Flood hazard on the Taieri Plain

Review of Dunedin City District Plan: Natural hazards

First revision: August 2015

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

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Report writers: Michael Goldsmith, Manager Natural Hazards
Dr Jean-Luc Payan, Senior Investigations Engineer
Dr Rachel Melrose, Natural Hazards Analyst
Jacob Williams, Natural Hazards Analyst

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Cover image: Taieri Plain looking south towards Scroggs Hill (June 4, 2015).

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1. Background

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 information on natural hazards to help inform this review. To assist in this process, the ORC prepared a series of reports in June 2014 to help inform the management of land use through the review of the District Plan.1 The full list of reports is as follows:

1. Project overview
2. Coastal hazards of the Dunedin City District
3. Flood hazard on the Taieri Plain and Strath Taieri[2]
4. Flood hazard of Dunedin's urban streams
5. The hazard significance of landslides in and around Dunedin City
6. Assessment of liquefaction hazards in the Dunedin City District

As part of the public consultation process for the District Plan review, the DCC and ORC held a series of 13 public meetings in June – August 2014. The natural hazards information contained in the above reports was presented, along with proposed land-use controls, to be implemented by the DCC through its District Plan. A public submission process allowed members of the public to provide feedback on the natural hazards information and the proposed land-use controls. Staff from both councils met with members of the public upon request to discuss particular issues relevant to their property.

Additional information and suggestions provided through this process has enabled the ORC to undertake additional work to refine natural hazards information in the Dunedin City District. This report provides an update to previous descriptions of flood-hazard characteristics on the Taieri Plain (ORC, 2014; ORC, 2013; ORC/DCC 2006).

[1] It is noted that this information will also assist with other activities, such as the development of local emergency management response plans, building consents and infrastructure planning, renewal and maintenance.

[2] From here-on, this will be referred to as ORC (2014).

2. Report outline

The format of this report is similar to that of ORC (2014), in that it separates the Taieri Plain into various flood-hazard areas, based on:

- topography
- proximity to watercourses
- the characteristics of those watercourses
- the influence of the Lower Taieri Flood Protection Scheme, and the East and West Taieri Drainage Schemes.

For completeness, this flood-hazard report includes much of the material presented in the 2014 version (in particular, descriptions of the environmental setting, flood-hazard characteristics and information on previous flood events). However, the current report also integrates information and feedback provided through the public submission process, along with additional investigations undertaken by ORC and GNS Science. Any changes to the extent or characteristics of the flood-hazard areas are described, along with an explanation of why those changes have been made, and how they relate to feedback received from residents and landowners. Note that submissions relating to land-use controls are not addressed in this report, and submissions to do with land-use controls and activity status are being considered by DCC.

Where no changes to the mapped flood-hazard area extents have been made, this is also noted. A summary of the changes made is shown in Appendix 1.

Also for completeness, Chapter 5 of this report provides a summary of the flood hazard characteristics of the Strath Taieri area. No changes have been made to this section from what was provided in ORC (2014).

3. Scope

The geographical scope of this report is the Taieri Plain, which is a low-lying, relatively flat expanse of land, located to the west of Dunedin City (Figure 1), covering an area of 21,000 hectares. Used for rural, residential, commercial and industrial activities, the Taieri Plain 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 situated at the centre of the plain.

The largest settlements are located adjacent to major waterways, including the Taieri River (Outram and Allanton) and the Silver Stream (Mosgiel).

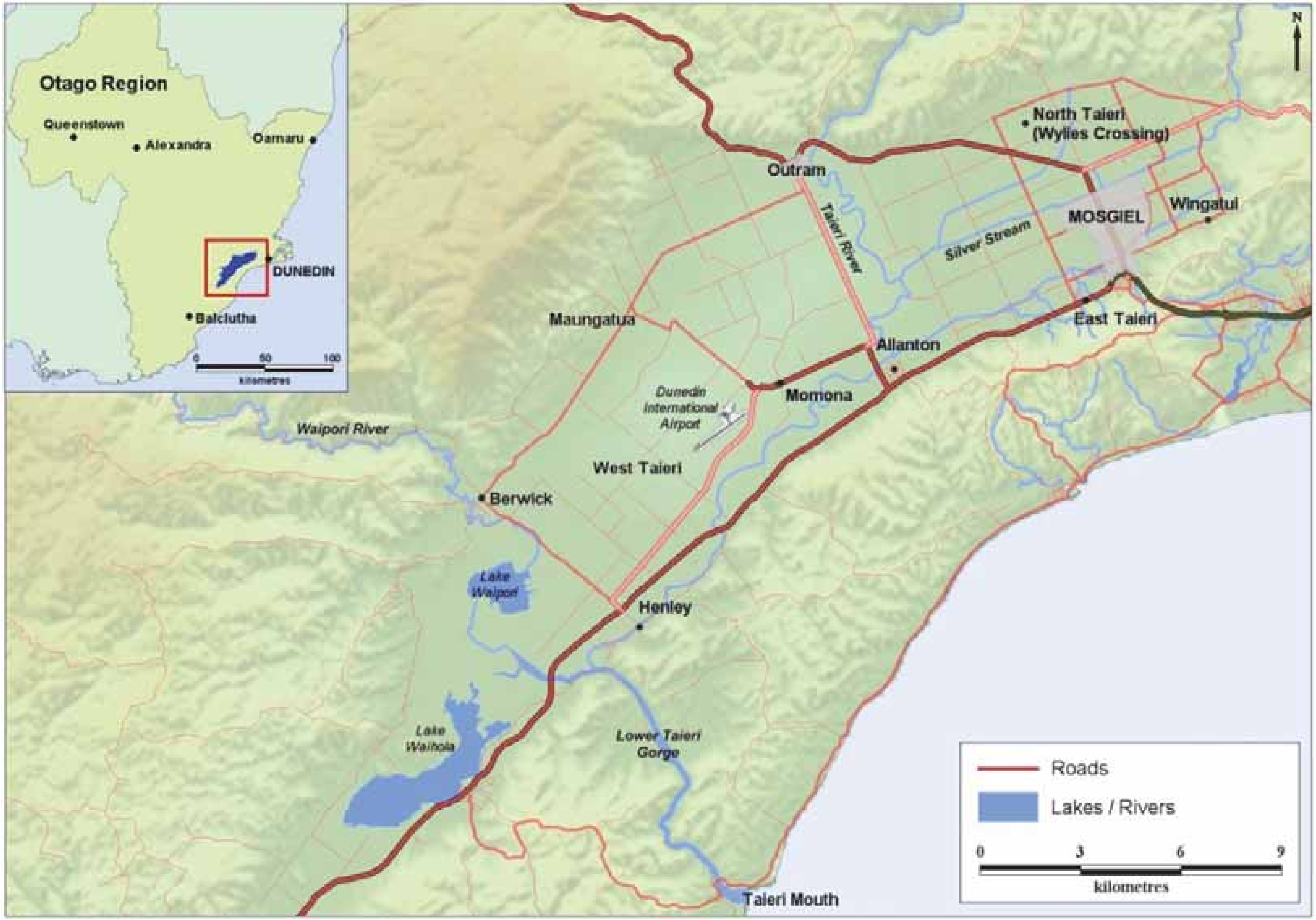

Figure 1. **Location map showing the topography and communities located on the Taieri Plain**

4. Flood-hazard characteristics of the Taieri Plain

Further analysis has been undertaken to refine the mapping of flood hazard across the Taieri Plain. This builds on initial mapping undertaken in 2006, following a flood in April of that year (DCC/ORC, 2006). Later refinements occurred in 2013 and 2014. The boundaries of mapped flood-hazard areas have been refined, using pre-existing information, additional information supplied by residents and recent alluvial-fan mapping on the margins of the East Taieri Plain.

The information used to refine the flood-hazard mapping and to investigate the matters raised in the public consultation and submission process is described below.

- Alluvial-fan-hazard and floodplain-hazard areas were differentiated using geomorphological mapping by GNS Science (2014). This work provided more detailed information than was previously available on the likely extent and flood-hazard characteristics of alluvial-fan areas on the margins of the East Taieri floodplain.
- Detailed (+/-0.15m accuracy) elevation models of the Taieri Plain. These allow for elevation profiling of the landscape so floodplain extents can be determined. This also allows for the identification of artificial floodbanks, drains and landforms that may impede or direct flow.
- Historical flood extents and flood-extent photos. This information was also used to inform previous flood-hazard mapping, and has been used here to verify the extents of any proposed changes to the boundaries of the flood-hazard areas.
- Observations by local residents, landowners and ORC field staff during previous flood events. Much of this information was also used previously, but was reviewed to verify any proposed changes to flood-hazard-area boundaries. Additional field visits were made by ORC natural-hazards staff to re-assess particular sites relating to specific submissions.

As a result of this work, ORC has further refined the mapped extent of some flood-hazard areas on the Taieri Plain. An overview map showing these refinements is presented in Figure 2, while more detailed maps for each area are included in the report. A summary of the changes made is shown in Appendix 1.

As indicated in Section 2, the Dunedin City District Plan is the primary means of providing sufficient control over land-use activities to avoid any net increase in flood risk, and to ensure areas with unacceptable flood risk are avoided. This report has been prepared by the ORC to inform the hazard maps and land-use controls to be included in the revised District Plan.

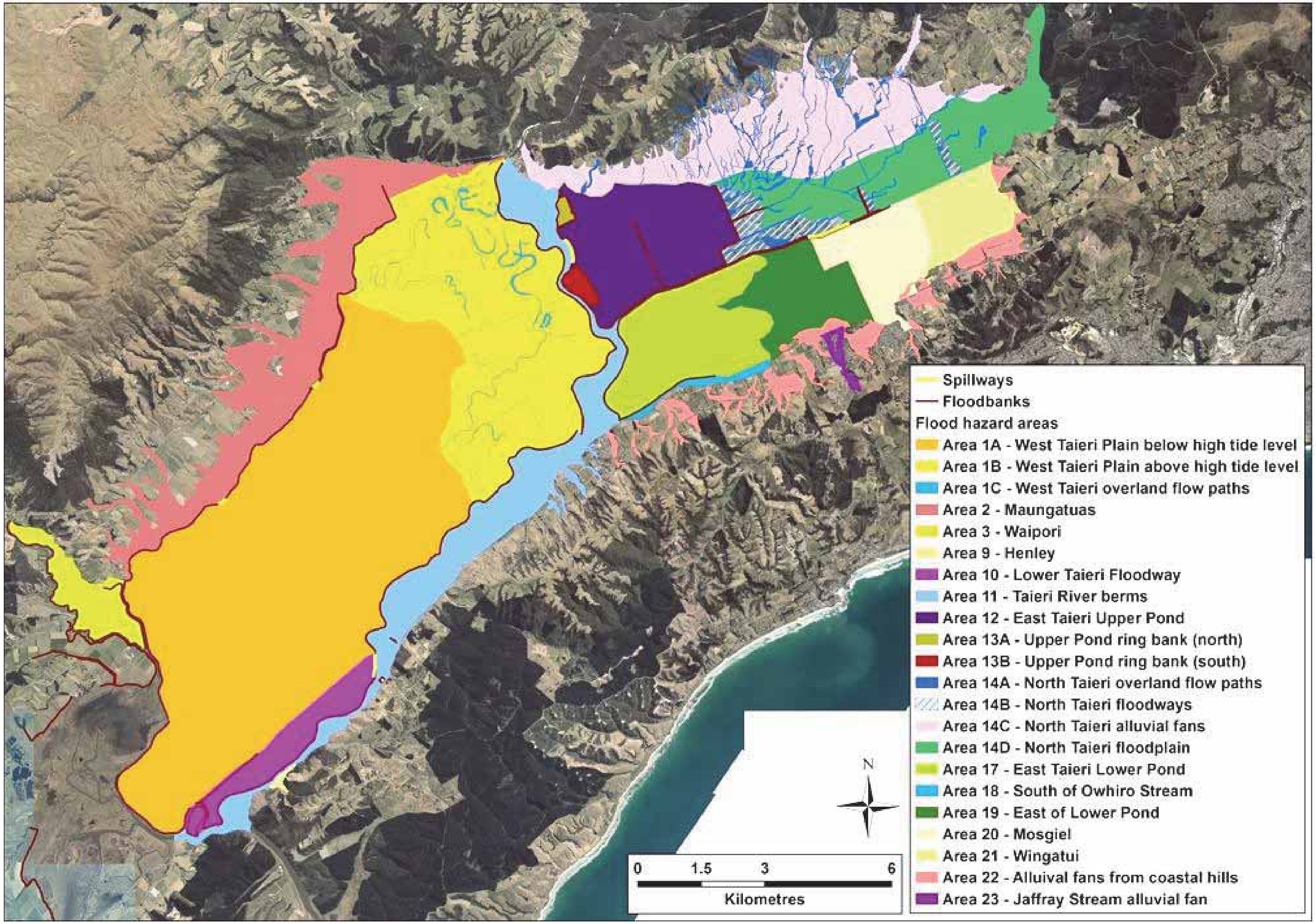

Figure 2. **Revised flood-hazard areas of the Taieri Plain**

4.1. Area 1A West Taieri Plain (below high-tide level)

Setting: As all of Area 1A is at, or below, the current high-tide level[3], it relies on Lower Taieri Flood Protection Scheme floodbanks to prevent it from being inundated on a day-to-day basis[4] and during flood events. The contour channel (to the north) intercepts and diverts runoff from the Maungatua Range to Lake Waipori. Flow from the Taieri River, Waipori River and runoff from the Maungatua Range would naturally flood Area 1A. This occurred not only during the February 1868 and May 1923 flood events, when the level of flood protection was more limited, but also during the June 1980 flood, due to numerous floodbank failures (ORC, 2013).

As gravity drainage is very limited, the area relies on two West Taieri Drainage Scheme pump stations and a network of drains to remove runoff and floodwater. Following flood events, it may take a considerable length of time to drain water ponding in Area 1A, due to the large volume of water that could pond in this area.

Flood-hazard characteristics and effects: Extensive ponding is the main type of hazard in this area, with depths ranging from less than 0.5m on the margins, to more than 3m in some places (Figure 3). Sources of flooding include the Taieri River to the south, Waipori River to the west, Maungatua Range to the north and internal runoff from areas 1A, 1B and 1C. The flood hazard associated with these waterways can be significant (ORC, 2013). The natural tendency of waterways to inundate Area 1A is mitigated to some extent by flood-protection and drainage schemes. As a result, flood hazard in this area is generally limited to ponding of a moderate depth and duration and low-velocity flows (see Scenario 1 and Figure 4 below).

However, the effects of flooding would be considerably greater if the flood protection and drainage schemes were to fail (i.e. they could no longer provide the intended level of protection), or if they were overwhelmed by a flood event larger than their intended design (see Scenario 2 and Figure 5). In these situations, significant damage to buildings and other assets could occur, and, in some circumstances, the velocity, depth and unpredictable nature of flood flows could be life-threatening (particularly in a floodbank breach situation).

The likely attributes of floodwater (depth, velocity and duration) during each of these two scenarios are listed below.

Scenario 1: **Flood protection and drainage schemes remain operational, and events smaller than design**	**Scenario 2:** **Flood protection and/or drainage schemes fail, or events larger than design**
Depth of water: 0.9 to 1m, but up to 3m in places if rainfall was exceptional **Duration of flooding: Few days to a few weeks** **Velocity: Generally low, apart from defined floodways and drains (Figure 3)**	**Depth of water: Generally 1m, but up to 3m in places** **Duration of flooding: Several weeks** **Velocity: Low in ponding areas to very high in close proximity to where failure or overtopping of floodbanks occurs**

[3] Normal tidal variation along the east coast of Otago is approximately 1m above or below mean sea level (NIWA, 2005).
[4] i.e. by the normal range of tidally influenced water levels experienced in the lower Taieri and Waipori rivers

4.1.1. Public submissions

One public submission relating specifically to flood hazard in Area 1A was received. The submission was that a particular property is more elevated than the surrounding land, and should therefore not be included within the flood-hazard area. Figure 3 shows that there are a few small pockets of land within Area 1A that are elevated slightly above the surrounding low-lying areas. However, extreme flood events or failure of the Lower Taieri Flood Protection Scheme can result in situations where these areas are isolated for extended periods, and/or are affected by low-level inundation (Figure 5). The effects of climate change and rising sea level will likely accentuate these issues.

No changes have been made to the extent of Area 1A.

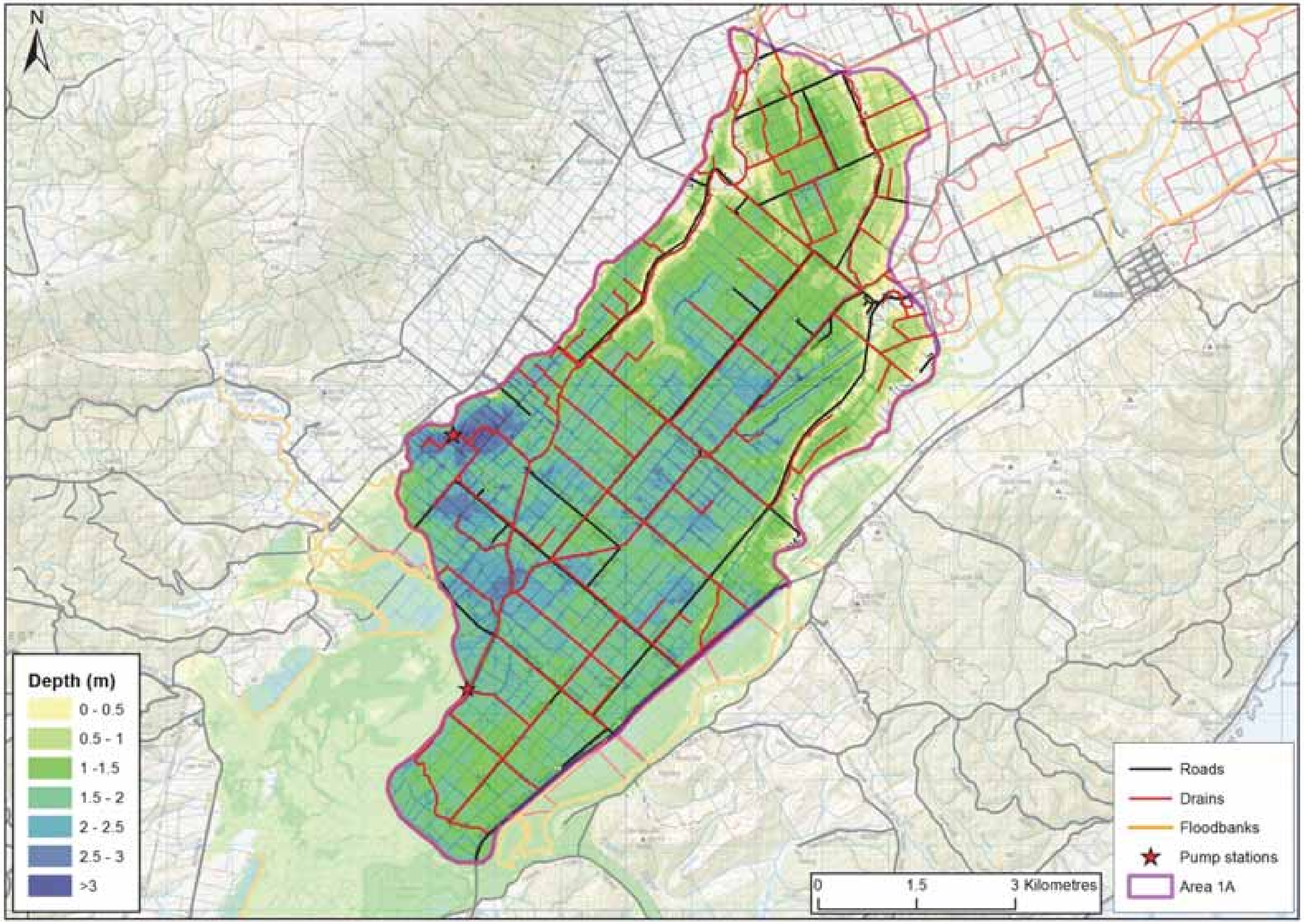

Figure 3 **Depth of inundation on the lower West Taieri Plain (Area 1A) at a water level of 1.5m above msl (the estimated level of the June 1980 flood)**

Figure 4. **Aerial view of ponding on the West Taieri Plain, resulting from internal runoff from areas 1A and 1B during heavy rainfall in June 2013 (195mm over eight days at the Riccarton Road rain gauge). Lakes Waipori and Waihola can be seen in the distance.**

Figure 5. **Aerial view (looking south) of flooding on the West Taieri, following the June 1980 flood event. Area 1A is to the right (west) of the 'flood-free' highway, while Areas 9, 10 and 11 are to the left.**

4.2. Area 1B West Taieri Plain (above high-tide level)

Setting: Area 1B is elevated sufficiently to be above the current tidal range (as observed in the lower reaches of the Taieri and Waipori rivers). However, it is still a natural flood plain, and historical records show it was inundated in February 1868, May 1923 and June 1980 (ORC, 2013). Parts of Area 1B are affected by internal runoff during heavy rainfall events, which can typically occur every few years (Figure 7). The area relies on Lower Taieri Flood Protection Scheme floodbanks and the Contour Channel to prevent it from being inundated during higher flows. It also relies on a network of drains to remove runoff. These scheduled drains and other natural overland flow paths (now mapped as Area 1C) provide an important function by conveying floodwater downslope to Area 1A, and to the two West Taieri Drainage Scheme pump stations. Structures and earthworks can impede or redirect this flow of water.

Flood-hazard characteristics and effects: Sources of flooding include the Taieri River to the east, the streams that drain the Maungatua Range to the north, and internal runoff and overland flow (ORC, 2013). The effects of flooding could be significant if Lower Taieri Flood Protection Scheme floodbanks were to fail (breach), or were overtopped by a flood event larger than their intended design. In such a situation, the velocity and depth of flood flows could damage buildings and other assets, move vehicles and make walking difficult or unsafe, and therefore present a possible risk to life. The consequences of a floodbank breach near Outram, in particular, would be significant, due to the potential impacts on this community.

Parts of Area 1B that are elevated relative to the surrounding land may still be isolated for extended periods, and/or be affected by low-level inundation.

The likely attributes of flood flows (depth, velocity and duration) during a floodbank breach or overtopping scenario, and also in the case of smaller (less than design) events are:

Scenario 1: **Flood protection and drainage schemes remain operational, and events smaller than design**	**Scenario 2:** **Flood protection and/or drainage schemes fail, or events larger than design**
Depth of water: 0.5m to 2.0m in runoff areas;[5] up to 2.5m in the natural-ponding area labelled X in Figure 6[6] **Duration of flooding: Few hours (runoff) to few days (ponding)** **Velocity: Low to medium (higher in drains and swales**	**The depth, duration and velocity on the downslope side of the Contour Channel and Taieri River floodbanks would vary, depending on the amount of water overtopping the bank, or the nature of floodbank failure** **Likely attributes for a failure of the Taieri River floodbanks are:** **Depth of water: 0.5m to 2.0m in runoff areas; up to 2.5m in the natural ponding area labelled X in Figure 6** **Duration of flooding: few hours (runoff) to several days (ponding)** **Velocity: medium to very high (highest near point of failure or overtopping).**

[5] Most (but not all) of these areas are now identified as Area 1C.
[6] Note that water can enter this low-lying area due to internal runoff (e.g. Scenario 1), or from more significant sources of flooding such as the Taieri River (Scenario 2)

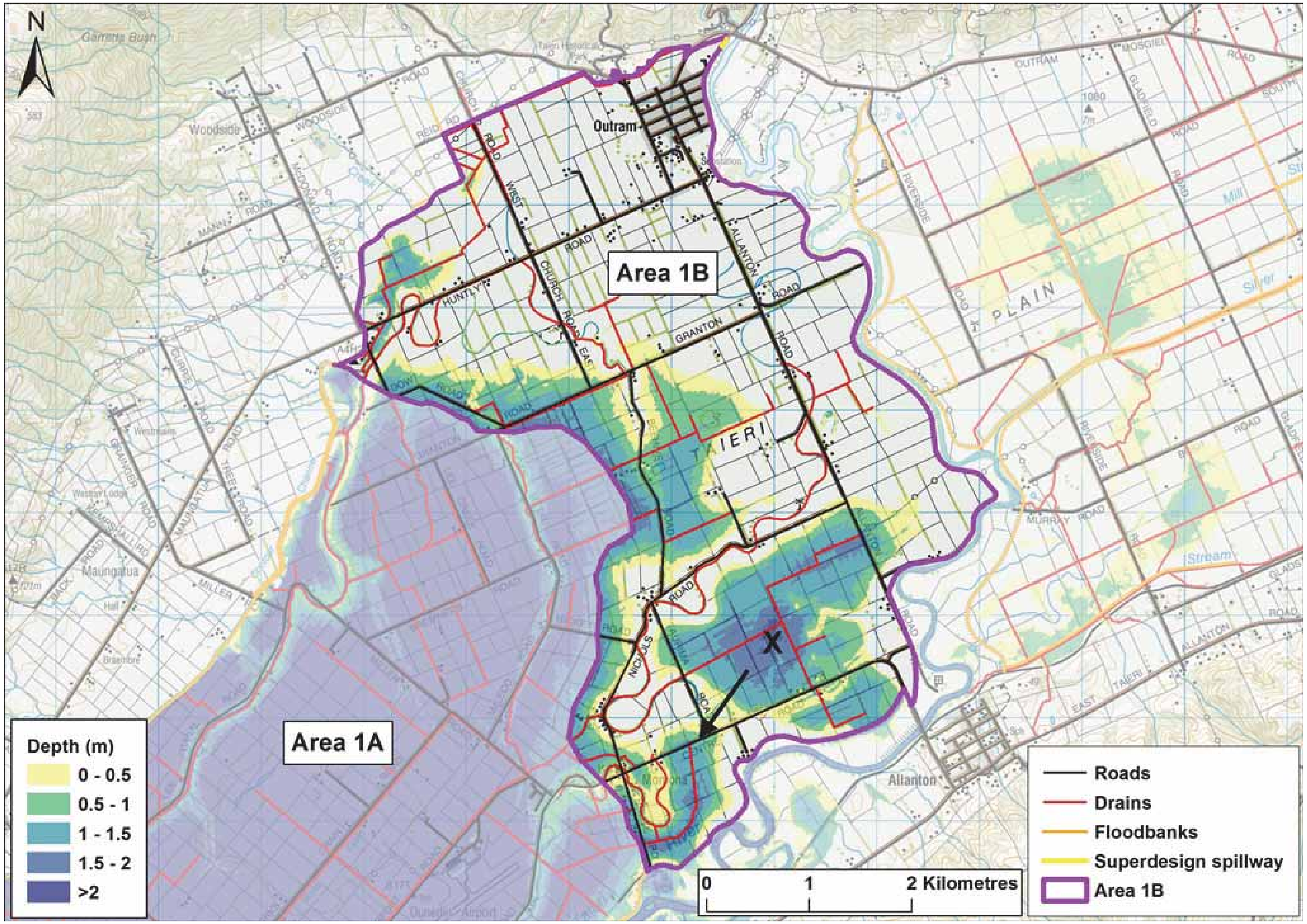

Figure 6. **Depth of inundation in the lowest-lying part of Area 1B if water was at a level where it began to overtop the ponding area labelled X (3.1m above msl). The black arrow shows the approximate location where water would initially overtop from 'X' and flow downslope to the southwest.**

Figure 7. **Top: Aerial view of ponding on the West Taieri Plain (looking south), resulting from internal runoff during heavy rainfall in June 2013 (195mm over 8 days at the Riccarton Road rain gauge). Bottom: Looking northeast across Area 1B, with the lowest-lying part (labelled X in Figure 6) circled in red, August 1978. The ponding areas can be seen in the distance.**

4.2.1. Public submissions

No submissions from the public were received relating specifically to Area 1B, and no changes have been made to the extent of the area. However, the parts of this area that are particularly low-lying, and/or are critical for the conveyance of floodwater, have been mapped separately as Area 1C.

