Natural Hazards on
the Taieri Plains, Otago

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

ISBN: 978-0-478-37658-6

Published March 2013

Prepared by: Kirsty O'Sullivan, natural hazards analyst
Michael Goldsmith, manager natural hazards
Gavin Palmer, director environmental engineering and natural hazards

Cover images

Both cover photos are from the June 1980 floods. The first image is the Taieri River at Outram Bridge, and the second is the Taieri Plain, with the Dunedin Airport in the foreground.

Executive summary

The Taieri Plains is a low-lying alluvium-filled basin, approximately 210km^2 in size. Bound to the north and south by an extensive fault system, it is characterised by gentle sloping topography, which grades from an elevation of about 40m in the east, to below mean sea level in the west. At its lowest point (excluding drains and ditches), it lies about 1.5m below mean sea level, and has three significant watercourses crossing it: the Taieri River, Silver Stream and the Waipori River. Lakes Waipori and Waihola mark the plain's western boundary and have a regulating effect on drainage for the western part of the plains.

The Taieri Plains has a complex natural-hazard setting, influenced by the combination of the natural processes that have helped shape the basin in which the plain rests, and the land uses that have developed since the mid-19th century. The natural setting of the plains exposes the area to flooding, alluvial-fan hazard, landslides, seismic activity and tsunamis. The level of risk that these events present varies greatly across the plains, depending on the nature and scale of the particular hazard and the nature and vulnerability of the features exposed to that hazard.

The area is one of the largest expanses of flat land close to Dunedin city, and is mainly used for agricultural purposes, an activity that was established with the arrival of European settlers to the area in the mid-1800s. A large residential community is located in and around Mosgiel, with a number of smaller communities established at Outram, Allanton and North Taieri. Identified in the early settlement plans of Otago, each of these communities are located beyond the observed-flood extents of the early 19th century, indicating an early awareness of flood hazard on the Taieri Plains.

Flooding has been a fact of life for those living on the Taieri Plains, with a number of significant floods occurring since early European settlement in the mid-1800s. Modification of the flood hazard, through extensive engineering works, has reduced the incidence of flooding; however, a residual flood risk still exists.

Previous assessments of natural hazards on the Taieri Plains have generally focused on the mitigation and subsequent modification of flood risk through the engineering works of the Lower Taieri Flood Protection Scheme and the schemes that it subsumed. This report combines information about residual-flood risks with alluvial-fan, seismic, landslide and tsunami hazard information. A description of the social and environmental settings, which together create the hazardscape of the Taieri Plains, is also provided.

The report also provides a detailed description of how the flood hazard varies across the Taieri Plains. This description is a refinement and extension of that presented in a report prepared jointly with Dunedin City Council in 2006 (report titled '*Mosgiel Flood Event 25/26 April 2006 and Future Action')*.

Spatial and temporal changes in extreme rainfall (storm) events have been analysed, using rainfall records from the lower Taieri River catchment. These records show that there is localised variability in extreme rainfall patterns, and that the northern end of the Taieri Plains (including within the Silver Stream catchment) has experienced an increase in the intensity and frequency of extreme rainfall events since the 1960s.

The risk associated with interactions between different types of hazard is explained. In particular, the effect of a fault rupture or severe ground shaking (associated with a high

magnitude earthquake) on flood risk is considered. Information about the possible effects of a predicted warmer climate and higher sea level is also presented.

Decisions on land use need to take the complex hazard setting of the Taieri Plains into consideration to ensure that activities are compatible with the hazard exposure and the residual risk across the range of natural hazards. This report is intended to help inform those decisions and other risk-reduction initiatives.

Table of contents

1. Introduction

The Taieri Plains is a low-lying, relatively flat expanse of land located to the west of Dunedin city (Figure 1.1), covering an area of 21,000 hectares. Used for rural, residential, commercial and industrial activities, the Taieri Plains is home to about 15,000 people, mostly clustered in and around the urban area of Mosgiel. The main land use is agriculture, an activity that was established with the arrival of the first European settlers in the mid-1800s. The land is highly productive, with fertile soils providing ideal conditions for crop and pasture growth. Dunedin International Airport is also nestled at the centre of the plains.

Figure 1.1 The Taieri Plains (looking south from Flagstaff).

A number of small rural and rural-residential communities are located at the edges of the plains (Figure 1.2). The proximity of the plains to Dunedin city and the flat landscape have contributed to the area's popularity for rural-residential development. Census data (1996 to 2006) show that the population on the northern side of the Silver Stream (North Taieri) has increased from 530 in 1996 to 698 in 2006 (~25% increase). During the same period, Mosgiel experienced a population increase of about 504 (a 5% increase), compared to an increase of about 0.5% in the wider Dunedin City district.

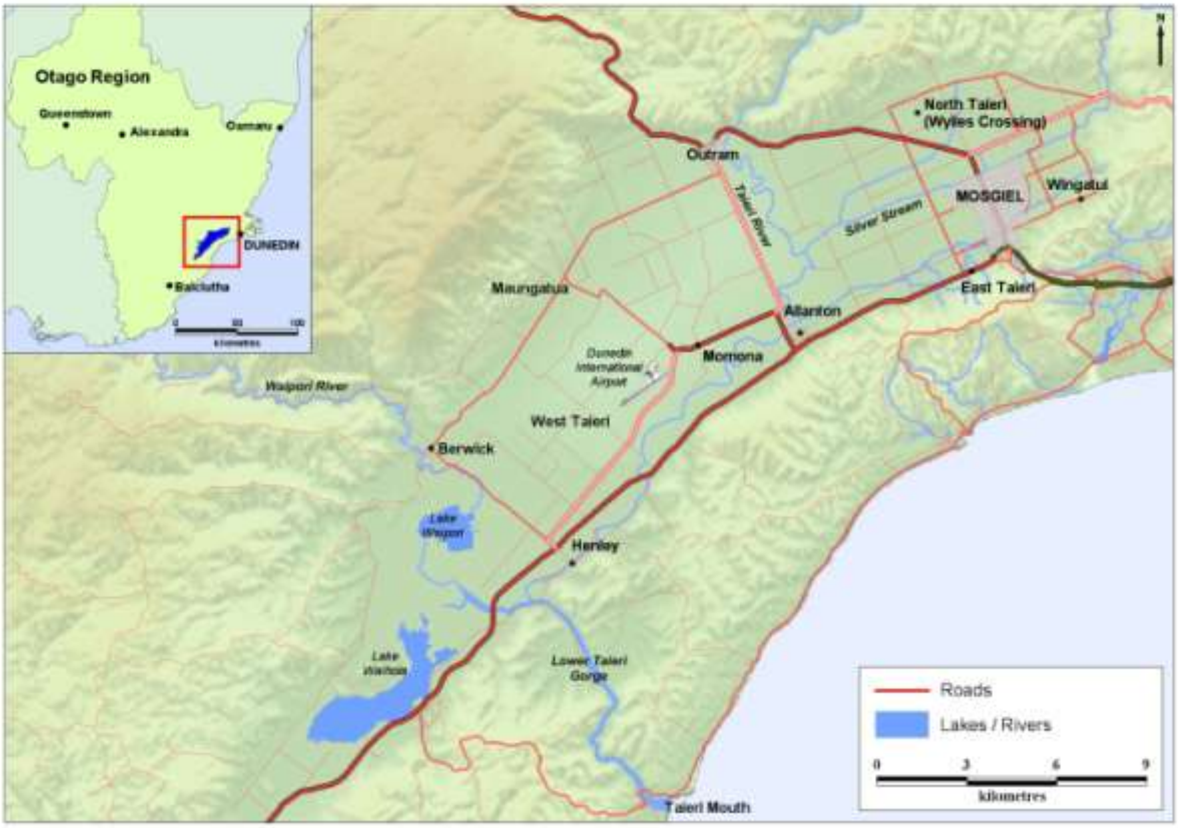

Figure 1.2 Communities on the Taieri Plains.

The alluvium-filled basin that makes up the Taieri Plains is bound by an extensive fault system to the north and south. The gentle topography, which grades from about 40m in the east to below sea level in the west, provides the largest expanse of flat land near Dunedin city. The Taieri River, the second longest river in Otago and fifth longest in New Zealand, meanders across the Taieri Plains before flowing out to sea at Taieri Mouth, via the Lower Taieri Gorge. The Taieri River is tidal at least as far upstream as Allanton, with lakes Waihola and Waipori also influenced by the rise and fall of the tide. Two major tributaries of the Taieri River also cross the Taieri Plains: the Silver Stream, from the north-east, and the Waipori River, from the south-west.

The Taieri Plains and environs have a complex-hazard setting that has shaped it and affects how it is used. Possible hazards include the plain's exposure to flood inundation from various sources, seismic activity and, to a lesser degree, landslides, alluvial-fan and tsunami hazard. Other weather-related features, such as strong winds and heavy snow (Figure 1.3), also present hazards, although these are not discussed in detail in this report. The level of risk these hazards present varies across the plains, depending on the nature and scale of the hazard and the nature and vulnerability of the features exposed to that hazard. Therefore, decisions on land use need to take these hazards and their variability into account to ensure that human activities are compatible with the hazard exposure. This report is intended to help inform those decisions and other risk-reduction initiatives.

Earlier reports about natural hazards on the Taieri Plains have tended to focus on flood-hazard mitigation and the subsequent modification of flood hazard, usually through engineering works, and often associated with a particular locality or issue. This report combines information about residual-flood risks (the part of the risk that is not managed), and attempts to assess the residual risks of alluvial-fan, seismic, landslide and tsunami on the plain in general.

The following sections describe the social and natural setting of the Taieri Plains and the wider Taieri River catchment, and give an overview of how the flood hazard has been modified (but not eliminated) through engineering works over the past 150 years. The report then goes on to outline the risk of flooding, alluvial-fan, landslide, seismic and tsunami hazards, including their possible effects, based on knowledge of the natural processes of the area.

Figure 1.3 Heavy snow on the Taieri Plain, August 2004 (Source: Otago Daily Times).

2. Social setting

Residential activity is generally clustered around four areas: Mosgiel, Outram, Allanton and North Taieri. An awareness of flood hazard through knowledge of flood history appears to have influenced the placement of these settlements, with all four being largely located beyond the flood extents observed in the late 19th century (Figure 2.1 and Figure 2.2). This awareness of flood history apparently led to an early desire for engineered modifications of the Taieri River, Silver Stream and many other parts of the plains (Figure 2.2), including land-drainage works.

