Extent and characteristics of alluvial fans in the northeastern sector of the Taieri Plain, Otago

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EXECUTIVE SUMMARY

An alluvial fan is an accumulation of river or stream (alluvial) sediments that form where streams emerge from hill country onto a valley floor. Floods of sediment-laden water generated during major rainstorms can sometimes spread across parts of the fan surface. These may include fast-moving slurry-like flows of debris that can be damaging to buildings or other infrastructure such as water supplies or roads, and pose safety threats to people. A region-wide evaluation of alluvial fan hazards initiated in 2006 by Otago Regional Council (ORC) identified extensive potentially active alluvial fans in the northeastern part of the Taieri Plain. In 2013, ORC engaged GNS Science to review and re-evaluate the alluvial fan hazards in that area. This report presents the results of that re-evaluation.

The assessment was largely office-based, involving review of existing information, and the examination of aerial and satellite photography, and ORC high-resolution lidar topographic imagery. An interpretive map of landforms, focused on the alluvial fans and their catchments was made from those information sources, and a one-day field check was carried out.

The work has shown that alluvial fans are less extensive in the northeastern sector of the Taieri Plain than was previously thought. There is little sign of active erosion in the catchments, and the maturity of soils on the fans indicates that there has been little deposition of sediment on them within the last few hundred years at least. Nonetheless, floodwater is likely to spread over low-lying parts of many of the fans during rainstorms, and water inundation is a hazard to watch out for, particularly close to the active stream channels, whether natural or engineered, on the fans. A consideration along the southern side of the Taieri Plain is extensive embankments and cuttings associated with State Highway 1 and the Main Trunk Railway. These structures provide considerable flood control, and protection for areas downstream of the embankments, but potentially enhanced hazards on the upstream side were there to be blockage of culverts, and ponding of water or sediment.

The present condition of the fans could be altered by future natural or human-induced events, such as the occurrence of a significant landslide event, or events, in a fan catchment that could provide an abundant source of sediment that is transported down onto the fan, or material that is mobilised into debris flows that may run out onto the fan.

The main hazard currently presented by the fans is flooding close to active stream channels. However, one cannot discount the possibility of a change in catchment stability, and a consequent increase in sediment supply to the fans with attendant flooding and sedimentation hazards. The fan of Jaffray Stream at East Taieri is potentially sensitive to changes in its catchment, and on account of the number of residential dwellings on its fan, is suggested as warranting further hazard evaluation.

1.0 INTRODUCTION

An alluvial fan is an accumulation of river or stream (alluvial) sediments that forms a sloping landform, shaped like an open fan or segment of a cone. Alluvial fans typically form where streams emerge from hill country onto a valley floor. Although the stream that constructed the fan usually occupies a narrow channel on the fan surface, floods generated during major rainstorms can sometimes overtop the stream channel and spread across parts of the fan surface, and the stream may forge a new, sometimes unexpected, path. Hazards associated with alluvial fans include fast-moving sediment-laden floods and slurry-like flows of debris. Fan sediment-laden floods or flows may be damaging or destructive to anything in their paths, and pose a threat of injury or death to people. Less serious hazards include sediment build-up, which may cause damage to productive land, crops or various types of infrastructure, such as water supplies or roads.

In 2006, Otago Regional Council (ORC) initiated a region-wide evaluation of alluvial fans, the nature and extent of associated hazards, and potential impacts on communities. The aim of that project was to improve our knowledge of alluvial fans, so that their associated hazards may be able to be mitigated in an appropriate manner. The region-wide study (Grindley and others, 2009) was supplemented by a more in-depth evaluation of alluvial fan hazards at particular locations in Otago, selected by ORC in consultation with territorial authorities. The supplementary report (Barrell and others, 2009) developed a method for assessing fan hazards that includes mapping of landforms in the catchment of streams, as well as on their fans.

The region-wide study (Grindley and others, 2009) identified extensive alluvial fans in the northeastern part of the Taieri Plain. This was not one of the areas selected for more detailed investigation in the 2009 supplement, and questions remain as to the extent and severity of hazards posed by alluvial fans in the northeastern sector of the Taieri Plain. Accordingly, ORC commissioned GNS Science to re-evaluate the mapping and classification of alluvial fans in that area (Figure 1). This report presents the results of that re-evaluation.