4.3. Area 1C West Taieri overland flow paths

4.3.1. Setting and hazard characteristics

The physical setting of land mapped as Area 1C is similar to that of Area 1B, in that it is elevated sufficiently to be above the current tidal range, and that it relies on Lower Taieri Flood Protection Scheme floodbanks and the Contour Channel to limit the effects of flooding during higher flows. However, the 1C areas (Figure 8) comprise palaeochannels,[7] drains and natural overland flow paths within the wider 1B area that can convey and/or temporarily store runoff. As such, they can be exposed to floodwater flows and extensive ponding (Figure 7, Figure 10). The land within Area 1C, which may be affected by flooding, is defined approximately, as the characteristics of each flood event will differ, depending on the relative contributions of each catchment and the conditions within each flow path at the time of the event (e.g. debris blockages, antecedent water levels).

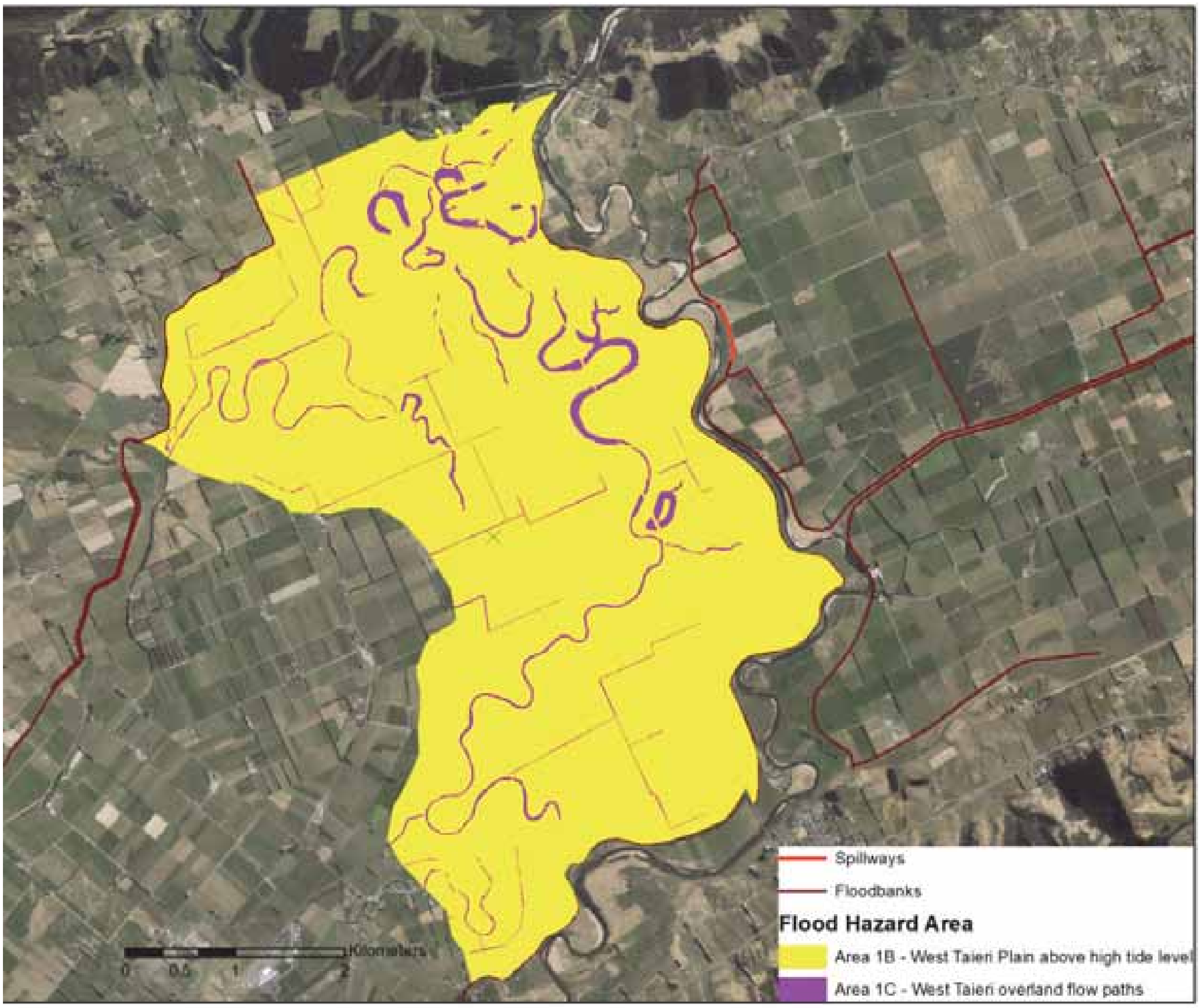

Figure 8. West Taieri overland flow paths (Area 1C), located within Area 1B

The Area 1C flow paths can provide an important function by conveying floodwater downslope to Area 1A, and to the two West Taieri Drainage Scheme pump stations. Structures and earthworks can impede or redirect this flow of water.

[7] inactive river or stream channels that may have been partially filled by younger sediments

The depth of water in these features ranges from reasonably shallow (<0.5m) (Figure 10) to more than 2m in the larger and more defined features (Figure 9). Similarly, the velocity of floodwater can vary from relatively slow to fast (more than 1m/s) in the major drains. Where the flow path is not currently impeded, the duration of flooding may be limited to a few hours during the time of peak-rainfall intensity. However, where there is no clear outlet, or where obstructions, such as road embankments, impede the drainage of water, the duration of flooding may be much longer, and in some cases require pumping to remove floodwater.

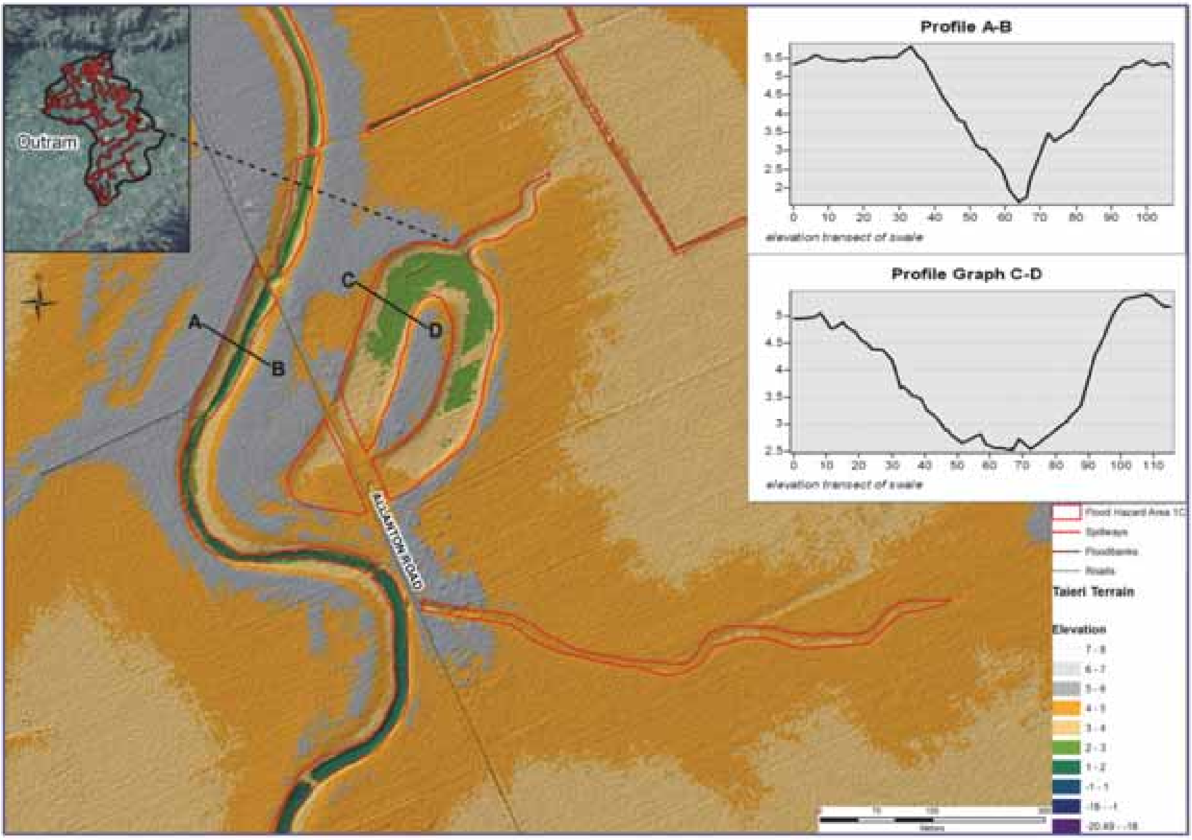

Figure 9. **Examples of palaeochannels (Profile C-D) with no obvious outlet, and drainage features (Profile A-B) mapped within Area 1C**

Figure 10. Water ponding around a residential property located within Area 1C, in July 2013

4.3.2. Public submissions

No submissions from the public were received relating specifically to land within Area 1C, or to the wider 1B area within which it sits. However, Area 1C is an additional flood-hazard area, which has been created and included in this report, following discussions with DCC staff and members of the public during the public submission process in June – August 2014.

The methodology used to map Area 1C is consistent with the approach taken on other parts of the Taieri Plain (e.g. Area 14A). Palaeochannels, swales and drains were mapped and the guidelines for mapping were the same as for Area 14A overland flow paths where a feature must have a catchment area upstream greater than 50 hectares, or the feature is greater than 500m in length, or the feature is greater than 400mm deep.

4.4. Area 2 Maungatuas

Setting: This gently sloping area (Figure 11 and Figure 12) is located between the steeper slopes of the Maungatua Range, and the flat, low-lying West Taieri Plain. Runoff from the streams that drain the Maungatua Range is collected by the Contour Channel and diverted into Lake Waipori. High-sediment loads in these streams have built alluvial-fan features (ORC, 2013) and can reduce the capacity of the Contour Channel during high-flow events. During peak flow, excess floodwater from the Contour Channel overflows into Areas 1A and 1B at numerous locations, including at two defined spillways (near Otokia and Miller Roads – see Figure 2).

Area 2 comprises the active-floodwater-dominant alluvial fans, mapped by Opus / GNS (2009), as well as other gently sloping land that lies between the 20m contour and the Contour Channel.

Flood-hazard characteristics and effects: Flood hazard in this area is derived from:

- the Contour Channel (although this is generally restricted to parts of Area 2 that lie immediately upslope from the Contour Channel)
- overland flow due to overtopping of the streams that drain the Maungatua Range
- the floodwater-dominant alluvial fans that have formed on the margins of these streams
- surface runoff.

Although sometimes ephemeral, the streams that drain the Maungatua Range can carry deep (up to 1m) and medium to fast flows during heavy-rainfall events, with large amounts of sand and gravel adding to their volume (Figure 13). Structures and earthworks can impede or redirect this flow of water. Flows of this nature are sufficient to damage buildings or other assets. Alluvial fans are dominant morphological landforms in this area (Figure 11), but can be inactive for long periods of time and their streams are often dry or inconspicuous, creating the impression that little or no hazard exists. Channels are often very mobile, quickly and easily changing position during high-flow events. This, combined with their steep gradient and limited warning of flood events, means they have the potential to be destructive and unpredictable.

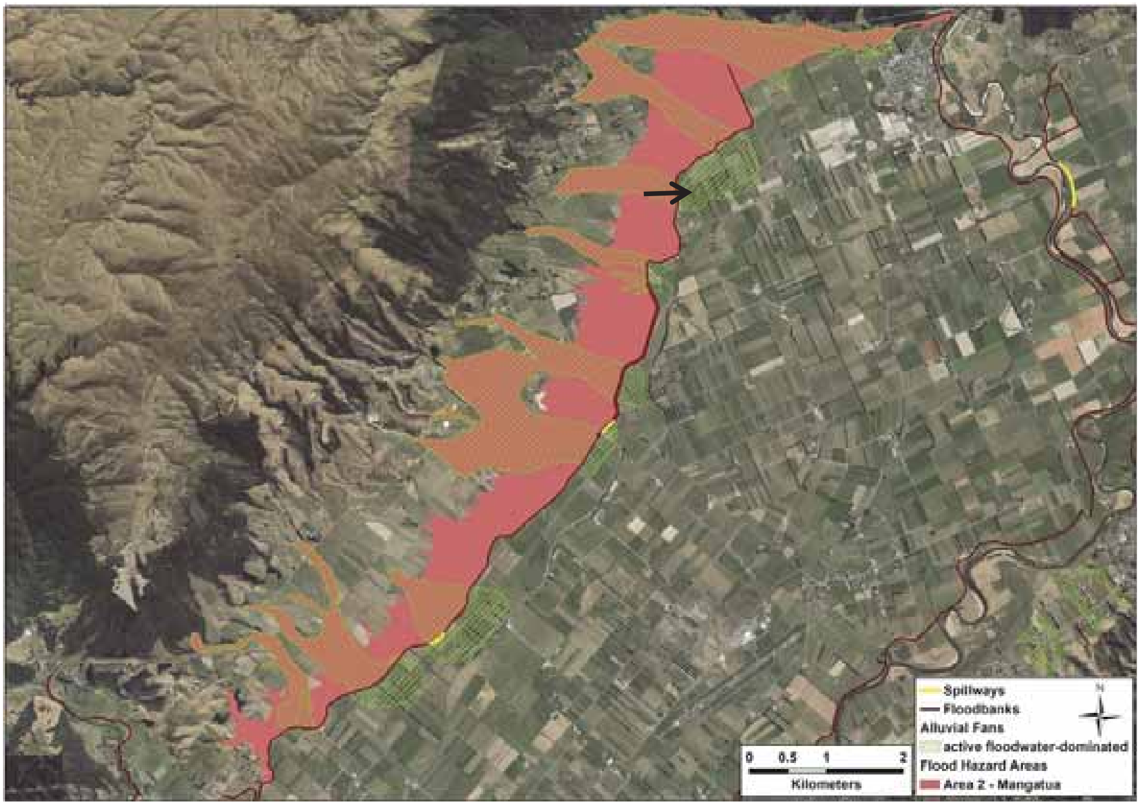

Figure 11. **Extent of Area 2, and alluvial-fan features, mapped by Opus / GNS Science (2009). The black arrow identifies the approximate location and direction of the view shown in Figure 12.**

Figure 12. **Looking east across the lower reaches of an active flood-water-dominant alluvial fan that drains from the Maungatua Range**

Figure 13. Deposition of gravel in the Contour Channel from a tributary hill stream

4.4.1. Public submissions

No submissions from the public were received for this area, and there were no changes made to its extent.

4.5. Area 3 Waipori

Setting: Area 3 is situated downstream from where the Waipori River exits the steep hill country to the west and discharges onto the flat, low-lying West Taieri Plain. A number of smaller streams also converge on this area, and runoff from the Maungatua Range is directed past this area by the Contour Channel from Area 2 and diverted into Lake Waipori.

A significant part of this area (which includes the settlement of Berwick) lies at, or below, the current high-tide level.[8] Figure 18 shows that the topography of this floodplain area gradually slopes from about 6m above msl in the northwest, to below msl in the southeast. This figure also shows (as a contour) the highest-water level experienced in Lake Waipori since records began in 1985.[9]

This area was extensively inundated in the floods of 1868, 1923 and 1980 (ORC, 2013) (Figure 15). Floodbanks that are part of the Lower Taieri Flood Protection Scheme provide a low level of protection during flood events. The ability of floodwater to drain from this area is affected by the level of Lake Waipori, which in turn can be affected by conditions at the mouth of the Taieri River.

Flood-hazard characteristics and effects: Extensive ponding is the predominant type of flood hazard in this area, although surface runoff and peak-river flows can also create a hazard. It is exposed to flood hazard from the Waipori River, the streams along the Maungatua Range (via the Contour Channel)[10] and Lake Waipori. Flood-hazard effects are likely to be exacerbated by changes in climate or sea level.

Flood-hazard characteristics can be variable across Area 3 due to variations in topography, and can also vary between flood events due to the relative contributions of different catchments and the performance of Lower Taieri Flood Protection Scheme assets. Inundation depths of up to 2m are possible, with velocities ranging from slow (in ponding areas) to fast where surface runoff occurs.

The reliance on earth floodbanks for flood protection in Area 3 means that there is some residual risk[11] exposure (failure before the design capacity is reached). This is of particular relevance to the settlement of Berwick given the topography and its close proximity to the Waipori River true-left floodbank (Figure 14).

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[8] Normal tidal variation along the east coast of Otago is approximately 1m above or below msl (NIWA, 2005).
[9] 1.967m above msl, observed on 30th May, 2010
[10] The Contour Channel intercepts runoff from the Maungatua Range and discharges these flows into Lake Waipori.
[11] Residual risk is that part of the risk that is not mitigated, and includes risks due to events larger than the assumed design event.

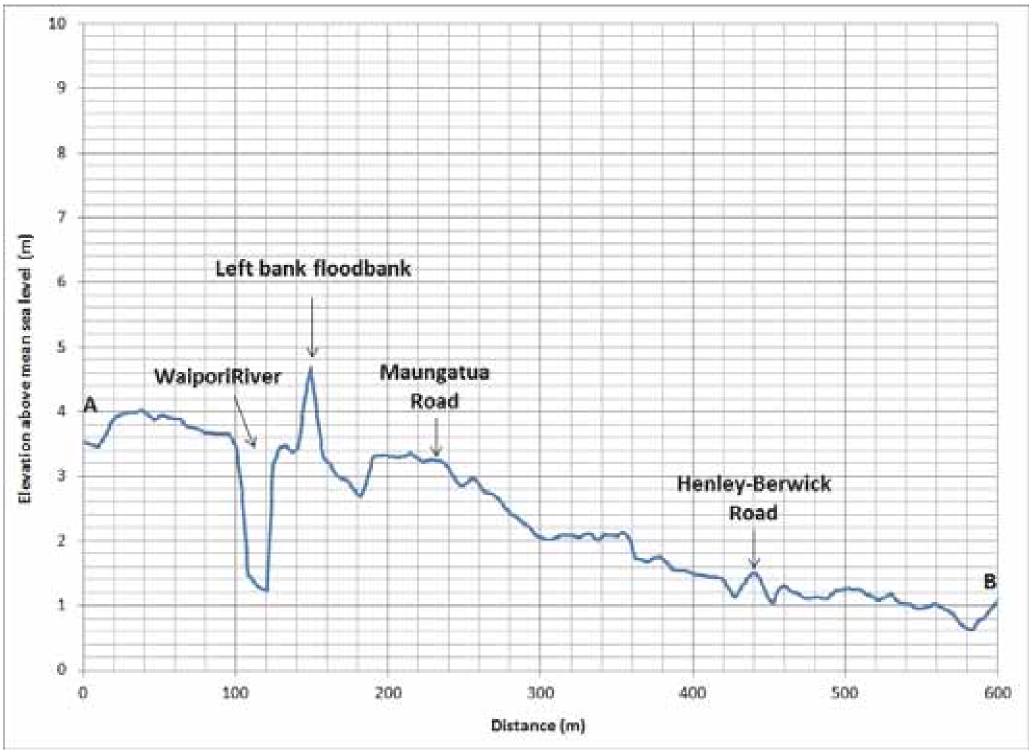

Figure 14. Cross-section A-B through Berwick, showing the low-lying elevation of the settlement relative to the Waipori River main channel and berm areas, and to the Waipori River true-left floodbank. The location of the cross-section is shown in Figure 19.

Figure 15. West Taieri Plain, looking north, with Berwick in the left foreground, June 1980. The photo was not taken at the maximum extent of flooding.

