Review of Dunedin City District Plan – Natural Hazards

Coastal hazards of the Dunedin City District

Karitane and Waikouaiti Beach

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Part 1: Introduction

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 of 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).

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.

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.

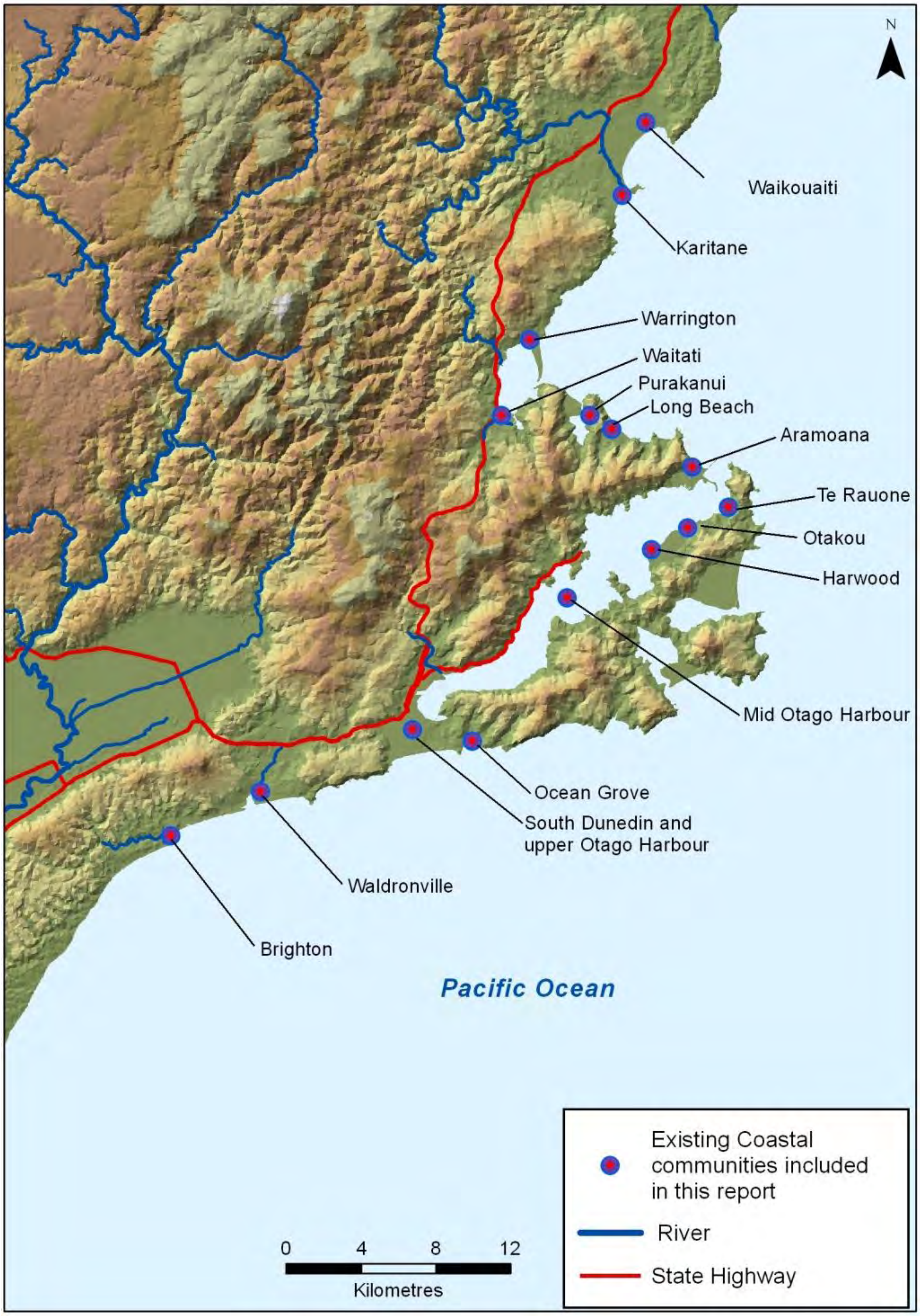

Figure 1. Dunedin City coastal communities included in this report

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 future development may possibly 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).

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]

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[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

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

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.

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

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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.

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 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).

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 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.

Brighton and Ocean View

Setting

Brighton and Ocean View are located on the south coast of the Dunedin District, approximately 16 km south 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.