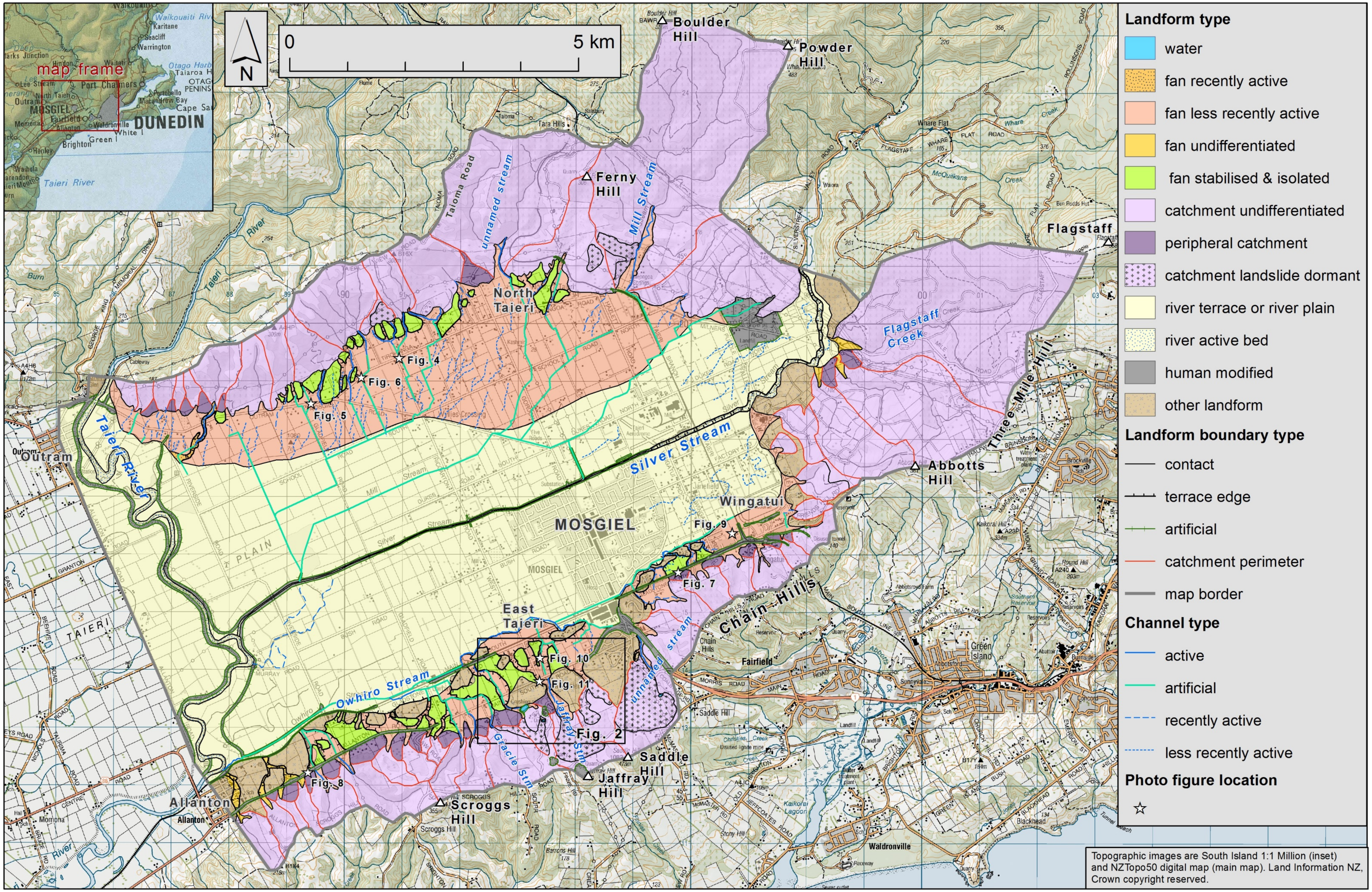

Figure 1 Interpretive map of alluvial fans, their catchments, and other adjacent landforms in the northeastern sector of the Taieri Plain. The channel mapping is not exhaustive, but is intended simply to depict the general character of channel distribution. The Taieri River and Silver Stream floodbanks are mapped as human modified ground, flanked by 'artificial' landform boundary lines; this relationship is difficult to resolve by eye at the map scale.

2.0 REVIEW OF PREVIOUS MAPPING

The 1:250,000 regional-scale geological map (quarter-million-scale; also called QMAP) that encompasses the Dunedin area (Bishop & Turnbull 1996) classified all of the floor of the northeastern sector of the Taieri Plain, northeast of about Gladfield Road, as an alluvial fan formed by Silver Stream and minor streams draining off the surrounding hills. The reason of this approach was that because of the rules governing the compilation of the QMAP geological maps, there was no other way of differentiating between the deposits of the Taieri River, which underlie the central to southwestern sectors of the Taieri Plain, and the more locally derived stream sediments underlying the northeastern sector of the plain. By classifying the Silver Stream deposits as 'alluvial fan' rather than 'river alluvium', Bishop & Turnbull (1996) could show the extent of Taieri River sediments beneath the Taieri Plain.

For consistency, Barrell and others (1998) followed the approach of Bishop & Turnbull (1996). A slightly different approach was used by Barrell and others (1999) in that they mapped the Taieri Plain in a more geomorphological way than the traditional geological maps, and they did not identify the Silver Stream sector of the Taieri Pain as an alluvial fan, but rather as a river plain.

In the region-wide assessment of alluvial fans by Grindley and others (2009), the datasets from Bishop and Turnbull (1996) and Barrell and others (1998) were used as the basis for mapping in the Taieri Plain area. It is for that reason that the 2009 report showed extensive areas of alluvial fans in the northeastern sector of the Taieri Plain.

This has had the consequence of implying the possible existence of alluvial fan hazards across large parts of the northeastern sector of the Taieri Plain. However, this has arisen because the original mapping was primarily for geological emphasis, rather than oriented towards landform processes and related hazards. The river plain that forms much of the northeastern sector of Taieri Plain is a product of usual river processes by Silver Stream, and is subject to river flooding hazards. In regard to evaluating alluvial fan flooding hazards, it is necessary to amend the mapping to a more geomorphological focus, and differentiate the river plain from the alluvial fans that encroach upon the margins of the plain.

3.0 REVISED ALLUVIAL FAN MAPPING

3.1 METHODS

This report applies the methodology of Barrell and others (2009) to the mapping of alluvial fans and other relevant landforms in the northeastern sector of the Taieri Plain. The new map is presented in Figure 1. Tabulated definitions and descriptions of the map features are provided in Appendix 1 (Table A1–Table A3). However, those tables are taken directly from Barrell and others (2009), and not all of the feature types in those tables occur within the area mapped in the present report.

Figure 1 presents an interpretation of the nature, origin and relative age of landforms. The interpretation was made by the writer specifically for this report. The map was drawn directly into a GIS database, using on-screen display of lidar[1] imagery supplied by ORC (Figure 2), the NZTopo50 1:50,000-scale digital topographic map, and high-resolution satellite imagery available through ArcGIS, the software that was used for this project. Google Earth, and in particular the 'Street View' module, was also used as a resource for the mapping and landform interpretation. Information from soil survey maps (e.g., Beecroft and others 1991; growOTAGO; growRural Dunedin) aided the fan interpretation.

This report is based largely on existing publicly-available information and the interpretation of aircraft and satellite imagery. The landform map was field-checked during a one-day inspection undertaken from vantage points on public roads. The GIS shapefiles from which the Figure 1 map is rendered are available from ORC on request, and are described in Appendix 2. Because the mapping work did not involve detailed field examination, the scale of mapping is given as 1:15,000, a representative scale at which the lidar imagery provides useful resolution. This specified scale distinguishes this assessment of the northeastern Taieri Plain from more comprehensive 1:10,000-scale alluvial fan mapping undertaken at other locations in Otago, documented by Barrell and others (2009).

The map presented in this report is generalised in nature. For any activities requiring site-specific information, such as hazard assessment for specific subdivisions, buildings or other infrastructure, the map interpretations should be verified on site by an appropriately qualified or experienced geotechnical professional.

[1] Lidar = light and radar. It is analogous to radar, but uses laser beams rather than radio waves.