Figure 16. **Aerial view of Waipori River No. 1 contour channel bridge, looking towards Berwick, May 1977. The photo was not necessarily taken at the peak of the flood.**

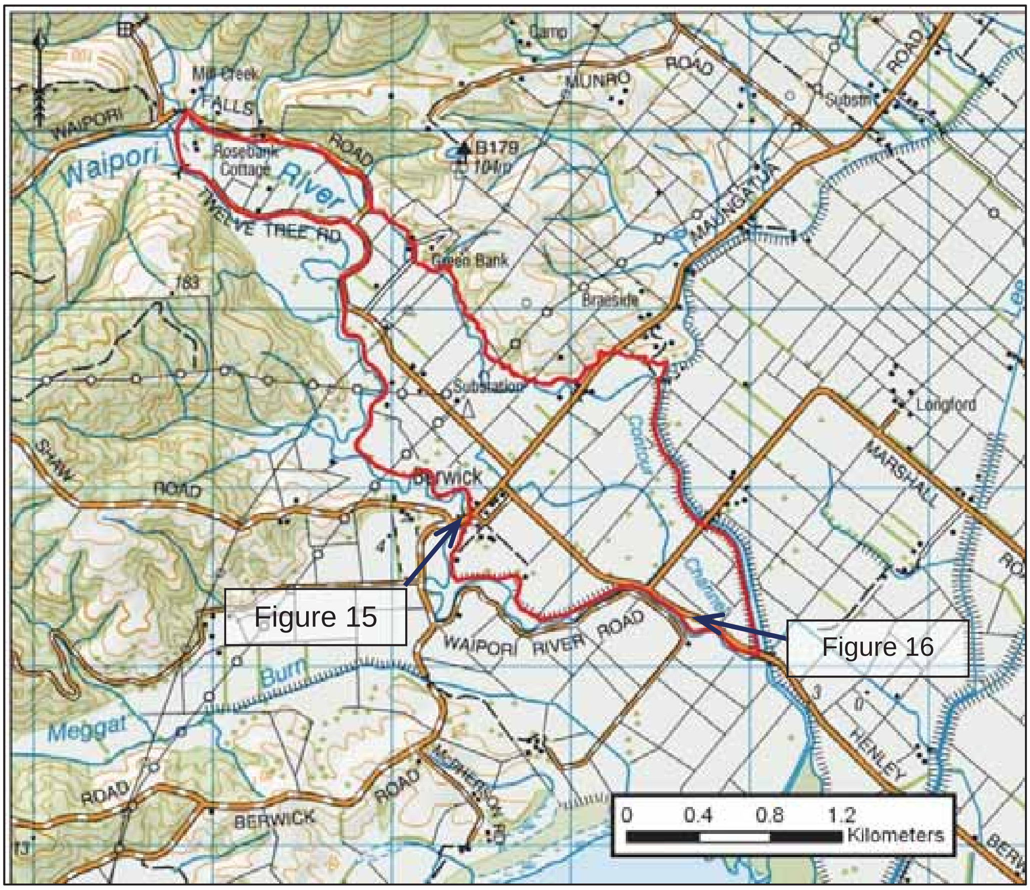

Figure 17. **Map of Area 3 (outlined in red), along with the location and direction of aerial views shown in Figure 15 and Figure 16**

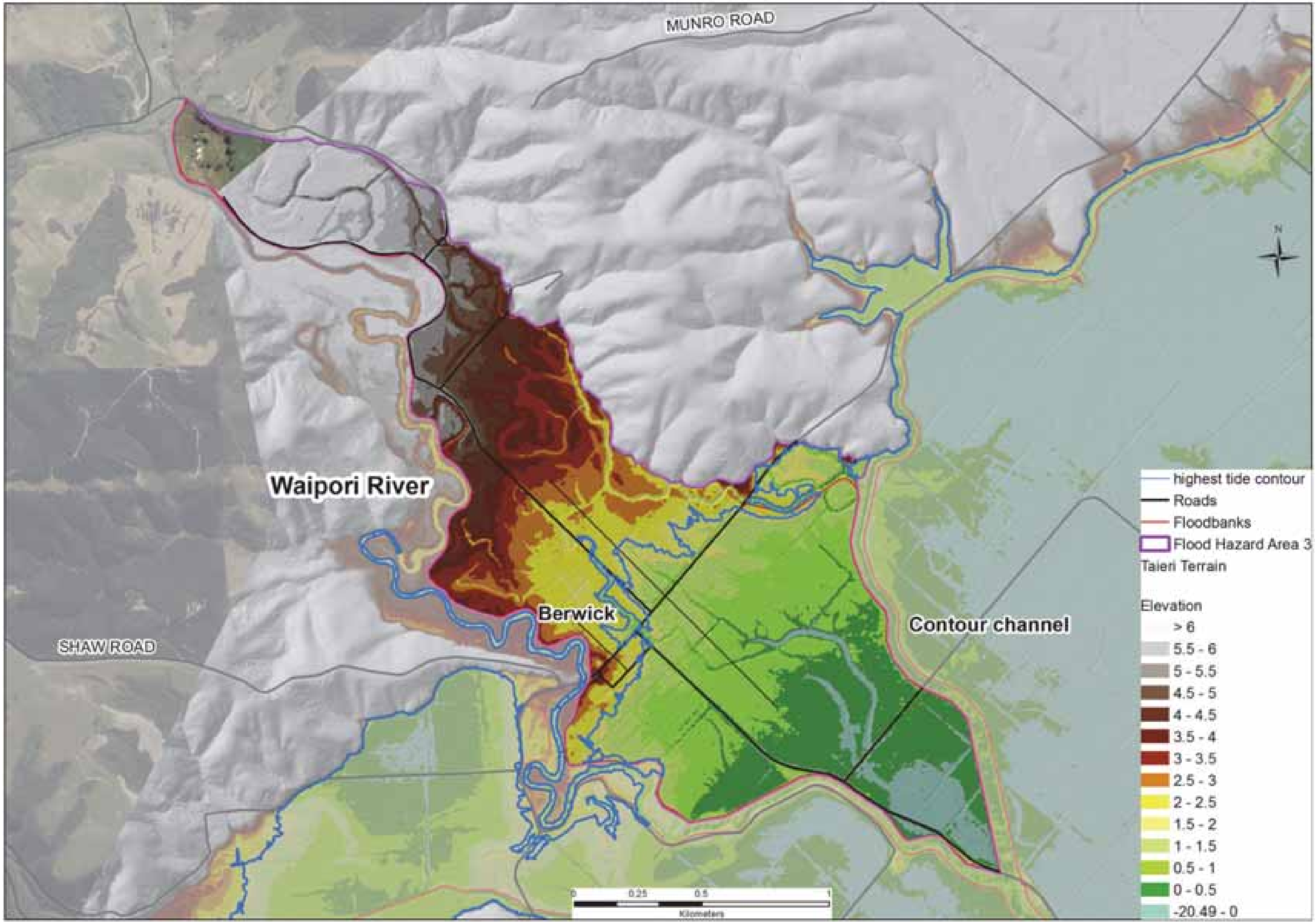

Figure 18. **Topography of Area 3, showing the highest-tide level observed at Lake Waipori of 1.967m above msl (blue line)**

4.5.1. Public submissions and further assessment of flood hazard

Six public submissions were received specifically relating to flood hazard in Area 3, all from residents of Berwick. Not all of these relate directly to the hazard mapping; although several state that specific properties are not prone to flooding. Most submissions refer to the restrictions on land use proposed by the DCC in 2014 as being too restrictive, based on the level of hazard in Berwick.

Observations of previous flood events (e.g. Figure 15) and LiDAR[12] elevation data (Figure 19) show that much of this area has been, or is likely to be, affected by flooding. While some historical flood events may not have inundated all of Berwick, large events are likely to inundate much of the settlement. Figure 18 and Figure 19 show that there are small pockets of land within Area 3 that are elevated slightly above surrounding lower-lying areas. However, large flood events or floodbank failure can result in situations where these areas are isolated for extended periods, and/or be affected by low-level inundation.

In previous events (including April 2006), Lake Mahinerangi has acted as a ‘buffer’ to reduce the effects of flood events, through the temporary storage of peak flows in the Waipori River. Antecedent conditions, including flood events with extended or multiple peaks, may result in Lake Mahinerangi having limited-storage capacity, which may, however, reduce any buffering effect. The level of protection from the Waipori River provided by Lower Taieri Flood Protection Scheme floodbanks is limited, roughly equivalent to a peak flow with a 10% chance of occurrence in any year (i.e. a ‘10-year flood’).

[12] **Li**ght **D**etection and **R**anging – a mass of spot-height information captured over a wide area using an aircraft mounted laser. ORC’s LiDAR dataset on the Taieri Plain has a vertical accuracy of +/- 0.14m and was collected in 2004.

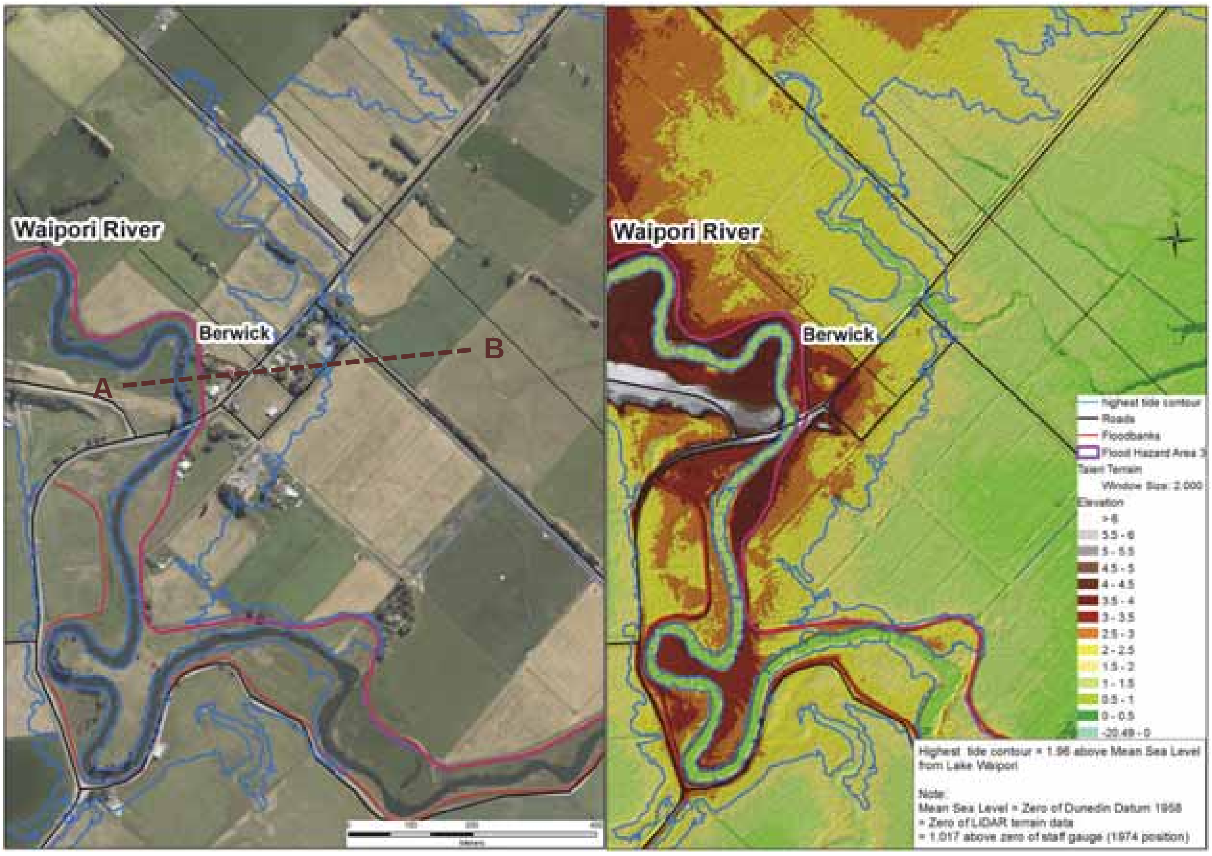

Figure 19. **The highest-tide level observed at Lake Waipori of 1.967m above msl (blue line) at Berwick, and topography of the same area. The location of cross section A-B (as shown in Figure 14) is shown on the left image.**

Much of the area is below the current high-tide level. Predicted changes in climate and sea level will probably exacerbate the effects of flooding, through larger or more frequent flood events, higher sea levels[13], or a combination of these processes.

4.6. Areas 4 & 5 South of Waipori and South of Meggatburn (Clutha District)

The characteristics of flood hazard in these two areas are similar to those in Area 3. See ORC (2013) for more detail.

4.7. Areas 6, 7 & 8 Lakes Waipori and Waihola (Clutha District)

These areas are below current msl and are exposed to flood hazard from surrounding hill catchments and lakes Waipori and Waihola. See ORC (2013) for more detail.

[13] Resulting in higher levels in the Taieri River and the Waipori and Waihola lakes complex.

4.8. Area 9 Henley

Setting: Henley is a low-lying area, with much of the land being less than 1m above current msl (Figure 20). The area has been flooded on numerous occasions (ORC, 2013). A low floodbank constructed on the true-left bank of the Taieri River, near the Henley settlement in the 1990s, is part of the Lower Taieri Flood Protection Scheme and provides protection from small-flood events in the Taieri River. Despite the floodbank, flooding of parts of this area typically occurs every few years. This part of the Taieri River is subject to tidal influences.

Runoff from the coastal hills to the south flows into this area during rainfall events (Figure 24). The runoff is generated mainly by one catchment (about 138ha), whose outlet is located at the southern end of the Henley township. A basic drainage network, composed of short ditches and flap-gated culverts (located under the road and the low-lying floodbank), convey the runoff from the coastal-hill catchments to the Taieri River.

Flood-hazard characteristics and effects: Sources of flooding include the Taieri River, and runoff from the hills to the south. During and after significant rainfall events, high-water levels in the Taieri River prevent the runoff from the hill catchments from discharging into the Taieri River. The outlet culverts of the drainage network, collecting the runoff from the coastal-hill catchments, are equipped with flap gates that shut when the Taieri River is high, resulting in ponding on the landward side of the floodbank. Depending on the extent and depth of ponding, houses with low-floor levels can be flooded. Additionally, if these flap gates cannot close properly, water from the Taieri River can flow back up in the drainage network and flood the area located on the landward side of the low-lying floodbank.

Runoff from two smaller catchments behind Henley (3ha and 8ha, as shown in Figure 24), and from rainfall accumulation within Area 9, also contribute on a smaller scale to the ponding on the landward side of the floodbank when the Taieri River is high.

The maximum depth of inundation during the June 1980 flood in the Taieri River was approximately 1.5m, and lasted for a few days on the more elevated margins of Henley to a few weeks on lower-lying areas (Figure 23). Velocity of floodwater is generally slow.

This area can also be affected by sedimentation in the form of debris and/or floodwater flows from the coastal hills to the south, during extreme rainfall events. The effects of flooding will be exacerbated by changes in climate or sea level. The Henley community is regularly isolated during flood events, and the threat of heavy-rainfall / high-flow events can cause anxiety for local residents.

Figure 20. **Left: 2013 aerial photo of the Henley area showing the extent of Area 9. Right: Topography of the Henley area**

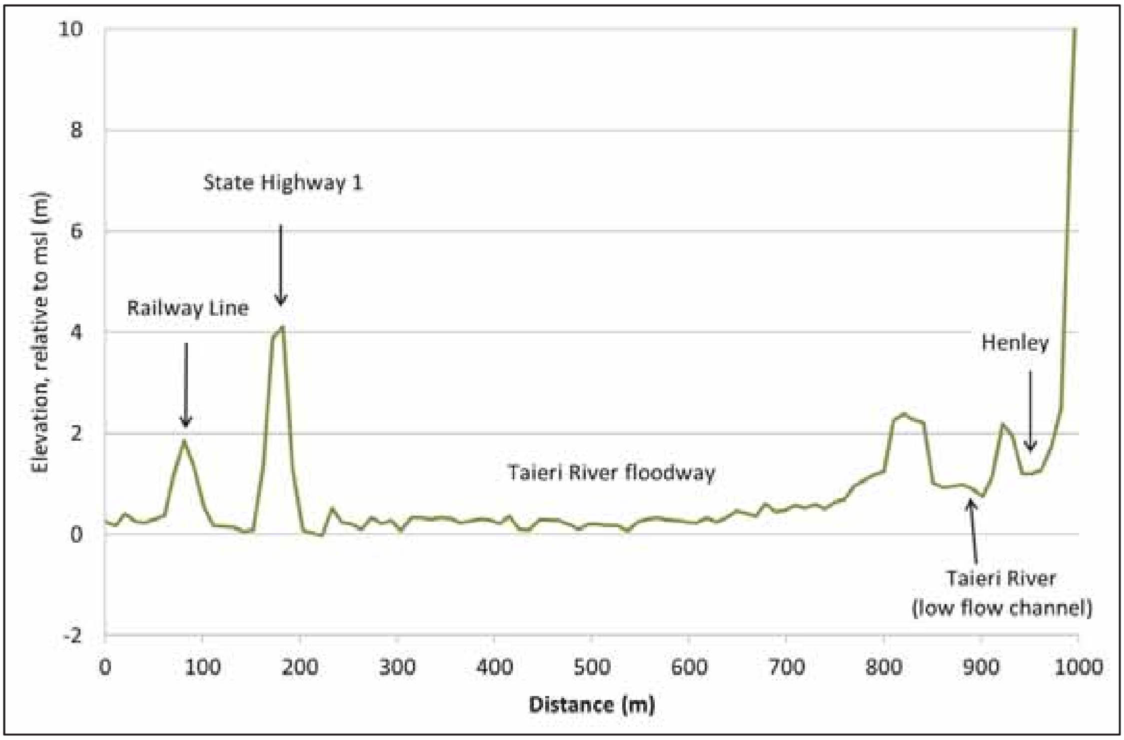

Figure 21. **Cross-section from the West Taieri Plain to Henley, just upstream of Henley-Berwick Road**

Figure 22. **Henley, 29 May 2010 (Source: ODT)**

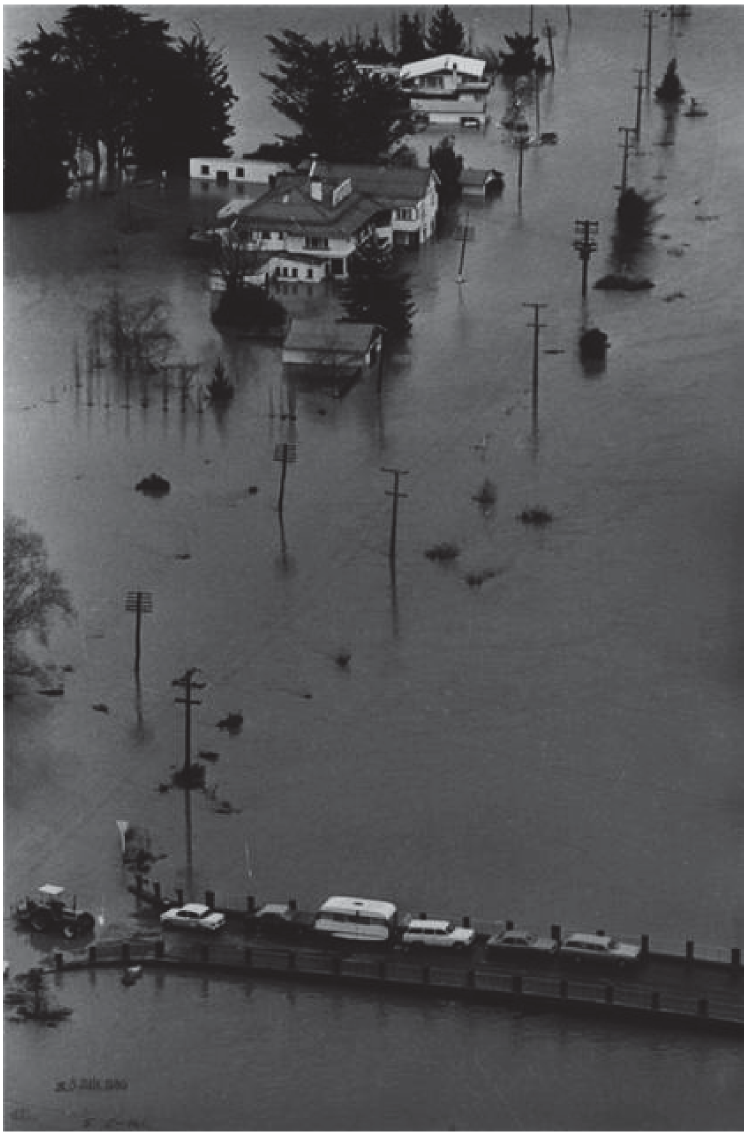

Figure 23. Henley, 5 June 1980 (Source: ODT)

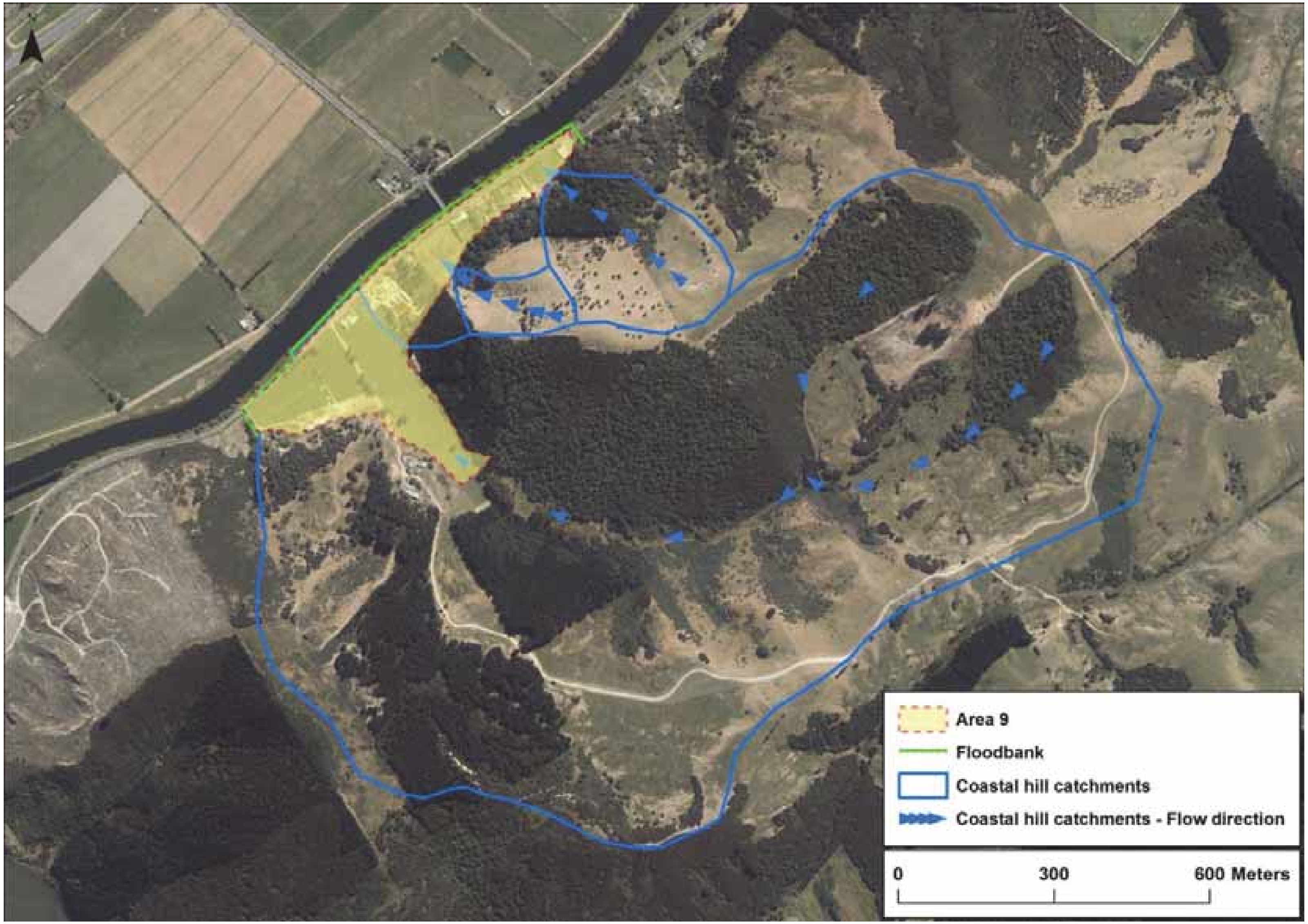

Figure 24. **Coastal-hill catchments behind Henley, and general-flow direction**

4.8.1. Public submissions

No formal submissions from the public were received that related specifically to Area 9. However, an on-site meeting between three landholders and ORC natural-hazards staff was held in September 2014. The feedback received at that meeting was that the southern boundary of Area 9 (adjacent to the village) could be refined further, but that there were few, if any, suitable locations for new houses to be built within the village, and that Henley was regularly isolated during flood events.

The extent of Area 9 has been modified slightly, and now follows the 4m contour more precisely along the base of the hills adjacent to the village. The 4m contour is the crest level of the 'flood-free' highway, upstream of the SH1 – Henley-Berwick Road intersection.

4.9. Areas 10 & 11 Lower Taieri Floodway and Taieri River berms

Setting: These areas consist of the berms that lie between the Taieri River floodbanks, or downstream of Allanton, between the foothills on the true-left bank and the Taieri River floodbank on the true-right bank (Figure 25). They are exposed to flooding from the Taieri River, and to a lesser degree, the Silver Stream and Owhiro Stream. They play a crucial role in the conveyance and temporary storage of floodwater and hence the mitigation of flood hazard for other parts of the Taieri Plain. Area 10 is generally lower lying than Area 11, and therefore has less ability to drain by gravity. Tidal effects are observed as far upstream as Allanton, although these are largely drowned out and have little effect on river levels during floods. Low-lying parts of Allanton are situated within Area 11, and some were flooded in June 1980 (ORC, 2013), although there are very few residential dwellings in this area.

Flood-hazard characteristics and effects: These areas are typically flooded annually. The maximum depth during a major Taieri River flood event is 2.5 to 4.5m, with velocities of over 1m/s in some places. Any buildings or other assets located in these two areas would be significantly damaged or destroyed during major-flood events and, in many circumstances, the velocity, depth and unpredictable nature of flood flows would be life-threatening. The effects of flooding will be exacerbated by changes in climate or sea level.

Figure 25. Lower Taieri floodway, looking downstream to Henley, 31 July 2007. Several rows of trees and balage lie perpendicular to the direction of flow.

4.9.1. Public submissions and further investigations

Five submissions were received from residents of Allanton that relate to Area 11. In general, these identified that the boundary of Area 11 in the vicinity of Allanton did not accurately represent the true-flood hazard extent. One resident identified that their residential dwelling sits on an elevated mound well above the maximum-flood level of the Taieri River, and it is only the gully next to the house that floods. Further investigation by ORC natural-hazards staff has resulted in a revised flood-hazard extent to better represent low-lying, flood-prone land, adjacent to Allanton, and this is shown in Figure 28.

The further investigations relied on topographic data (LiDAR), the surveyed crest level of the floodbank on the true-right (northern) bank of the Taieri River and historical imagery (e.g. Figure 26 and Figure 27).