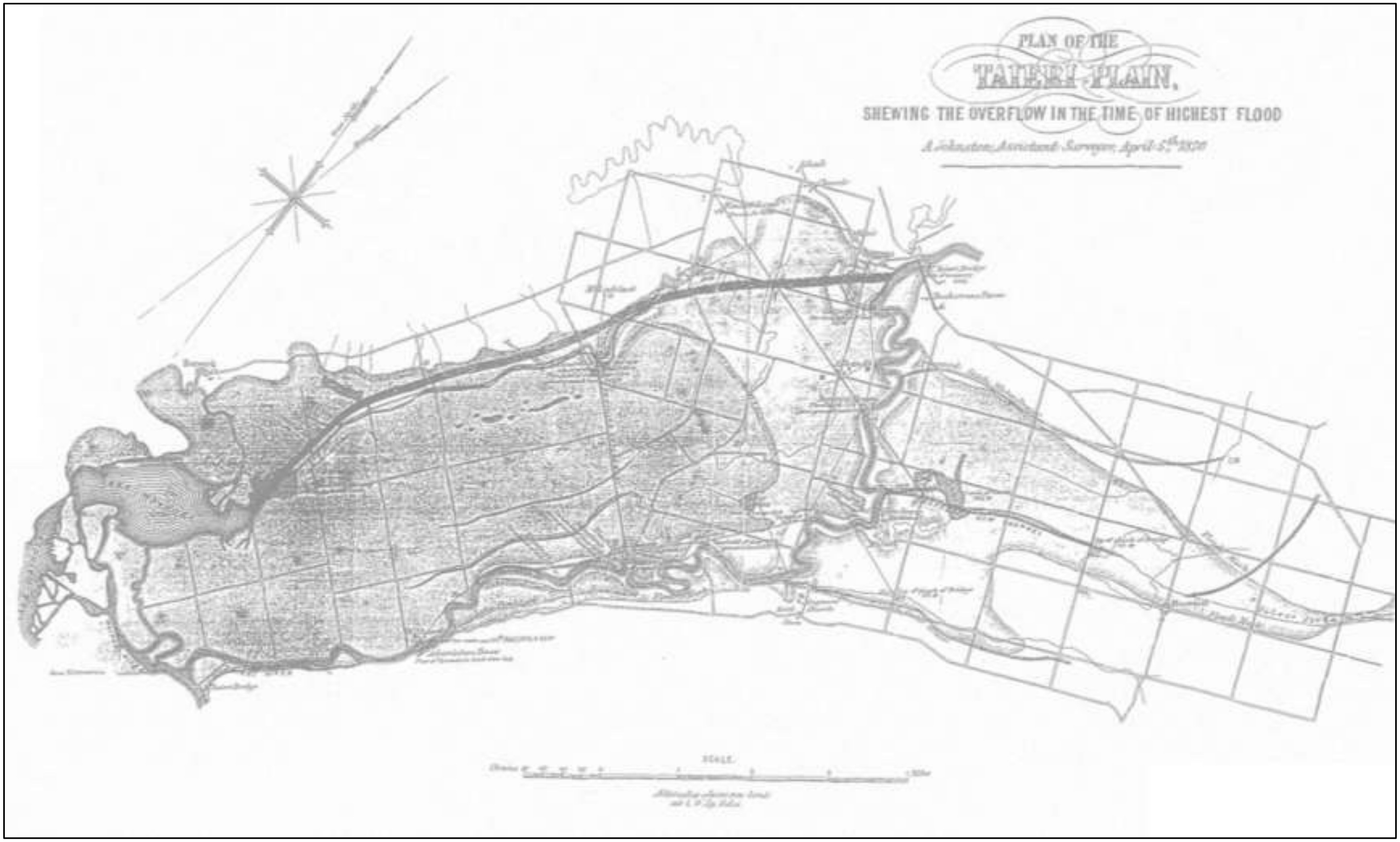

Figure 2.1 Extent of flooding in February 1868, and proposed flood-protection and land-drainage works.

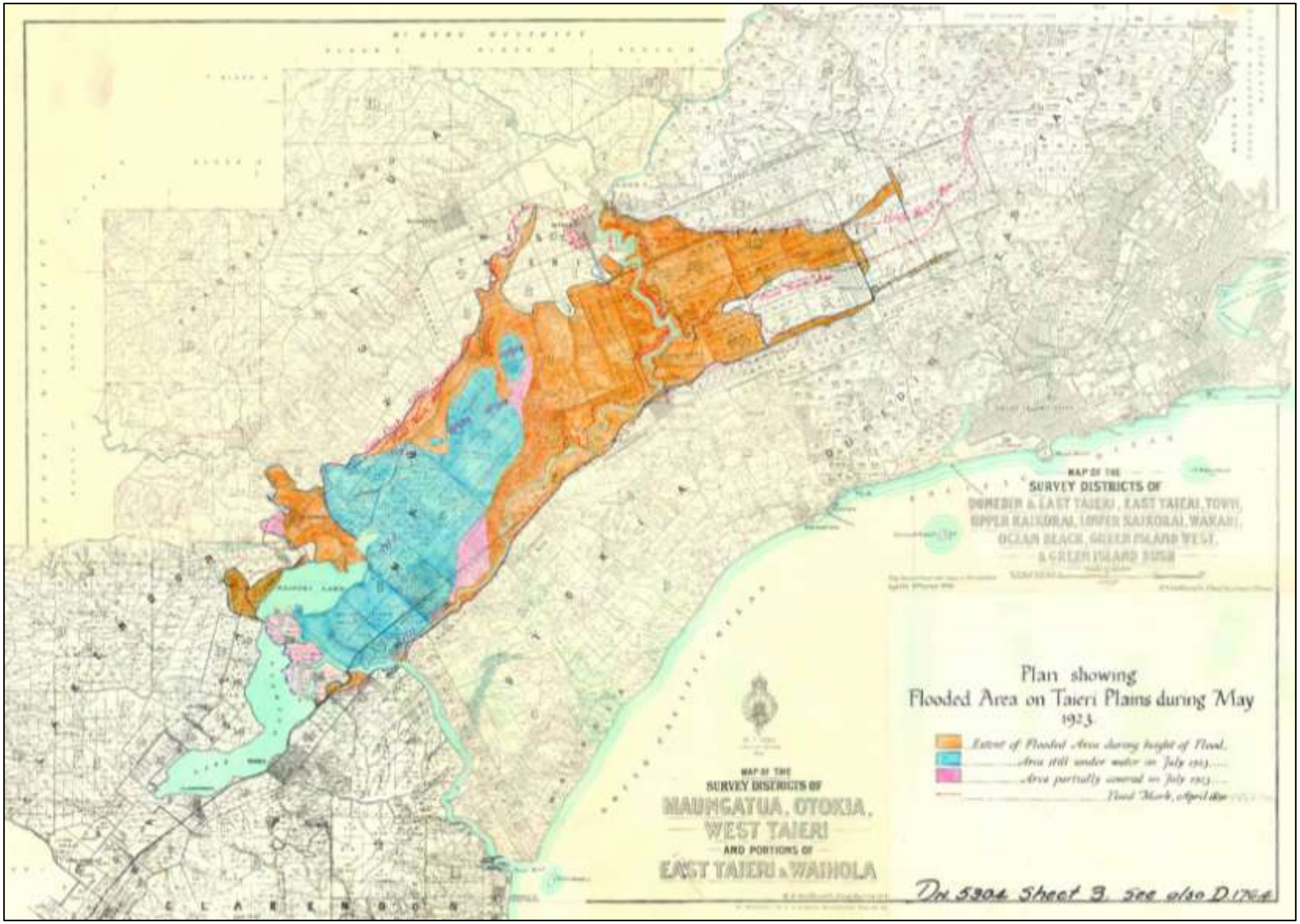

Figure 2.2 Extent of flooding in May 1923, showing the communities of Mosgiel, Allanton and Outram. The map also records the extent of flooding in 1868, from Figure 2.1.

As settlers arrived in Dunedin during the mid-1800s, the search began for expanses of flat land to develop into farms and market gardens. Despite being one of the largest areas of flat land near Dunedin city, the Taieri Plains were not considered suitable at first. During a visit in 1844, with Frederick Tuckett, official surveyor to the New Zealand Company, Dr David Munro, a politician and speaker of the House of Representatives, noted that:

'About the upper third of the Taieri basin is, in my opinion, available but the two lower thirds can hardly be called 'terra firma', being, in fact, an immense grass – tree swamp, through which canals of black sluggish water wind in various direction, and interspersed with stagnant lagoons. And I very much fear that this swamp is not susceptible of being drained, for its level is not above that of the sea' (Houston, 1966).

Dr Munro's observations suggest that, before European settlement and later drainage of the plains, the plain was subject to flooding from even a modest variation in flows of the Taieri River (Houston, 1966). Overland flow from the Maungatua Range, variations in the level of Lake Waipori and tidal influences contributed to the western part of the plains being in a permanent state of swampiness (Figure 2.3).

Figure 2.3 Artist, George O'Brien (1821-1888) impression of the Taieri Plains, 1867. (Source: Hocken Collections, Uare Toaka o Hakena, University of Otago).

However, it was Frederick Tuckett who later realised the value of such an expanse of alluvial lowland so close to a large centre of population (Houston, 1966). The plain was subdivided into 20-25ha sections of land, with wheat, oats, grass and potatoes grown on the upper third. The lower part needed extensive drainage to bring it up to a suitable standard for production. However, the development of refrigerated shipping and the construction of the Burnside Freezing Works saw a movement towards intensification of farming, making the drainage of this land viable (ORC, 1993). This marked the beginning of the modification of the plain's natural-drainage systems, and the ongoing reliance on these changes for land-drainage and flood protection.

The initial construction of flood-protection works began in the late 1800s (1870-1879) with the construction of floodbanks along the western side of the Taieri River, between Outram and the Waipori River (Figure 2.1) (ORC, 1993). The unified approach of settlers on the West Taieri Plain lead to the development of a local drainage board that collectively undertook work in that area, including the construction and ongoing maintenance of the early flood banks, drainage schemes and the West Taieri Contour Channel (Figure 2.4).

Figure 2.4 Early construction of the Contour Channel on the West Taieri Plain (circa 1915).

About the same time, Mosgiel, located on the plain's elevated eastern section, continued to develop as the area's main population centre. The introduction of the rail system and a major woollen mill in the 1870s caused a rapid growth in Mosgiel's population. Today, approximately about 15,000 people live on the Taieri Plains, with most still living in and around Mosgiel (Figure 2.5), which provides the services and amenities of a small satellite town, including a commercial precinct along Gordon Road, the town's main street. Smaller communities include Outram (Figure 2.6), Wingatui, East Taieri, Momona, Henley and Berwick, most of which were also established in the late 19th century (Figure 2.1 and Figure 2.2).

Figure 2.5 Mosgiel, located on the east of the Taieri Plains. The Maungatua Range is on the horizon (Source: NZ Stock Library).

Figure 2.6 The community of Outram is located to the west of the Taieri River, at the foot of the Maungatua Range. In the foreground is the Taieri River, near the Riverside spillway and 'the chute' (refer to Section 4). To the right is the gorge where the Taieri River emerges onto the Plains.

Table 2.1 Population of local communities on the Taieri Plains (2006 Census) and the capacity to expand (from the 2006 Dunedin City Council Residential Capacity Study).

Community	Population (2006)	Population (1996)	Projected population (2031)	Total dwelling capacity (DCC, 2006)
Mosgiel	9144	8640	9820	414
Wingatui	1173	954	1790	512
Outram	642	636	670	46
East Taieri	1383	1281	1910	866
Greater Taieri Plains	2316	2001		288
Wyllies Crossing	288	267	310	

Agriculture, established by the first settlers, is still the plain's main land use. The highly productive and fertile soils provide ideal conditions for crop and pasture growth. The dominance of this land use is reflected in the Dunedin City District Plan, with about 90% of the plains zoned for 'Rural' purposes. Despite the underlying rural zoning, actual land use in some parts of the plain, particularly north of Mosgiel, is rural-residential, as a consequence of landholders subdividing their land.

In the District Plan, about 6km^2 of rural-residential-zoned land, located to the north and east of Mosgiel (Figure 2.7), has been allocated for rural-residential development. One residential unit per 2ha is permitted in rural-residential zones, and one residential unit per 15ha is allowed in rural zones. The rural-residential-zoned land, therefore, has the potential to accommodate a higher density of residential development. Under the current District Plan provisions, the wider Taieri Plains has the potential to absorb a significant amount of residential development (Table 2.1).

The main areas of industry are located to the south-west of Mosgiel (Gladstone Road South), North Taieri (Dukes Road North) and around Dunedin International Airport. The industrial-zoned land to the north of the airport is currently used for agriculture.

