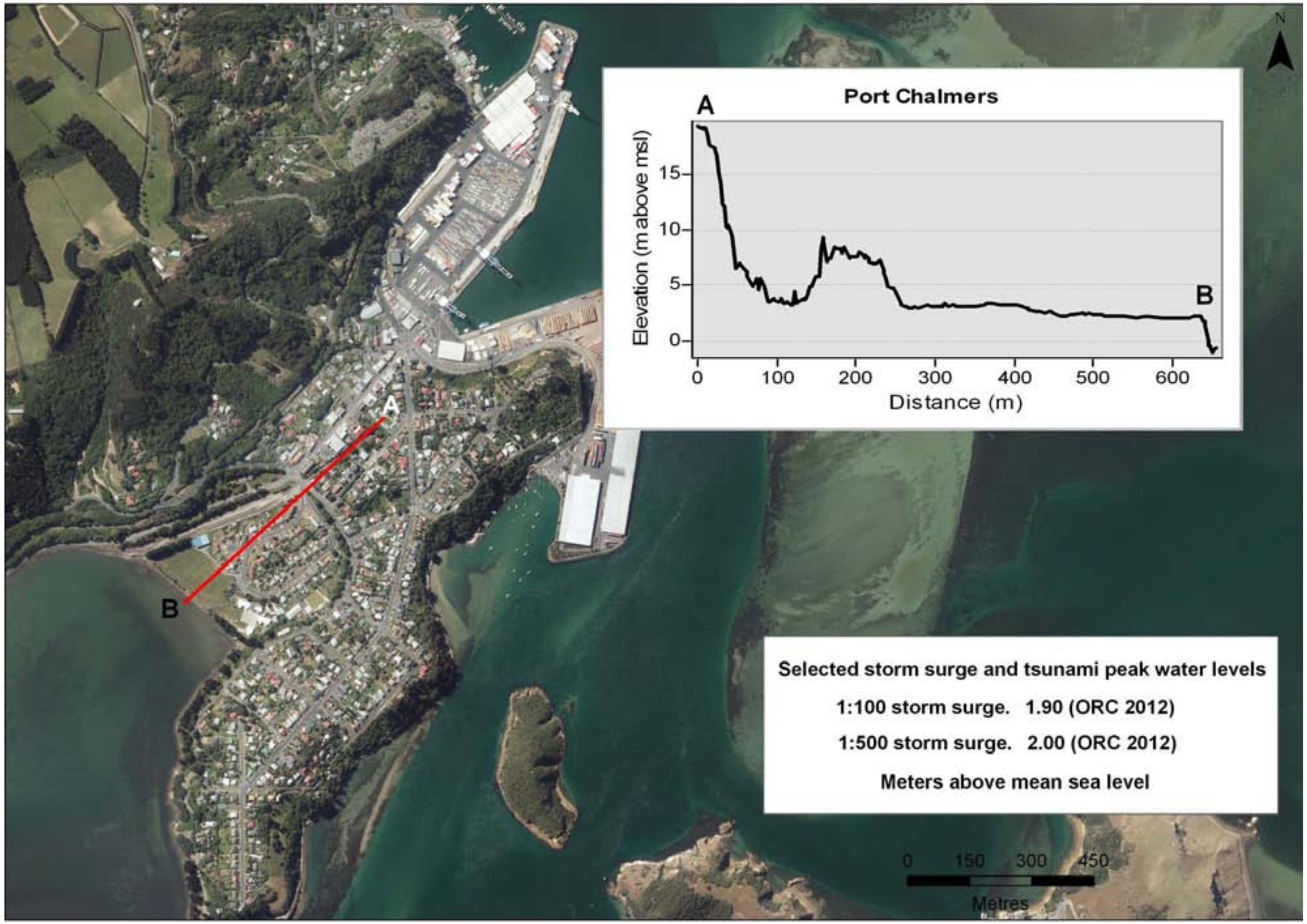

Figure 80 Cross section A-B through Port Chalmers, and peak water levels associated with selected high magnitude storm surge and tsunami events