Figure 2. Topography of Brighton and the surrounding area

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 to Figure 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)

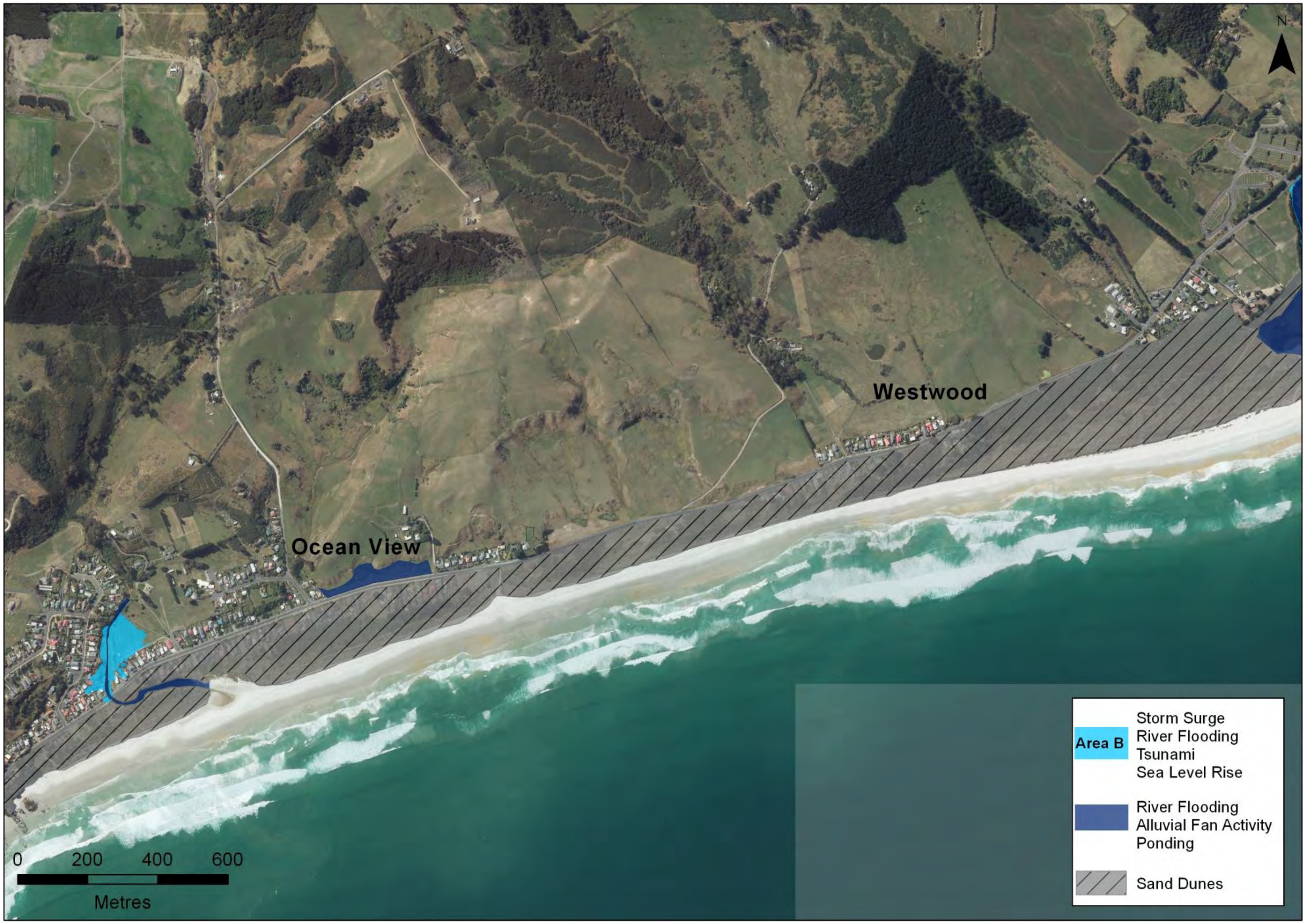

Figure 5. Mapped natural hazard areas in Brighton (north)

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)

Waldronville and Westwood

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.