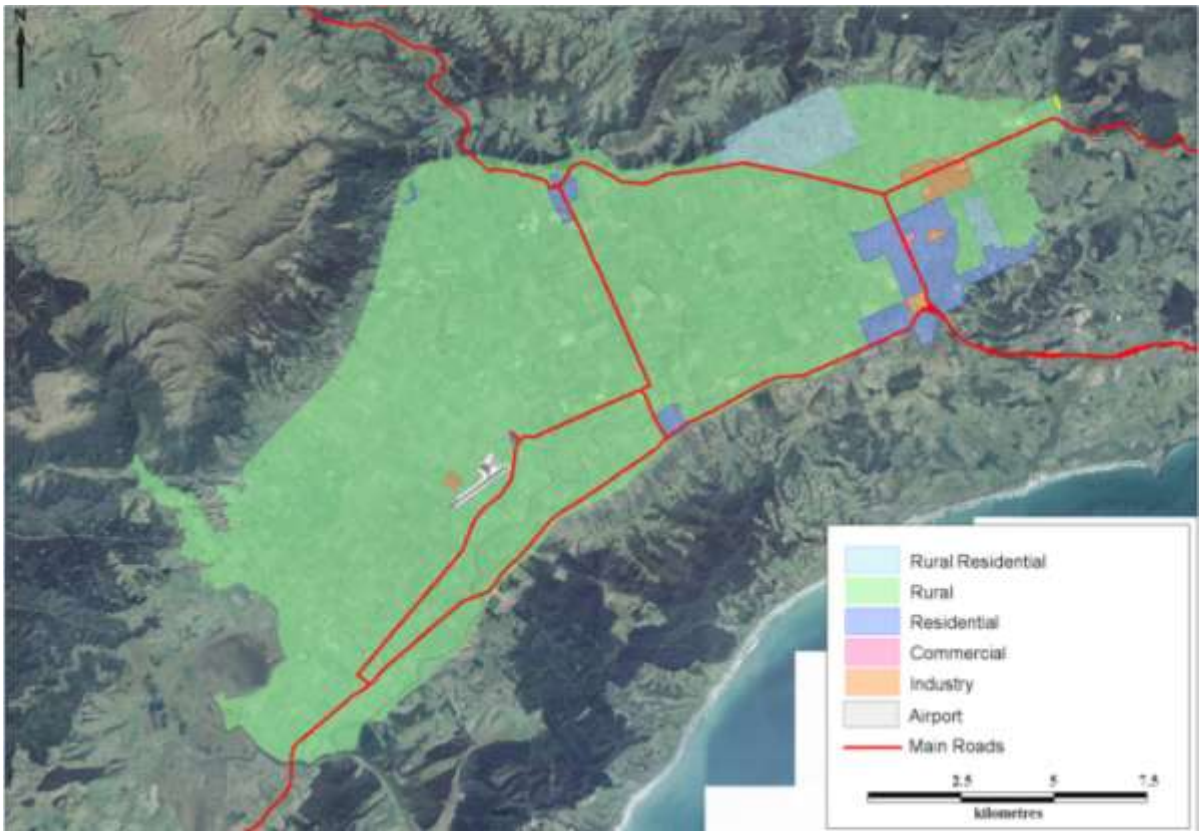

Figure 2.7 Land uses on the Taieri Plains, as defined in the Dunedin City District Plan (DCC, 1999).

Figure 2.8 Dunedin International Airport, following the June 1980 flood. The airport was closed for 53 days.

Dunedin International Airport was established in 1962 near the centre of the Taieri Plains, on land that is approximately one metre above mean sea level (msl) (Figure 2.8). The airport, which carries about 776,000 passengers per year (Dunedin International Airport Ltd, 2011), replaced the Taieri Aerodrome, near Mosgiel, as the main airport for Dunedin city and surrounds.

State highways (SH) 1, 86 and 87 connect Mosgiel with Dunedin city, and regionally connect Dunedin city with Invercargill, Central Otago and the smaller communities on route. Traffic volumes on SH1 average 9,700 vehicles per day near Mosgiel, reducing to 6,168 vehicles just south of Allanton (NZTA, 2010). SH87 provides one of three routes from Dunedin to Central Otago. Through Mosgiel, this network carries about 13,400 vehicles per day, reducing significantly to 2,700 vehicle movements at Outram (NZTA, 2010). SH86, which carries about 3,500 vehicles per day (NZTA, 2010), mainly serves as a link between SH1 and Dunedin International Airport.

Between Otokia and the Waipori River Bridge, SH1 is colloquially referred to as the 'flood-free highway'. Although not part of the flood-protection scheme, the elevated highway embankment prevents flood flows from the Taieri River entering onto the western plain. During the June 1980 flood, this section of highway was one of the few areas to remain free of flooding on the West Taieri plain. During the same flood event, the SH87 bridge over the

Taieri River, near Outram, suffered significant damage. The central bridge piers and bridge deck were completely demolished by flood flows in the Taieri River (Figure 2.9).

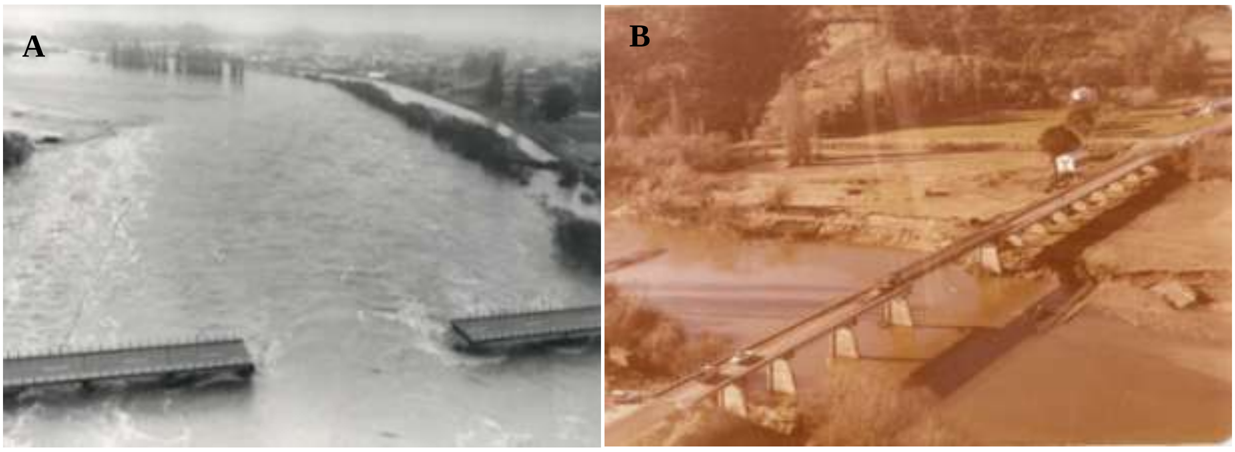

Figure 2.9 A. Outram Bridge during the June 1980 flood (6 June at 3pm); B. Outram Bridge, with temporary Bailey bridge constructed post-event.

The South Island Main Trunk Railway crosses the southern part of the Taieri Plains and, for the most part, runs close to and parallel with SH1. The railway is built on an embankment elevated above the plain, but can be overtopped by floodwater at several locations (Figure 2.10), disrupting train operations.

A second railway line deviates from the main trunk near Wingatui, providing a rail connection between Dunedin and Middlemarch, used mainly by the Taieri Gorge excursion train. A siding provides access to the industrial precinct in North Taieri.

Figure 2.10 South Island Main Trunk Railway, after the April 2006 flood on the Taieri Plains. The south-bound train was forced to stop and wait.

3. Environmental setting

Tectonic, climatic and sea-level changes have influenced the landscape of the Taieri Plains, creating a complex environmental setting, which engineering and land drainage works have further modified. The environmental setting gives rise to the plain's natural hazards, such as flooding and liquefaction; however, its positive attributes, such as its fertile land and reliable rainfall, both of which allow the land to be intensively developed and occupied, have also increased the risks of these hazards.

The topography of the Taieri Plains is largely determined by its geology and that of the wider Taieri River catchment within which it lies; its climate is influenced by its topography and setting. Climate and topography affect surface-water hydrology and are determined in part by the plain's elevation and catchment, relative to sea level. Groundwater is also influenced by elevation relative to sea level and geology. These aspects of the plain's setting are discussed next, in the context of natural hazards. Each natural hazard is discussed in more detail in subsequent sections.

3.1 Geology and topography

The Taieri Plains are part of the wider Taieri River catchment, which covers an area of approximately 5,700km between Central Otago and the Pacific Ocean coastline. The Taieri River catchment is dominated by schist-block mountains and fault-controlled basins (OCB, 1983). Between 99 and 2.6 million years ago[1], the schists were uplifted by tectonic processes. Over time, these have eroded to form the Otago peneplain surface, on which sediments have subsequently been deposited (Norris and Nicholls, 2004). Throughout the catchment, the peneplain surface is broken by numerous post-peneplanation faults, of which those associated with the Taieri-Tokomairiro depression are the most significant (Bishop and Turnbull, 1996). The Taieri Plain and the Tokomairiro Plain, to the south, formed within this depression. The peneplain is also obscured beneath distinct landforms, such as the Dunedin Volcano Complex to the north-east.

The Taieri-end of the depression rests between the Maungatua and North Taieri faults to the north-west and the Titri Fault to the south-east. Movement along these faults has resulted in the north-west (Maungatua) and south-east (coastal) mountain blocks being up-thrust relative to the basin floor (ORC, 2010b) (Section 7). Continued movement along these faults (over long geological timeframes) has also resulted in subsidence of the basin floor. It is not known whether the basin floor is still subsiding (Irricon, 1994). Any further subsidence would have implications for hazards on the Taieri Plains that are influenced by the difference between ground level and sea level.

As with the wider Taieri River catchment, Otago Schist forms the basement rock beneath the Taieri Plains. The depth to the schist basement is estimated to be between 150 to 300m in places (Bishop and Turnbull, 1996; Irricon, 1994).

The Quaternary[2] geology of the area reflects the depositional and tectonic processes of the past 2 million years. The underlying depression is largely filled with Quaternary silts, sands

[1] The geological time period between 99 to 65 million years before present is also known as the 'Late Cretaceous' period. The 'Early Tertiary' period refers to a geological time period about 65 to 2.6 million years before present. Refer to Appendix 1 for a geological timeline.
[2] See the Glossary for a definition of this and other geological terms. See Appendix 1 for a geological timeline.

and gravels derived from the Otago schists (Tonkin & Taylor, 2005). On the West Taieri Plain, the Taieri and Waipori rivers have built extensive alluvial surfaces (Barrell *et al*., 1999). Young alluvial fans grade into these surfaces, most notably along the margins of the Maungatua Range. On the East Taieri Plain, an extensive alluvial surface has established from the Silver Stream and the merging of the lower portions of alluvial-fan features from the surrounding hill catchments.

Sea-level change has also had an influence on the topography of the Taieri Plains area, and the composition of the stratigraphy which underlies them (as discussed in Section 3.4). Much of this area was rapidly inundated by the sea and estuary waters between 8,000 and 4,000 years ago. The toes of many intermediate and old alluvial fans and the distribution and morphology of cliff and gully features suggest that they were formed by wave action at the margins of an extensive body of standing water (lake or marine inlet) during the Holocene period (Barrell *et al*., 1999).