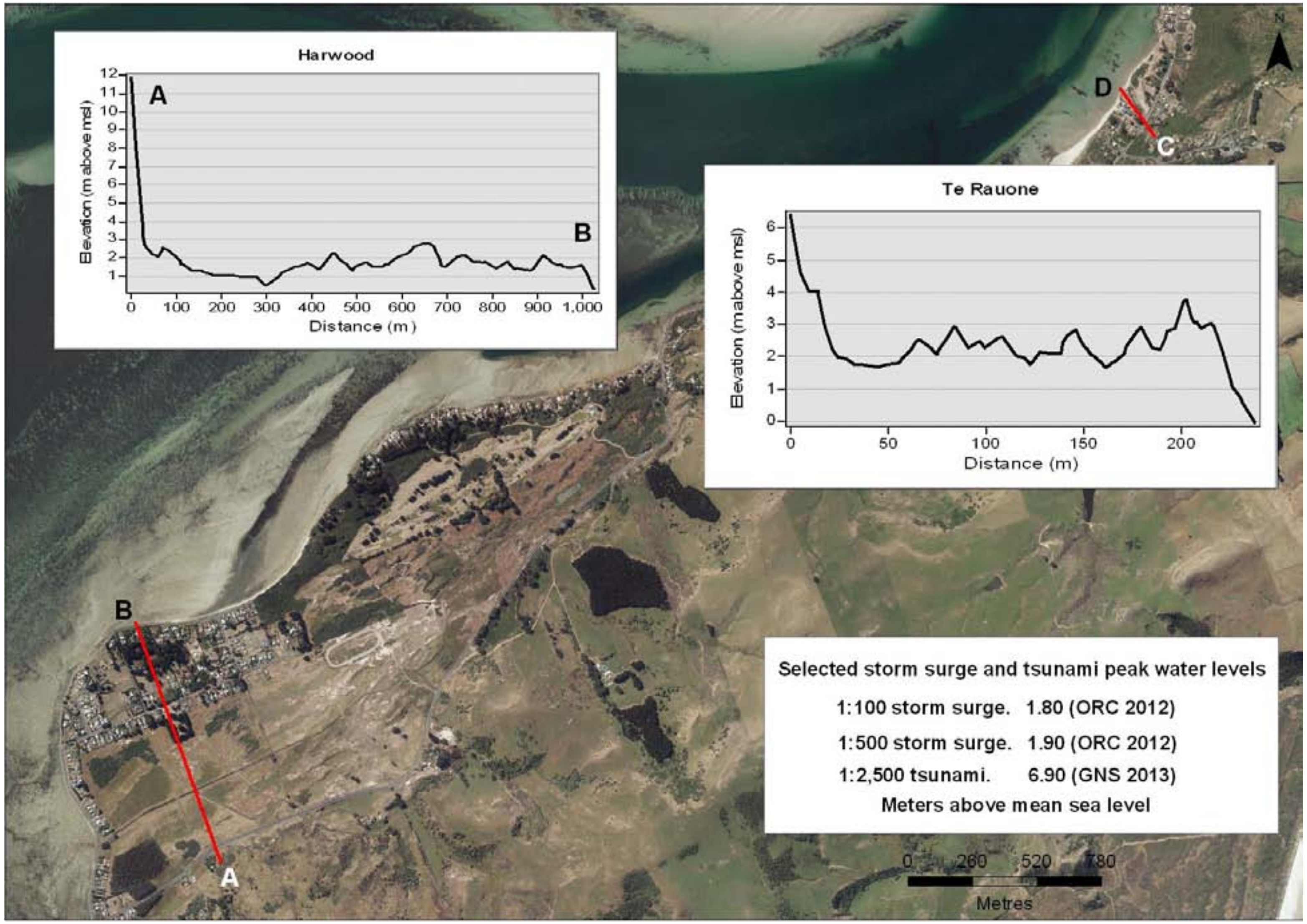

Figure 81 Cross section A-B through Harwood and C-D through Te Rauone, and peak water levels associated with selected high magnitude storm surge and tsunami events