Figure 26. **Aerial view (towards the southwest) of Areas 10 and 11, following the 1980 flood**

Figure 27. Aerial view (towards the north) of Area 11, following the 1980 flood

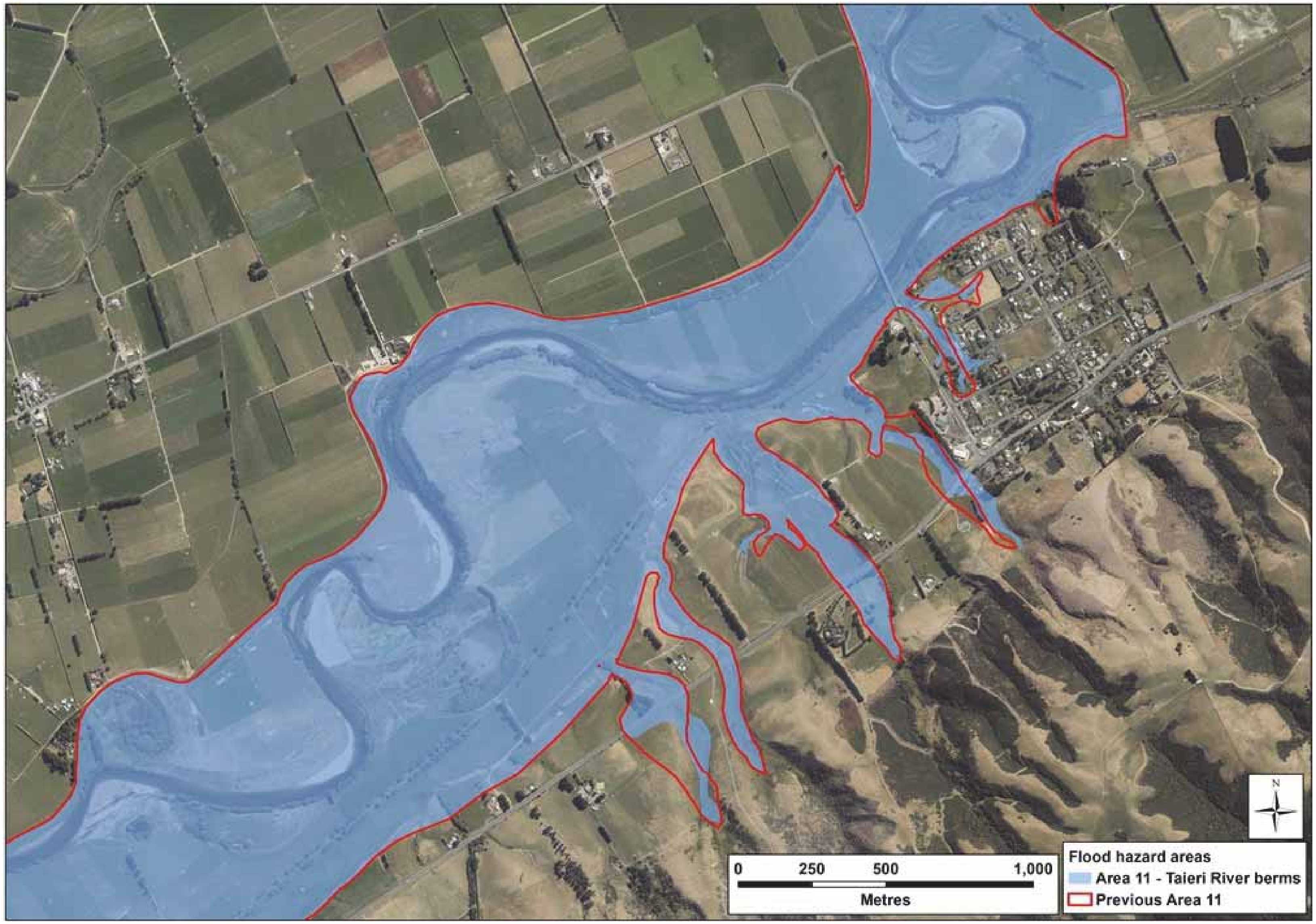

Figure 28. **The Allanton area, showing the revised extent of Area 11 (shaded blue) and the original extent (red line)**

4.10. Area 12 East Taieri Upper Pond

Setting: Historically, this area flooded frequently for long periods because it is naturally low-lying. The perimeter of Area 12 is the possible extent of ponding within the East Taieri Upper Pond. The eastern boundary of the area is defined by the Upper Pond cut-off bank (Figure 31). Without the cut-off bank, the pond would extend further east. The northern extent of Area 12 generally follows the 108.4m contour, which is the height of the Upper Pond cut-off bank and the Silver Stream true-right floodbank.

The area is separated from the Taieri River to the west by floodbanks that are part of the Lower Taieri Flood Protection Scheme. Water from the Taieri River enters this area over the Riverside spillway at a flow (in the Taieri River at Outram) that has an assessed return period of about ten years (Figure 29, Figure 30). The Riverside spillway was destroyed by a flood event in December 1993 (ORC, 2013), and improvements were made to the integrity of the spillway in 2013 to reduce the likelihood of it failing while in operation and causing rapid uncontrolled release of water from the Taieri River into the Upper Pond.

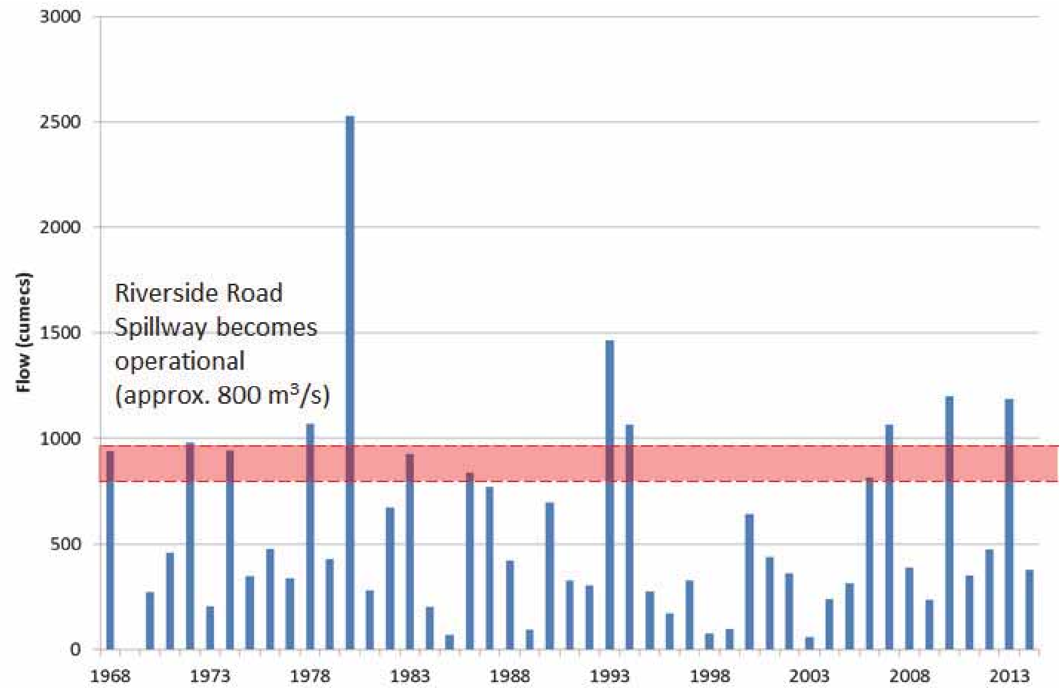

Figure 29. **Taieri River observed flood peaks, 1968 - 2014**

Flood-hazard characteristics and effects: Flood hazard relates mainly to the Taieri River, but also to the Silver Stream, Mill Creek and hill catchments to the north and internal runoff. Flooding can occur from any one of these sources, or in combination. Ponding can reach depths of up to 4m or more if water was to reach the crest of the cut-off bank or the Silver Stream floodbank (Figure 32), and can last for several weeks. If the Taieri River floodbanks, Silver Stream floodbank or the Riverside spillway were to fail, or if they were overwhelmed by a flood event larger than their intended design, then the effects of flooding may also include water travelling at medium to high velocities, particularly in close proximity to that failure.

4.10.1. Public submissions

No public submissions were received that specifically relate to Area 12, and no changes have been made to the extent of this area.

Figure 30. Taieri River flows spilling into Area 12 on 29 May 2010. (Photo courtesy of Otago Daily Times)

Figure 31. Water ponding in Area 12 on 31 May 2010. The Upper Pond cut-off bank is at the bottom of the image.

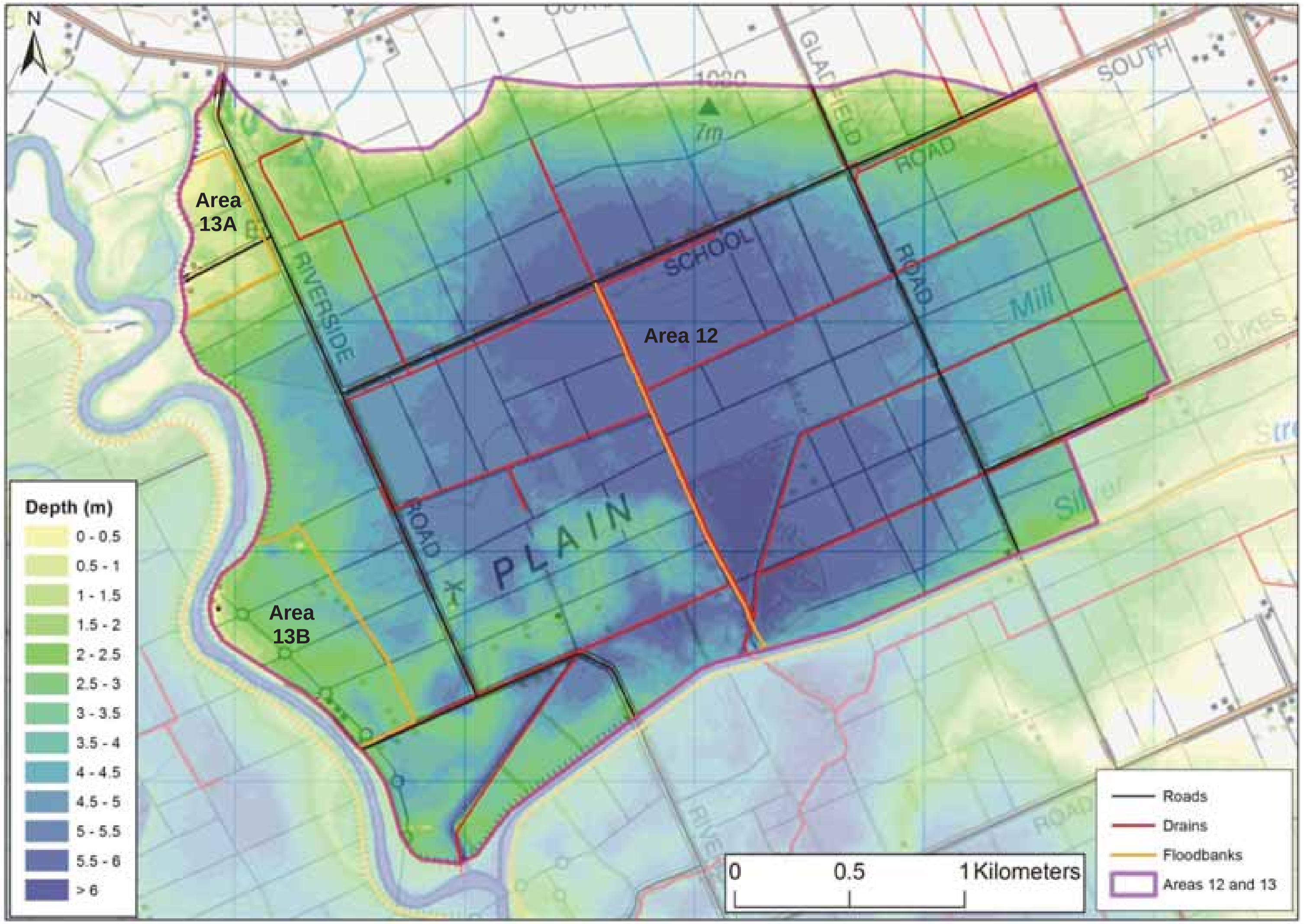

Figure 32. **Depth of inundation in Areas 12, 13A and 13B if water were to reach the crest of the upper pond cut-off bank, or the Silver Stream floodbank**

4.11. Area 13 Upper Pond Ring Banks

Setting: Land that has been isolated from Area 12 by the construction of ring banks in the 1990s, and therefore provided with a higher standard of protection, is included within Area 13. The ring banks around these two areas supplement rather than replace the primary floodbanks on the Taieri River and Silver Stream. The two areas are separated from the Taieri River to the west by floodbanks that are part of the Lower Taieri Flood Protection Scheme (Figure 32). As for Area 12, these areas historically flooded frequently for long periods because they are naturally low-lying and are in close proximity to the Taieri River. These two areas were flooded in the 1868, 1923[14] and 1980 events (Figure 33).

No changes have been made to the extent of Area 13, as their margins are well defined by the ring banks. However, for clarity, they have been labelled Area 13A (north) and 13B (south), as shown on Figure 32.

Flood-hazard characteristics and effects: As for Area 12, flood hazard relates to the Taieri River, Silver Stream, Mill Creek, hill catchments to the north and internal runoff. If water were to reach the crest of the cut-off bank or the Silver Stream floodbank, ponding could reach depths of 1m or more in Area 13A, and 2.5m or more in Area 13B (Figure 32), and could last for several weeks. If the Taieri River floodbanks or Area 13 ring banks were to fail, or if they were overwhelmed by a flood event larger than their intended design, then the effects of flooding may also include water travelling at medium to high velocities, particularly in close proximity to that failure.

As well as experiencing a greater depth of ponding than Area 13A, Area 13B is more likely to be isolated by floodwater during large events, and the duration of ponding is likely to be longer. The ring bank surrounding Area 13B (along with the Riverside spillway into the Upper Pond) was breached during the December 1993 event, as shown in Figure 36.

[14] The significance of the 1868 and 1923 events, being just two of many floods on record, is that they occurred before the construction of any major, coordinated flood-protection works, and therefore reflect the underlying flood hazard of the Taieri Plain.

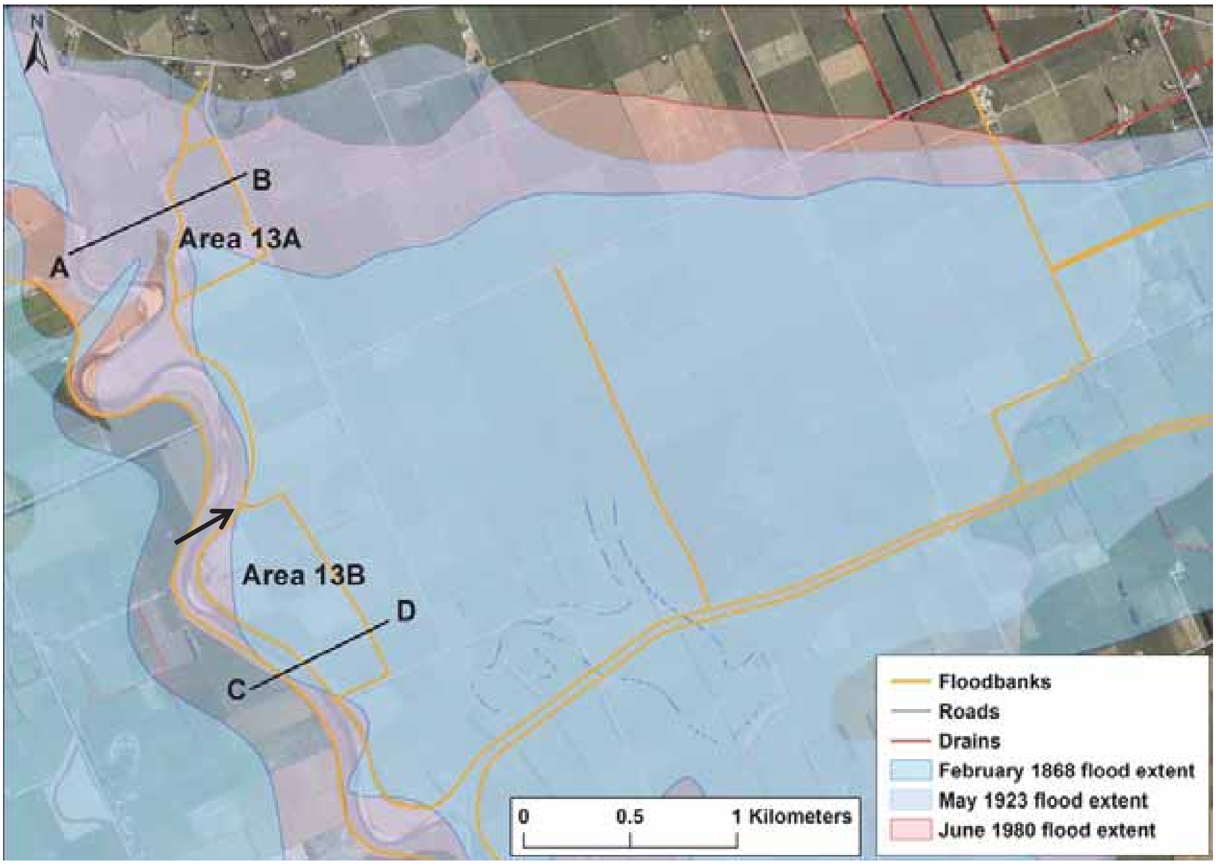

Figure 33. **Aerial photo showing the location of Areas 13A and 13B, and the indicative extent of the 1868, 1923 and 1980 floods. The location of the cross-sections shown in Figure 34 and Figure 35 is also shown, along with the location and direction of the photo shown in Figure 36 (black arrow).**

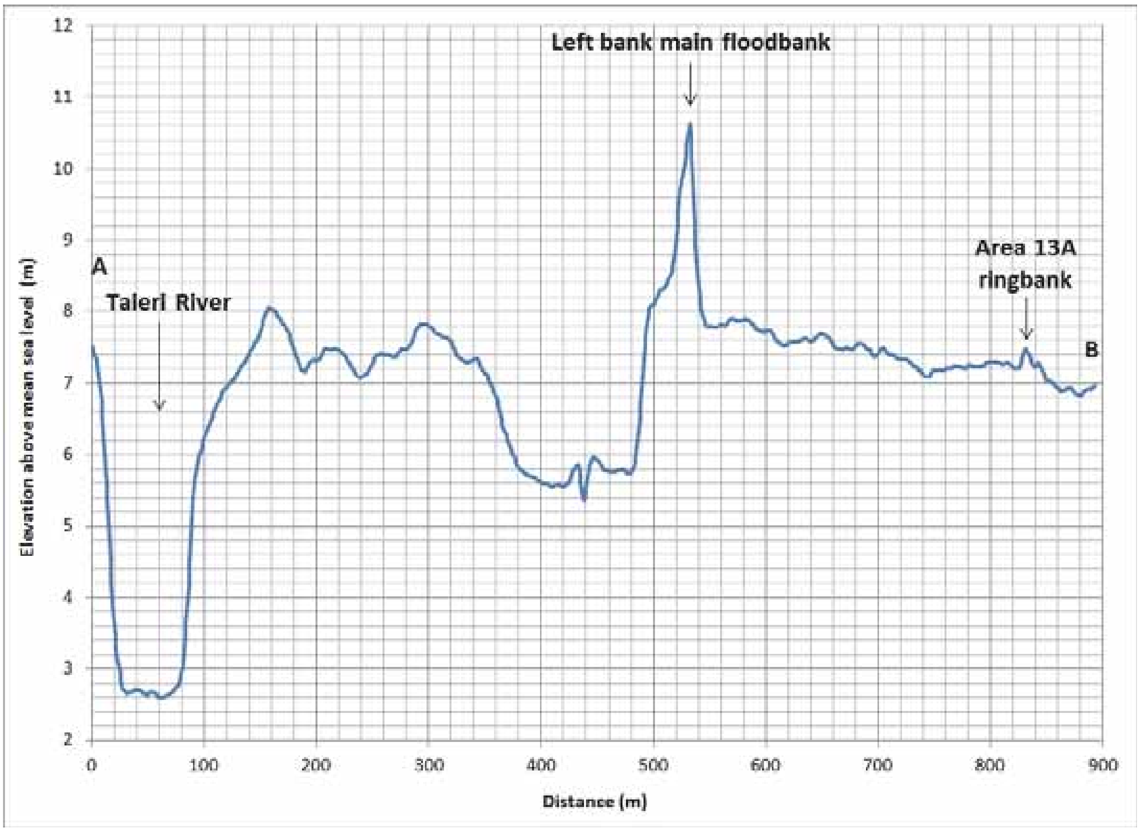

Figure 34. **Cross-section A-B, through Area 13A**

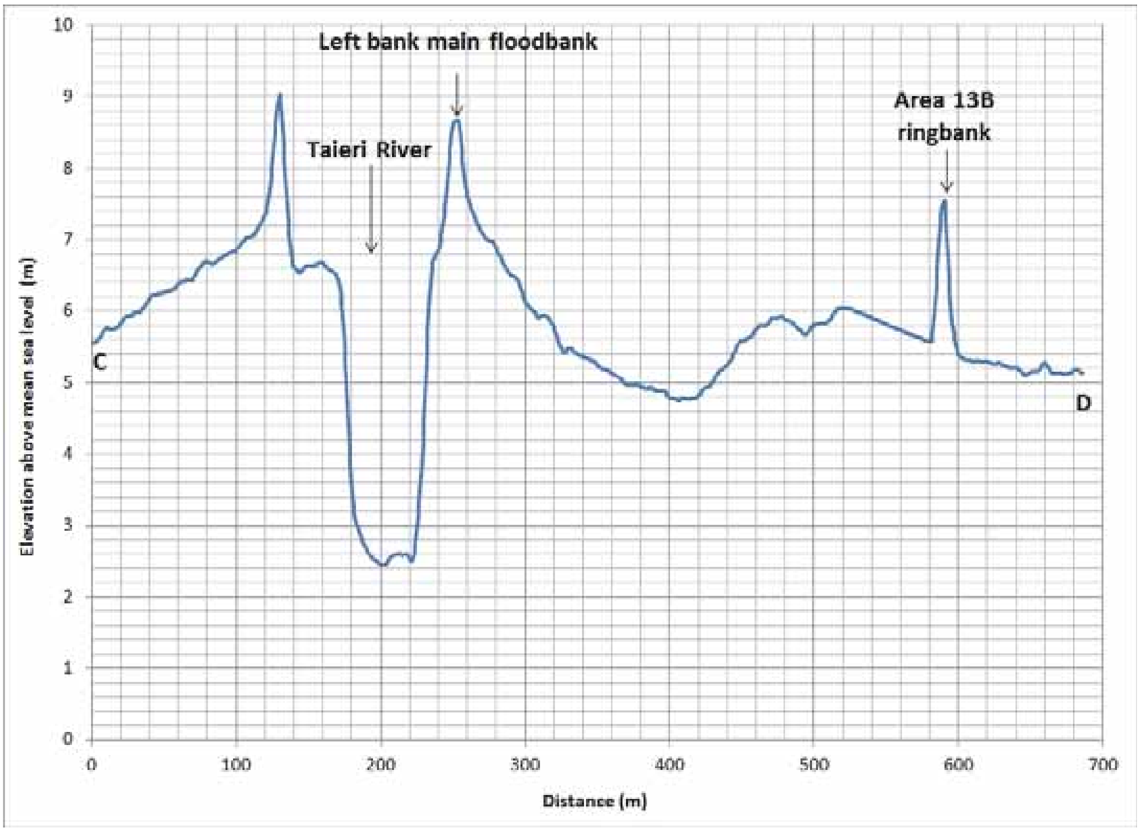

Figure 35. **Cross-section C-D, through Area 13B**

Figure 36. Breach of the northern section of the Area 13B ring bank during the December 1993 flood event. The location and direction of this photo are shown in Figure 33.

4.11.1. Public submissions

One public submission was received specifically relating to Area 13, which identified that this area is higher than the upper ponding area (Area 12), and that the land has a very low risk of flooding due to the effects of the Lower Taieri Flood Protection Scheme.

Area 13 is visited regularly by ORC natural-hazards staff, and the most recent inspection during a flood event was in June 2013, when the Taieri River at Outram peaked at 1,185 cumecs, and water entered the Upper Pond via the Riverside spillway.

4.12. Area 14 North Taieri

Setting: The North Taieri area is bounded by a range of 300 to 500m high hills to the north, Silver Stream to the south and the East Taieri Upper Pond cut-off bank to the west and Milners Road to the east. Other features of note within this area include SH 87, which links Mosgiel and Outram, Taieri Aerodrome, and the Five Roads and Wyllies Crossing intersections. Area 14 comprises the three areas identified in ORC (2013) as areas 14, 15 and 16 and is shown in Figure 37.

North Taieri is the highest-elevated part of the Taieri Plain, with the land gradually sloping downslope to the south and west. A series of active floodwater-dominated alluvial fans emerge from the hill catchments in the north. These fans grade into an extensive alluvial plain in the south, with a corresponding change in elevation from about 40m down to less than 10m (ORC, 2013). Further work has been undertaken to differentiate alluvial-fan areas from the Silver Stream / Mill Creek floodplain, and this is described below.

High flows and surface runoff, resulting from heavy rainfall, can occur in this area with little warning, due to the short, steep and relatively high (500m+) upstream catchments that discharge onto this northern part of the Taieri Plain.[15] The area is crossed by a number of ephemeral swales (overland flow paths) that can carry significant overland flow during heavy rainfall events (Figure 37). Along with a number of smaller catchments, the area is exposed to flood hazard from Mill Creek and the Silver Stream. The Upper Pond cut-off bank is intended to prevent water from the Taieri River entering this area.