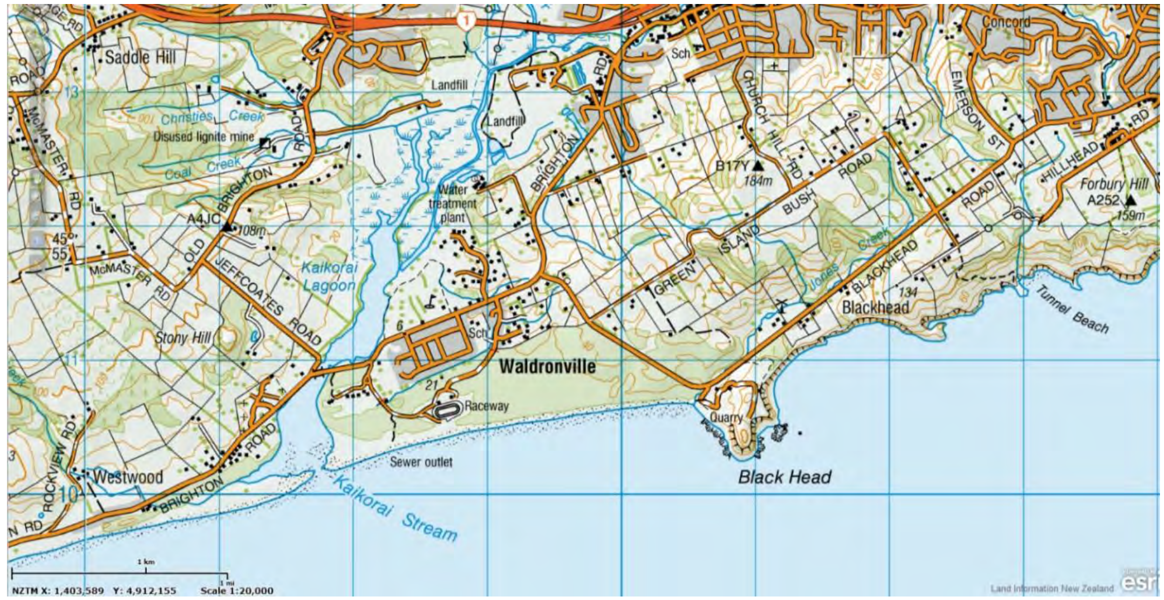

Figure 9. Topography of Waldronville and surrounding areas

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.