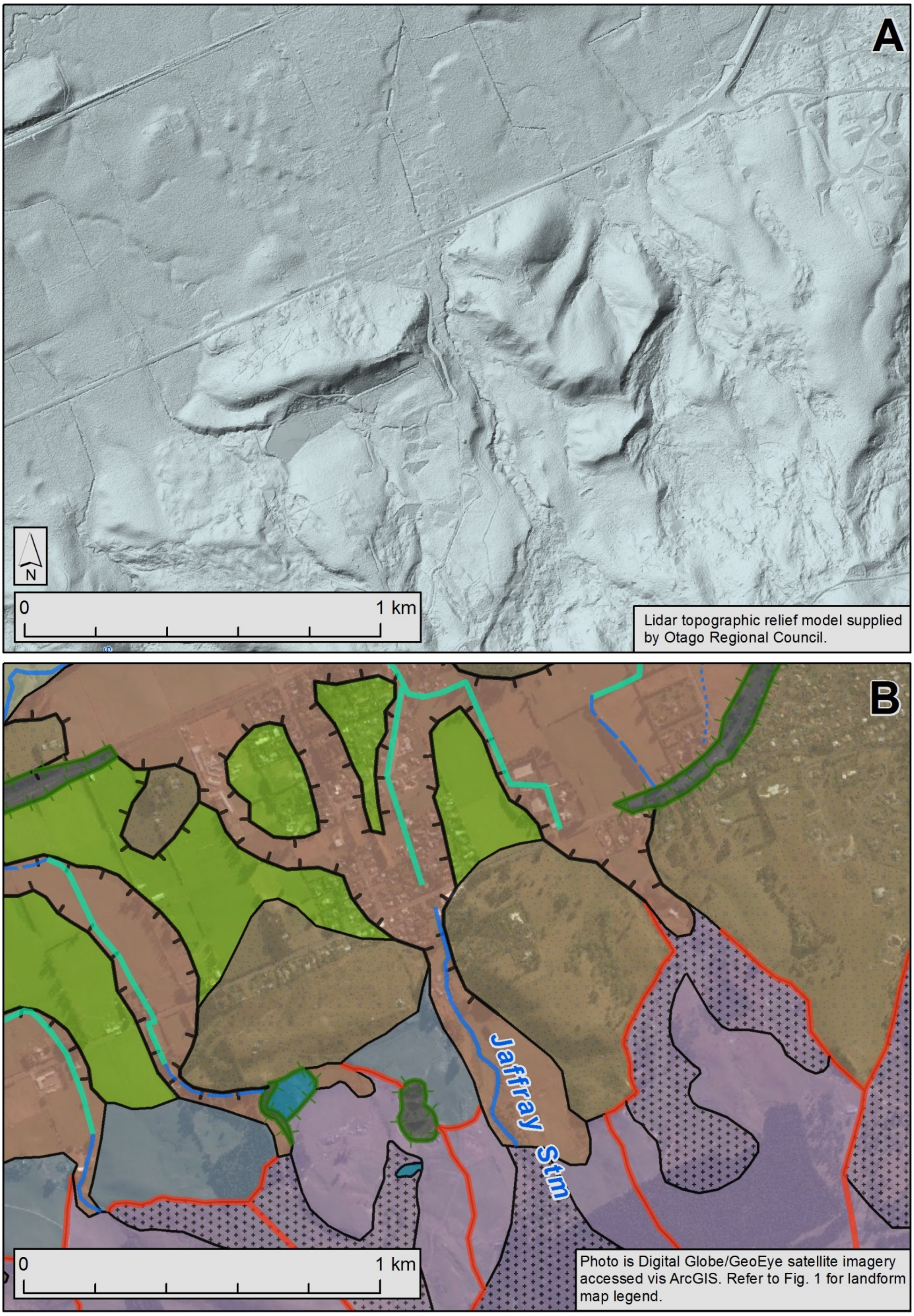

Figure 2 Topographic relief image generated from lidar data (A) and the landform map produced for this project, overlaid on a high-resolution satellite photo (B). Both maps cover the same area; map scale is 1:15,000. East Taieri township (upper centre) is built on the terraced fan of Jaffray Stream, while the Kinmont suburb of Mosgiel is at upper right. Note the prominent railway cutting and embankment (upper left) and motorway embankment (upper right).

3.2 OVERALL SETTING OF THE FANS AND THEIR CATCHMENTS

The character of the fans and catchments of the northeastern sector of the Taieri Plain reflect their geological setting. The Taieri Plain is a tectonic depression (Taieri Basin) resulting from the long-term effects of movements on geological faults, which have uplifted the northern and southeastern flanks of the basin. The Titri Fault runs along the southeast side of the Taieri Plain, while the North Taieri Fault runs along the northern side of the plain (Bishop & Turnbull 1996; Litchfield 2001; O'Sullivan and others, 2013). These faults show no indications of having moved within the past few tens of thousands of years, but they were more active prior to that (Litchfield 2001). The vertical movement on both faults diminishes towards the northeast, and the high ground enclosing the northeastern end of the plain is part of the eroded remains of the Dunedin Volcano. Although long-extinct, with last activity about 10 million years ago, the volcanic complex still has topographic prominence, with notable high points overlooking the Taieri Plain such as Abbotts Hill, the Three Mile Hill ridge, and Flagstaff. Saddle Hill, Jaffray Hill and Scroggs Hill are the remains of subsidiary vents of the Dunedin Volcano.

Southwest of Wingatui and North Taieri, the Titri and North Taieri fault escarpments are prominent. Runoff into the plain comes from minor catchments eroded into these ancient fault escarpments (Figure 1). However, towards the northeast where the fault scarps diminish, larger catchments such as Mill Stream drain onto the plain, and Flagstaff Creek which drains off the volcanic massif.

Silver Stream drains a large catchment in the hinterland to the north, and has formed a river plain draining southwest down the Taieri Plain, where it merges with the plain of the Taieri River. These are river plains, rather than the steeper gradient alluvial fans built out into the Taieri Plain by the small streams.

3.3 RESULTS

3.3.1 Features mapped

The fans, as well as their catchment areas, were mapped as areas (polygons), and classified according to the framework of Barrell and others (2009; see Appendix 1). The rationale for the mapping of catchments as well as fans is that conditions in the catchments are an important aspect to consider when evaluating the nature of the fans and implications for hazard assessment and mitigation. The basin-ward faces of ridges separating hill catchments were mapped as 'peripheral catchment'. The reasoning is that drainage from these areas is onto the fan margins, but does not contribute to the stream that emerges onto the head of the fan. Also, areas of relatively high ground within the fan area, or hill slopes where there are no fans, were mapped as 'other landform'. They include knobs or ridges of local bedrock, and tectonically elevated remnants of old fans or river terraces that are no longer part of the fan or river plain system.

Channels on the fans were mapped as lines where they were evident on the lidar. This was particularly useful on the northwestern side of the assessment area, where the change from basin-ward channel azimuths, to down-plain channel azimuths helps to define the toes of the fans. However, the mapping of these channels is not exhaustive, but is confined to delineating some of the most obvious hydrological features. The channels mapped in Figure 1 are not a comprehensive depiction of hydrologic features of the assessment area.

Major constructed embankments associated with the flood protection and management scheme of the Taieri Plain are substantial landforms and are included on the landform map (Figure 1). Areas of notably modified ground, especially relating to road or railway embankments, are also on the map, as these are potentially relevant to alluvial fan flooding hazards, in regard to culverts, etc. The mapping of embankments is illustrative rather than comprehensive. For more complete information on flood banks and constructed channels on the Taieri Plain, readers should refer to the report by O'Sullivan and others (2013).