Because of the generally subtle topography of Area 14, the depth and extent of flooding is also influenced by local features, such as embankments, fences, shelterbelts and buildings, which can impede natural-downslope drainage.

The characteristics of flood hazard in this area are described below, along with a summary of public submissions, additional work undertaken, refinements to the flood-hazard mapping, and appropriate flood-risk management methods. The areas that are critical for the conveyance or storage of water during flood events are described first (Areas 14A and 14B), followed by the residual areas where flooding associated with alluvial-fan activity (Area 14D), or overflow from Mill Creek and Silver Stream onto the wider floodplain (Area 14C), may occur.

4.13. Area 14A (North Taieri overland flow paths)

Overland flow paths are features that convey runoff downslope from the northern hills towards the Upper Pond. The overland flow paths that comprise this area are exposed to floodwater runoff and extensive ponding.

Figure 37 shows the network of ephemeral swales that convey runoff downslope towards Upper Pond. The depth of water in these features ranges from 0.5m in the wider or smaller features to 2m in the larger and more defined drains.[16] Similarly, the velocity of floodwater varies from relatively slow in the wider-flow paths, to very fast (more than 1m/s) in the major

[15] ORC (2013) found that the northern end of the Taieri Plain (including the Silver Stream catchment) has experienced an increase in the intensity and frequency of extreme rainfall events since the 1960s.
[16] Maps of scheduled drains and overland flow paths owned or under the control of the ORC are contained in ORC (2012).

drains. The duration of flooding is generally limited to a few hours during the time of peak rainfall intensity. Note that these areas can only be defined approximately, as the characteristics of each flood event (including the relative contributions of each catchment) will differ. The depth and extent of flooding in Area 14A can be influenced by local features, such as embankments, fences, shelterbelts and buildings, which can impede natural-downslope drainage.

4.13.1. Public submissions

Nine submissions relating to Area 14A overland flow paths (or 'swales'), or to the wider alluvial-fan landform, through which the swales flow (now mapped as Area 14C), were received from residents of Tirohanga Road. These submissions generally do not object to the ORC swale-mapping accuracy, and several submissions identified that swales do direct water through or past their property. Most of the concerns relate to the 'moderate' risk zoning, proposed by the DCC in June 2014 for the alluvial-fan areas beyond the overland flow paths. This is discussed further under Area 14C.

4.13.2. Further investigations

Additional mapping of the upper extent of Area 14A's overland flow paths was undertaken using LiDAR elevation data and imagery, as well as aerial photos and topographic maps where the LiDAR was not captured further upslope in some areas. The features were extended upslope to the point where they become deeply incised steep channels that drain the upper parts of the northern hill catchment. In the previous edition of this report (ORC, 2014), these features were terminated at a contour line at a specific elevation above the floodplain. This did not accurately represent the full extent of the hazard due to runoff during heavy rainfall events from the upper catchment and downstream along these pathways.

An additional overland flow path feature has been added to Area 14A towards the western end of Outram-Mosgiel Road. This feature was identified by GNS Science (2014) as a narrow alluvial fan that has been recently active, and which conveys water into the Upper Pond (Figure 37). The revised extent of Area 14A overland flow paths is shown in Figure 37.

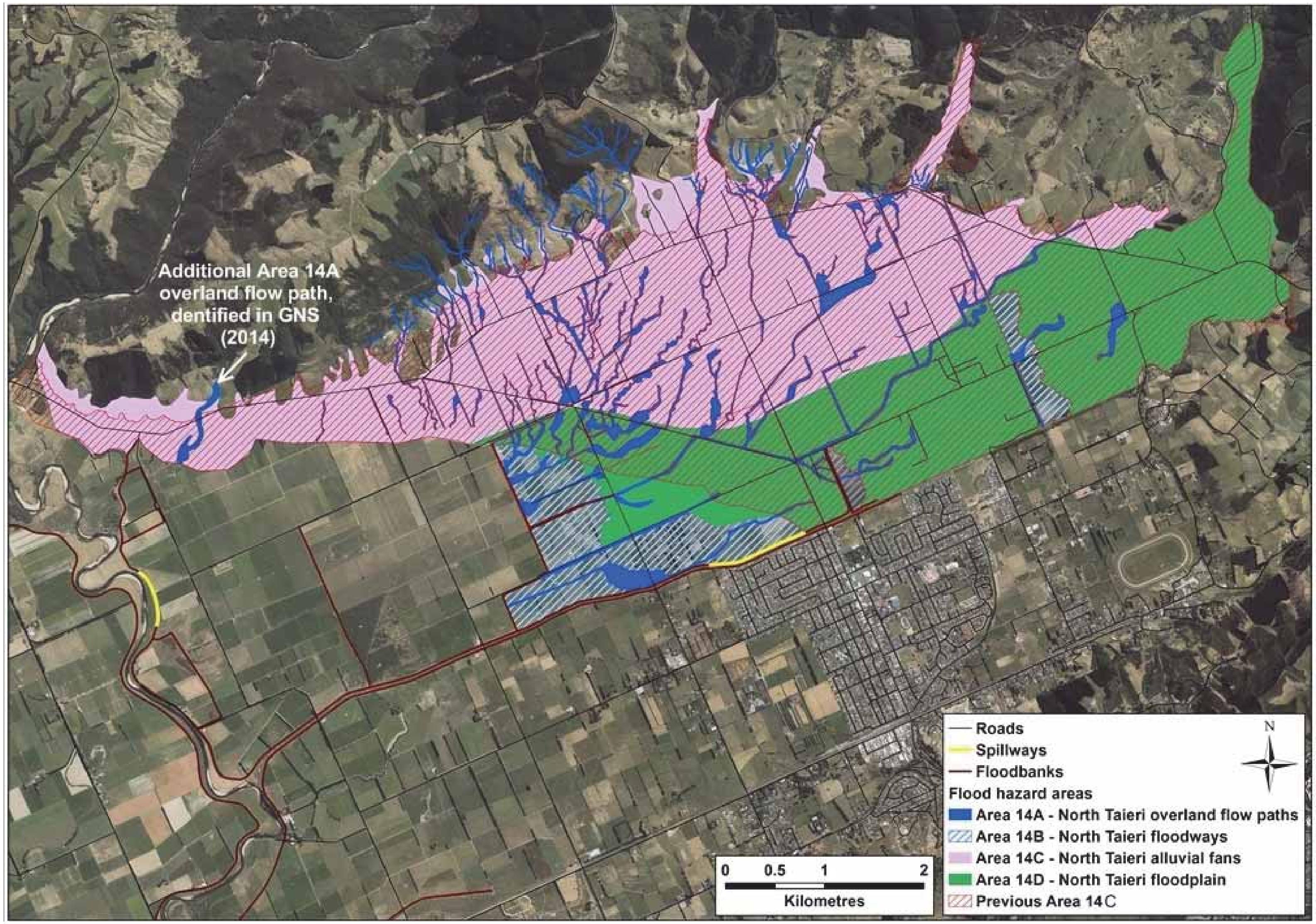

Figure 37. **Area 14 Comprising Area 14A (overland flow paths), Area 14B (floodways), Area 14C (alluvial fans), and the new Area 14D (floodplain). The original extent of Area 14C is also shown (as identified in ORC, 2014).**

4.14. Area 14B (North Taieri floodways)

Area 14B consists of three areas (shown in Figure 37) where overland flow and/or ponding are deeper, faster and more extensive than in Area 14A. These are below the Gordon Road Bridge on the true right of Silver Stream, behind the Mill Creek Diversion, and along the north-eastern side of the Taieri Gorge Railway between Puddle Alley and Hazlett Road. Flooding can start to affect these areas with minimal warning (<3 hours). They provide for the conveyance and/or temporary storage of floodwater on the East Taieri Plain, and hence provide mitigation of flood hazard for other areas.

Large overland flows and significant ponding occurs when Silver Stream overtops the true-right bank below the Gordon Road Bridge. This occurs when flow in Silver Stream exceeds 150-170m^3/s at the Gordon Road Spillway (ORC, 2013), which occurred in April 2006 (Figure 38), June 2007, and was imminent in May 2010 and April 2014 (Figure 39). Due to the lack of any defined path, these flows tend to spread out over a wide area on-route to the upper pond cut-off bank, combining with flows from Mill Creek and the hill catchments to the north. The depth of water ranges from 0.5 to 1m, with velocities of up to 1m/s, and therefore poses a high hazard for people, stock, buildings and other structures.

The deepest and swiftest flows in this area would be associated with a failure of the upper pond cut-off bank, which could produce flows 2.5-3m deep, with a high velocity, as water drained rapidly from the Upper Pond (Area 12). The ability of this bank to contain water for a prolonged period and to a depth of up to 3m has not been tested in a flood event since it was built in the 1990s. The lower part of Area 14B can also be affected by water ponding to the east of the upper pond cut-off bank to a depth of 3m, over a period of several hours. The rate at which ponded water can drain away depends on the rate at which Area 12 (Upper Pond) drains.

Figure 38. Silver Stream flows spilling over the Gordon Road spillway (April 2006)

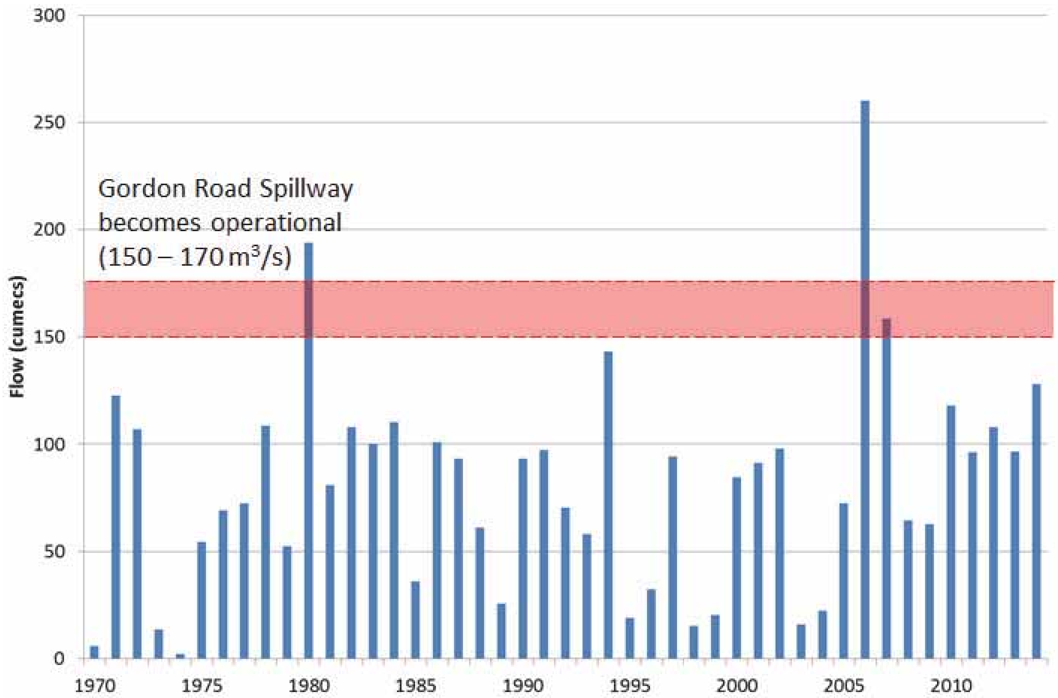

Figure 39. Silver Stream observed flood peaks, 1970 - 2014

The second part of Area 14B is the land behind the Taieri Gorge Railway embankment, between Puddle Alley and Hazlett Road. This area can be inundated to a depth of 1.5m due to surface runoff and excess flow from Mill Creek, as occurred in April 2006 (Figure 40).

The third part of Area 14B is the land behind the Mill Creek Diversion, true left (eastern side of the channel) floodbank (Figure 37).

Because of the generally subtle topography of Area 14B, the depth and extent of flooding can also be influenced by local features, such as embankments, fences, shelterbelts and buildings, which can impede natural downslope drainage.

Figure 40. Water ponding behind the Taieri Gorge Railway, 26 April 2006

4.14.1. Public submissions

Four public submissions were received relating specifically to flood hazard in the Gordon Road floodway component of Area 14B. These raise a number of points, including that:

- controls over land use are not necessary, as risk can be adequately mitigated by a range of measures, including minimum-floor heights and improved maintenance of council drains
- flood hazard in some areas on the margin of Area 14B is not sufficient to warrant the most restrictive land-use controls.

4.14.2. Further investigations

Additional work has been undertaken to refine the extent of Area 14B. This included field visits, the use of LiDAR elevation data, reviewing previous observations of flood events and information provided by Riccarton Road residents. The original[17] and revised extents of the Gordon Road floodway component of Area 14B are both shown in Figure 41.

The revised extent comprises land where the characteristics of floodwater are such that they can present a risk to the health and safety of people and stock, and will affect buildings and other structures. The revised extent is smaller than the mapped extent of the April 2006 flood event.

No changes were made to the part of Area 14B adjacent to the Taieri Gorge Railway (Figure 42).

[17] As shown in ORC, 2014

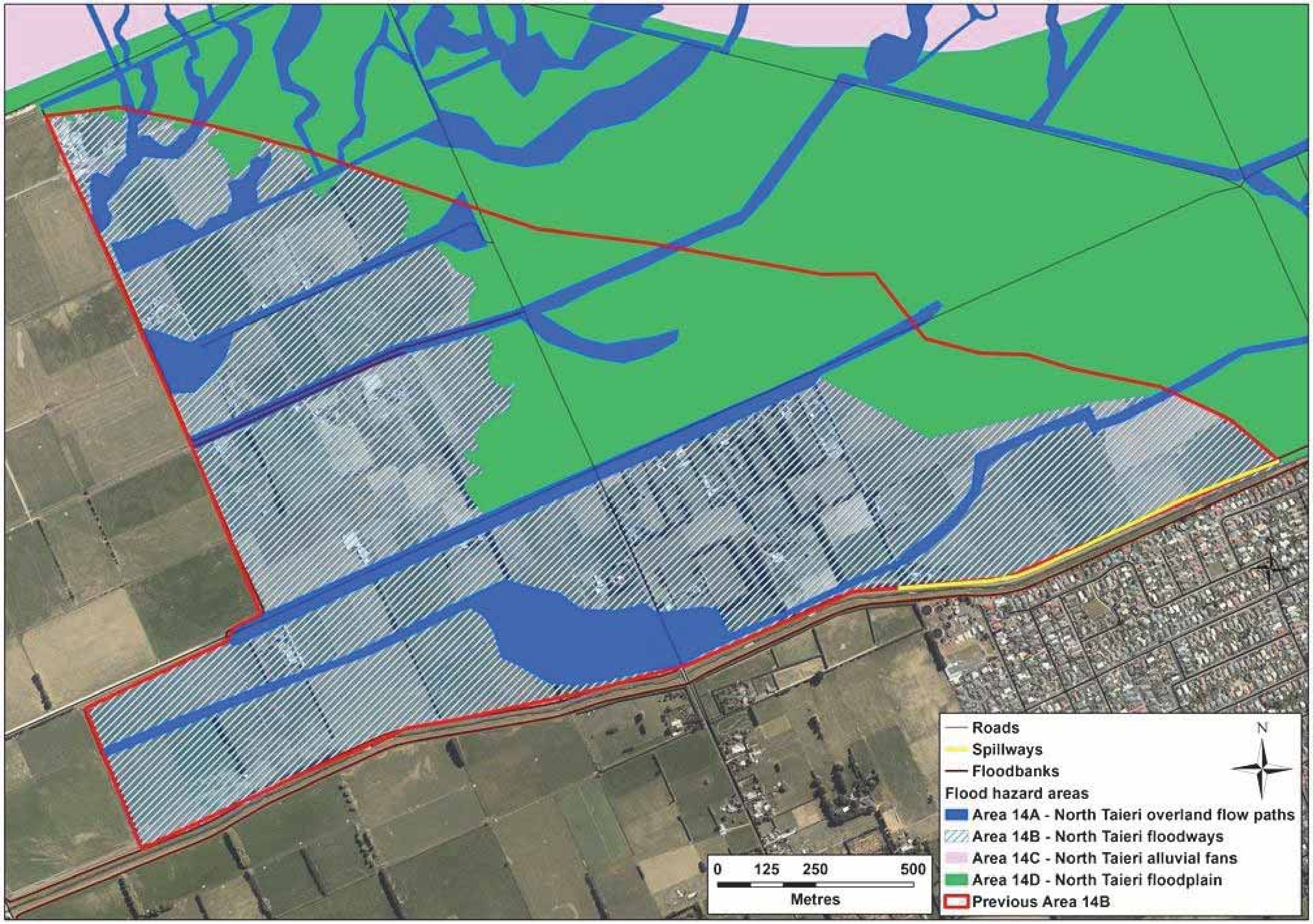

Figure 41. **Gordon Road spillway component of Area 14B, showing original and revised extent, and Area 14A overland flow paths**

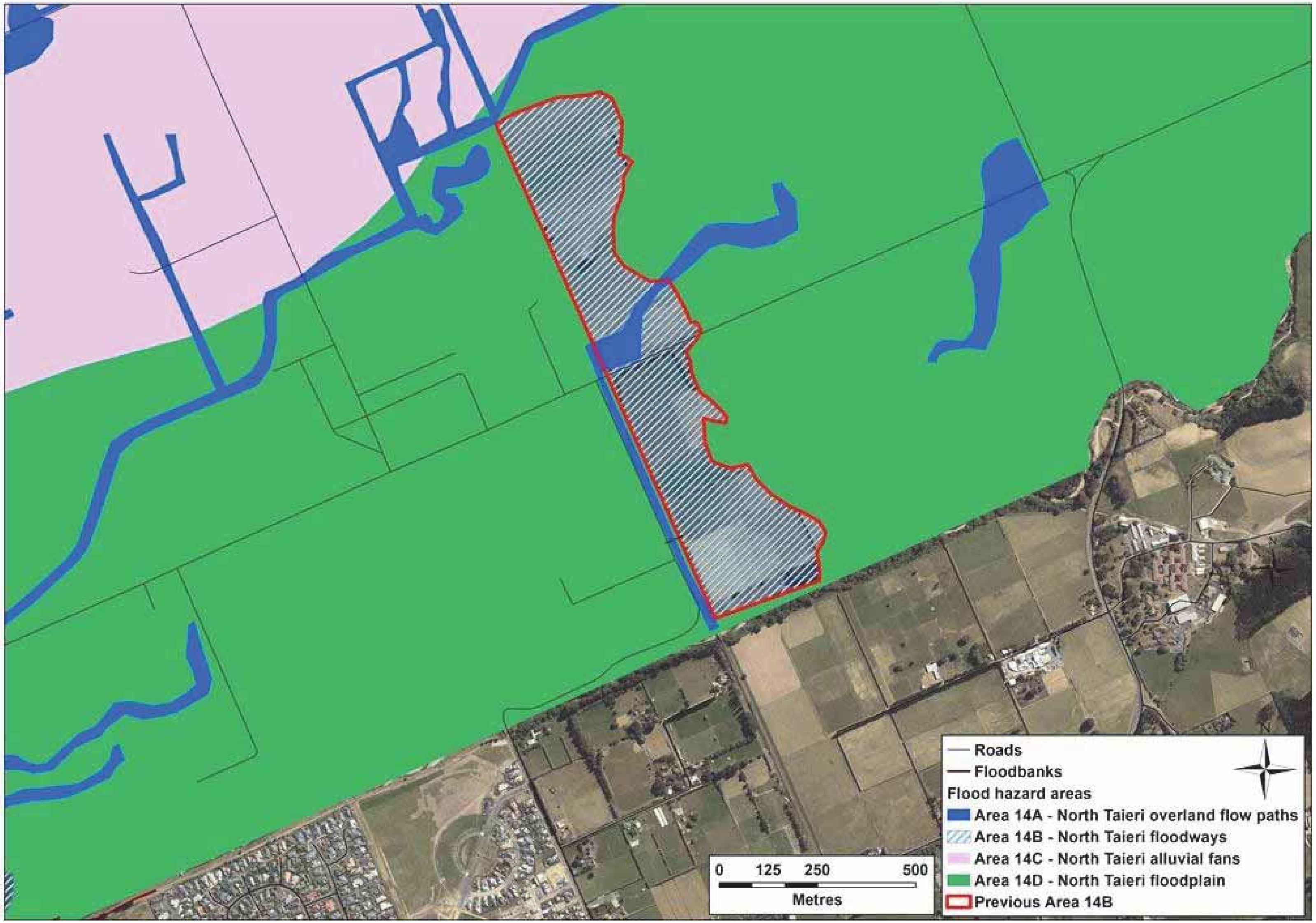

Figure 42. **Taieri Gorge Railway embankment component of Area 14B, and Area 14A overland flow paths**

4.15. Area 14C (North Taieri alluvial fans)

Further work has been undertaken to differentiate alluvial-fan areas in Area 14 from the Silver Stream / Mill Creek floodplain. The extent of Area 14C has been amended, based on investigations by GNS Science (2014) and verification of that work by ORC. The land mapped as Area 14C now comprises only the alluvial-fan areas that have formed at the base of the hill catchments to the north, and grade into the more gently sloping floodplain to the south (Figure 37).

The upper margins of the land mapped as ‘fan less recently active’ by GNS Science have been used to establish the upper extent of the alluvial-fan hazard,[18] and the lower margins of the fans have been used to define the downslope extent of Area 14C. The additional work identifies that flood-hazard characteristics on the alluvial-fan areas differ from those on the wider floodplain; and consist primarily of flooding close to stream channels, sheet run-off on the upper-fan slopes and some floodwater ponding on low-lying parts of the fans.[19] There is also some potential for sedimentation to occur, particularly in close proximity to stream channels.

The method used to define the boundary between Area 14C and the rest of the floodplain involved an analysis of slope angle and direction to differentiate between:

- land that has a steeper slope, and drains towards the south (alluvial fan)
- land with a gentler slope that drains towards the southwest (floodplain).

It is noted that the transition from alluvial fan to river-flood plain is almost imperceptible in places, due to the low gradient at the base of the fans. For planning purposes, however, a distinction between the two landforms is necessary, and has been identified using the above methodology. The effects of flooding near this boundary during an event will be influenced by the relative contributions of water sourced from the fan surface, from swales (i.e. Area 14A), and from the floodplain (Area 14D). Natural variability in the relative contribution of these components is confirmed by the extent of historical flood events that do not always conform to the boundary of the mapped alluvial fans (Figure 43). During a flood event, it may not be possible to differentiate between these sources of floodwater. However, elevation profiles (Figure 44) confirm the natural ‘break in slope’ between floodplain and alluvial-fan areas.

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[18] Land upslope of this margin is described by GNS Science as the steep hill-slope catchment areas that overlook the plain.
[19] In comparison, overbank flooding on the floodplain area has the potential to be deeper and of longer duration than that experienced on the alluvial fan.