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

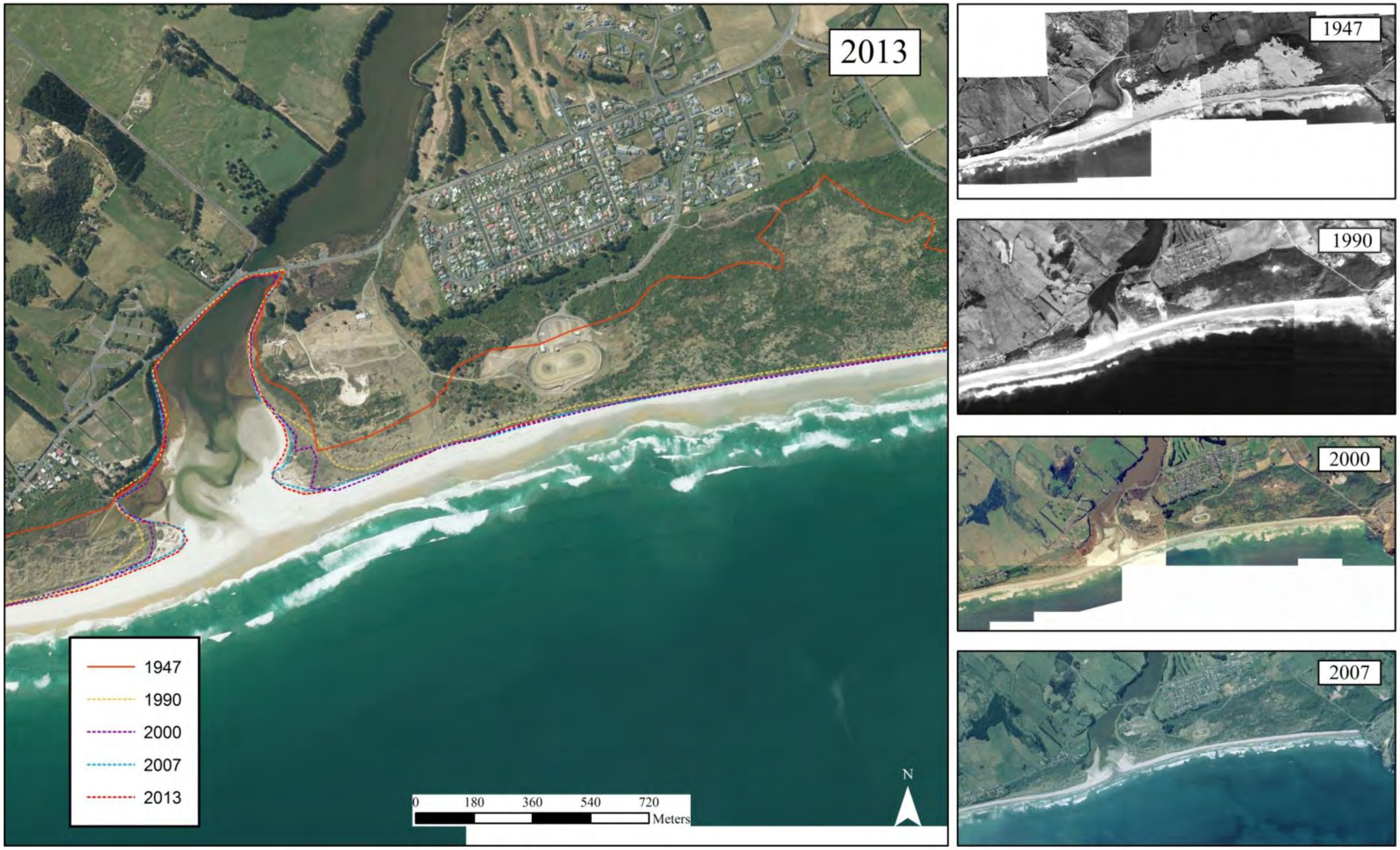

Figure 11. Main image: changes in the extent of the vegetated foredune near Waldronville between 1947 and 2013, overlaid on an aerial photograph collected in 2013. Smaller images: the historical aerial photos used to determine changes in the location of the vegetated foredune. (Source: DCC).

South Dunedin and the upper Otago Harbour

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.

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

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.

[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

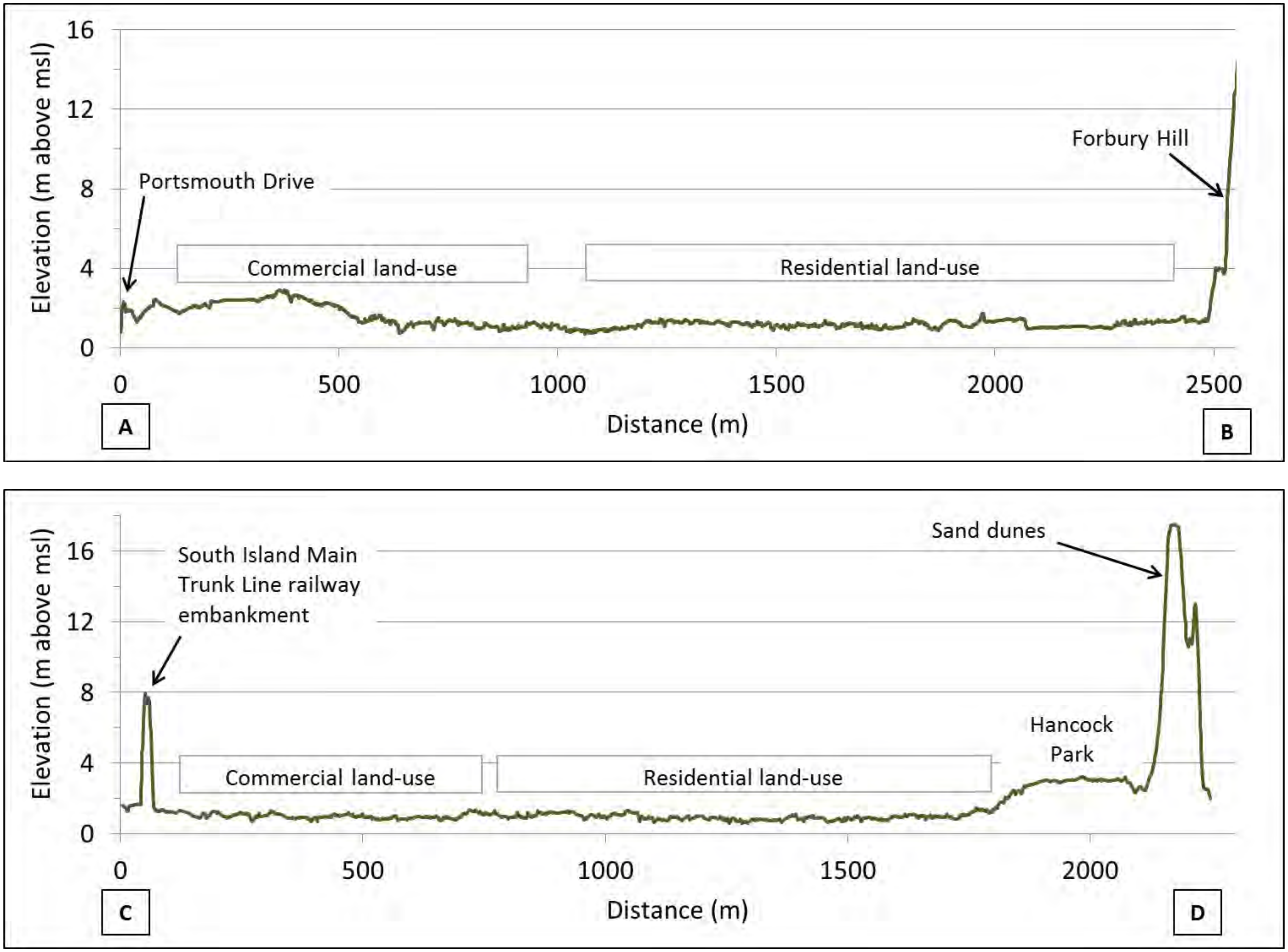

Figure 13. Cross-sections A-B and C-D (as shown on Figure 12) through South Dunedin

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 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.