3.3.2 Catchment and fan characteristics

The fan catchment areas were mapped as 'undifferentiated', except for a few areas of obvious landslide terrain, which were mapped as 'catchment landslide dormant/creeping' (e.g., see Figure 2 and description in Table A1). Note that for reasons of space, the landslides are labelled in the Figure 1 legend as 'catchment landslide dormant' because space did not allow the inclusion of '/creeping'. As none of the mapped landslide areas were inspected on the ground as part of this assessment, it was not possible to determine whether any parts of these landslide areas are currently active. Classifying them as 'dormant/creeping', which is the default class for landslides in the Barrell and others (2009) data structure, was judged to be the appropriate option for this study. There are no notable areas of deep-seated active gully erosion in the catchments, and for the most part the catchments appear to have good soil and vegetation cover. No attempt was made to map landslide areas in detail, and there are numerous small areas of landslide terrain in many of the catchments that are included in the 'catchment undifferentiated' unit. Readers should refer to other datasets maintained by Otago Regional Council or Dunedin City Council for information on landslides in the catchments shown in Figure 1. A general overview of the hazard significance of landslides in the Dunedin area is provided by Glassey and others (2014). Readers seeking information on geology in these catchments should consult Bishop & Turnbull (1996) and references therein.

The character of the fans varies from place to place in the assessment area (Figure 1). A key point of information from the soil maps (Beecroft and others 1991; growOTAGO; growRural Dunedin) is that no immature (i.e., 'raw') soil groups are identified on the fans. This indicates that there has been no significant sediment accumulation on the fans in recent times (i.e., at least the last 300 years). As a consequence, the fans have largely been mapped as 'less recently active', following the classification scheme of Barrell and others (2009). Only one area of 'recently active' was identified, in an incised channel about 2.5 km east of Outram (Figure 1). This identification is tentative, as the soils were not examined, but this channel has a morphological freshness suggestive of recent activity. In places, there are areas of terraced fans (Figure 3), and the fan terraces that are sufficiently above the level of modern streams to be out of reach of flood activity were mapped as 'stabilised and isolated'. Near Allanton and at the foot of Three Mile Hill, some narrow fans were mapped as 'undifferentiated' (Figure 1) because it seems likely that they could be potentially active in major floods, but this would need further evaluation if it were important to establish.

The apparent lack of active erosion in the catchments accords well with an absence of very young soils on the fans. Undoubtedly, the streams draining onto and down the fans carry water during wet seasons and in particular during major rainstorms, but it would appear that the sediment carried by these floodwaters, predominantly sand, silt or clay in suspension, is conveyed down the fans to the river plain with little sediment deposition occurring.

3.3.3 Fans on the northern side of the Taieri Plain

On the northern side of the Taieri Plain, the catchments of the fans are very small, comprising the steep hillslopes that overlook the plain. The fans from these catchments have overlapped and formed a coalesced apron (Figure 1 and Figure 4). East of Gladfield Road, numerous remnants of an older set of terraced fans protrude above the young coalesced fans (Figure 5). The young coalesced fans are of low gradient, and merge almost imperceptibly with the river plain (Figure 1). In contrast, west of about Gladfield Road, the coalesced fans are relatively steep and voluminous, and there are almost no older fan terraces. The size of these fans is particularly notable when driving on Outram-Mosgiel Road between Gladfield Road and Riverside Road, where there is a large rise onto the crest of each fan.

In the area east of Gladfield Road where there are terraced fans, it seems likely that, at some time in the past, Silver Stream flowed close to the northern margin of the plain, trimming the toes of the fans, and causing the streams to cut down into their fans, producing fan terraces. West of Gladfield Road, the toes of those fans were not trimmed, and the older fan deposits, which occur in fan terraces farther east, presumably lie buried under the younger coalesced fans. This implies that the former course of Silver Stream diverted back to the south at about Gladfield Road, and did not continue west towards Outram. This accounts for the relatively large and steep fans west of Gladfield Road – their size can be explained by their having been forming for a much longer period than the fans to the east, whose formation was interrupted by an episode of erosion by Silver Stream. The reason that this is important is that it affords a plausible explanation for the character of the fans in this area, and allays any possible concerns about whether the larger steeper fans west of Gladfield Road indicate a more vigorous history of fan growth there, than farther east. All of the youngest fans are aggradational, but appear to be behaving more like equilibrium fans, due to the small supply of sediment from the catchments, as indicated by soil maturity. A consequence of the low gradient of the fans east of Gladfield Road is a lack of stream incision into the fans, and substantial artificial channels have been cut to control floodwater (Figure 6).

Another feature of note is that at Mill Stream (also known as Mill Creek), and the adjacent catchment draining south from Ferny Hill (Figure 1), the substantial embankment of the Taieri Gorge Railway crosses the fan heads, largely isolating the lower reaches of the fans from their catchments. Mill Stream is conveyed around the eastern side of the embankment into a series of deep artificial channels that deliver the most of the water to Silver Stream just upstream of Gordon Road through the Mill Creek Diversion. In contrast, there is no embankment across the valley of the ‘unnamed stream’ that drains a large catchment between Taioma Road and Ferny Hill (Figure 1). Thus, its flow is unimpeded and is conveyed via a partly excavated natural channel down its fan, where it discharges to a straight artificial channel, marked as ‘Mill Stream’ on the topographic map, and by a sign on the bridge where the Outram-Mosgiel Road crosses the channel. Apart from water that can be carried by a small artificial channel along Dukes Road and Outram-Mosgiel Road, water from the Mill Stream catchment no longer reaches this channel. Observations made during very high flow events in Silver Stream (such as April 2006) suggest that the Mill Creek Diversion captures some of the flow from Silver Stream and conveys it in a northerly (reverse) direction along Dukes Road (O’Sullivan and others 2013).