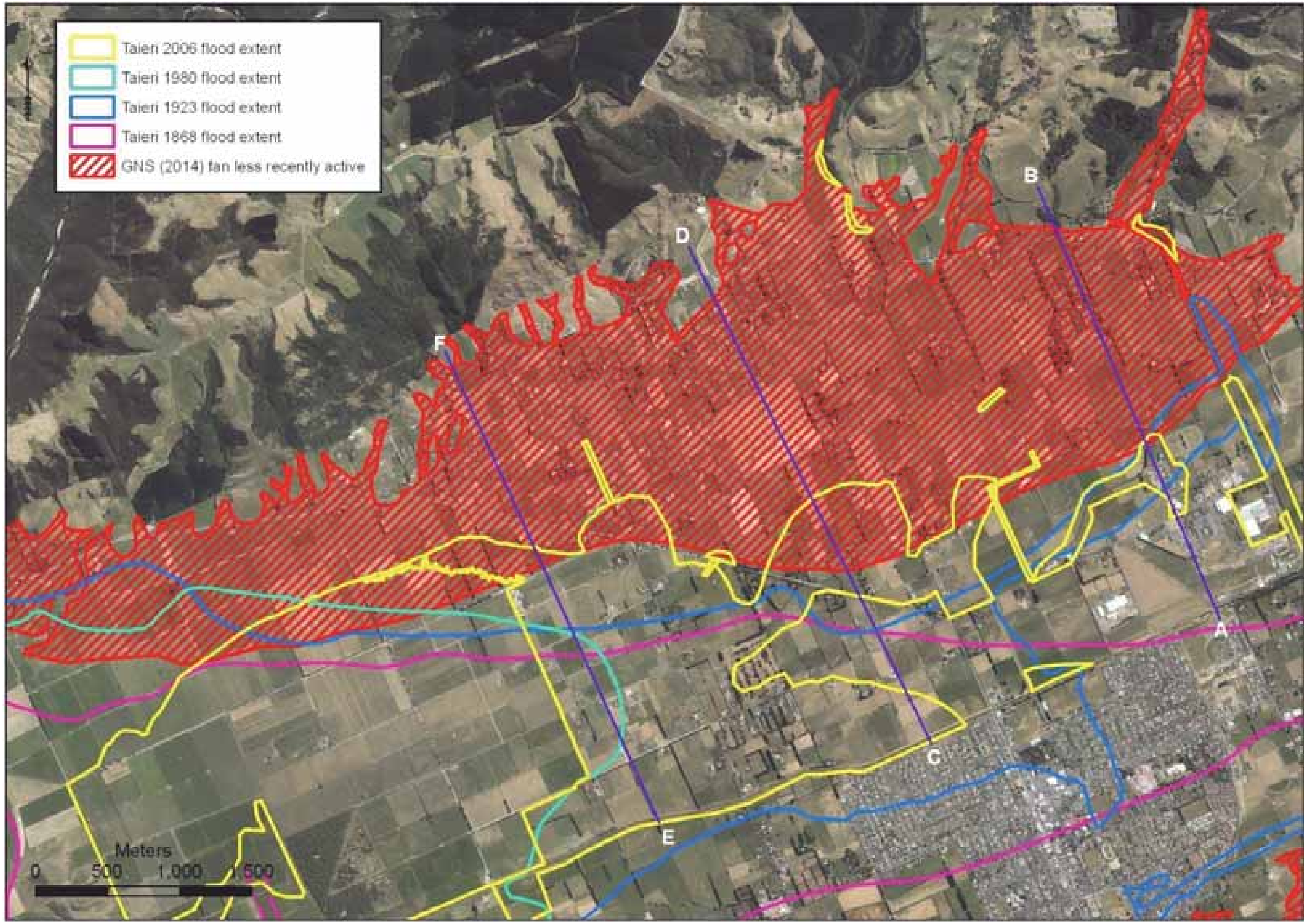

Figure 43. **The extent of the alluvial-fan area mapped by GNS Science, and the extent of historical flood events (mapped from observations). The location of elevation profiles across the fan and floodplain are also shown (in Figure 44).**

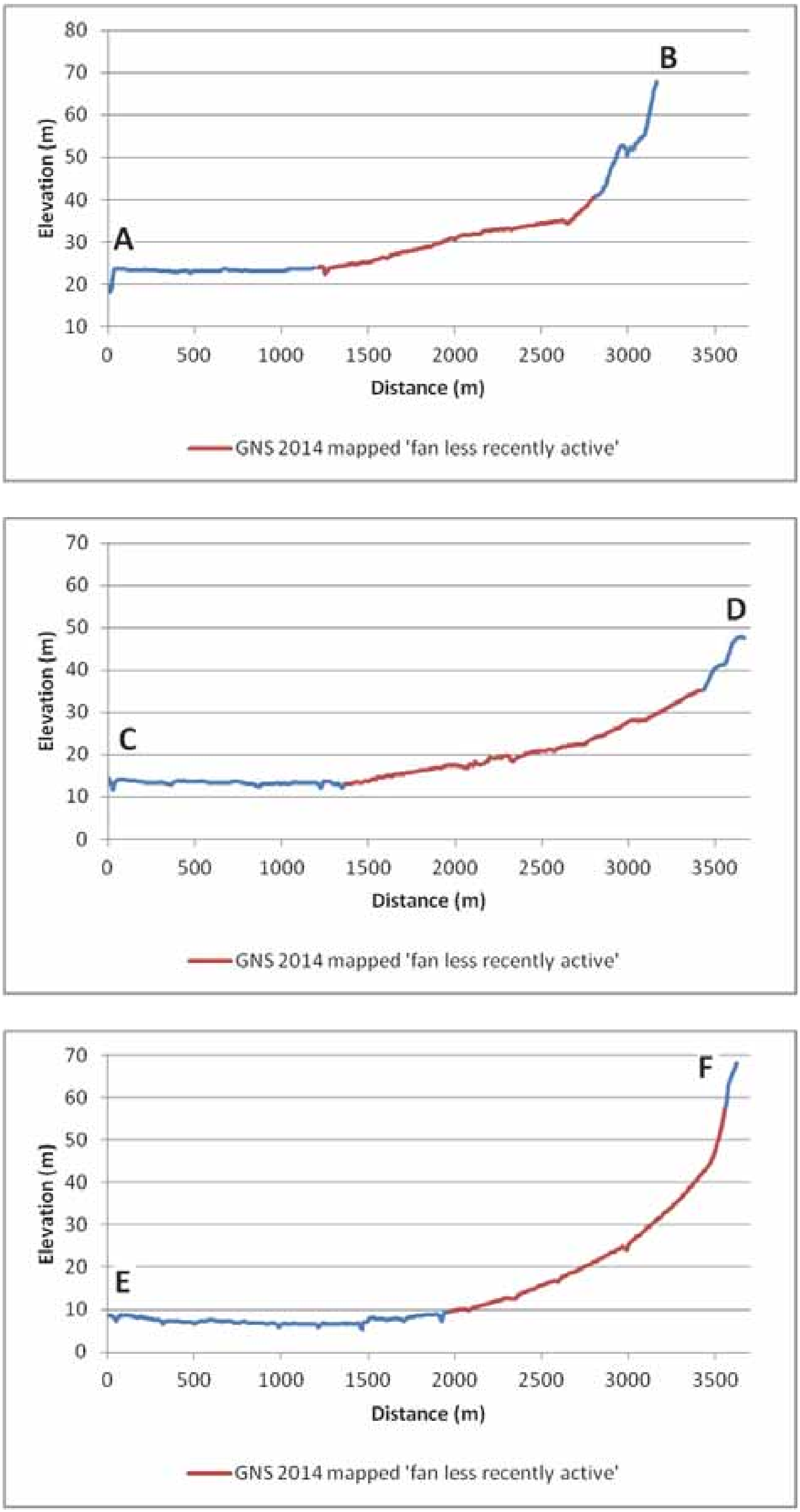

Figure 44. **Elevation profiles A-B (top), C-D (middle) and E-F (bottom), as shown on Figure 43**

The exception to the methodology used to define Area 14C (as outlined above) is where artificial floodbanks change the flood-hazard characteristics, and this occurs where Area 14C meets Area 12, the East Taieri Upper Pond (Figure 45). Water enters the Upper Pond from the Taieri River over the Riverside spillway (Figure 30) and remains there for long periods of time due to the low-lying nature of the area and its design as a ponding area. The northern extent of the Upper Pond generally follows the 108.4m contour, which is the height of the Upper Pond cut-off bank and the Silver Stream's true-right floodbank. The level of the Upper Pond floodbanks determines the boundary in this case, since they artificially hold water in that area.

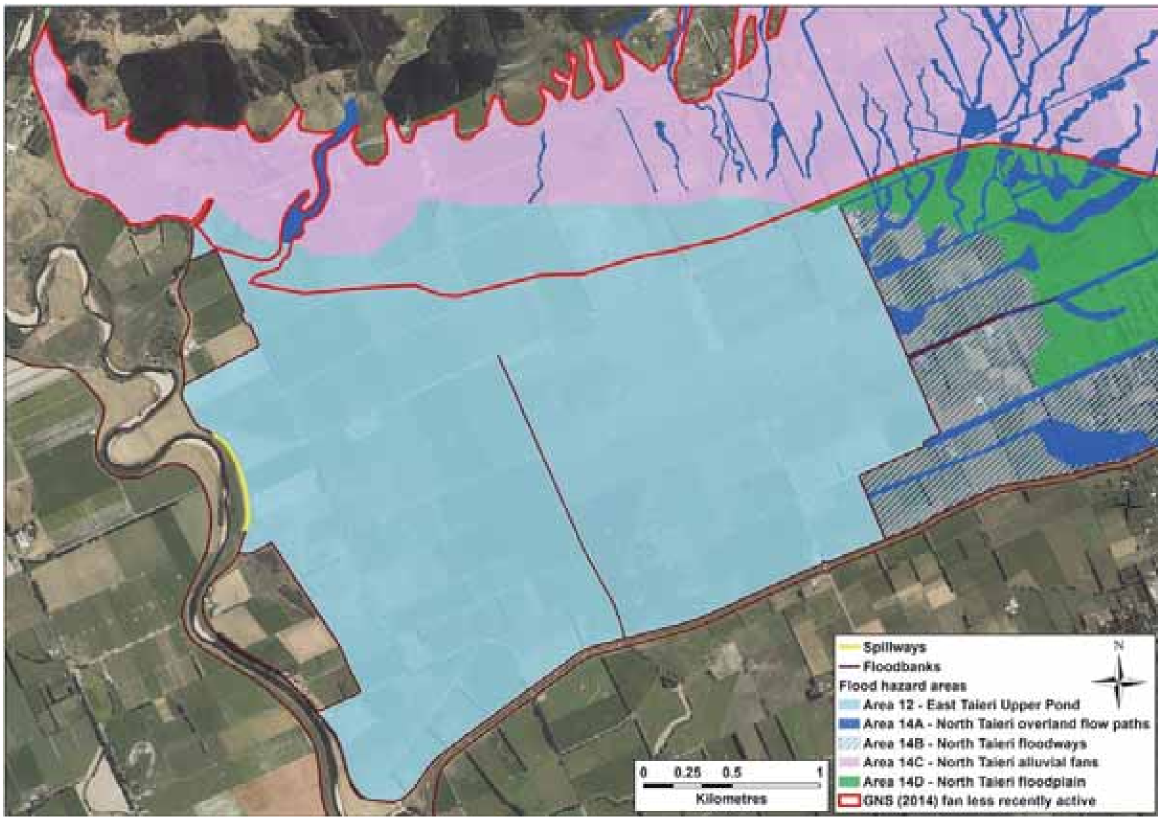

Figure 45. **Map showing the overlap between the floodwater-dominated alluvial fan, mapped by GNS Science (2014) (Area 14C) and the East Taieri Upper Pond (Area 12)**

4.15.1. Public submissions

Ten submissions that specifically relate to Area 14C were received, including nine from Tirohanga Road residents, and one from School Road. Most of the concerns revolve around the level of hazard implied by the 'moderate' risk zoning that was proposed in June 2014 for the residual areas outside of the overland flow paths (14A) and the floodplain (now identified separately as Area 14D). Several of the submissions (as well as residents visited by ORC natural-hazards staff in 2014) identified that these residual areas are not susceptible to flooding as they are sufficiently elevated. However, in some cases, residents did identify alternative flow paths, where water had previously overflowed from its normal channel during heavy-rainfall events (i.e. break-out flows). These observations, as well as others by ORC staff during flood events, help to confirm the flood-hazard characteristics described above and in GNS Science (2014).

4.16. Area 14D (North Taieri floodplain)

Flood hazard in this area is derived from Silver Stream, Mill Creek, hill tributaries to the north and from internal runoff. This area is sufficiently elevated not to be affected by the Taieri River. The predominant type of flood hazard is overland flow, although localised ponding can occur in places where vegetation, topography or man-made structures block the conveyance of water. There is also some potential for sedimentation to occur in conjunction with the floodwater-dominated alluvial fans to the north.

The velocity of runoff is generally slow to medium, and runoff generally does not last more than a few hours, during the period of peak-rainfall intensity. As this area excludes the major drains and overland flow paths (Areas 14A and 14B), the depth of flooding is generally limited to 1m or less (Figure 46). However, this combination of depth and velocity is sufficient to create a ‘moderate’ flood hazard, where wading becomes unsafe, and damage to structures may occur due to inundation and floating debris. Because of the generally subtle topography of Area 14D, the depth and extent of flooding is also influenced by local features, such as embankments, fences, shelterbelts and buildings, which can impede natural-downslope drainage.

Figure 46. Flooding of residential properties within Area 14D (looking down Hazlett Road to Dukes Road north (April 2006)

4.16.1. Public submissions

Five submissions regarding the land now identified as Area 14D were received: two from residents of Hazlett Road, and one each from Saunders, Riccarton and Dukes roads, asserting that their properties have not flooded.

As described above, the original Area 14C has now been separated into two separate areas: alluvial fan (which remains Area 14C) and the floodplain (Area 14D), as shown in Figure 37.

It is likely that there are pockets of land within Area 14D that are elevated above the surrounding low-lying areas, and that may not be directly inundated during most flood events. However, these areas have not been identified separately, or removed from Area 14D, as they may be isolated due to flooding elsewhere, and/or be affected directly during extreme particular flood-event scenarios.

4.17. Area 17 East Taieri Lower Pond

Setting: The perimeter of this area is the likely extent of ponding because of flows from the Taieri River. Historically, the area flooded frequently and for long periods because it is naturally low-lying (ORC, 2013). The floodbanks located next to the Taieri River, Silver Stream and Owhiro Stream have reduced the frequency, but not the potential consequences of, flooding.

Flood-hazard characteristics and effects: Flood hazard relates to the Taieri River, and also to Silver Stream, Owhiro Stream (Figure 47) and the hill catchments to the south. Ponding can reach depths of over five metres if water were to reach the minimum-crest level of the Taieri River true-left floodbank (Figure 48) and can last for several weeks. The extent, depth and duration of ponding during each flood event depend on the flood's duration and size. If any of the surrounding floodbanks were to fail, then the effects of flooding may also include water travelling at medium to high velocities, particularly in close proximity to that failure. A significant volume of water could pond in Area 17 (particularly if there were inflows from the Taieri River), and land could therefore be flooded for a prolonged period.

Figure 47. Overtopping of the Owhiro Stream into Area 17 (August 2012)

4.17.1. Public submissions

Four public submissions were received that specifically relate to Area 17. These all identified that a 'prohibited' status for additional dwellings or commercial activities is too strict, and excludes the opportunity for further development where flood risk could be adequately mitigated. No submissions questioned the extent of this area.

No changes have been made to the extent of Area 17, or the description of flood hazard, outlined above.

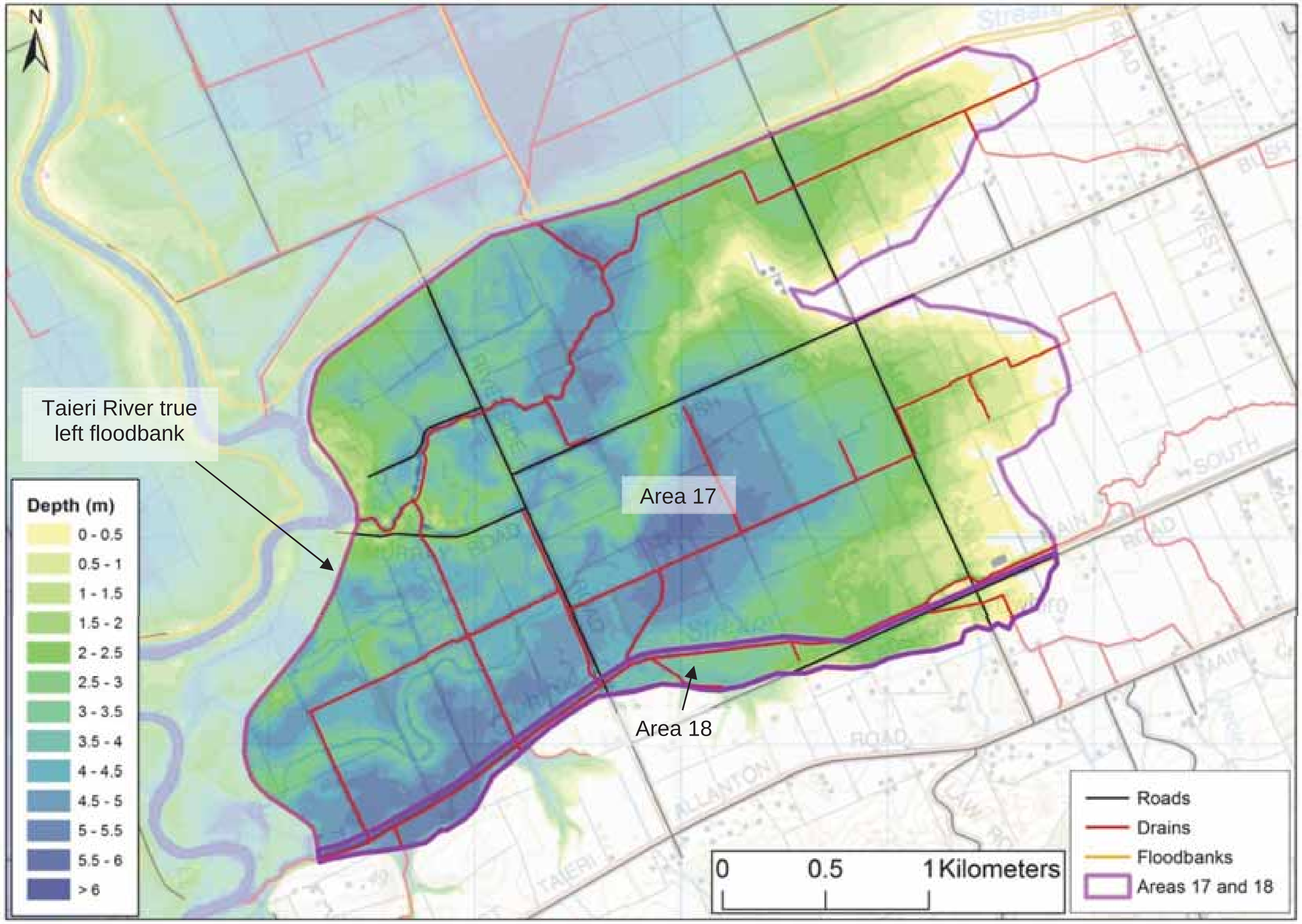

Figure 48. **Depth of inundation in Area 17 and Area 18 if water were to reach the crest of the Taieri River true-left floodbank**

4.18. Area 18 South of Owhiro Stream

Description: This area can be affected by flooding in the Owhiro Stream, as well as the Taieri River and runoff (which may include sedimentation) from the hill tributaries to the south. The Owhiro Stream Gated Outfall Structure (OSGOS) is designed to prevent flow from the Taieri River entering this area, while providing the capability for the Owhiro Stream to discharge by gravity into the Taieri River whenever water levels in the river are lower than those in the stream. Ponding occurs behind (to the east of) the flood gate during high-flow events. There is some connectivity between Area 17 (East Taieri Lower Pond) and Area 18, via culverts in the railway embankment that continues in an easterly direction along the edge of the Lower Pond.

Ponding can reach depths of 5m if water were to reach the minimum-crest level of the Taieri River true-left floodbank (Figure 48), and can last for several days. The extent, depth and duration of ponding during each flood event depend on the flood's duration and size.

4.18.1. Public submissions

No submissions were received relating specifically to Area 18, and no changes have been made to its extent.

Looking towards the southwest following a high-flow event in October 1978. Allanton can be seen in the distance, Area 18 is to the left of the floodbank, and Area 17 (East Taieri Lower Pond) is to the right.

4.19. Area 19 East of lower pond

Description*:* Internal runoff is the predominant source of flooding in this area, although it is also exposed to flooding from Silver Stream[20] and Owhiro Stream (ORC, 2013) (Figure 49). The southern part of this area was affected by flood flows in the Owhiro Stream in April 2006, making Gladstone Road south impassable to vehicles and pedestrians. Scheduled drains and other overland flow paths provide an important function by conveying floodwater downslope to Area 17 (Figure 49). Structures and earthworks can impede or redirect this flow of water. It is noted that drains that form part of the East Taieri Drainage Scheme provide land drainage to a rural standard.

The depth of water can range from 0.25m in smaller and wider overland flow paths, through to 2m in some drains. Velocity of runoff tends to be relatively slow, although higher speeds can occur due to water overtopping adjacent floodbanks and in the larger drains.

4.19.1. Public submissions

No submissions were received relating specifically to Area 19.

Additional work was undertaken by GNS Science in 2014 to differentiate between areas of alluvial fan and floodplain on the margins of the East Taieri Plain. As a result of this work, the extent of Area 19 has been modified to align with the boundary between these two morphological landforms. The extent of Area 19 is now limited to land identified as river terrace (or broad floodplain) by GNS Science, and is shown in Figure 49.

[20] The floodbanks along the southern side of Silver Stream are designed to contain flows of 260m^3/s or more.

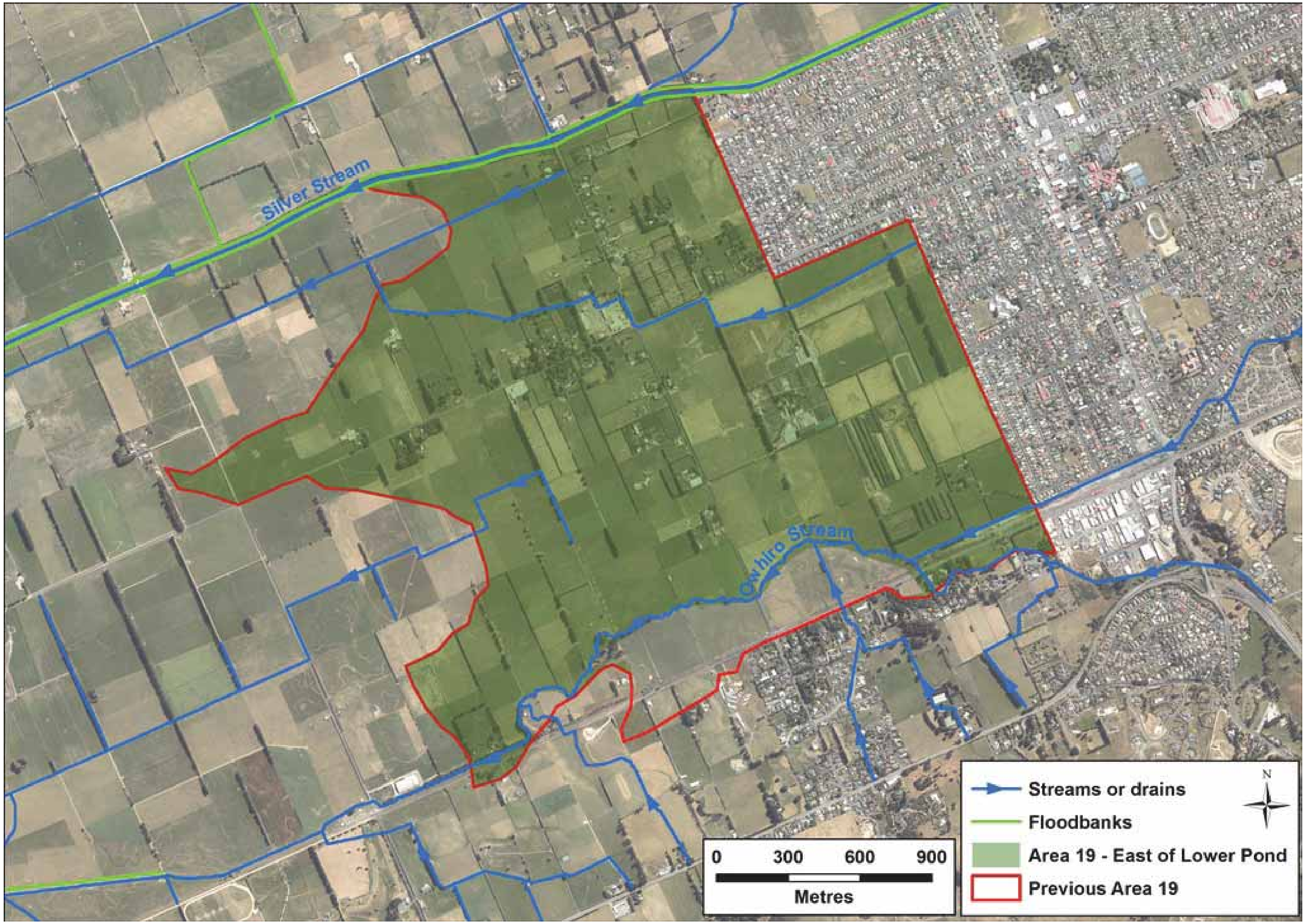

Figure 49. **Area 19 Streams and drains and general direction of flows in Area 19. The previous extent of this area is also shown.**

4.20. Area 20 Mosgiel

Description: Most of the Mosgiel urban area is elevated slightly above the land on the northern side of Silver Stream (Figure 50) and the land to the south alongside the Owhiro Stream. As such, it has limited exposure to flood hazard from Silver Stream, Owhiro Stream, Quarry Creek, internal runoff from within Area 20, and downslope runoff from Area 21. The floodbanks along the southern (true-left) side of Silver Stream are designed to contain flows that have an assessed return period of about 100 years.