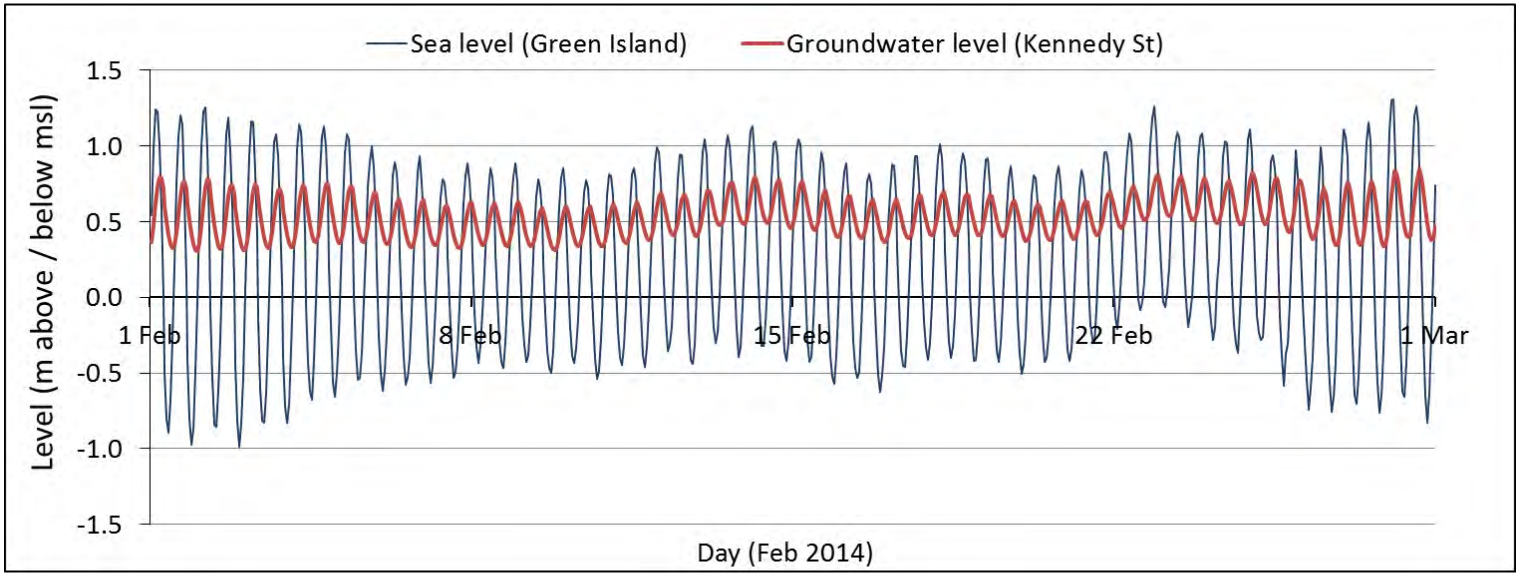

Figure 14. Graph showing sea level at Green Island and groundwater level at Kennedy Street, during February 2014. The typical ground level at the Kennedy Street bore is 1.4m above msl (Figure 12).

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 groundwater level 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.

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.

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[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).

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’.