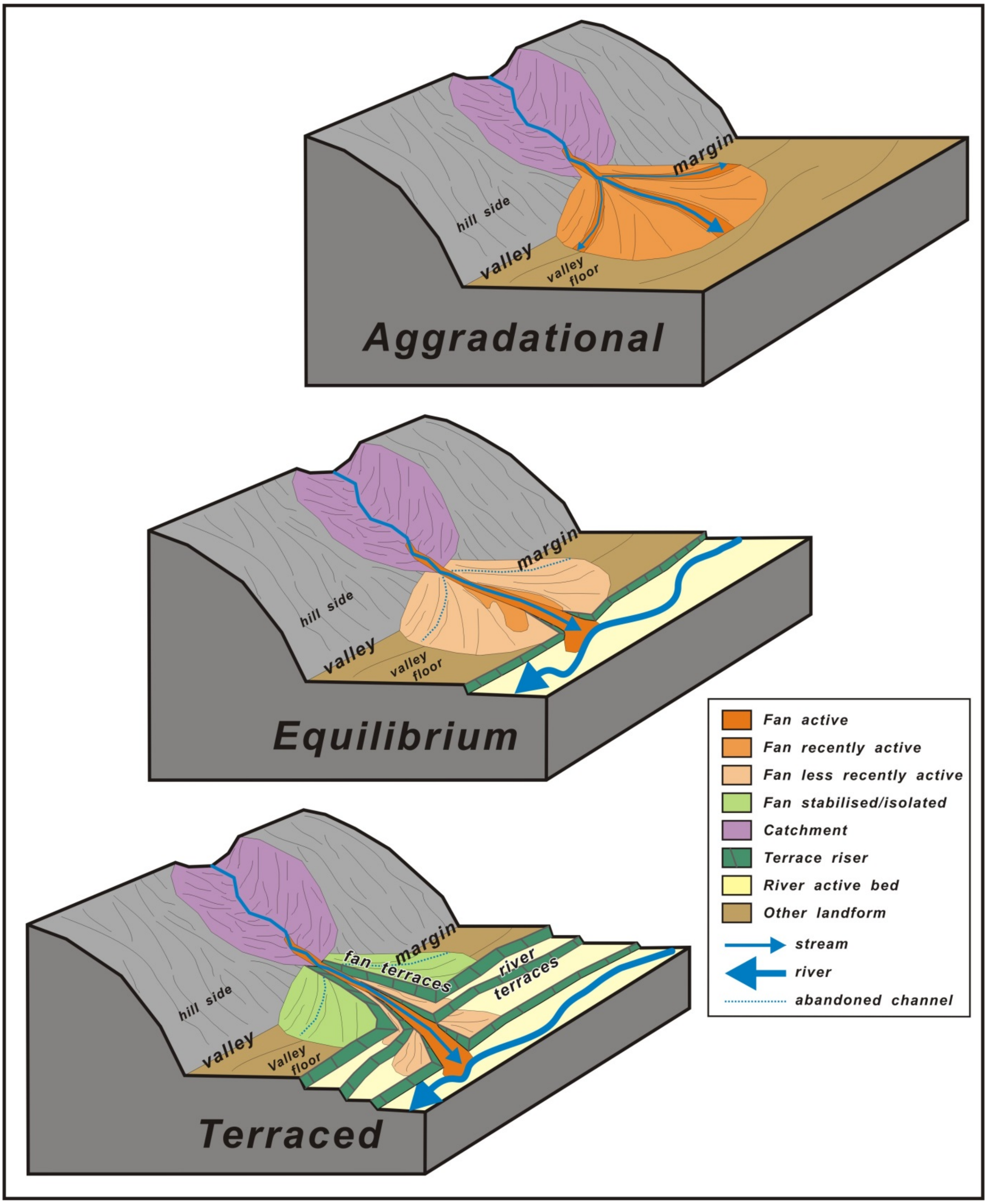

Figure 3 Concept diagrams illustrating three main types of alluvial fan. Differences in fan type depend largely on whether there is a mechanism for removing sediment from the fan system, such as a river. Diagram from Barrell and others (2009).

Figure 4 A view east-northeast along Tirohanga Road from the Riccarton Road intersection. The road rises and falls as it crosses the axes of alluvial fans. The fans overlap with one another, forming a coalesced apron of fan landforms (Figure 1). The catchments lie to the left of this view, and the fans descend gently to the right, and merge imperceptibly with the Silver Stream river plain near Wyllies Crossing, about 1 km to the right (southeast) of this location. In contrast, the Outram-Mosgiel Road, west of about Gladfield Road, crosses a set of much steeper alluvial fans, and the rise and fall of the road is much more marked as it crosses those fans. The fans in this view have very low gradients, and are of the aggradational type, but are currently in an equilibrium condition (see Figure 3). Photo: D.J.A. Barrell, 17 February 2014, GNS Science.

Figure 5 A view east from Outram-Mosgiel Road, about 200 m east of Gladfield Road. The fans here are terraced (see Figure 3). The houses are situated on a fan terrace, mapped as ‘stabilised & isolated’ in Figure 1. An inset natural channel running centre left to right along the foot of this terrace appears to be of sufficient depth and width to contain runoff from the catchment (upper left) because no attempt has been made to cut an artificial channel. Although the fan surface in the foreground, mapped as ‘less recently active’, is of an aggradational type, it is currently in an equilibrium condition because there are few if any sites of active erosion (and therefore sediment supply) in its catchment. Photo: D.J.A. Barrell, 17 February 2014, GNS Science.

Figure 6 A view southeast from Tirohanga Road, about 0.6 km east of Outram-Mosgiel Road, showing a large artificial channel. There are no deeply inset natural channels on this fan, and doubtless motivated the excavation of this ~3 m deep ditch to capture and convey the runoff from the ~100 hectare hill catchment of this fan. Photo: D.J.A. Barrell, 17 February 2014, GNS Science.

3.3.4 Fans at the northeastern end of Taieri Plain

Flagstaff Creek has the largest catchment of all the minor streams in the assessment area, yet has one of the smallest fans (Figure 1). Small fans also occur at the mouths of two smaller, but still notably large, catchments draining from the Three Mile Hill and Abbotts Hill areas. These are good examples of true equilibrium fans (Figure 3), where the presence of Silver Stream flowing past their toes carries away any sediment brought down from these catchments, and therefore their fans cannot currently grow any larger than their present size.

3.3.5 Fans on the southern side of the Taieri Plain

An apron of coalesced aggradational-equilibrium fans lies east of about Wingatui Road, while a set of terraced fans, closely associated with hills or terraces of ‘other landform’, extends from Wingatui Road south to about Allanton (Figure 1, Figure 7 and Figure 8). Most of the ‘other landform’ features probably relate to uplift along the Titri Fault, during its most recent episode of activity many tens of thousands of years ago. The uplift may have contributed to the terracing of the fans, but the main reason for the terracing is likely to have been erosion of the toes of the fans by Silver Stream, at times when it has flowed along the southern margin of the plain.

A notable feature of this area is the extensive systems of embankments or cuttings along the South Island Main Trunk Railway and State Highway 1 (Figure 1). The embankments have in some instances isolated the upper and lower sectors of fans (Figure 9), with the effect of reducing or even eliminating alluvial fan flooding or sedimentation hazards downstream of major embankments, but potentially increasing the impact of those hazards upstream of embankments.

Figure 7 A view northwest from Gladstone Road, about 1 km northeast of Gordon Road. At the far side of the paddock is a low ridge mapped as 'other landform'. This is a remnant of a river terrace that is interpreted to have been raised up during the most recent phase of movement of the Titri Fault. The streams draining into the plain have cut broad channels across the 'other landform'. The fan surface in the middle ground occupies one such broad channel, and is mapped as 'stabilised & isolated'. The streams have subsequently cut down even more deeply, forming inset channels mapped as 'less recently active'. The railway formation here is in a cutting about 3 m deep, and lies at the interface between the 'stabilised & isolated' fan surface, and a hill slope mapped as 'peripheral catchment' (behind the photographer). Photo: D.J.A. Barrell, 17 February 2014, GNS Science.