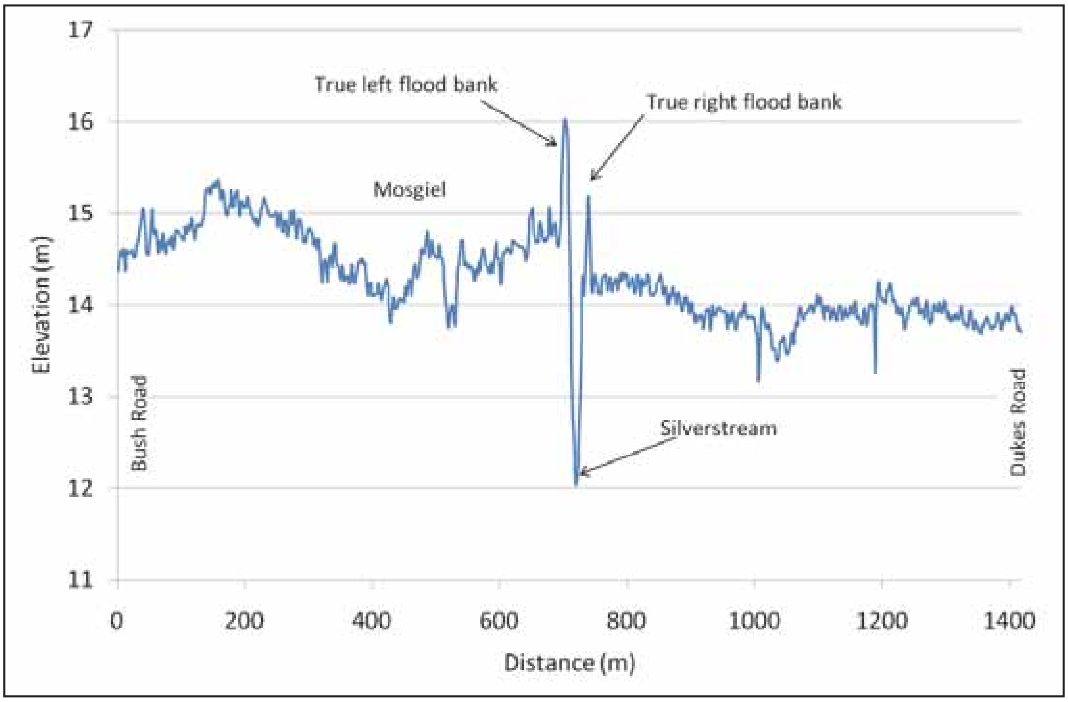

Figure 50. Cross-section through Silver Stream (from Bush Road in Mosgiel to Dukes Road in Area 14), looking downstream

The characteristics of flood hazard (including depth, duration and velocity) within urban Mosgiel are determined in part by the capacity of the drainage network, and most of Area 20 is serviced by an urban standard storm-water network. Heavy-rainfall events that exceed the design capability of this network can result in internal runoff and ponding of floodwater (Figure 51).

During periods of heavy rainfall, surface flooding and runoff from the eastern hills can cause localised ponding, especially in the industrial, southern part of the urban area, near Quarry Creek (ORC, 2013) (Figure 52). The flooding in the industrial area is not directly caused by Quarry Creek overtopping its true-right bank but is the result of an undersized stormwater network (Figure 53). The flooding is exacerbated by the location of the stormwater-network outlets discharging into Quarry Creek. When the water level in the creek is high, flood water can impede the stormwater discharge, and water can back up through the stormwater network causing flooding in the industrial area.

Figure 51. Surface flooding on Gordon Road, November 2012. (Source: Otago Daily Times)

4.20.1. Public submissions

Despite having a population of more than 9,000 people, no submissions were received relating specifically to Area 18.

Additional work was undertaken by GNS Science in 2014 to differentiate between areas of alluvial fan and floodplain on the margins of the East Taieri Plain. As a result of this work, the extent of Area 20 has been modified to align with the boundary between these two morphological landforms. The extent of Area 20 is now limited to land identified as river terrace (or broad floodplain) by GNS Science, and is shown in Figure 52.

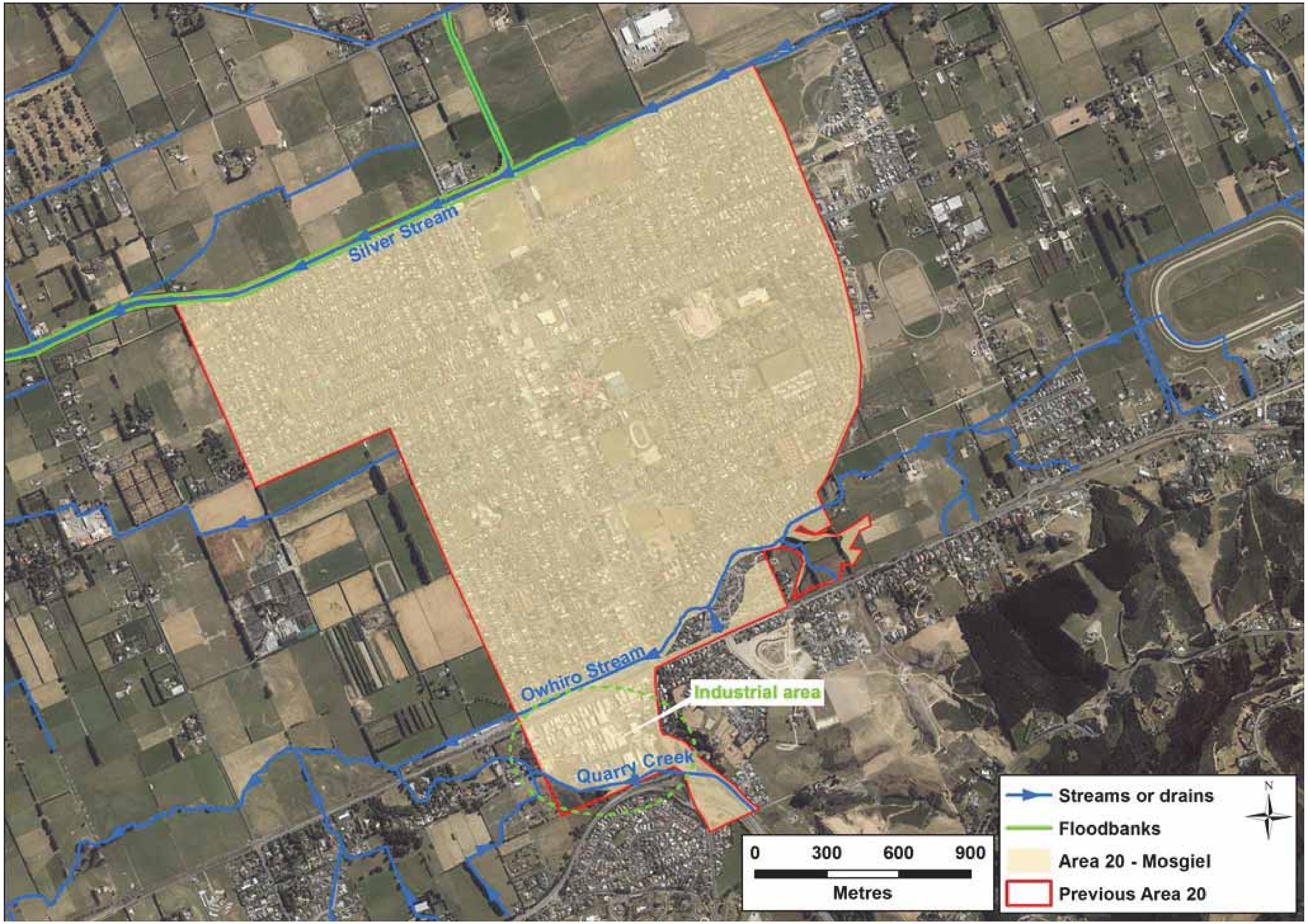

Figure 52. **Area 20 Streams and drains, and the location of the industrial area at the southern end of Area 20. The previous extent of this area is also shown.**

Figure 53. **Area 20 Industrial area and location of the stormwater network and outlets. The previous extent of this area is also shown.**

4.21. Area 21 Wingatui

Description: The Wingatui area is exposed to flood hazard from internal runoff, the hill catchments to the east and south, the Owhiro Stream, and to a lesser extent, Silver Stream[21] (ORC, 2013). A series of active floodwater-dominated alluvial fans emerge from the adjacent hill catchments (Abbotts Hill (360m) to the east, and Chain Hills (about 150m) to the south) (GNS Science, 2014). These fans grade into an extensive alluvial plain, with a corresponding change in elevation from about 40m down to 25m near Mosgiel. Surface runoff and ponding resulting from heavy rainfall can occur in this area with little warning, due to the short, steep upstream catchments that discharge onto this eastern part of the Taieri Plain (Figure 54).

There are a limited number of formal drains that cross Area 21, and the location of these is shown in Figure 55. These drains carry much of the overland flow that flows towards the southwest during heavy rainfall events. Because of the generally subtle topography (as shown in Figure 56), the depth and extent of flooding can also be influenced by local features such as embankments, fences, shelterbelts and buildings, which can impede natural downslope drainage. The area lies within the East Taieri Drainage Scheme, which provides land drainage to a rural standard, and Figure 55 and Figure 56 show the location of scheduled drains (as defined in ORC, 2012).

Figure 54. **Overland flow, which has drained from the adjacent hill catchment, ponding near Puddle Alley, at the northern end of Area 21 (June 2013)**

[21] The length of the Silver Stream, which is adjacent to Area 21, is deeply incised.

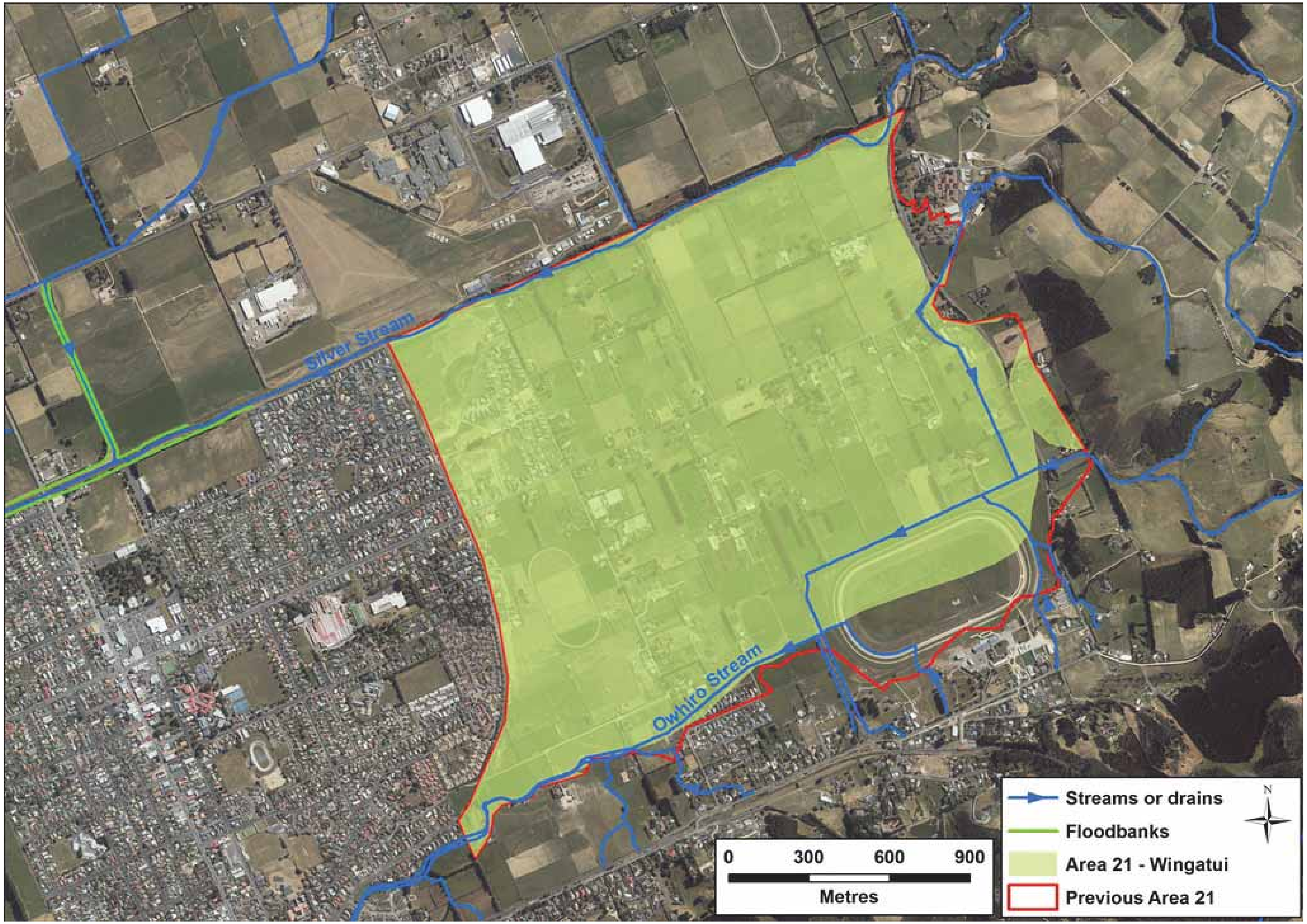

Figure 55. **Area 21 Streams and drains and general direction of flows in Area 21. The previous extent of this area is also shown.**

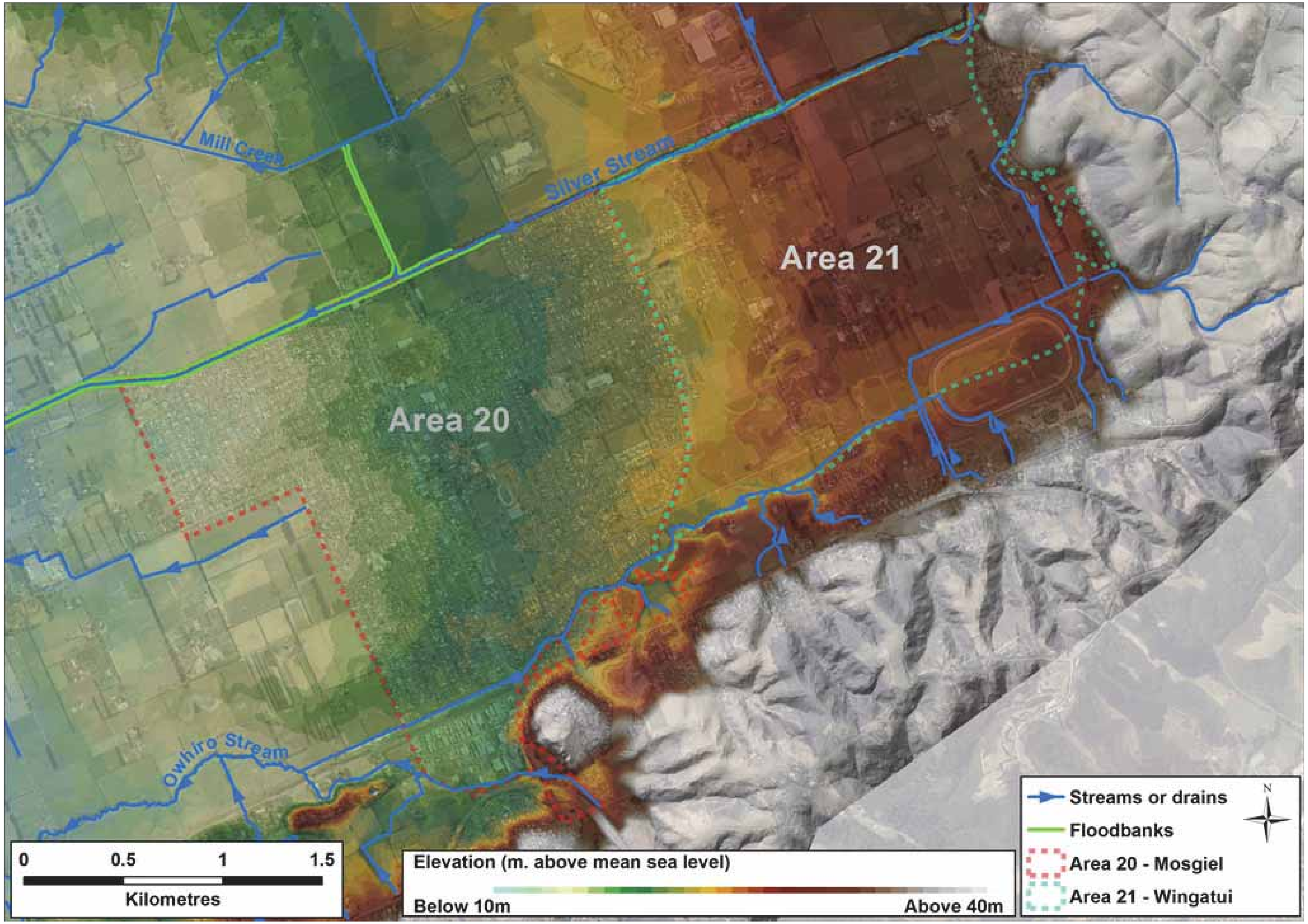

Figure 56. Topography of Area 20 and 21 (Mosgiel and Wingatui)

4.21.1. Public submissions and further investigations

No submissions were received relating specifically to Area 21.

As noted previously, additional work was undertaken by GNS Science in 2014 to differentiate between areas of alluvial fan and floodplain on the margins of the East Taieri Plain. As a result of this work, the extent of Area 21 has been modified to align with the boundary between these two morphological landforms. The extent of Area 21 is now limited to land identified as river terrace (or broad floodplain) by GNS Science. Changes to the margins of Area 21 are shown in Figure 55.

4.22. Area 22 Alluvial fans on flanks of coastal hills

Further investigations: The extent of Area 22 has been modified to represent more accurately the alluvial fans that flank the southern slopes of the coastal hills. The extent of this area is now limited to land identified as active floodwater-dominated alluvial fans (GNS Science, 2014). Various other landforms mapped by GNS Science as 'alluvial fan stabilised' or 'other landforms' have been removed from Area 22, as they are unlikely to present a level of flood hazard requiring land-use planning control. The township of East Taieri, which is built on the alluvial fan of Jaffray Stream, has been identified separately as Area 23.

Changes to the margins of Area 22 are shown in Figure 60.

As a result of this work, the title of Area 22 has also been changed to represent more accurately its morphology. The original description of flood hazard outlined in ORC (2014) applies more closely to the modified extent of Area 22, and is presented again below.

Description: This area is sufficiently elevated not to be affected by the Taieri River or Silver Stream. Flood hazard is derived from Quarry Creek (Figure 57), Owhiro Stream, Jaffray Stream and other hill tributaries to the south and east (Figure 58), as well as surface runoff and overland flow. High-stream flows, surface runoff, and ponding resulting from heavy rainfall, can occur in this area with little warning, due to the short, steep upstream catchments that discharge onto the Taieri Plain. The depth of flooding can range from less than 0.25m through to about 2m in the deeper drains. The velocity of runoff is generally slow to medium, and it generally does not last more than a few hours, during the period of peak-rainfall intensity.

Quarry Creek is a short watercourse that drains the north-facing slopes of Saddle Hill. It has a catchment area of about $3.5km^2$. The creek passes through a culvert under SH1 adjacent to Kinmont Park and in part flows through Area 20 (see Area 20 description and Figure 53) and the East Taieri School grounds before joining the Owhiro Stream about 400m below Cemetery Road (Figure 59). The area adjacent to the creek between the culvert under SH1 and Cemetery Road Bridge is low-lying (Figure 59). During periods of heavy or extended rainfall, the creek can cause flooding of these low-lying areas, in particular the car park of the East Taieri School and parts of the school grounds. The school car-park area and part of the East Taieri School grounds are located at a relatively low level, adjacent to a breakout point (Figure 59). Given the topography of the area (flat and low-lying), the flood hazard is significantly influenced by the backwater effect from the Owhiro Stream. High-water levels in Quarry Creek can also cause the bridge on Cemetery Road to flood.

Figure 57. Quarry Creek at Cemetery Rd Bridge, April 2006. Photo not taken at the time of peak flow.

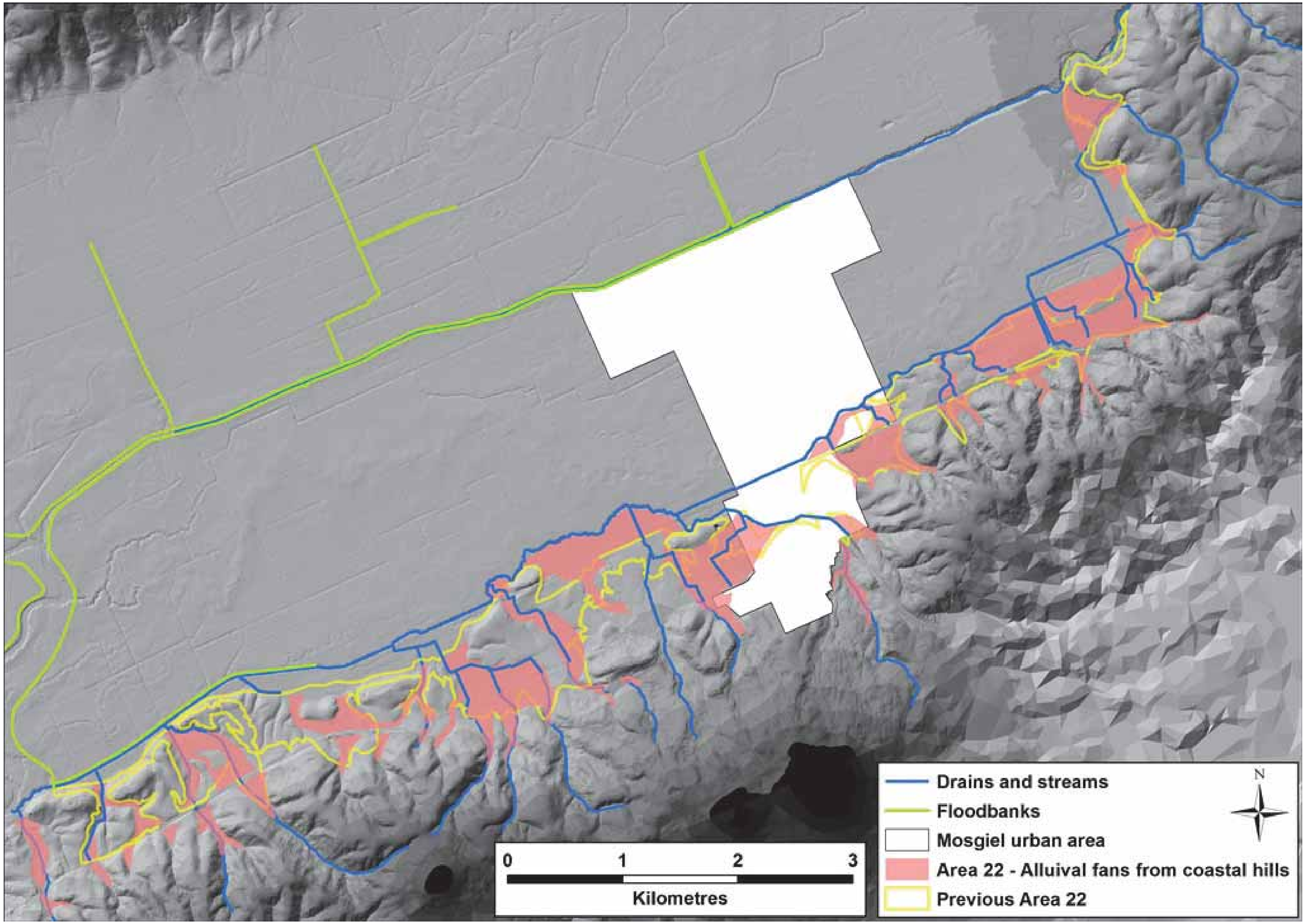

Figure 58. **Coastal-hill catchments that traverse Area 22. The previous extent of this area is also shown.**

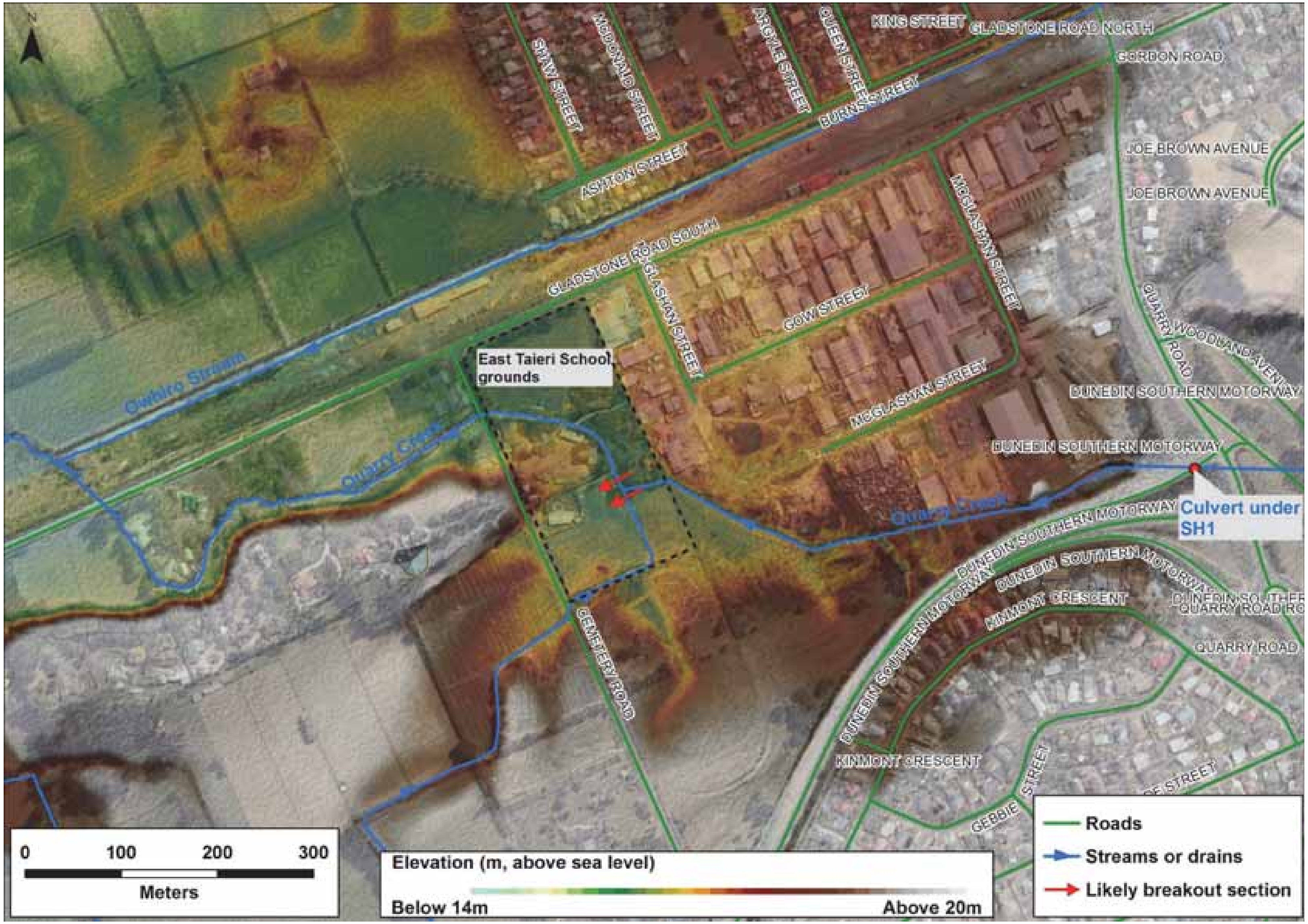

Figure 59. **Topography in the vicinity of the East Taieri School grounds and Quarry Creek**

4.22.1. Public submissions

Two submissions were received relating specifically to Area 22, including one from a resident of Gladstone Road south and another from Allanton. These identified that parts of their properties were elevated sufficiently so as not to be vulnerable to flooding. This was confirmed by the alluvial-fan mapping undertaken by GNS Science and additional, property-specific topographic analysis by ORC. As described above, the extent of Area 22 has been amended to reflect these further investigations and, based on ORC's current knowledge of flood hazard, the dwelling on these two properties[22] is now not within a flood-hazard area.