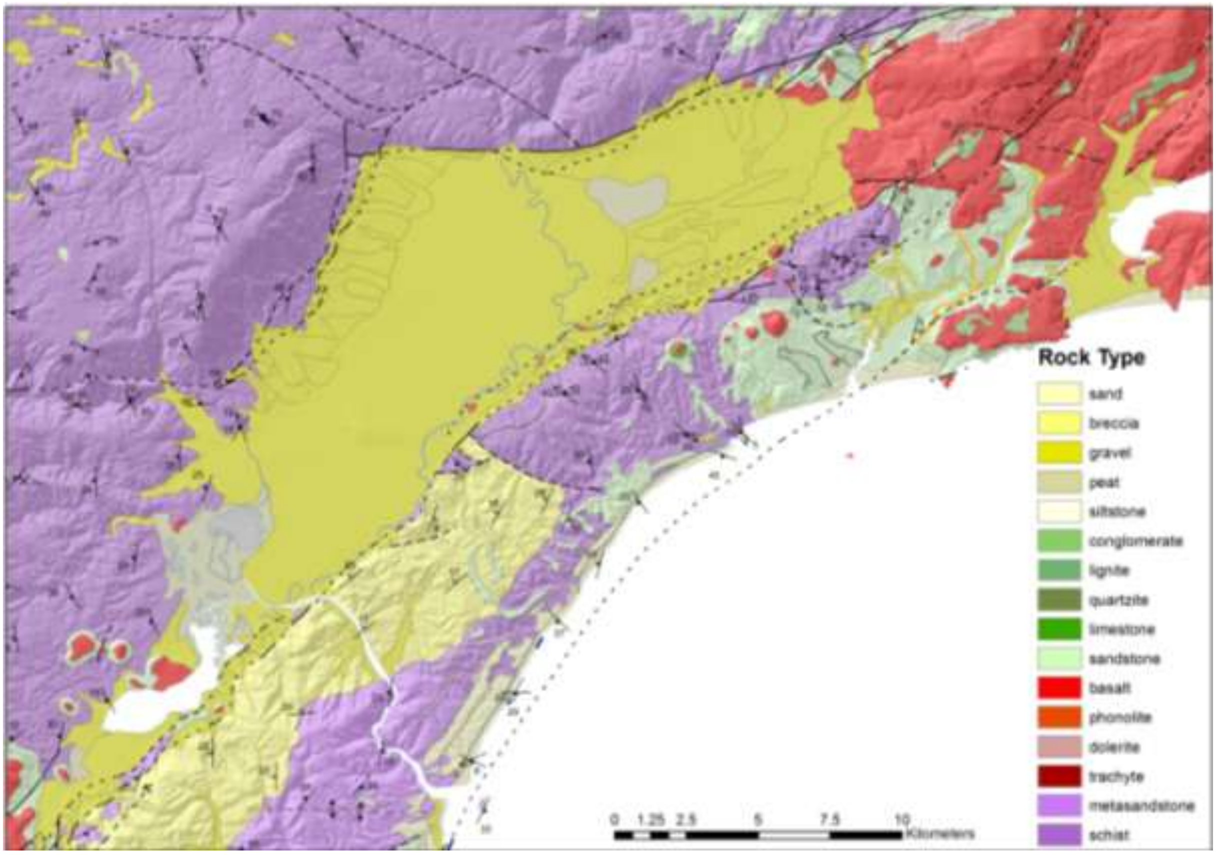

Figure 3.1 Geology of Taieri Basin (adapted from Bishop and Turnbull, 1996).

The Taieri Plains have formed in a basin, about 30km long, and orientated northeast-southwest at the southern end of the Taieri River catchment (Figure 3.2). The plains are bound to the north by the Maungatua Range (865m), to the east by the flanks of Flagstaff (668m), to the west by lakes Waipori and Waihola, and to the south by the lower coastal hills (Chain Hills, Saddle Hill, Scroggs Hill, Otokia Hill) (Figure 3.3). They are connected to the coast by the narrow, 10km long Lower Taieri Gorge.

The Taieri Basin is characterised by flat, gently sloping land, and dissected by the meandering Taieri River, which creates two distinctly separate areas, locally referred to as 'East Taieri' and 'West Taieri'. Elevated about 40m above msl at its northern end, the land grades down to within a couple of metres of sea level to the south-west (ORC, 2010b). The lowest parts of the plains (excluding drains and ditches) lie about 1.5m below msl (Figure 3.7).

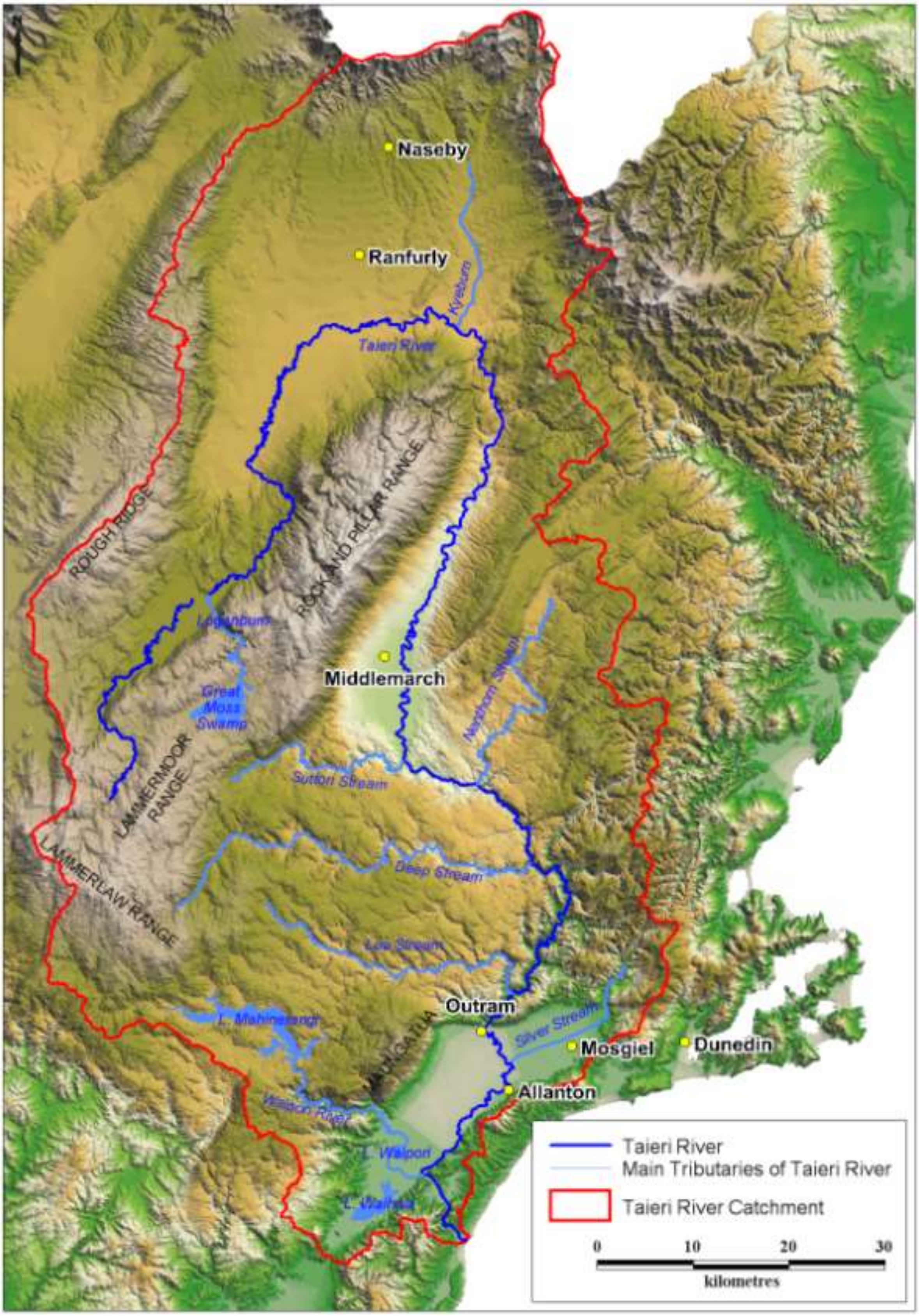

Figure 3.2 Topography of the Taieri River catchment.

Figure 3.3 Digital Elevation Model of the Taieri Plains. Oblique image, looking north-east, up the Taieri Basin.

3.2 Precipitation

The frequency and magnitude of hazards such as flooding, landslides and alluvial fans are closely related to the rainfall events from which they are derived. Antecedent conditions (driven by longer-term weather patterns) within the catchment can also have a direct influence, by affecting groundwater and soil-moisture levels, for example.

The coastal sector of the Taieri River catchment is characterised by a cool, temperate, sub-humid maritime climate (Glassey *et al*., 2001). Mean annual rainfall is generally between 650-750mm/year in the Taieri Basin (Table 3.1), and up to 1,300mm/year in the Maungatua Range to the west and Silver Peaks to the north. Further inland, the upper Taieri River catchment includes some of the driest areas in New Zealand, with less than 500mm of rain per year in some places. The upper to central catchment area is characterised by a semi-arid, semi-continental climate, with hot summers and cold frosty winters.

Table 3.1 Rainfall characteristics of the Taieri Plains and the hills to the north, as at December 2011. The location of the measurements is shown on Figure 3.4.

Site and length of record	Altitude (m)	Mean annual rainfall (mm)	Maximum annual rainfall (mm)	Minimum annual rainfall (mm)	Maximum daily rainfall (mm)
Silver Stream at Riccarton Road (1989-2011)	15	654	1024.5 (2000)	416 (1990)	164.5 (26 Apr 2006)
Mosgiel (1952-2011)	8	684	1023.8 (2000)	415 (1985)	147.2 (26 Apr 2006)
Maungatua (1971-2011)	25	787	1060 (1994)	448 (1985)	122 (26 Apr 2006)
Dunedin Airport (1963-2011)	1	654	904.6 (1983)	412 (1985)	134.8 (26 Apr 2006)
Deep Stream at SH87 (1994-2011)	369	556.66	737.88 (1994)	381 (2003)	85.5 (26 April 2006)
Three O'clock Stream at Lamb Hill (Aug 2010-2011)	160	N/A	N/A	N/A	95.2 (18 Oct 2011)
Silver Stream at Swampy Spur (2008-2011)	630	1325	1429 (2010)	1220 (2008)	164 (25 May 2010)

The more elevated parts of the upper catchment (i.e. Rock and Pillar Range, Rough Ridge and the Lammerlaw Range) (Figure 3.2) experience a colder, wetter climate, typical of more mountainous areas. Annual precipitation across the peaks of the ranges exceeds 1,200mm, with much of this falling as snow during the winter.

A number of perceptible trends in annual rainfall were evident across the lower South Island during the latter part of the 20th century, including an increase in rainfall in the west and in south Otago, and a trend towards drier conditions in the east (Mojzisek, 2005). No obvious trends were evident at rainfall sites on the Taieri Plain during this period, although these sites generally have relatively short records, or extensive periods of missing record.[3]

[3] ORC has provided additional information about the spatial distribution of average (annual and seasonal) rainfall on the Taieri Plain and surrounding area through growOTAGO (http://growotago.orc.govt.nz).

Figure 3.4 Locations of the rainfall measurements presented in Table 3.1.

Of more importance to weather-related natural hazards (such as flooding) are the characteristics of extreme rainfall events (i.e. storms). Precipitation extremes in the east of the South Island generally became less frequent and less intense between 1951 and 2003 (Mojzisek, 2005). Stations with long-term records nearest to the Taieri Plains (Musselburgh and Ross Creek) showed a similar trend, with decreases in rainfall intensity and very wet days[4] occurring during that period.

Rainfall stations on the Taieri Plains generally have a shorter record than those used by Mojzisek, or are missing data from the early part of their record. Figure 3.5 gives an updated analysis (using Mojzisek's methodology) of the full length of continuous record up to December 2011 at stations within the lower Taieri catchment. The figure shows changes over time (since records began) for the following parameters: (a) the highest 5-day precipitation amount (b) total annual precipitation (c) the number of wet days[5] (d) the average intensity of rainfall (e) the number of very wet days and (f) the percentage of annual rainfall falling on very wet days.

Figure 3.5 shows that the trends identified by Mojzisek (i.e. a reduction in the number and intensity of heavy rainfall events) are also evident at Dunedin Airport between 1963 and 2011. However, at the northern end of the plain, the Mosgiel station shows a statistically

[4] Mojzisek used the number of very wet days as an indicator of extreme precipitation frequency. It refers to the number of days with rainfall totals in the top 5% of those recorded at a particular site.
[5] Wet days are those where daily precipitation exceeds 1.0mm.

significant[6] increase in the number of very wet days (Figure 3.5e). Both Mosgiel and the nearby Riccarton Road station also show a general increasing trend[7] in the percentage of rainfall which falls on very wet days (Figure 3.5f) and the highest 5-day precipitation amounts (Figure 3.5a). Figure 3.5 shows that there is localised variability in extreme rainfall patterns, and that the northern end of the Taieri Plain (including the Silver Stream catchment) has experienced an increase in both the intensity and frequency of extreme rainfall events.