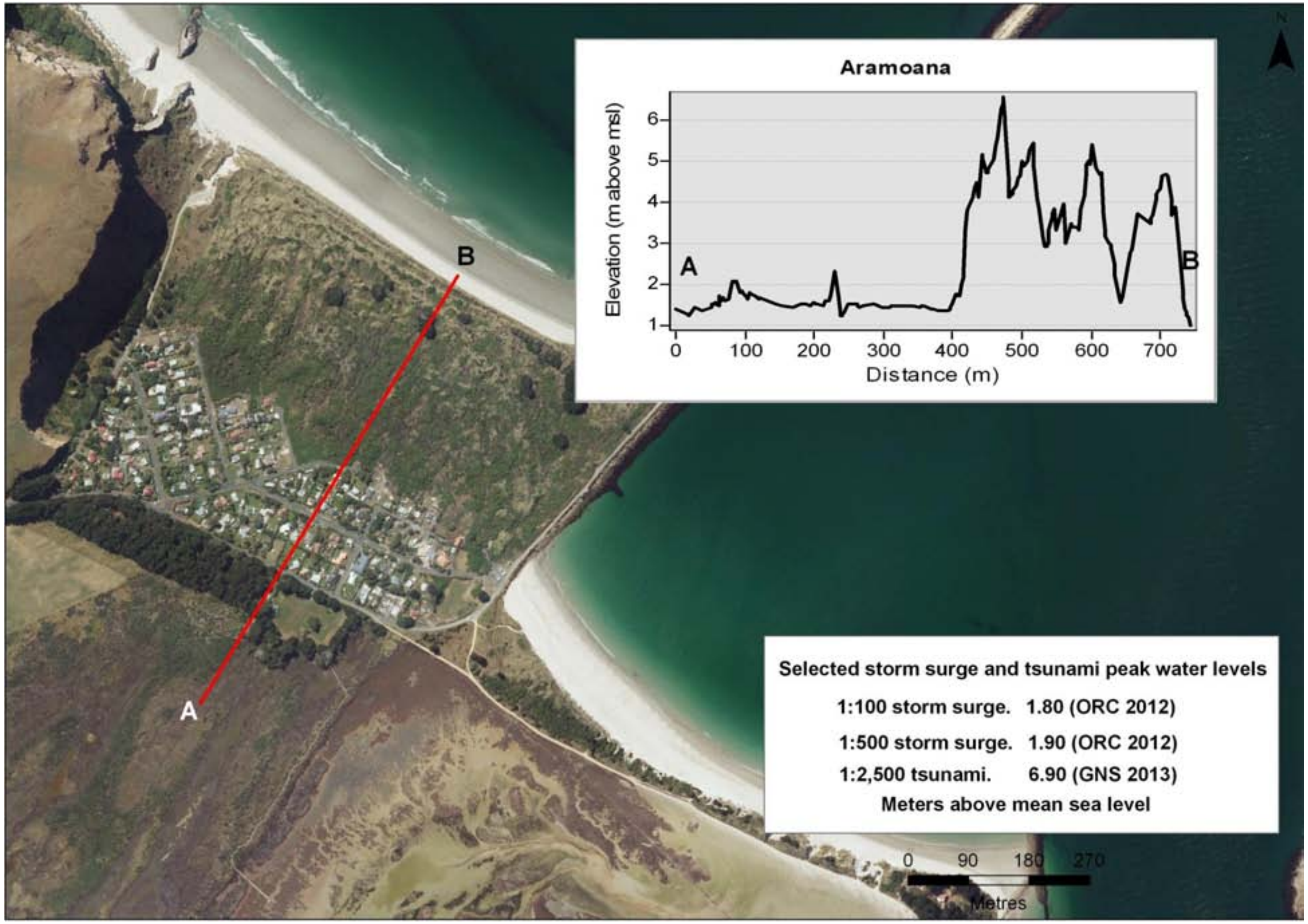

Figure 82 Cross section A-B through Aramoana, and peak water levels associated with selected high magnitude storm surge and tsunami events

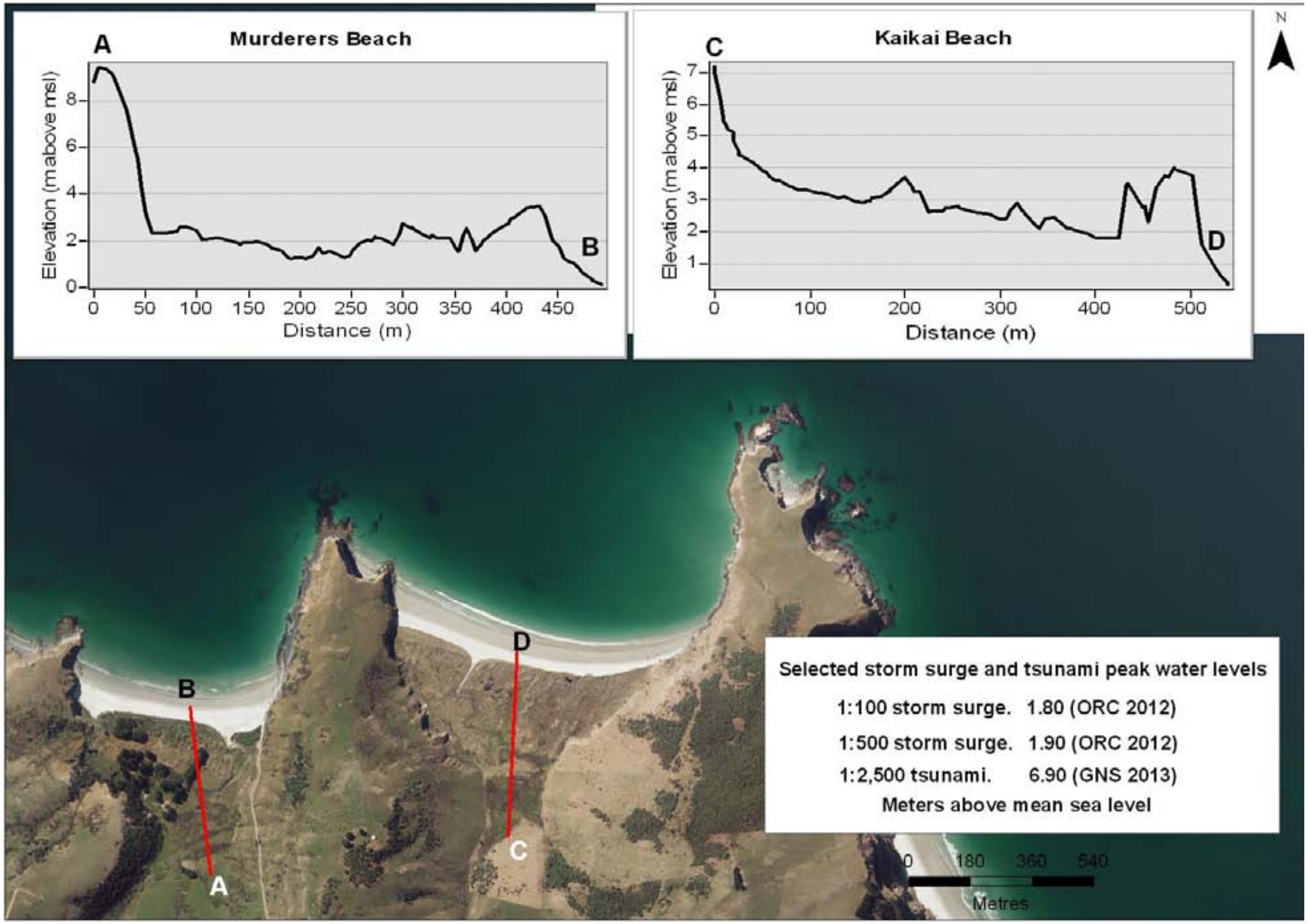

Figure 83 Cross sections A-B through Murdering Beach and C-D through Kaikai Beach, and peak water levels associated with selected high magnitude storm surge and tsunami events