[22] As well as other properties that are sufficiently elevated so as not to form part of the wider floodplain, or form part of the active floodwater-dominated alluvial fans identified by GNS (2014)

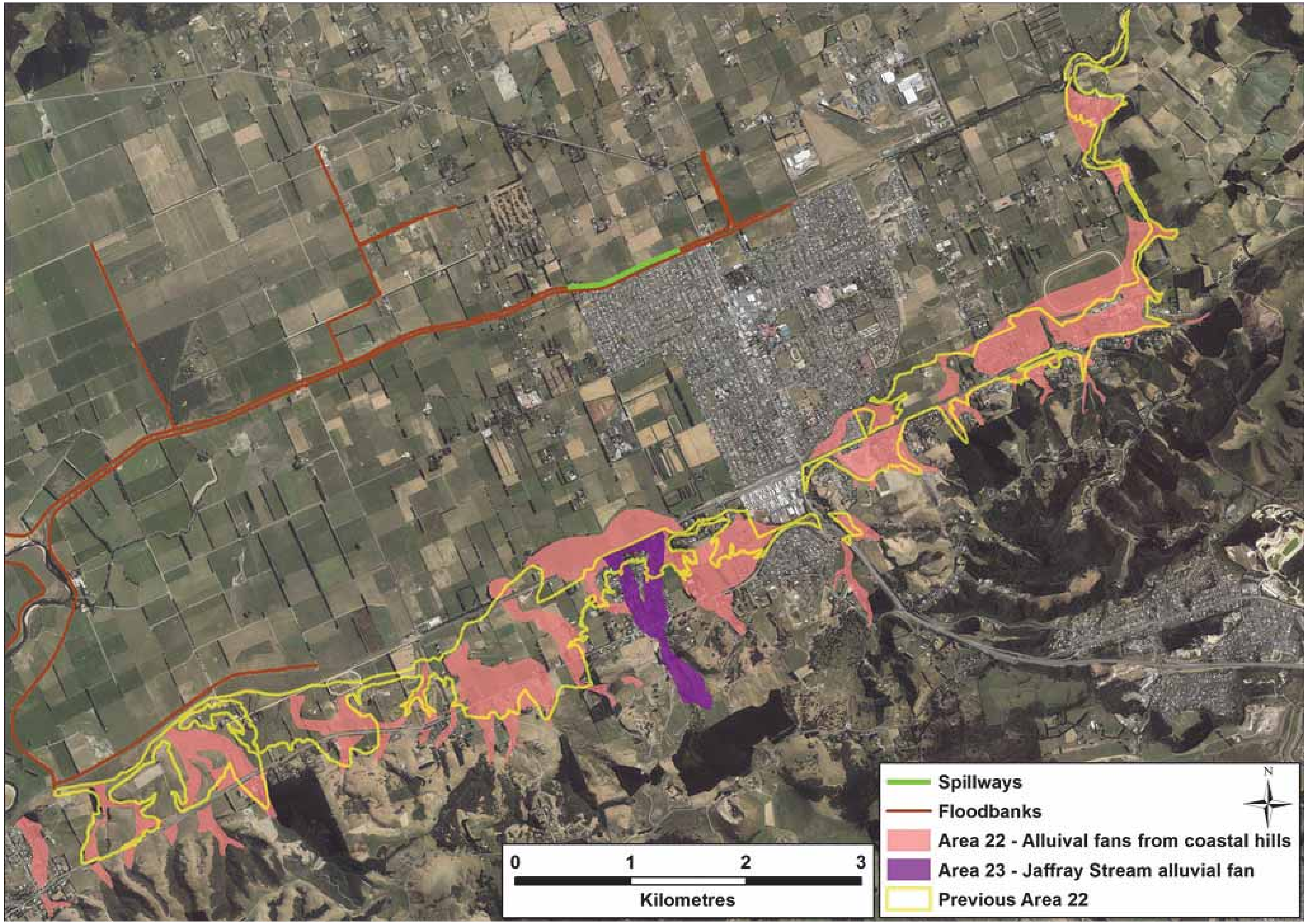

Figure 60. **The original (as identified in ORC, 2014) and amended extents of Area 22. Area 23 (a new area, comprising the Jaffray Stream alluvial fan) is also shown.**

4.23. Area 23 Jaffray Stream alluvial fan

Area 23 is a new flood-hazard area that comprises the Jaffray Stream alluvial fan (Figure 60). This area has been separated from other alluvial fans identified in Area 22, as further investigations indicate it is more susceptible to alluvial-fan flooding or sedimentation. The stream is scarcely incised into its fan, and is conveyed through the residential area and under the highway in an engineered channel and culvert that has potential to become obstructed by debris during a flood event (GNS Science, 2014). Additional photos and explanation from the GNS Science report are reproduced in Figure 61 and Figure 62.

Figure 61. **A view northeast along SH1 at East Taieri township, showing the fan of Jaffray Stream. The road rises over the fan axis, and Jaffray Stream is conveyed in a culvert at the point where the road goes out of sight. If the culvert were to become blocked by debris during a major rainstorm, there is potential for flooding and sedimentation on the fan surface. (Photo: D. Barrell, 17 February 2014, GNS Science.)**

Figure 62. **The engineered channel of Jaffray Stream at Orchard Grove, East Taieri. The head of its approximately 70ha catchment extends between Saddle Hill (left) and Jaffray Hill (right). (Photo: D. Barrell, 17 February 2014, GNS Science.)**

Figure 63. **Debris marks and channel aggradation in Jaffrays Stream, following a heavy rainfall event on 3 June 2015**

5. Flood hazard characteristics of the Strath Taieri

The Strath Taieri area is located in a basin of the Taieri River, which is bounded by steeper gorge areas upstream near Hyde, and downstream below Sutton (Figure 64). The flood hazard in this area is derived from both the Taieri River and the tributaries that drain the ranges to the east and west. Some minor control works and channel maintenance has historically been undertaken on both the Taieri River and some tributaries, although there is no formal flood protection scheme.

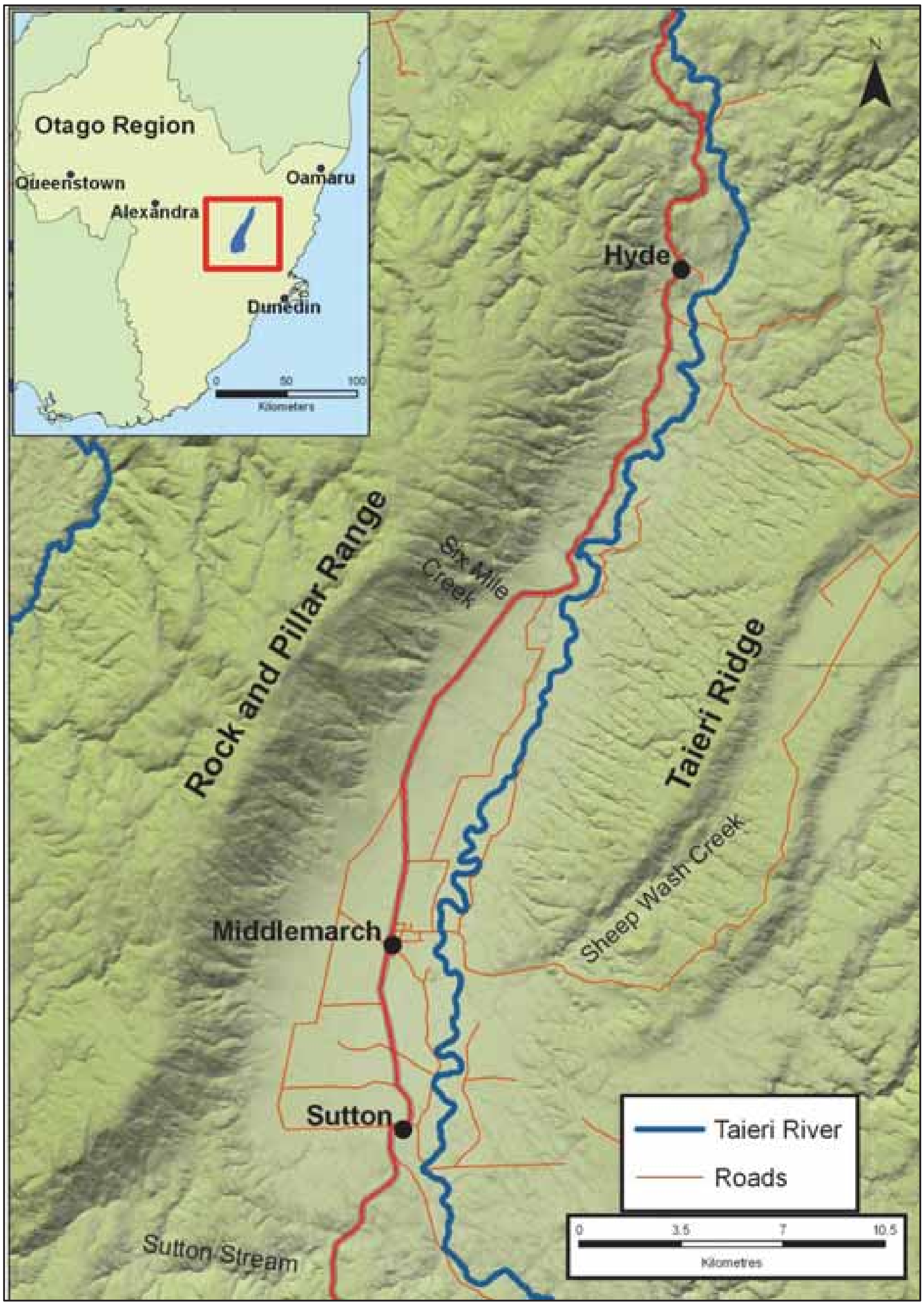

Figure 64 **Location map showing the topography and communities located on the Strath Taieri**

5.1. Taieri River flood hazard

The Taieri River upstream of Sutton has an extensive catchment area of more than 6,000 km^2, which extends to the Kakanui Mountains and Ida Range in the north, Rough Ridge in the west, and the Lammerlaw Range in the south. Prolonged heavy rain in the headwaters of the Taieri catchment will eventually result in high flows further downstream, although flood peaks can take several days to reach the Strath Taieri, due to the moderating influence of the Taieri scroll plain wetlands.

The Taieri River flood-hazard area (as shown on Figure 69) has been mapped primarily using information from flood events in June 1980 and December 1993. These are the two largest floods since records began in 1960. The flood-hazard area extends 20km from the confluence of Last Creek with the Taieri River in the north, to Sutton in the south. It covers an area of 85km2 and is almost 2km across at its widest point. There have been relatively few large flood events since the mid-1990s, and the peak flow at Sutton during the June 2013 flood was considerably smaller than during previous events. Recent experience of flood events may therefore not represent the full spectrum of risk associated with flood hazard. However, Figure 65 shows that there have been occasions when several large floods have occurred within 12 months or less (March 1986 to March 1987, and December 1993 to July 1994).

Characteristics of flood hazard, such as depth, velocity and duration for this area have not been specifically calculated by ORC. However, anecdotal evidence of previous flood events show that inundation of 1m or more can occur (Figure 66 and Figure 67), and that the area can be affected for up to one week following major flood events (ORC, 1993).

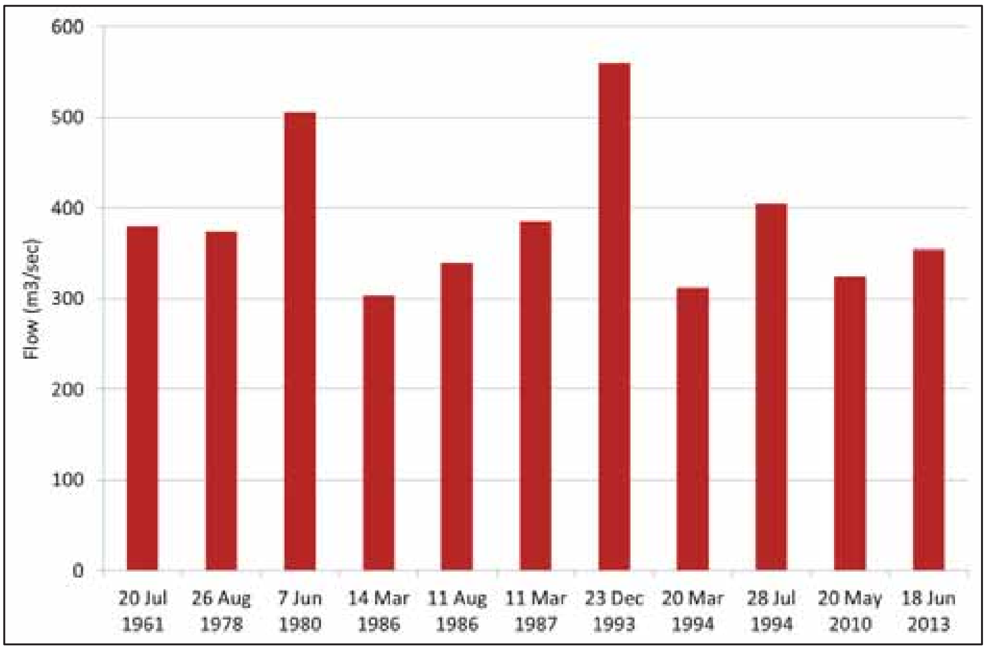

Figure 65 **The ten highest flows in the Taieri River at Sutton since records began in August 1960**

Figure 66 **Inundation of rural land near Creamery Creek (Middlemarch) following the May 1957 flood. Note the lines of fence posts just visible above the water level.**

Figure 67 **Inundation of rural land on the margins of the Taieri River on 18 June 2013, following a prolonged period of heavy rainfall. This photo was taken six hours after the flood peak, when flow in the Taieri River at Sutton had dropped from 354m3/s to 326m3/sec. The ORC natural hazards database (www.orc.govt.nz) contains other photos of the Strath Taieri taken on this day.**

5.2. Tributary / alluvial-fan flood hazard

The largest tributary streams in the Strath Taieri include Sheepwash Creek on the eastern side of the valley, and Six Mile Creek, Sutton Stream and several other short, steep tributary streams that have their source high on the slopes of the Rock and Pillar Range to the west. ORC (1993), Opus (2009) and GNS (2009) all describe the alluvial fan-building processes that occur at the base of these western tributaries. Some streams have a tendency to break out of their existing channels at times of higher flows, and ORC (1993) lists several events where flooding has occurred on higher river terraces (including in Middlemarch) due to high flows in adjacent creeks. GNS (2009) found that flooding is the dominant process associated with alluvial fans in this area, with fan-building activity and sedimentation limited to areas close to the present stream channels. However, GNS did consider that larger debris flows were a prominent feature of some alluvial fans at some stage in the past, judging by the large boulders on parts of the lower fan surfaces.

The extent of 'active' alluvial fan surfaces, as mapped by Opus (2009) and GNS (2009), is also shown in Figure 69. The Opus maps were produced at a scale of 1:50,000 and are derived from pre-existing geologic and landform maps. The GNS maps were produced at a scale of 1:10,000 and were created using both existing information and field checks.[23] The alluvial fan features shown on Figure 69 include the more detailed GNS information where it is available and the 1:50,000 mapping elsewhere. The features shown include:

- 'active' fan areas, which may be prone to surface flooding, or channel floods carrying sediment within the next 100 years or so (from Opus, 2009)
- 'fan recently active' areas, where sedimentation has occurred within the last 300 years, or where the stream is more likely to break out of its channel during periods of high flow (from GNS, 2009).

Recently active landslides and areas of gully erosion in upper catchment areas are also shown (as mapped by GNS, 2009). As well as indicating areas of land instability, landslides and erosion can provide a source of sediment for downstream alluvial fan features.

Figure 68 Taieri River at Sutton Bridge, during the June 1980 flood

[23] The Opus (2009) mapping has an estimated accuracy +/-100m, while the accuracy of the GNS (2009) data is +/-20m.

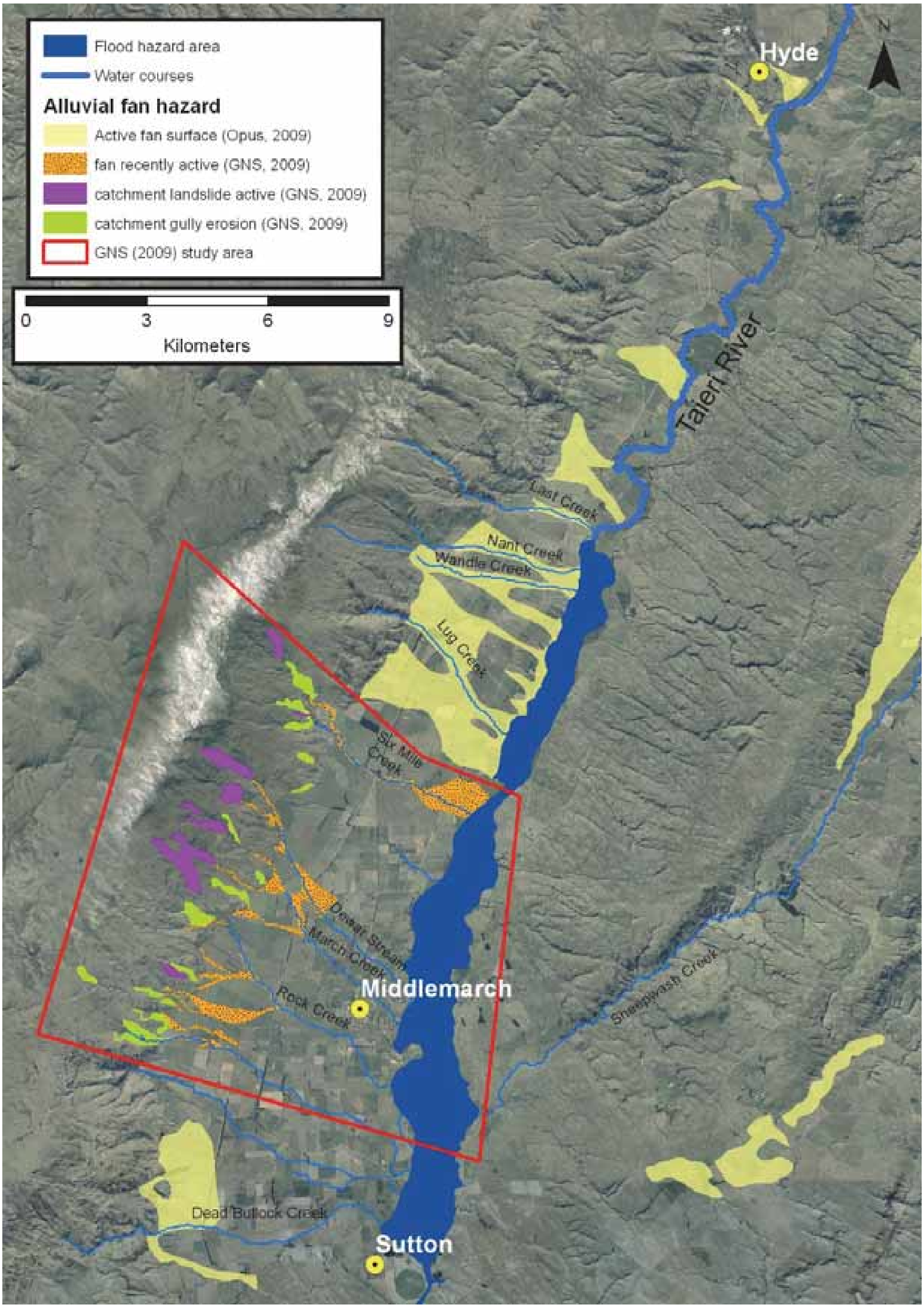

Figure 69 **Strath Taieri flood-hazard area (ORC, 1993), and active alluvial-fan surfaces (GNS, 2009 and Opus, 2009)**

5.3. Strath Taieri flood hazard: Summary

The largest floods in the Strath Taieri occur when slow moving fronts pass from west to east over the catchment, and the flood peak from the upper catchment coincides with the maximum local runoff in tributary streams (ORC, 1993). Figure 69 shows valley floor areas that may be subject to river flooding, as well as alluvial-fan areas that may be subject to debris and/or flood flows in the tributaries that drain from the Rock and Pillar Range.

Flooding can be compounded by the effect of the gorge below Sutton, which can restrict the drainage of floodwater. Damage from previous flood events has included inundation of buildings, houses and roads, scouring of river banks and road embankments, and substantial damage to bridges and fences (Figure 66 and Figure 68). Localised heavy rainfall events, or ‘cloudburst’, can occur with little warning, and result in surface flooding and sedimentation when tributary streams break out of their channels. Much of the area can become isolated due to high flows in the Taieri River or its tributaries.

Appendix 1. Summary of changes to the mapped flood-hazard areas presented in ORC (2014)

DESCRIPTION	Original label	Revised label	Summary of changes
Area 1A - West Taieri Plain below high-tide level	1A	1A	No changes made to the mapped extent
Area 1B - West Taieri Plain above high-tide level	1B	1B	No changes made to mapped extent, overland flow paths within 1B identified as 1C
Area 1C - West Taieri overland flow paths	1B	1C	New area - overland flow paths within 1B
Area 2 - Maungatua	2	2	No changes made to the mapped extent
Area 3 - Waipori	3	3	No changes made to the mapped extent
Area 9 - Henley	9	9	No changes made to the mapped extent
Area 10 - Taieri Floodway	10	10	No changes made to the mapped extent
Area 11 - Taieri River berms	11	11	Minor changes to mapped extent at Allanton
Area 12 - East Taieri Upper Pond	12	12	No changes made to the mapped extent
Area 13A - Upper Pond ring bank (north)	13	13A	No changes made to the mapped extent, identified separately to 13B
Area 13B - Upper Pond ring bank (south)	13	13B	No changes made to the mapped extent, identified separately to 13A
Area 14A - North Taieri overland flow paths	14A	14A	Extended further upslope to where they become deeply incised channels
Area 14B - North Taieri floodways	14B	14B	Revised extent of Gordon Road spillway component
Area 14C - North Taieri alluvial fans	14C	14C	Separated from floodplain, upper margins limited to extent of mapped alluvial fans
Area 14D - North Taieri floodplain	14C	14C	Separated from alluvial fan
Area 17 - East Taieri Lower Pond	17	17	No changes made to the mapped extent
Area 18 - South of Owhiro Stream	18	18	No changes made to the mapped extent
Area 19 - East of the Lower Pond	19	19	Southern margin amended, with alluvial fan areas removed
Area 20 - Mosgiel	20	20	Southern margin amended, with alluvial fan areas removed
Area 21 - Wingatui	21	21	Southern margin amended, with alluvial fan areas removed
Area 22 - Alluvial fans on flanks of coastal hills	22	22	Modified to only contain areas identified as alluvial fan
Area 23 – Jaffray Creek alluvial fan	22	22	New hazard area, separated from other alluvial fans

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