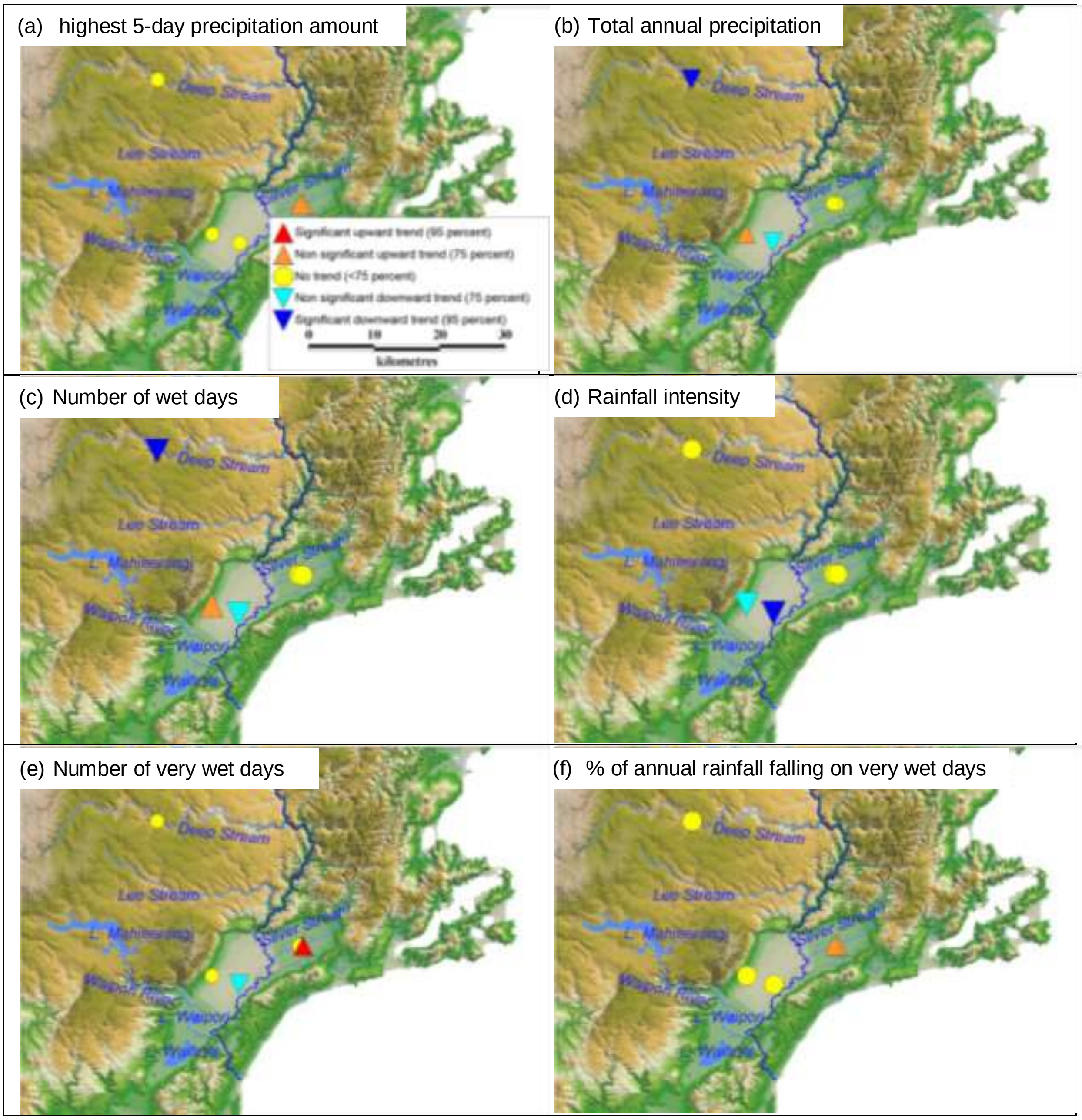

Figure 3.5 Spatial variability of extreme precipitation trends on the Taieri Plains and the hill catchments to the north. The trends shown are for the full length of record, until the end of 2011.

---

[6] 'Statistical significance' means that something is probably true (i.e. not due to chance). The most common level of significance, used to mean something is good enough to be believed, is 95%. This means that the finding has a 95% chance of actually having occurred, rather than just being a random event.
[7] at the 75% level of significance.

During the 20th century, climate stations near the Taieri Plains showed an overall warming trend (Brown, 2006; Salinger and Griffiths, 2001). In Dunedin city (which is nearby and experiences similar climatic conditions to the Taieri Plains), climate stations also showed an increase in temperature of between 0.5 to 0.8ºC over the past century. Furthermore, records show that, between 1940 and 1970, both the maximum and minimum temperature extremes for the area have warmed, suggesting cold extremes are becoming less frequent, and warmer extremes becoming more frequent. Since the 1970s, the warming trend has continued, but only for the colder values (Brown, 2006).

Average temperature is predicted to increase by another 2ºC by 2100. Given that a warmer atmosphere can hold more moisture, there is potential for storm events to bring heavier (or more intense) rainfall, and to occur more frequently than has previously been observed (MfE, 2008). Heavy rain events, resulting from subtropical depressions drifting southward over New Zealand, are likely to become more common. This type of event has the potential to produce daily rainfall totals well in excess of the maximum daily rainfall totals observed to date (Table 3.1).

However, a number of factors may influence regional trends in heavy rainfall patterns, including the rugged topography of the hills surrounding the plains, the susceptibility of the lower catchment to heavy rainfall events approaching from the east, and that the Taieri River catchment's location on the east coast of South Island is in the lee of the prevailing westerly airflow. It is difficult to assess whether local topography and location will intensify or moderate the effects of a warmer climate on extreme rainfall patterns in the Taieri River catchment and on the Taieri Plains themselves. Previous trends (as discussed above) indicate that changes in the intensity and frequency of heavy rainfall events has varied across the plains, and this spatial variation may also continue under a warmer climate.

3.3 Surface water

Rising in the Lammerlaw and Lammermoor ranges, the Taieri River flows from the headwaters for about 318km, before crossing the Taieri Plains and entering the Pacific Ocean 30km south-west of Dunedin (Figure 3.2). The river has eight main tributaries: the Loganburn and Kyeburn in its upper reaches; the Sutton, Nenthorn, Deep and Lee Streams in its central reaches; and the Silver Stream and Waipori River on its lower reaches. Other hydrologic features include lakes Mahinerangi, Waipori and Waihola, and the Great Moss Swamp, near the headwaters of the catchment.

The three main water courses on the Taieri Plains are the Taieri River, the Silver Stream and the Waipori River. However, many other, smaller watercourses, drains and ephemeral swales are associated with flood hazard (Figure 3.6 and Figure 4.3).

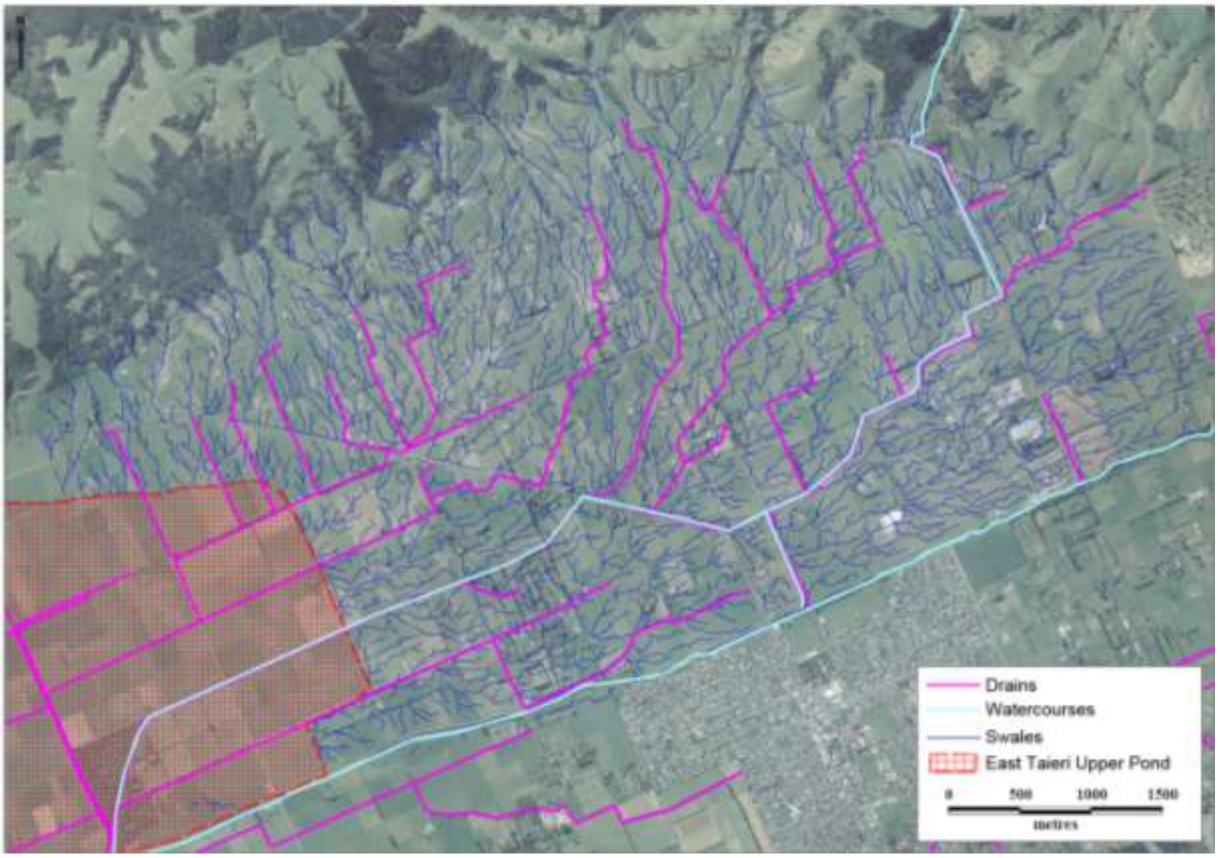

Figure 3.6 Watercourses, drains and swales on the East Taieri Plain. Swales also cross the plain on the south side of the Silver Stream (including through parts of Mosgiel), although these features are not shown.

The Silver Stream originates in the Silver Peaks and emerges from the north-eastern corner of the Taieri Plains. Initially flowing in a southerly direction, the Silver Stream follows a highly modified channel through the centre of the eastern part of the Taieri Plains, joining the Taieri River mid-way across the basin, about 4km upstream of Allanton. In the late 1800s, the Silver Stream, below Puddle Alley, was diverted from its natural watercourse into its present position, which flows straight to the Taieri River (Figure 2.1).

Flows from the Waipori River are semi-controlled by the Waipori hydro-electric scheme and Lake Mahinerangi, entering the Taieri Plains at the south-western corner near Berwick. The Waipori River is joined by the Contour Channel soon after emerging onto the plains, and discharges into Lake Waipori before joining the Taieri River at Henley Ferry.

The Taieri River emerges from its schist-rock gorge near Outram and meanders across the basin in a southerly direction before turning south-west at the foot of the coastal hills near Allanton. Following the foot of the hills, the Taieri River joins the Waipori River at Henley Ferry before exiting the basin through the Lower Taieri Gorge.