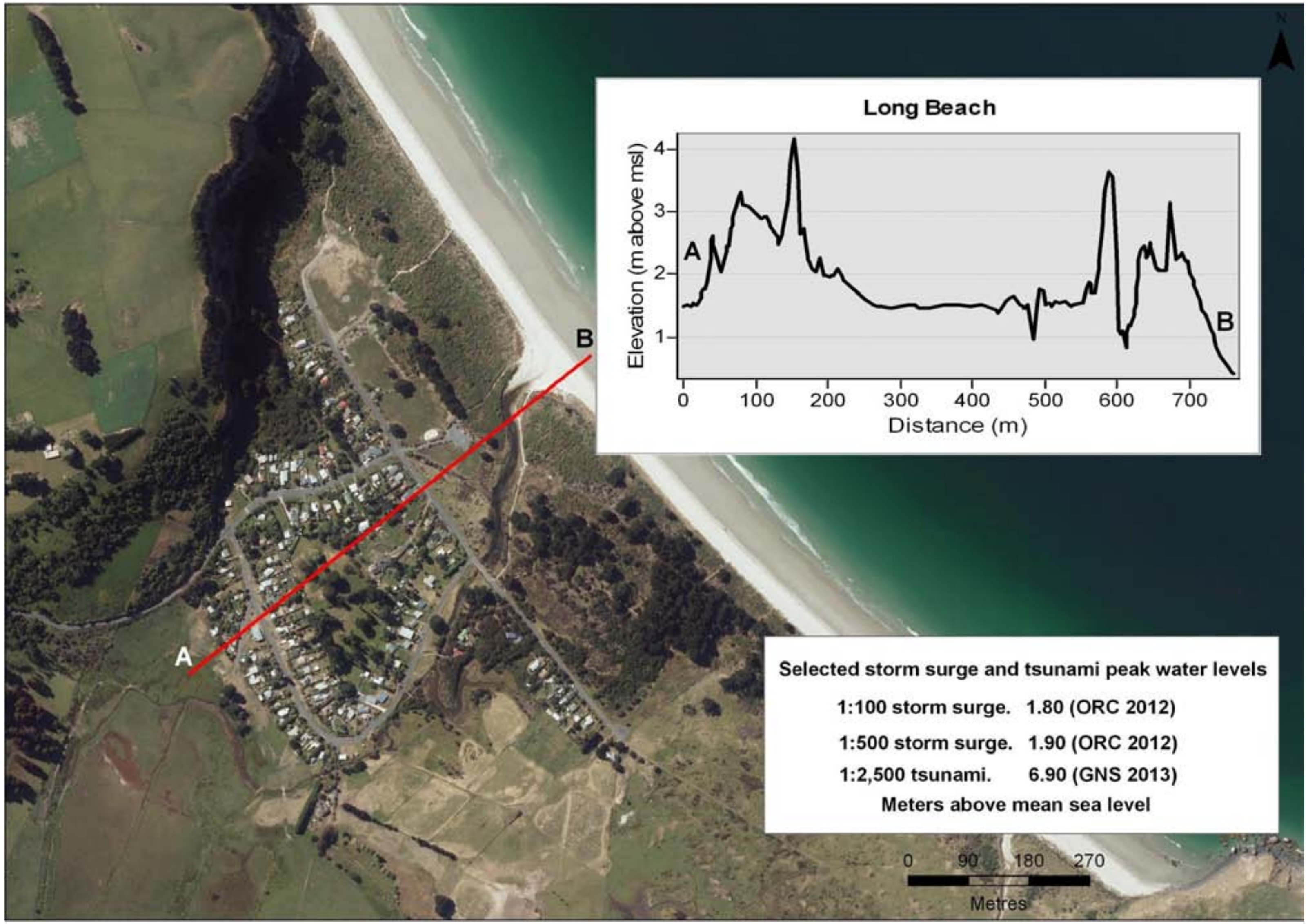

Figure 84 Cross section A-B through Long Beach, and peak water levels associated with selected high magnitude storm surge and tsunami events