Figure 8 A view north from State Highway 1, about 1 km northeast of Allanton, showing terraced fan surfaces set between low hills mapped as 'other landform'. The fan areas near the gully axes are mapped as 'less recently active', alongside of which are higher fan terraces mapped as 'stabilised & isolated'. The highway here is raised on an embankment that, similarly to the railway embankment at Wingatui (Figure 9), isolates the lower and upper parts of the fans. Photo: D.J.A. Barrell, 17 February 2014, GNS Science.

Figure 9 A view southeast along Henderson Street towards the catchments of the fans at Wingatui, on the northwestern flank of Chain Hills. These low-gradient fans form a coalesced apron, mapped as 'less recently active'. Note the fairly steep relief of the catchments, which are formed in schist rock that shows little sign of slope instability here. A significant feature at Wingatui is the railway formation, which for the most part is raised on a several-metre-high embankment, adorned with the word 'WINGATUI', rendered in shrubs, of which the 'ATU' is visible here. The embankment forms a substantial structure that separates the lower and upper parts of the fans. Consequently, the lower parts of the fans are now isolated from fan flooding or sedimentation, but on the other hand, low-lying parts of the fans on the upstream side of the embankment have enhanced potential for flooding and sediment accumulation. However, there are few if any notable sites of active erosion in the catchments, and the fans seem to be in an equilibrium state at present. Photo: D.J.A. Barrell, 17 February 2014, GNS Science.

There is considerable residential and some industrial development on the fans from Wingatui to East Taieri (Figure 1). The largest catchment of this area is that of an unnamed stream, whose catchment drains the area between Saddle Hill and the southwest end of Chain Hills (Figure 1). State Highway 1 crosses Chain Hills and descends towards Mosgiel down this catchment, which has been considerably modified by earthworks. Notably, the downstream end of the catchment is entirely confined by the large embankments of the Mosgiel interchange. Curiously, no discernible fan remains in that area, so perhaps it was modified or removed during development of the Mosgiel industrial area south of Gladstone Road. The area of greatest note is at East Taieri township, which is built on the fan of Jaffray Stream (Figure 2). The stream is scarcely incised into its fan, and is conveyed through the residential area and under the highway in an engineered channel, which may closely approximate the position of its original natural channel (Figure 10 and Figure 11). Of all the fans in the assessment area, this appears to be the one most susceptible to alluvial fan flooding or sedimentation, should the channel or culvert become obstructed by debris during a flood event.

Figure 10 A view northeast along State Highway 1 at East Taieri township, showing the fan of Jaffray Stream. The road rises over the fan axis, and Jaffray Stream is conveyed under the road 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.J.A. Barrell, 17 February 2014, GNS Science.

Figure 11 The engineered channel of Jaffray Stream at Orchard Grove, East Taieri. The head of its ~70 hectare catchment extends between Saddle Hill (left) and Jaffray Hill (right). Photo: D.J.A. Barrell, 17 February 2014, GNS Science.

3.4 IMPLICATIONS FOR HAZARDS

The main characteristic of the assessment area is that the catchments do not appear to have signs of large-scale recent erosion, or general instability. This is compatible with the generally subdued form of the fans, few indications of recent out-of-channel overbank sedimentation, and the typically single-thread (as opposed to braided) form of the stream channels. The fans on the northern side of the assessment area, between the Taieri River and where Silver Stream emerges onto the plain, are for the most part aggradational in character, but currently appear to be in an equilibrium state (Table A2). Fans on the southern side of the assessment area are for the most part terraced. This may partly be a consequence, long-term, of uplift and deformation on the Titri Fault, which bounds the southeastern side of the Taieri Plain, although indications are that the fault has had little if any activity in the past few tens of thousands of years (Litchfield 2001). Erosion by Silver Stream, at times when it occupied the southern side of its plain (prior to European settlement), or erosion by the Taieri River near Allanton, may have contributed to fan toe erosion, causing incision of the streams on the fans, and formation of fan terraces.

Collectively, the geomorphological evidence indicates that the fans of the assessment area are not particularly active at present, and the hazards presented are largely related to flooding in proximity to the active stream channels. However, it is important to appreciate that on any of the fans, these conditions could change in response to changes in the catchments, either natural or human-induced. For example, the formation, or reactivation, of landslides in a catchment may markedly increase the sediment supply, with downstream implications for flood hazard and channel management on the fan. Of particular note is the fan of Jaffray Stream at East Taieri. There is extensive landslide terrain in its catchment, considerable residential development on its fan, and limited freeboard in the existing channels to allow passage of voluminous sediment, or in particular a debris flow. It would be advisable to undertake an engineering and hydrological assessment of potential alluvial fan flooding and debris flow hazards at East Taieri. Were a significant risk to be identified, this fan may be well suited to engineered protection measures, such as a cross-valley embankment upstream of the township to contain debris in the event of a debris flow.

The March 1994 rainstorm generated many landslides, particularly in the catchments on the southern side of the assessment area (Stewart 1996). I am not aware of any landslides having caused fan aggradation during that rainstorm, but it illustrates the type of weather event that could cause changes in the catchments, with possible downstream effects on the fans.

4.0 CONCLUSION

Alluvial fans in the northeastern sector of the Taieri Plain are not as widespread or extensive as was implied in previous work. There is no geomorphological evidence for areas of rapid erosion in the fan catchments, nor any evidence for recent widespread sedimentation on the fans. The main hazard currently presented by the fans is flooding close to active stream channels. However, one cannot discount the possibility of a change in catchment stability, and a consequent increase in sediment supply to the fans with attendant flooding and sedimentation hazards.

5.0 ACKNOWLEDGEMENTS

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APPENDICES

APPENDIX 1: FAN CLASSICATION INFORMATION

The following tables are taken from Barrell and others (2009), and provide definitions of the features included on the fan map in the present report.

Table A1 Description of landform types (areas), landform boundaries (lines) and channels (lines) used on the Otago Alluvial Fans landform GIS maps (1:10,000-scale fan GIS) (from Barrell and others, 2009).