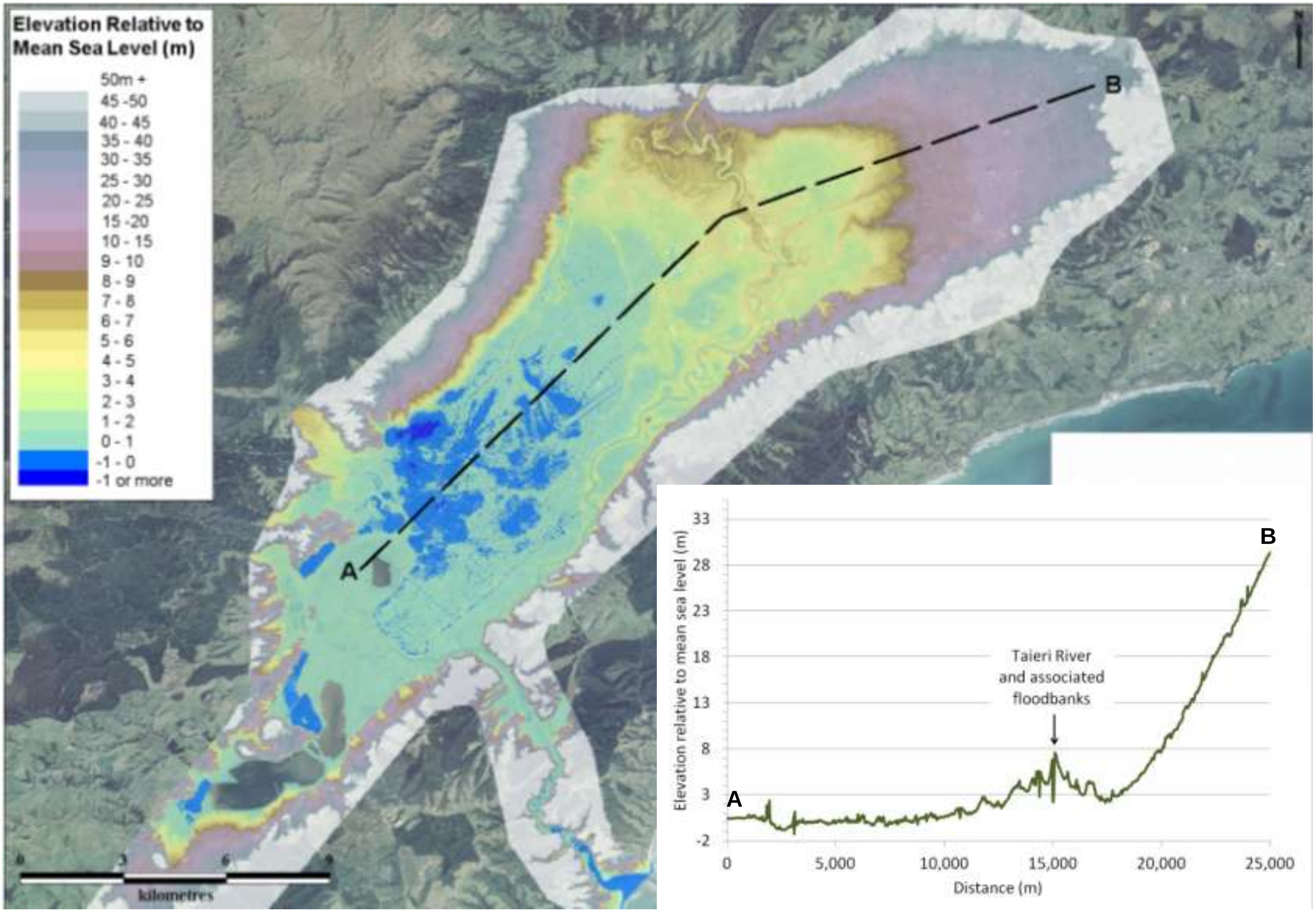

Figure 3.7 Elevation of the Taieri Plains (main image) and cross section A-B from south-west to north-east (inset). Land elevation is in metres, relative to msl.

Most of the flood-producing storms on the Taieri Plains are easterly or southerly in origin and are associated with depressions that slow or stall over Otago. Cold fronts, advancing from the south, bring heavy falls over the central Taieri River catchment, moderately heavy falls over the eastern areas and lighter falls in the northern regions (Houston, 1966; ORC, 2001). Unless coupled with pre-existing high flows (as observed during the May 2010 flood (Figure 3.8)), southerly fronts generally move swiftly across the catchment and are less conducive to widespread flooding.

Cold fronts from the west tend to bring relatively heavy falls to the north-western edge of the Taieri River catchment (including the Maniototo Plain). Heavy rainfall in the upper catchment and any subsequent higher flows in the upper reaches of the Taieri River tend to be moderated by the presence of the Taieri Scroll Plain (ORC, 2007b). Heavy falls in the upper catchment do contribute to higher flows in the Taieri River at Outram and extend the duration of flooding; however, by themselves, these events tend not to produce large floods on the Taieri Plains.

Conversely, flood-producing storms approaching from the east bring heavy rainfall to the eastern coastal regions, but produce little rain in areas west of the Rock and Pillar Range (i.e. the upper catchment) (ORC, 2007b). On many occasions, the persistent easterly fronts have brought the smaller tributaries of the Taieri Plains - the Silver Stream, Owhiro Stream, Quarry Creek and Mill Creek - into flood. If the event is sufficiently confined and isolated, easterly events can inundate parts of the East Taieri Plain adjacent to these watercourses, but cause no appreciable rise of the Taieri River. More widespread easterly events, reaching into Nenthorn, Sutton, Deep and Lee streams, can cause large flows in the Taieri River at Outram.

Due to the ‘horse-shoe’ shape of the upper Taieri River and the combination of plains, wetlands and narrow gorges through which it passes (Figure 3.2), the pattern of flows in the river can vary considerably along its length. High flows originating in the upper catchment take several days to reach the plain, while high flows originating from tributaries closer to the coast (e.g. Three O’clock Stream, Deep Stream and Silver Stream) can reach the plain in a matter of hours. In addition, the watercourses that traverse the plain (including the Taieri River, Silver Stream, Waipori River, Owhiro Stream, Quarry Creek and Mill Creek) will all respond differently during a flood event, depending on the distribution and intensity of rainfall across the catchment. As a result, the timing, magnitude and duration of the flood peaks in these tributaries and in the main stem of the Taieri River will vary across the plains.

From its headwaters, the Taieri River flows through four main basins: the Styx and Maniototo, in the upper catchment; the Strath Taieri, in the centre of the catchment; and the Taieri, near the outlet to the ocean. Each basin is connected by confined river gorges. Because of the essentially independent but hydrologically related basins, heavy rainfall events that cover the whole catchment can result in multiple-flood peaks in the Taieri River where it emerges onto the Taieri Plains at Outram (ORC, 1993) (Figure 3.8).

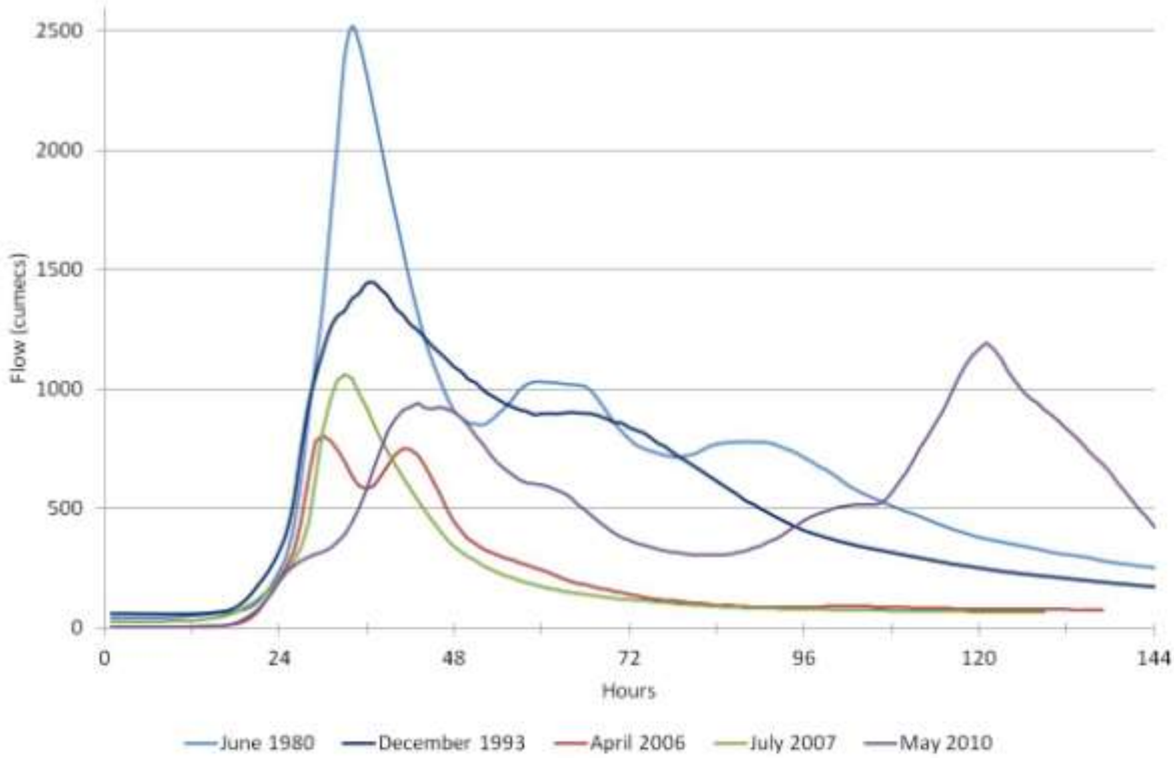

Figure 3.8 Changes in flow in the Taieri River at Outram during flood events in 1980, 1993, 2006, 2007 and 2010.

The first peak is generally the result of runoff from the catchment downstream of Sutton, including the major tributaries of Deep, Lee, Nenthorn and Three O'clock streams (Figure 3.2). The second peak is the result of runoff from heavy rainfall further up the catchment, with the moderating effect of the upper catchment (as described above) usually producing flow magnitudes lower than the first peak. Figure 3.8 shows that a second peak in flow can occur, for example, 12 (e.g. April 2006) or 26 hours (e.g. December 1993 and June 1980) after the first peak. During the May 2010 event, the second flood peak, observed three days after the first, resulted, in part, from a second, independent band of heavy rainfall crossing the catchment.

Downstream of Outram, flood flows from the upper catchment join with those from the Silver Stream. The Silver Stream can also have more than one peak, depending on rainfall patterns in its upper catchment. Peak flow in this tributary tends to be much smaller than in the main stem of the Taieri River, and typically only lasts a few hours. The Silver Stream normally peaks before the Taieri River at Outram, although peaks do occasionally occur at the same time (Figure 3.9) (Opus, 2010).

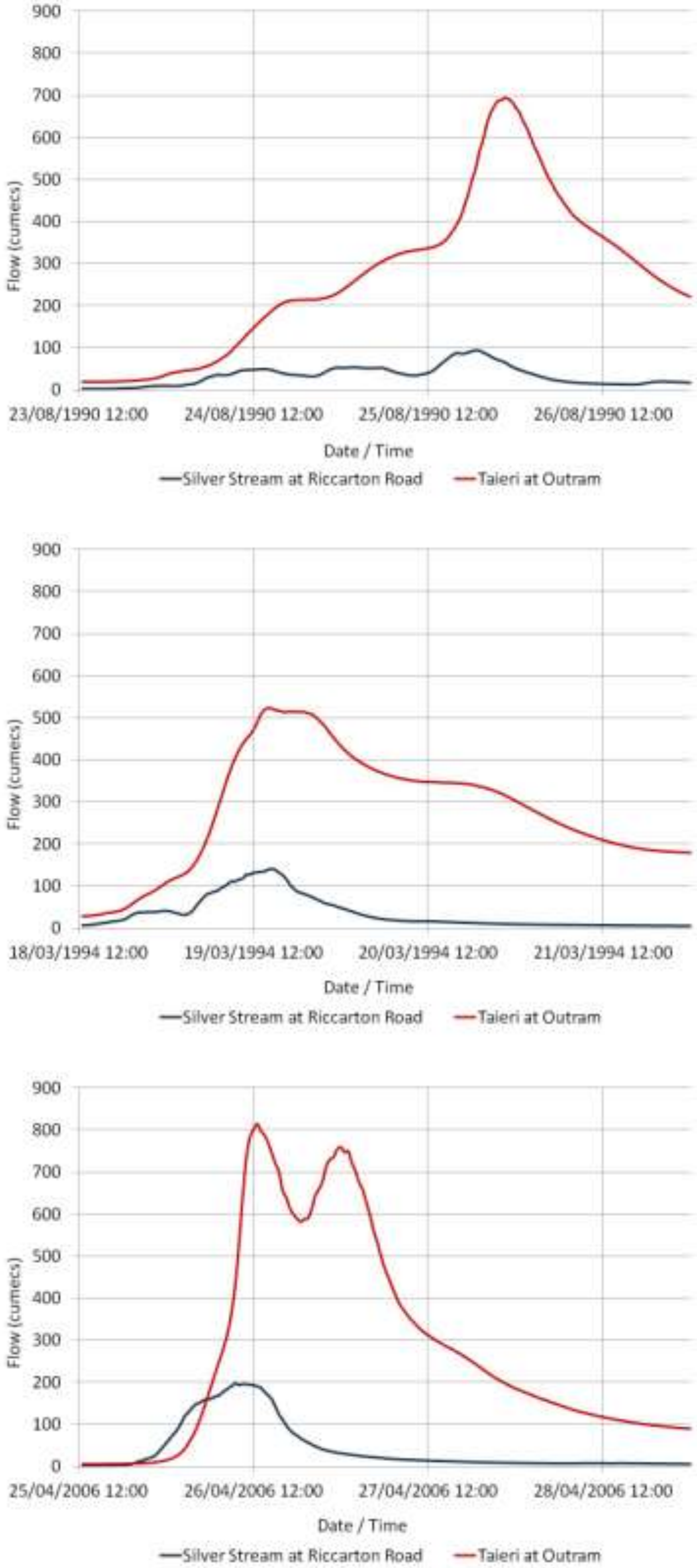

Figure 3.9 Examples of the Taieri River and Silver Stream flood hydrographs from events in August 1990, March 1994 and April 2006.