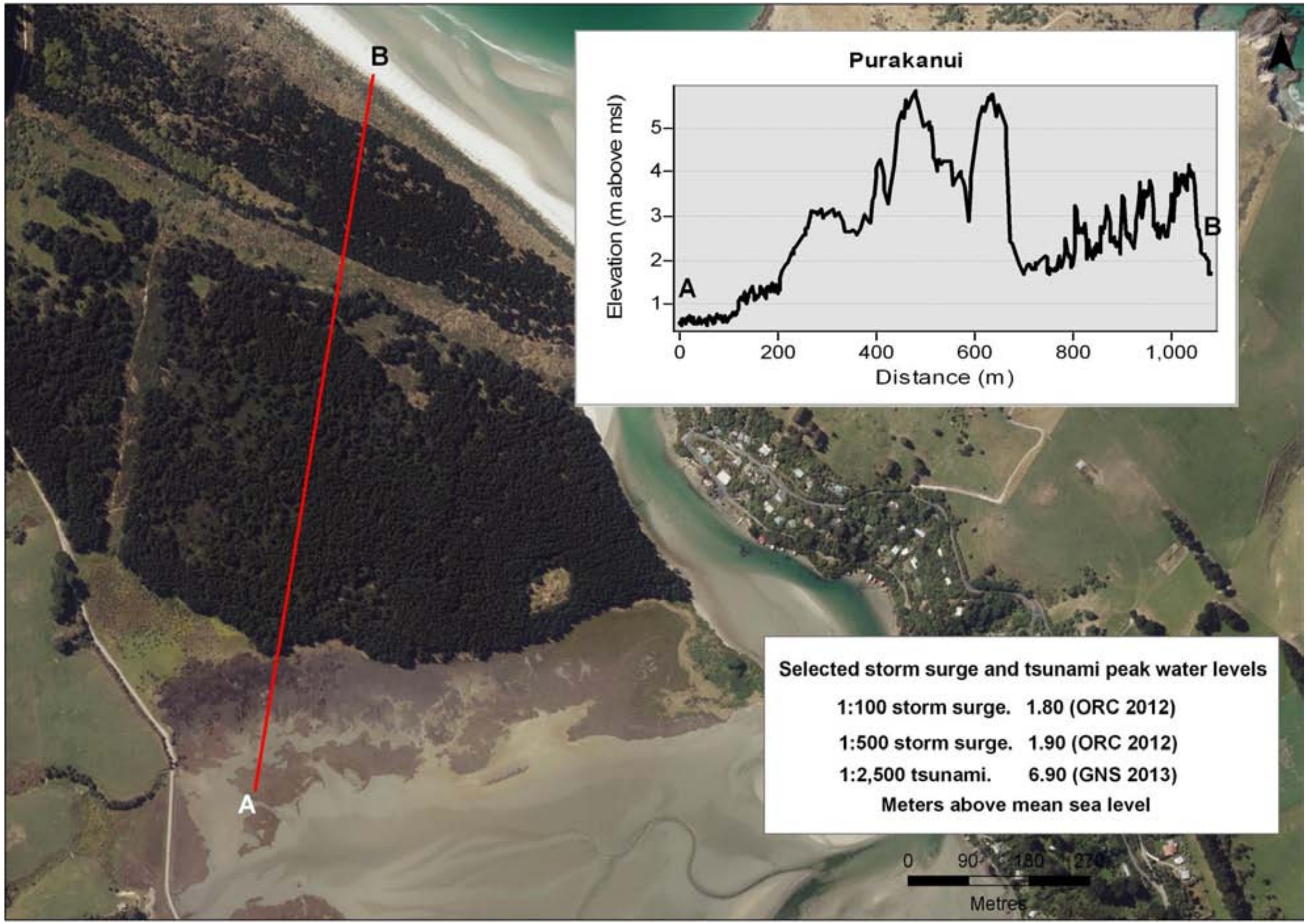

Figure 85 Cross section A-B through Purakanui, and peak water levels associated with selected high magnitude storm surge and tsunami events

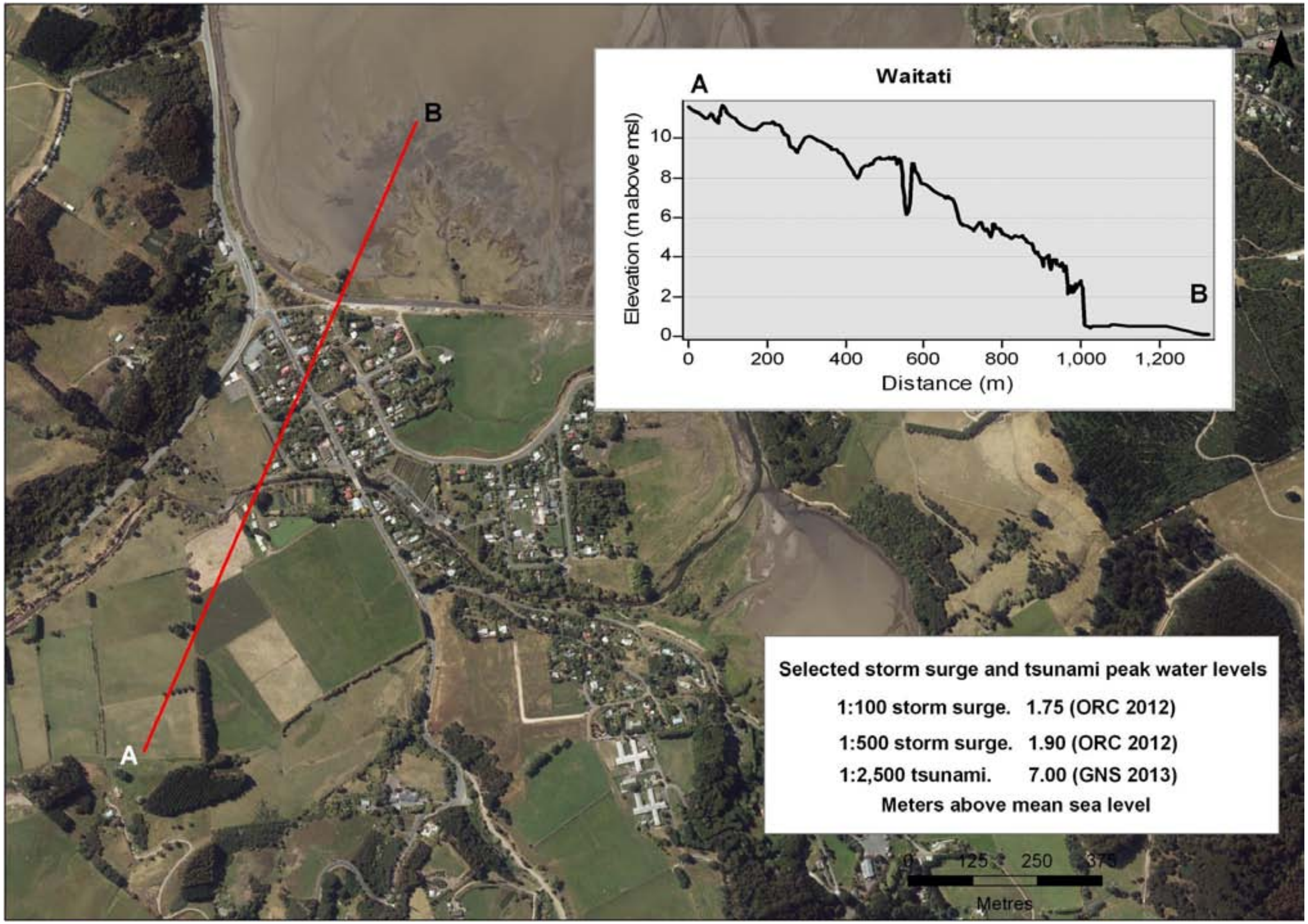

Figure 86 Cross section A-B through Waitati, and peak water levels associated with selected high magnitude storm surge and tsunami events