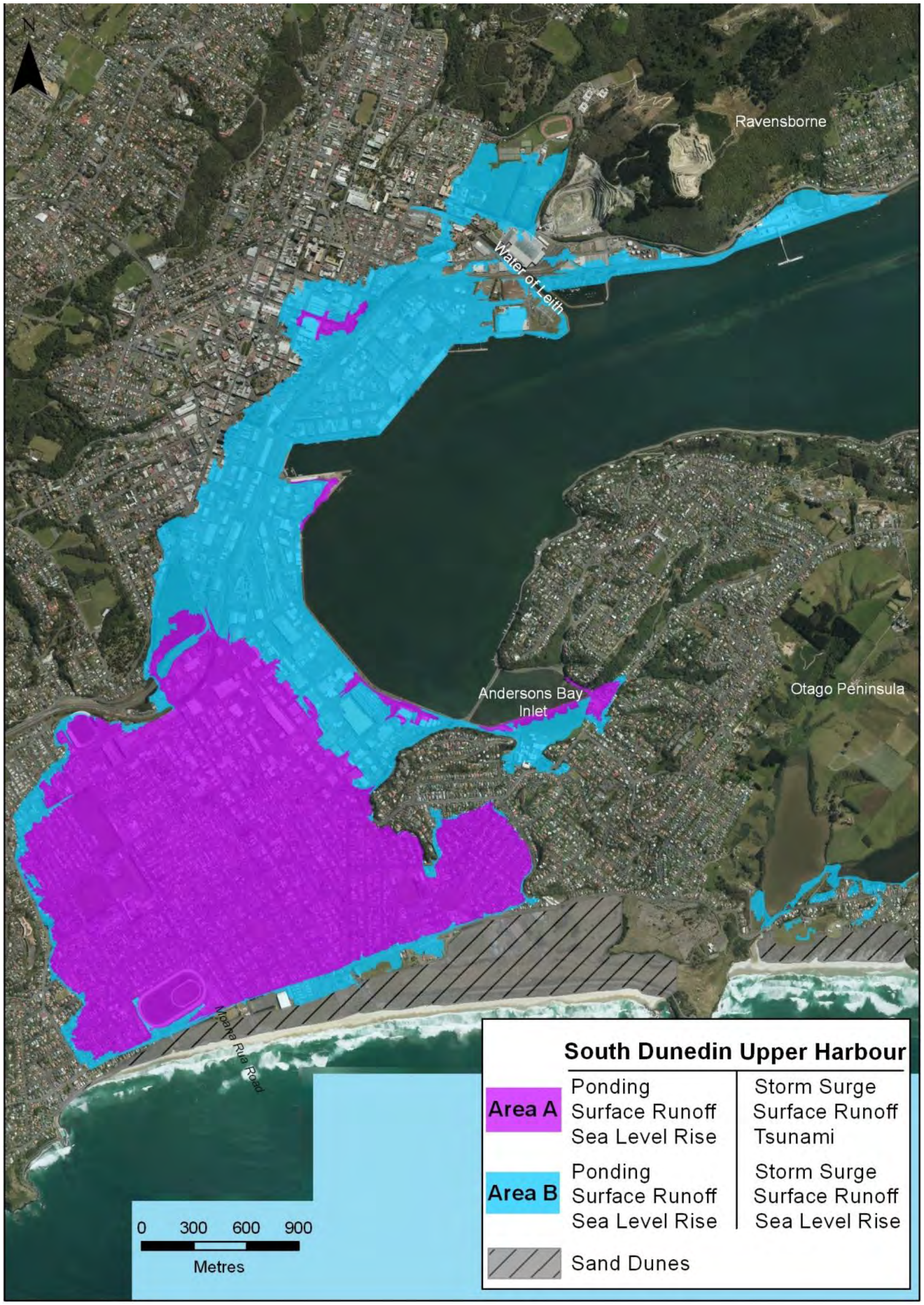

Figure 15: Mapped natural hazard areas in South Dunedin and around the upper Otago Harbour

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, underground 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.)

Ocean Grove

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.

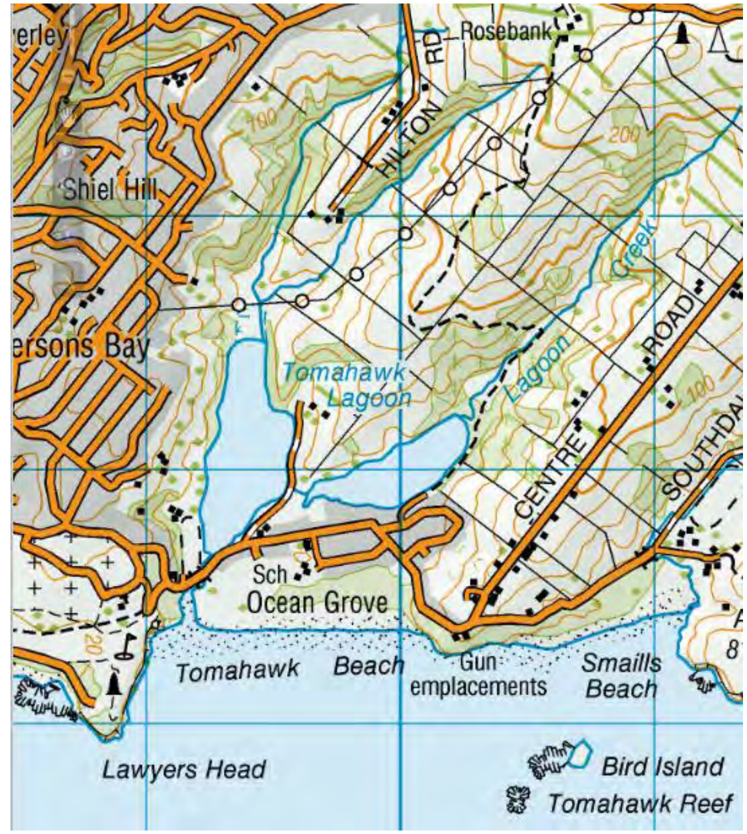

Figure 20. Topography of Ocean Grove and the surrounding area

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 4 and Figure 5.

❖ 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.