During flood events, the river level in the lower reaches of the Taieri River rises well above the level of the adjacent land on the West Taieri Plain. Figure 3.10 shows the maximum water level in the Taieri River at Henley, during the period October 2002 (when records began) to April 2012, in relation to the adjacent land.

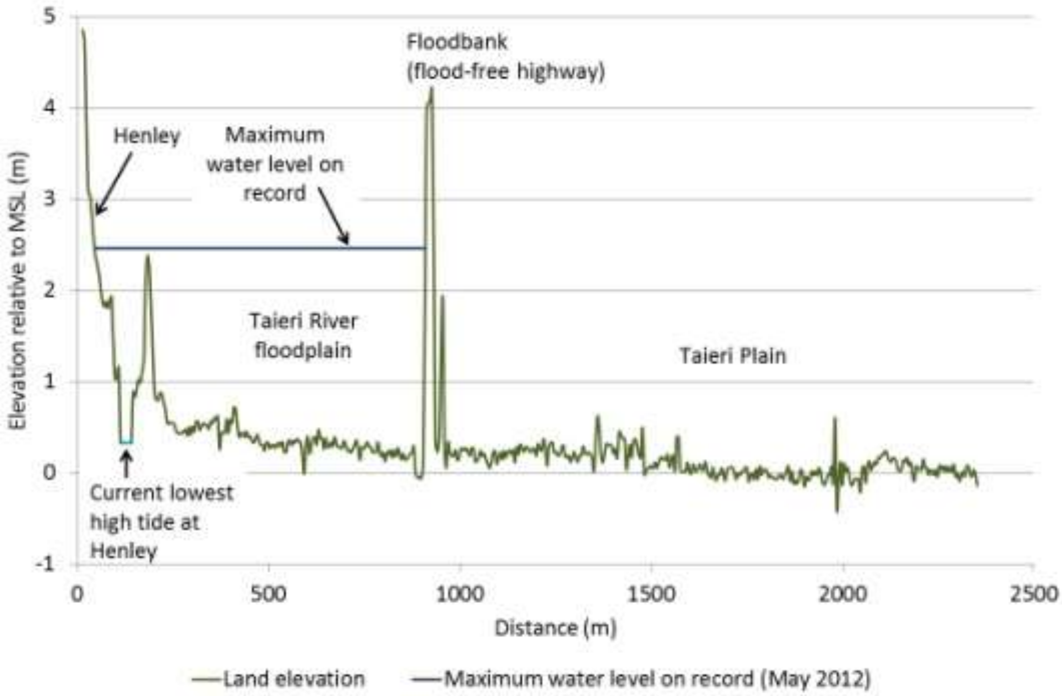

Figure 3.10 Cross section from Henley to West Taieri Plain (as shown in Figure 3.11), showing the maximum water level observed between October 2002 and April 2012. The water level in the Taieri River at Henley is shown as the current lowest high tide (Figure 3.15).

Figure 3.11 Location of the cross section shown in Figure 3.10.

There is also a significant tidal component to water level in the lower reaches of the Taieri and Waipori rivers. During low-flow conditions, the river level at Henley can rise and fall up to 0.7m due to the influence of the tide, and can reach 1 metre above msl (Figure 3.12 (bottom)). Therefore, flood water can pond for some time within the lower reaches of the Taieri River before it is able to drain out to sea. For example, during the May 2010 flood, the water level at Henley remained 2m or more above msl for about 4½ days (Figure 3.12 (top)). If sea level was significantly higher than at present,[8] the river level during flood events would be likely to peak at higher levels than under current conditions and remain at a higher level for a longer period.

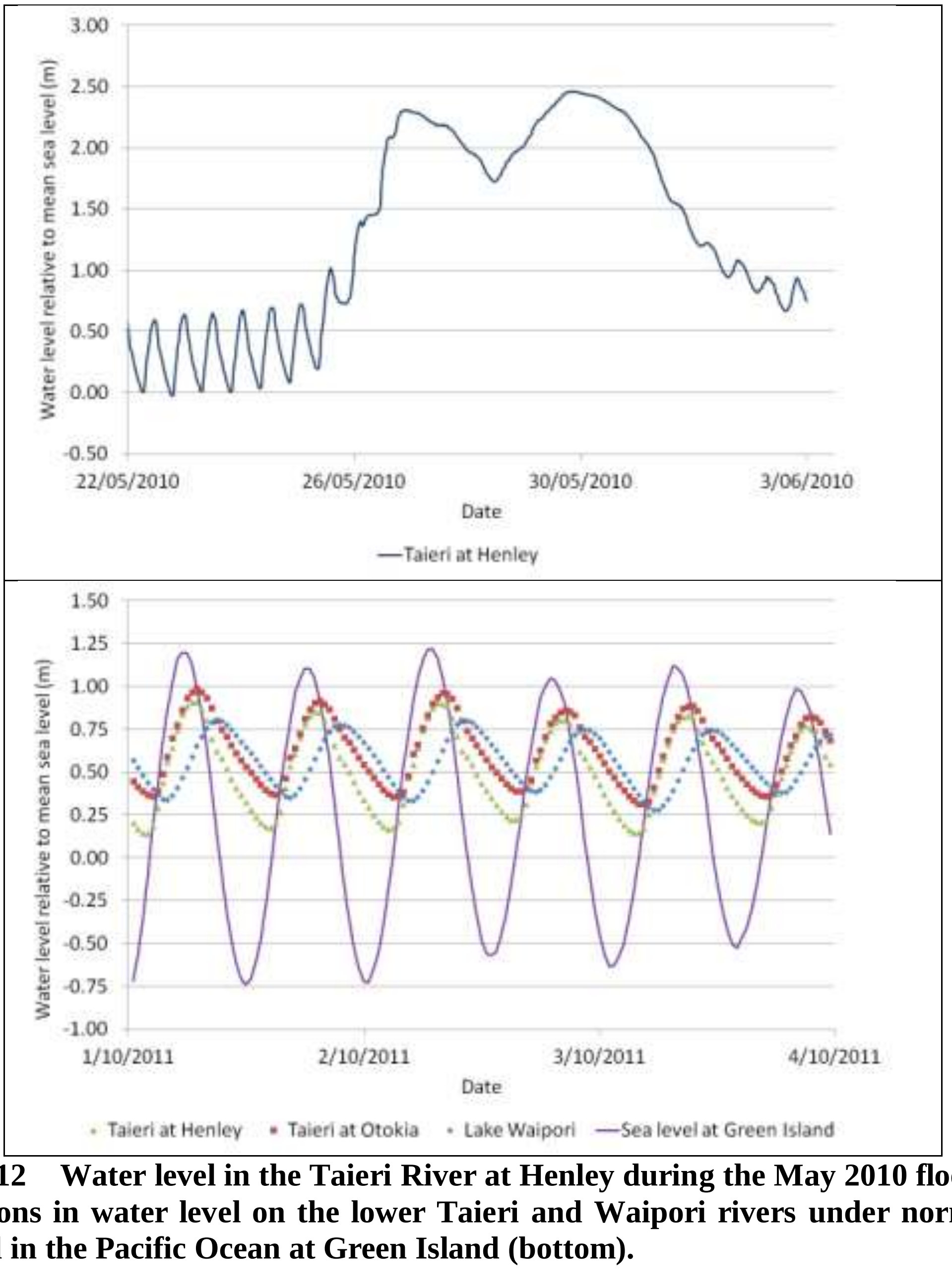

Figure 3.12 Water level in the Taieri River at Henley during the May 2010 flood (top). Fluctuations in water level on the lower Taieri and Waipori rivers under normal, low flows and in the Pacific Ocean at Green Island (bottom).

[8] The Ministry for the Environment recommends that decision makers should regard a rise in sea level of 0.3m by 2040 and 0.6m by 2090 as a baseline for future considerations. These estimates are based on projections released by the IPCC in their 2007 Assessment Report. However, further research since the release of this report suggests that melting of the polar ice sheets before the end of the century could contribute to as much as a 0.7m to 1.6m rise in sea level by 2090 (Fitzharris, 2010).

As most of the West Taieri Plain lies at or below current msl, it relies on the Waipori pumping station (Figure 3.13), even during normal low-flow conditions, to prevent it from transforming back to its former swamp-like state (Section 2). Water levels in Lake Waipori, to the west of this area, are generally elevated above the land on the eastern side of the flood bank (Figure 3.14), making the pump station and flood banks critical to the occupation and use of the land (ORC, 2007a; ORC, 2010d). This characteristic also has implications for seismic risk, as discussed later.

Figure 3.13 Waipori Pump Station and the inlet channel to the station (Main Drain). The underground chamber (installed in 1989) housing the two 'D' pumps is on the left, and the building housing the three 'F' pumps installed in 1929 is on the right. The three 'F' pumps are being replaced with two new submersible pumps in 2012/2013.