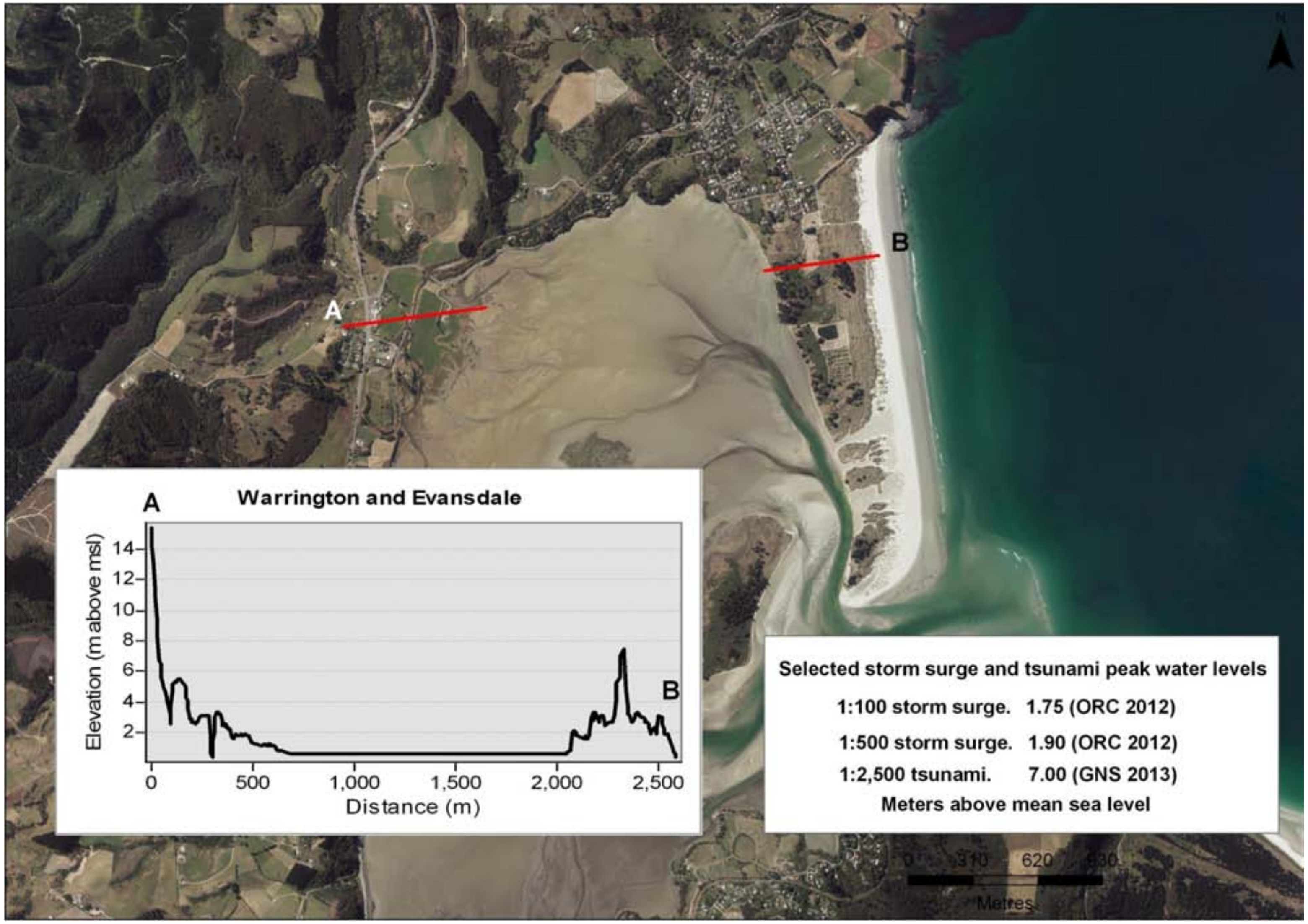

Figure 87 Cross section A-B through Warrington and Evansdale, and peak water levels associated with selected high magnitude storm surge and tsunami events