NAME	UNIT_CODE	DEFINITION
LANDFORM TYPE (GIS layer)		
fan active bed	fna	Area of active or very recent (e.g. less than about 20 years) stream activity. Bare sediment or raw soils. Mapping based on what appears on ORC orthophotos (2005-06). Includes terrace-riser slopes up to adjacent higher fan surfaces.
fan recently active	fra	Area of relatively recent (e.g. less than about 300 years) stream activity. Immature forest (if present) and raw or very immature soils. Alternatively, the stream may be flowing on the fan surface, in a channel less than about 1 m deep. Includes terrace-riser slopes up to adjacent higher fan surfaces.
fan less recently active	fla	Area of less recent stream activity (e.g. more than about 300 years). Mature native forest (if present) and immature to mature soils. Includes terrace-riser slopes up to adjacent higher fan surfaces.
fan stabilised-isolated	fsi	Abandoned fan terrace, isolated from current fan drainage; boundaries with active streams are terrace risers more than about 10 m high on steep fans, or more than about 5 m on gentle fans. Mature native forest (if present) and immature to mature soils.
fan undifferentiated	fun	Not possible to differentiate as part of this study. Default for fan areas.
fan gully erosion	fge	Area of gullied fan surface, typically at the down-slope end of terraces of 'fan stabilised-isolated'. Reflects the long term consequence of rainfall runoff flowing over the riser at the down-slope end of fan terraces.
catchment channel active	cca	Area of active or recent (e.g. less than about 20 years) stream activity within a catchment.
catchment gully erosion	cge	Catchment slopes with indications of active or relatively recent (e.g. less than about 300 years) gully incision or shallow slippage. Immature native forest (if present) and raw to immature soils.
catchment active scree	cas	Catchment slopes with bare or poorly vegetated rocky scree.
catchment landslide active	cla	Catchment slopes with indications of active or relatively recent (e.g. less than about 300 years) landslide movement. Features may include bare ground, open cracks, immature native forest (if present) and raw to immature soils.
catchment landslide dormant/creeping	cld	Catchment slopes with hummocky or irregular topography typical of landslide origin, without indications of recent large-scale movement (e.g. bare ground, open cracks). Mature native forest (if present); immature to mature soils.
catchment long stabilised	cst	Catchment slopes with relict landforms many thousands of years old, e.g. with Ice-Age erosion features. Mature soils.
catchment undifferentiated	cun	Default for catchment areas.
peripheral catchment	prc	Areas draining onto fan margins, but not contributing to the fan-head stream draining the main catchment area. Not differentiated further with regard to gullying, landslides or stabilisation.
human modified	hum	Human modified (i.e. filled or excavated) ground surfaces. Includes road or bridge embankments. Includes general urban or industrial areas.
river active bed	rva	River bed and active floodplain. Bare sediment, may have immature scrubby vegetation on islands or near channel margins. Mapping based on what appears in ORC orthophotos (2005-06). Includes terrace-riser slopes up to adjacent higher terrace or fan surfaces.
river terrace	rtc	River terrace. Not subdivided further on basis of relative height/age. Includes terrace-riser slopes up to adjacent higher terrace or fan surfaces.
terrace riser	tcr	Riser between two terrace levels (whether fan or river). Only differentiated where sufficiently extensive to map at the scales used in this project. Otherwise, terrace risers are included within the area of the lower of the two terrace levels.
beach ridge active	bra	Dynamic beach sediments (sea or lake).
beach ridge stabilised	brs	Abandoned beach ridge (sea or lake).
lake bed abandoned	lba	Drained former lake bed (especially around Lake Wakatipu area).
other	oth	Other landforms not classified. Typically includes bedrock outcrops or Ice Age moraines.
water	water	Still water body, e.g. sea or lake. Includes seasonally-intermittent water within ponds or reservoirs.
LANDFORM BOUNDARY (GIS layer)		
contact	c	Boundary between landforms, mostly without height difference. Default for boundaries.
terrace edge	t	Stream-cut or river-cut boundary between fan surfaces of different height. Positioned at top of the terrace edge or slope.
artificial	a	Human-constructed or modified channel edge, channel, or embankment.
map border	b	Boundary defining the spatial limit of mapping.
perimeter	p	Perimeter of a fan and its catchment area, in some cases marking the limit of mapping or a landform contact.
terrace perimeter	tp	Stream-cut or river-cut boundary between fan surfaces of different height. Marks the perimeter of a fan and its catchment area.
artificial perimeter	ap	Human-constructed or modified channel edge, channel or embankment. Marks the perimeter of a fan and its catchment area.
fault scarp crest	fc	Crest of fault scarp that has deformed fan surfaces or separates surfaces of different age.
fault scarp base	fb	Base of fault scarp that has deformed fan surfaces or separates surfaces of different age.
CHANNEL TYPE (GIS layer)		
active	acc	Active or recent (e.g. less than 20 years) stream channel. Bare sediment or raw soils.
artificial	art	Human-constructed or modified channel, commonly with an associated embankment levee.
recently active	rac	Recently active stream channel (e.g. less than 300 years). Immature soils.
less recently active	lac	Less recently active stream channel (e.g. greater than 300 years). Immature to mature soils.
unclassified	unc	Unclassified channel from NZMS260 map series digital topography.

Table A2 Fan stability classification – including type of fan, nature of slopes in the catchment, and conditions at the fan toe (from Barrell and others, 2009).

Category	Definition	Diagnostic features	Examples	Anticipated future behaviour
PRESENT FAN TYPE				
Aggradational	Net up-building of the fan surface and net out-building of sediment at the fan toe.	Fan built on abandoned river terrace, or other inactive landform, with fan toe remote from a lateral transport agency (e.g. active river channel, wave-eroding shoreline).	Flaxmill Creek, Makarora; Hospital Creek, Hawea Flat.	Expect rapid short-term changes in channel position and in the loci of sediment accumulation and flooding.
Equilibrium	Approximate balance between sediment supply and removal from the fan system.	Lateral transport agency (e.g. river, shoreline) active at fan toe, fan stream is at least slightly incised into fan surface(s).	Waikerikeri Creek, Alexandra; Luggate Creek, Luggate; fans near Dumbarton, Roxburgh.	Recognise a possibility of changes in channel position and in the loci of sediment accumulation and flooding, and that short-term changes in catchment or at toe could result in rapid change to an aggradational or degradational condition.
Degradational	Net removal of both dynamic and accumulated sediment.	Lateral transport agency (e.g. river, shoreline) active at fan toe, fan toe cliffed; fan stream within channel, most deeply incised at toe.	Possibly Landon Creek, Oamaru.	Expect that sediment accumulation or flooding will be confined to the incised active channel, but also expect erosion and cliff retreat of channel and toe margins.
Terraced	Complex fan environment, formed by successive phases of aggradation and degradation. The present active stream bed may be in any one of the three types listed above.	Nested sequence of fan terraces, fan stream may currently be in either aggradational, equilibrium or degradational state. Common at the margins of large rivers, downstream of Ice Age glacier termini.	Amisfield Burn, Cromwell; fans at Gibbston.	Recognise that the nature of hazards will depend on geometry and distribution of terraces and active channels, and that this is the most likely type of fan to have stabilised terraces remote (altitudinally and laterally) from presently active parts of the fan complex.
CATCHMENT SLOPE STABILITY				
Presently unstable	Ongoing delivery of large volumes of coarse sediment to fan stream.	Extensive areas of active landslides or active gully terrain.	Pipson & Flaxmill creeks, Makarora.	Assume continuation of present fan type.
Potentially unstable	Potential for the onset of, or significant increase in, delivery of coarse sediment to the fan stream.	Few if any areas of active landslides or active gully terrain, but extensive steep slopes and/or areas of dormant or creeping landslides.	Tinwald Burn, Cromwell.	Assume continuation of present fan type, and that any changes would be towards a more aggradational state.
Potentially stable	No major active sources of coarse sediment delivery or obvious sources of future increases in sediment.	Few if any areas of landslide or active gully terrain, and predominantly moderate slopes.	Landon Creek, Oamaru.	Assume continuation of present fan type.
FAN TOE CONDITIONS				
Potential aggradation	Decrease in fan stream sediment removal.	Presence of factors that could lead to a reduction in river or shoreline erosion (either natural or due to engineering measures).	Amisfield Burn, Cromwell; aggradation at toe of active channel due to formation of Lake Dunstan.	Assume that changes in fan type would be towards an equilibrium or aggradational state.
Status quo	Continuation of present conditions.	No obvious factors that may lead to changes in sediment transportation at fan toe.	Flaxmill Creek, Makarora (aggradational); Landon Creek, Oamaru (equilibrium/degradational, due to coastal cliff retreat).	Assume continuation of present fan type.
Potential degradation	Increase in fan stream sediment removal.	Presence of factors that could lead to an onset or increase in river or shoreline erosion.	Pipson Creek, Makarora, if the Makarora River active bed increases its undercutting of the toe of the fan.	Assume that changes in fan type would be towards a degradational or terraced state.