Ground subsidence or liquefaction as a result of seismic shaking has the potential to damage roads, power poles, 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

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 future development may possibly occur in the future. 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 24 to Figure 27.

❖ Low-lying land

Area A: Land which is below the height identified as the 1:100 year storm surge level (Table 1).

Area B: Land which is below the combined height of the 1:100 year storm surge level (Table 1), plus an additional 1m.

Both these areas may also be vulnerable to other hazards such as tsunami, including flooding and land instability, although these are not assessed in this report. As sea level rises, the likelihood that inundation resulting from these hazards will affect these areas will increase.

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

❖ Other Coastal Areas

Raised coastal terraces: A number of raised coastal terrace and dunes are located within these bays and inlets. 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 future changes in sea level or large storm events.

Figure 24. Mapped coastal hazard areas at Smaill's Beach

Figure 25. Mapped coastal hazard areas at Boulder Beach and Sandfly Bay

Figure 26. Mapped coastal hazard areas at Allan’s Beach and Hoopers Inlet

Figure 27. Mapped coastal hazard areas at Victory Beach and Papanui Inlet

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

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).

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.

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

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.

Harwood, Otakou and Te Rauone

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).

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

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 any 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 Harrington 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

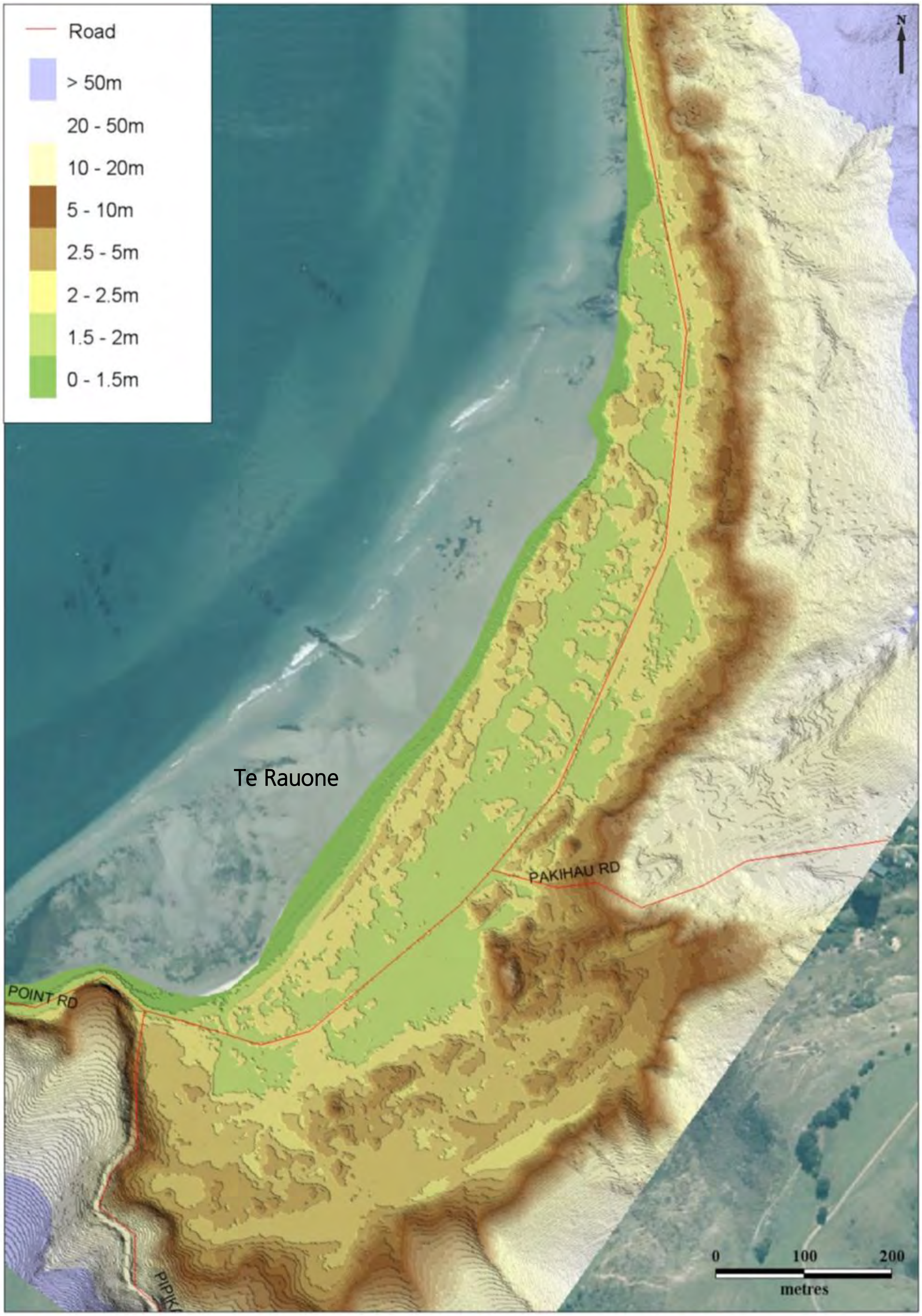

Figure 33. Elevation map of the Te Rauone area

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 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

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[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.