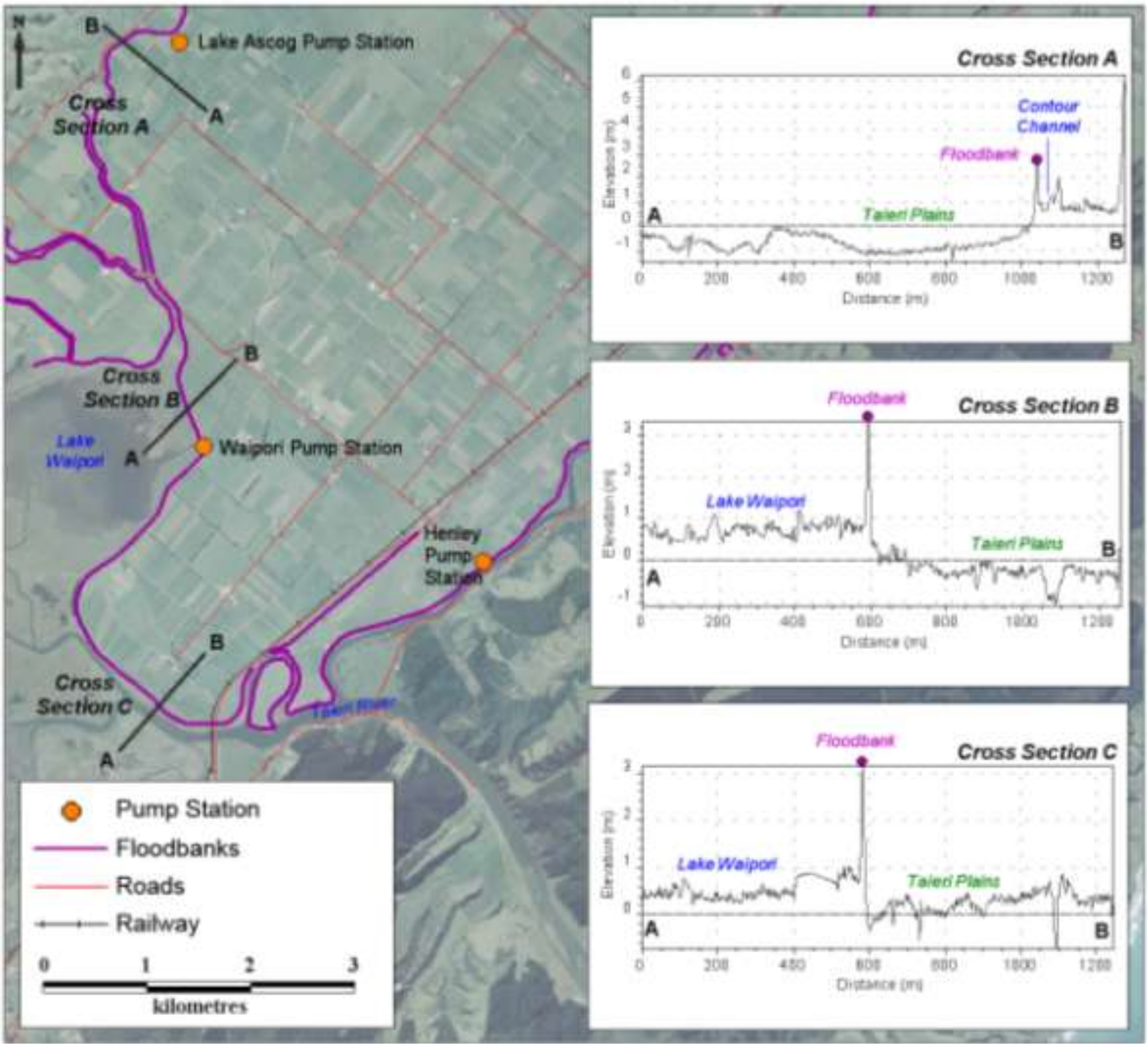

Figure 3.14 Cross section of three areas on the West Taieri Plain.

Figure 3.15 shows the vulnerability of the West Taieri Plain to sea level. Specifically, the figure shows the extent of inundation that would occur if the Lower Taieri Flood Protection Scheme flood banks next to Lake Waipori did not exist or were ineffective (for example, if they failed after a major fault rupture or significant ground shaking caused by a major earthquake). The scenarios shown are:

1. the extent of inundation if the water level on the West Taieri Plain was 0.33m above msl (i.e. the water level in the Taieri River at Henley at the current lowest high tide) (pink)
2. the extent of inundation if the water level on the West Taieri Plain was 0.83m above msl (as for 1, but with 0.5m sea level rise) (yellow)
3. the extent of inundation if the water level on the West Taieri Plain was 1.13m above msl (as for 1, but with 0.8m sea level rise) (green).

Seismic performance and foundation piping[9] risks for the flood banks on the Taieri Plains are discussed in later sections.

[9] See the Glossary for further explanation of these and other terms used in this report.

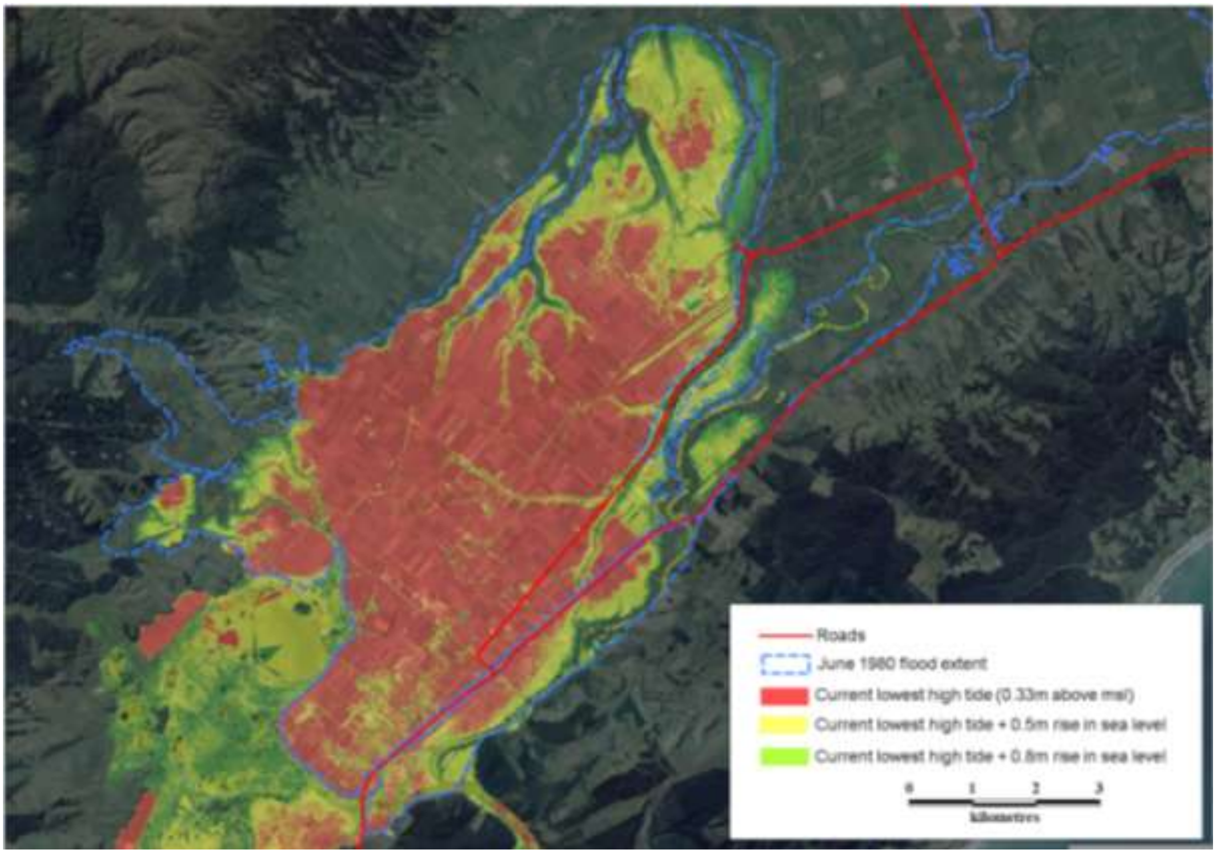

Figure 3.15 Potential landward extent of inundation during a 'flood banks down' scenario on the West Taieri Plain. Note the correlation with the June 1980 flood (Figure 4.1), where numerous breaches in the flood banks occurred along the Waipori River and Contour Channel.

3.4 Groundwater

The lower Taieri Basin is a tectonic depression resting between two major faults. Deposits of sand, gravel, silt, clay and peat have built up within the basin, and are thought to extend to depths of over 200m below the surface (ORC, 2010b). In the Mosgiel area, the mixtures of these different sediments are highly variable and thinly layered. By contrast, western parts of the Taieri Plain (from Henley to Riccarton Road) are more consistently layered. The groundwater aquifer is located within loosely sorted gravels, and, at the plain's western end, is overtopped by a 20-25m thick layer of fine-grained deposits with low permeability. This layer of silt and clay was formed over the underlying gravels when the Taieri Basin was inundated by the sea and estuary waters, following the post-glacial rise in global sea levels, about 4,000-8,000 years before present. This denser layer of silt and clay tends to confine and pressurise the underlying gravel layers to produce confined aquifers (Figure 3.16).

Accumulated or heavy rainfall, or high flow in the Taieri River and its tributaries, acts to recharge the aquifers beneath the Taieri Plain. However, the overlying silt and clay layer limits the ability of groundwater to surcharge out onto the surface due to their low permeability. As a result, flood events tend not to result in significant surface ponding due to groundwater, despite the fact that much of the surface of the western Taieri Plain is lower than the surrounding waterways (Figure 3.16) and the groundwater-pressure surface.[10] Ponding on the Taieri Plain during flood events is instead dominated by surface water runoff.

[10] The groundwater pressure surface is the equivalent level that groundwater would rise to in a bore.

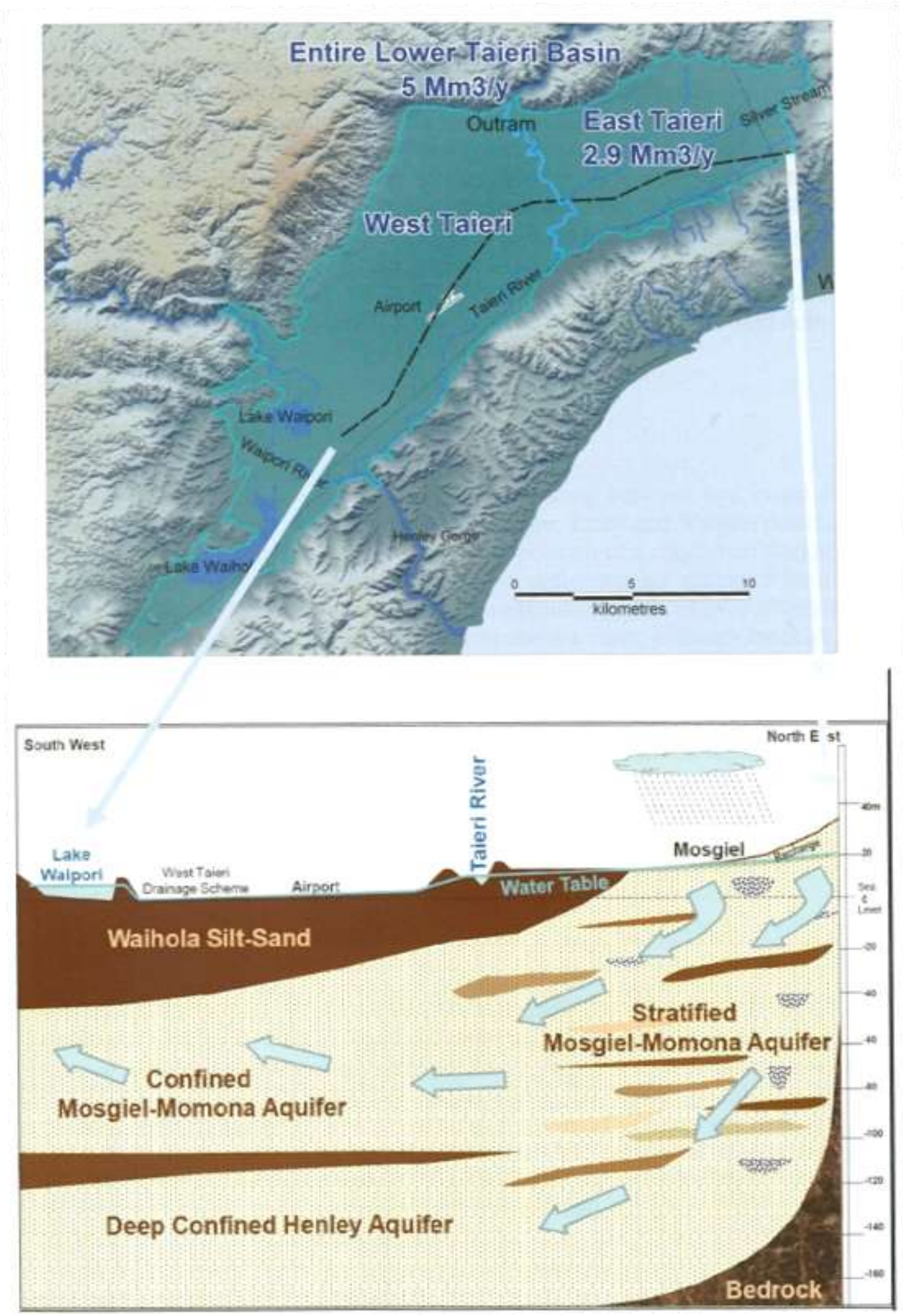

Figure 3.16 Map view of Lower Taieri Basin, with schematic cross section from Wingatui to Lake Waipori, showing groundwater-flow directions as arrows (ORC, 2010b).