Table A3 Fan landform types and boundaries in relation to hazard issues, the Grindley and others, 2009 report classification, and hazard assessment considerations (from Barrell and others, 2009).

NAME	UNIT_CODE	DEFINITION	HAZARD ISSUES	RELATIONSHIP TO '1:50,000-scale fan GIS' CLASSIFICATION (Grindley *et al.* 2009)	HAZARD ASSESSMENT CONSIDERATIONS
LANDFORM TYPE (GIS layer)					
fan active bed	fna	Area of active or very recent (e.g. less than about 20 years) stream activity. Bare sediment or raw soils. Mapping based on what appears on ORC orthophotos (2005-06). Includes terrace-riser slopes up to adjacent higher fan surfaces.	Present location of flooding/sedimentation activity. Currently unstable/hazardous.	Active	Site-specific hazard assessment recommended.
fan recently active	fra	Area of relatively recent (e.g. less than about 300 years) stream activity. Immature forest (if present) and raw or very immature soils. Alternatively, the stream may be flowing on the fan surface, in a channel less than about 1 m deep. Includes terrace-riser slopes up to adjacent higher fan surfaces.	Possibility of being reoccupied as location(s) of flooding/sedimentation activity.	Active	Site-specific hazard assessment recommended.
fan less recently active	fla	Area of less recent stream activity (e.g. more than about 300 years). Mature native forest (if present) and immature to mature soils. Includes terrace-riser slopes up to adjacent higher fan surfaces.	Possibility of being reoccupied as location(s) of flooding/sedimentation activity, particularly on aggradational- or equilibrium- fan types.	Active	Site-specific hazard assessment recommended.
fan stabilised-isolated	fsi	Abandoned fan terrace, isolated from current fan drainage; boundaries with active streams are terrace risers more than about 10 m high on steep fans, or more than about 5 m on gentle fans. Mature native forest (if present) and immature to mature soils.	Unlikely to be reoccupied under present conditions on the fan.	Inactive	Site-specific hazard assessment recommended if within 100 m of a terrace riser boundary with fna, fra or fla.
fan undifferentiated	fun	Not possible to differentiate as part of this study. Default for fan areas.	Uncertain. Requires further investigation.	Active or inactive	Site-specific hazard assessment recommended.
fan gully erosion	fge	Area of gullied fan surface, typically at the down-slope end of terraces of 'fan stabilised-isolated'. Reflects the long term consequence of rainfall runoff flowing over the riser at the down-slope end of fan terraces.	Erosion and slope stability hazards.		Evaluation of slope instability hazards recommended.
terrace riser (in fan areas)	tcr	Riser between two terrace levels (whether fan or river). Only differentiated where sufficiently extensive to map at the scales used in this project. Otherwise, terrace risers are included within the area of the lower of the two terrace levels.	Erosion and slope stability hazards.		Evaluation of slope instability hazards recommended.
LANDFORM BOUNDARY (GIS layer)					
contact (in fan areas)	c	Boundary between landforms, mostly without height difference. Default for boundaries.	Possibility of its position migrating due to erosion if the fan remains/becomes active at or near the contact. Loss of formerly stabilised ground, possibly creation of new ground.		A factor to consider in relation to any ground (defined above) for which site-specific hazard assessment is recommended.
terrace edge (in fan areas)	t	Stream-cut or river-cut boundary between fan surfaces of different height. Positioned at top of the terrace edge or slope.	Possibility of its position migrating due to erosion if the fan remains/becomes active at its toe. Loss of formerly stabilised ground.		A factor to consider in relation to any ground (defined above) for which site-specific hazard assessment is recommended.
artificial (in fan areas)	a	Human-constructed or modified channel edge, channel, or embankment.	Possibility that it may become inadequate for containing water/sediment due to aggradation or a flood event that exceeds the channel capacity.		Review of the adequacy of purpose of artificial features is recommended as part of any site-specific hazard assessment.

APPENDIX 2: DESCRIPTION OF GIS FILES

A new 1:15,000 GIS data set has been produced for the assessment area (see Figure 1 of report text). The individual layers are not intended to be viewed in isolation. Each GIS layer has been generated as an ArcMap shapefile, projected in New Zealand Map Grid (Geodetic Datum 1949). All contain metadata on the data source. This report presents work of regional extent. These data do not provide site-specific assessments of alluvial fan hazards, hazard zoning, or frequencies of hazard events. Such tasks are the role of site-focused engineering-based investigations. The layers are intended to underpin site-specific assessments of fan hazards and may assist territorial authorities in refining district plans, guide future community development and provide an additional source of information for assessing consent applications.

This GIS dataset can be obtained from Otago Regional Council, on request.

The layers are:

- orc_fans_northern_Taieri_Plain_landform_type_poly0414.shp

  A polygon shapefile depicting types of landforms in the assessment areas, mapped from aerial photographs, lidar data or field observations. Subdivided into different types of catchment, fan, river, or other landforms.

- orc_fans_northern_Taieri_Plain_landform_boundary_line0414.shp

  A line shapefile depicting the nature of boundaries between different landform types polygons, mapped from aerial photographs, lidar data or field observations. Classified within the area of landform mapping as artificial, contact, map border, perimeter or terrace edge.

- orc_fans_northern_Taieri_Plain_landform_channel_type0414.shp

  A line shapefile of channels mapped from aerial photographs, lidar data or field observations. Classified within the area of landform mapping as active, recently active, less recently active or artificial.

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