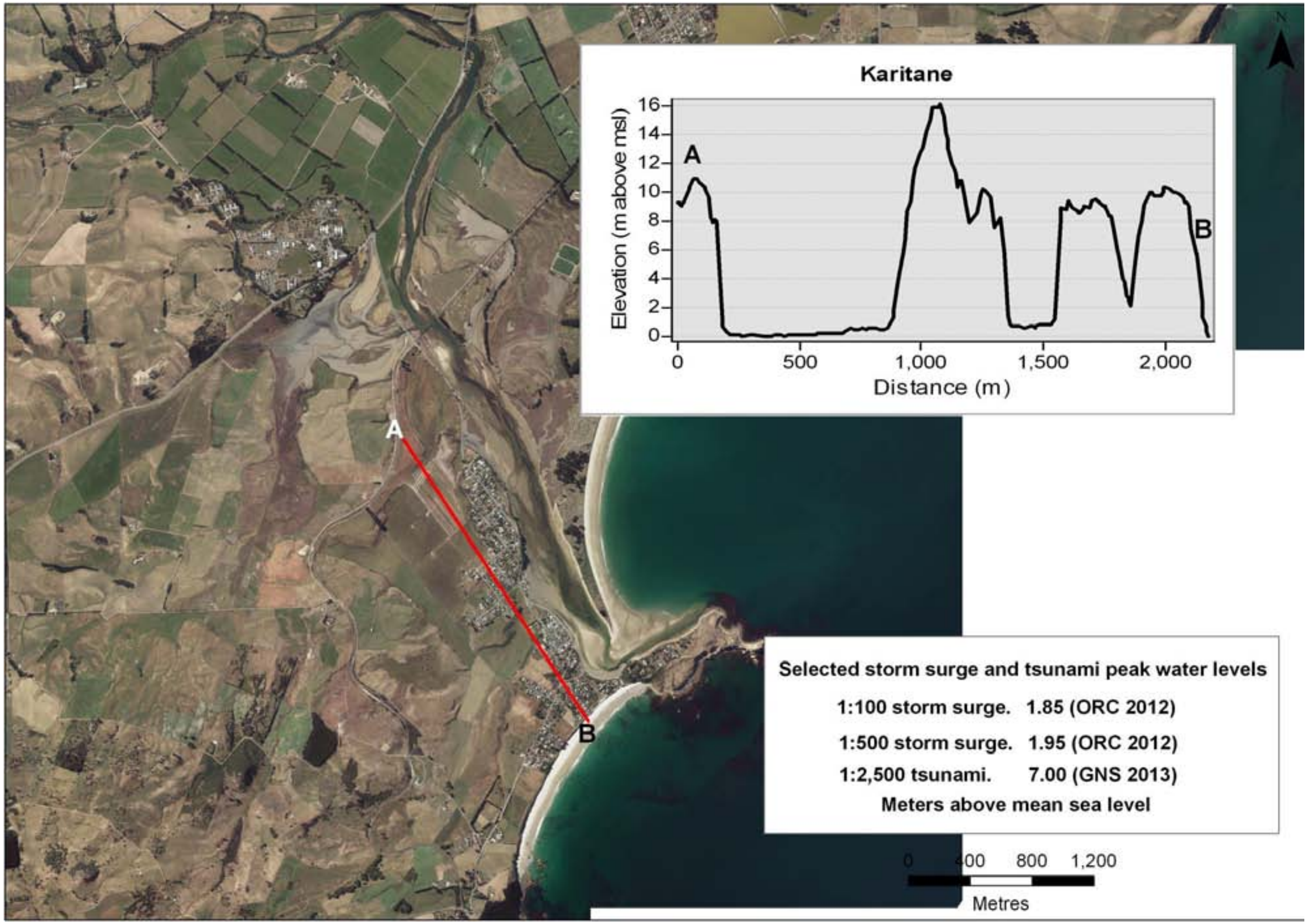

Figure 88 Cross section A-B through Karitane, and peak water levels associated with selected high magnitude storm surge and tsunami events