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 are considered very sensitive to stability factors and development on moderately to steeply sloping land needs to be subject to thorough geomorphic and geotechnical investigations. 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 center 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.

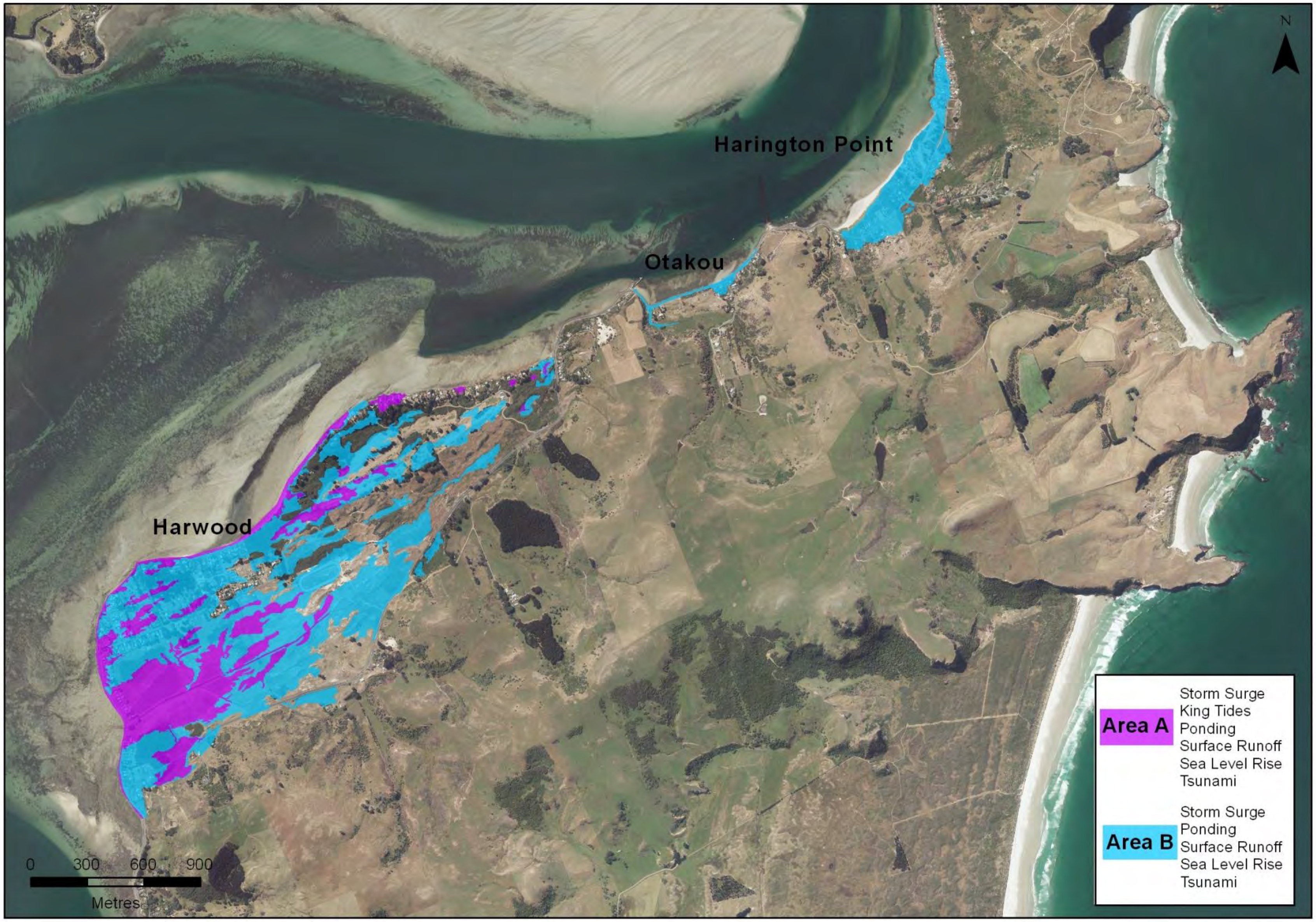

Figure 35. Mapped natural hazard areas in Harwood, Otakou and Te Rauone

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

Aramoana and Te Ngaru

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.

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

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 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.

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). Figure 41 shows that the dunes extended seaward between 1956 and 2013.
- 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 wetlands 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.

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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