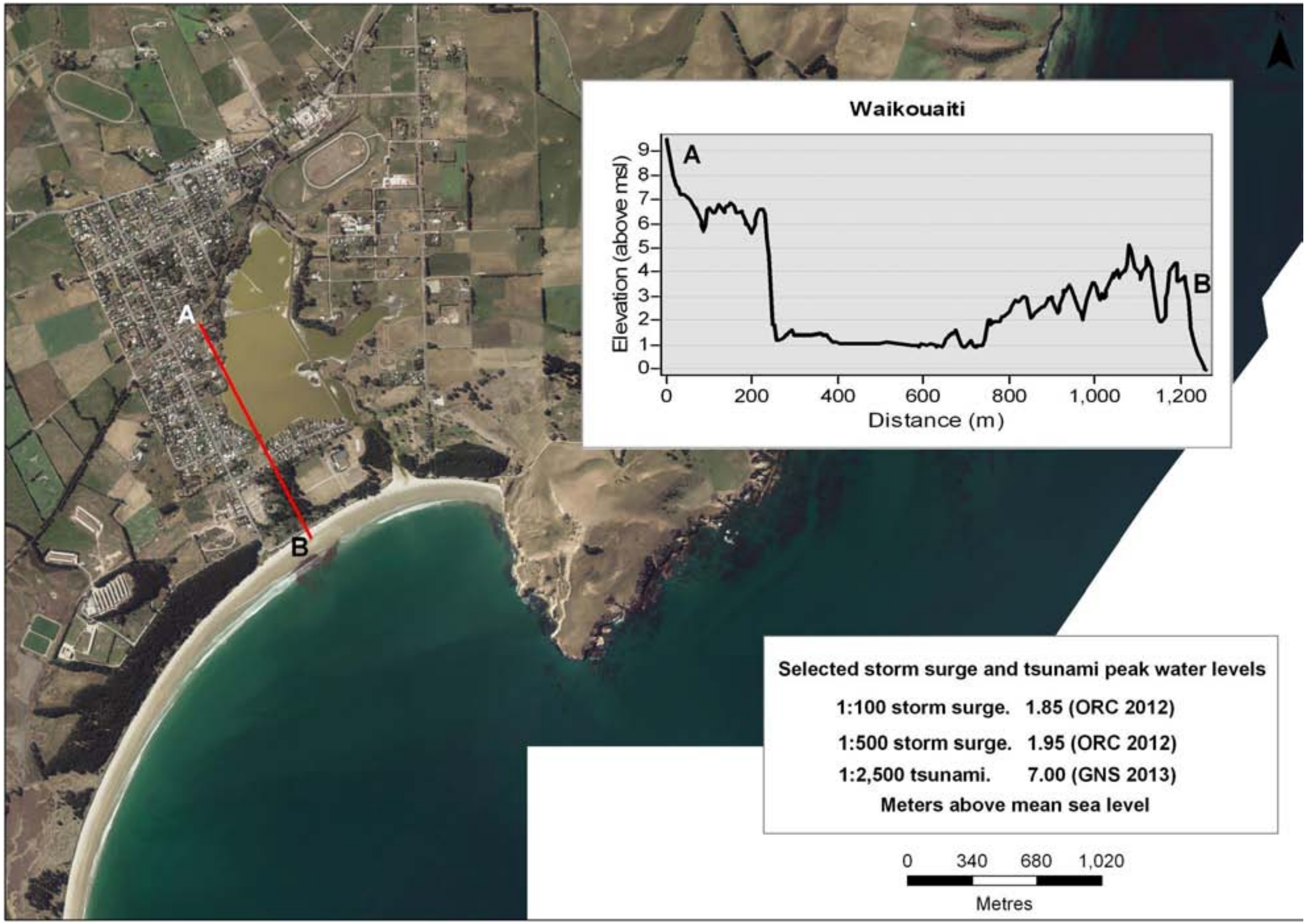

Figure 89 Cross section A-B through Waikouaiti, and peak water levels associated with selected high magnitude storm surge and tsunami events

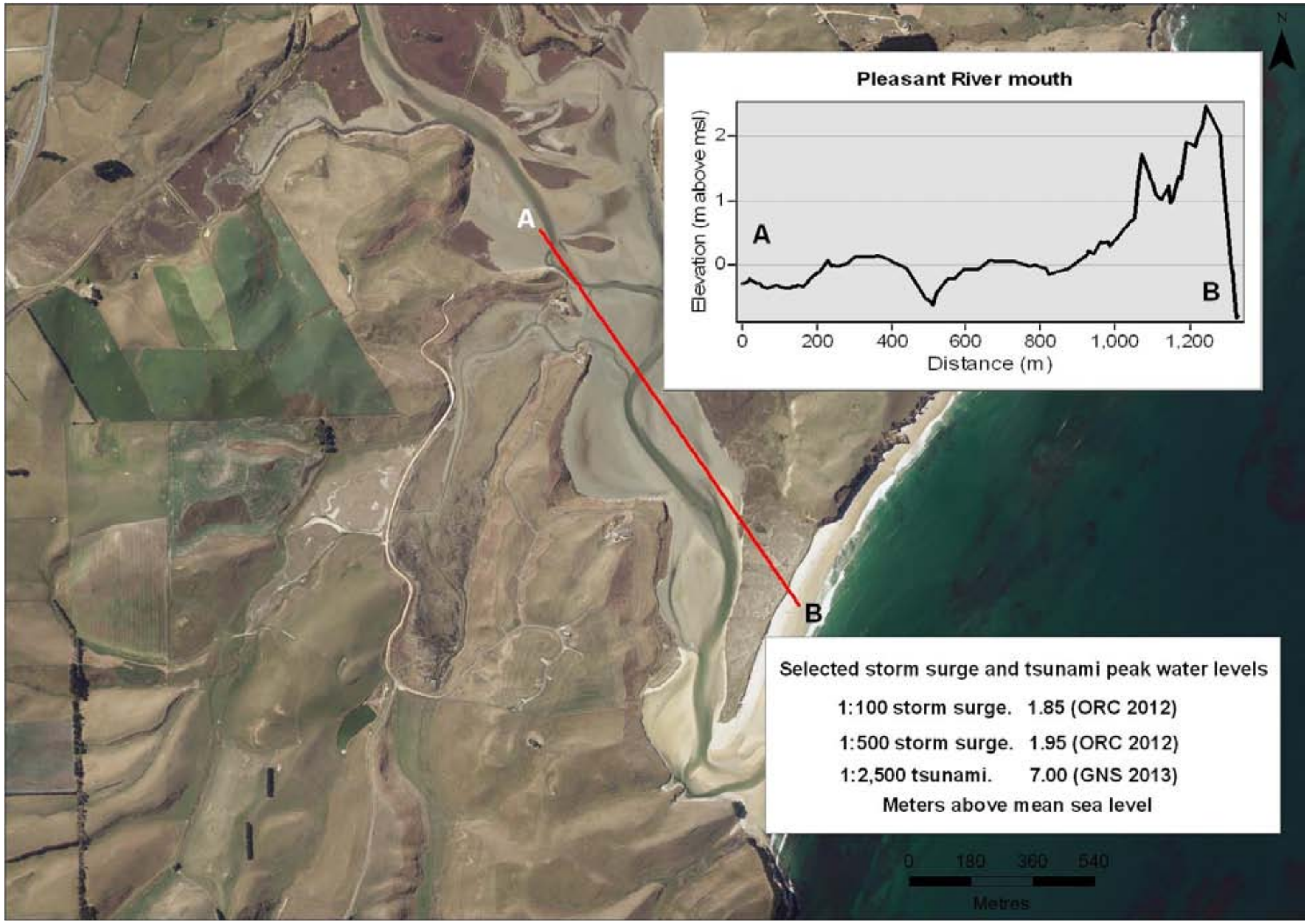

Figure 90 Cross section A-B through the Pleasant River mouth, and peak water levels associated with selected high magnitude storm surge and tsunami events