Otago Alluvial Fans Project: Supplementary maps and information on fans in selected areas of Otago

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EXECUTIVE SUMMARY

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. Of the hazards associated with alluvial fans, the most serious are fast-moving sediment-laden floods and slurry-like flows of debris. Such floods and flows may commonly break out from existing stream channels and forge new, sometimes unexpected, paths. 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.

The Otago Regional Council is leading the 'Otago Alluvial Fans Project', which aims to assess the nature and extent of hazards, and potential impacts on communities, associated with alluvial fans in Otago. The rationale of the project is that by improving our knowledge of alluvial fans, their associated hazards may be able to be mitigated in an appropriate manner.

Initiated in 2006, a general review of the hazards associated with alluvial fans (Opus report 'Otago Alluvial Fans Project', issued 2009) included a set of regional maps of alluvial fans in Otago, compiled largely from pre-existing data. Following consultation with Otago's territorial authorities to identify which areas of Otago would benefit most from additional information on alluvial fans, Otago Regional Council commissioned supplementary work on alluvial fans in selected areas of Otago, which is the subject of this report. The aims of this work are to:

- provide a more in-depth picture of the nature and characteristics of alluvial fans in these areas, set within a regional perspective of alluvial fan active processes;
- develop methods for the mapping and classification of Otago's alluvial fans, drawing on scientific (landform) evidence of flooding and sedimentation histories, and;
- produce an alluvial fan landform map data set for the selected investigation areas.

The report documents the methods and results of this work. Like the earlier phase of mapping, the alluvial fan map has been done using Geographic Information System (GIS) computer methods. The in-depth picture of the alluvial fans in each selected assessment area is conveyed by an 'information sheet' for each area, accompanied by maps. It is anticipated that the data sets accompanying this report will provide a foundation for the assessments of alluvial fan hazards. The data sets may also assist territorial authorities in the refinement of district plans and in guiding community and infrastructural developments.

An alluvial fan system comprises three major components: (i) its catchment; (ii) its stream and fan; and (iii) its downstream end (toe). Conditions in a catchment determine the quantities of sediment that are delivered to its fan, whereas conditions at the fan toe dictate whether the sediment is able to be taken away from the fan system. Accordingly, the maps prepared as part of the supplementary work include, in addition to the fans themselves, the catchments upstream of the fans, as well as what lies at and just beyond the toes of the fans.

The mapping relied largely upon interpretation of aerial photos, with selected field-checks. The fan mapping is based on landforms and the maturity of soils developed on the fans. Very

young ('immature') soils are easily recognisable by their appearance. The maps distinguish fan surfaces that have experienced flood sedimentation in the past few hundred years (with 'immature' soils, nominally less than 300 years old) from older fan surfaces ('mature' soils). This mapping approach provides a scientifically-based assessment of recent fan activity.

Catchments are subdivided according to an interpretation of how stable their slopes have been. Areas at and beyond fan toes were mapped according to their origin and activity (e.g. is there a river which can carry away sediment from the fan?). Additional information gathered included: (i) the nature of the boundaries between different landforms (e.g. terrace edges); (ii) the nature and activity of stream channels on the fans; and (iii) points of information such as the depths of channels.

The physical characteristics of alluvial fans and their settings in the landscape provide insights to the types of behaviour (and hazards) that can be expected. The dominant factor controlling the type of fan is the balance between: (i) sediment supply from a catchment; (ii) sediment transport down a fan by its stream; and (iii) sediment removal at the toe of a fan. On this basis, four types of fan are identified: aggradational (sediment builds up on the fan); equilibrium (sediment is transported down the fan and removed from its toe); degradational (sediment is eroded from the fan) and terraced (repeated cycles of aggradation and degradation have terraced the fan). Recognition of these behavioural types is expected to assist in identifying and assessing the nature and severity of fan hazards as part of future site-specific investigations. An aggradational fan is the most susceptible to channel break-out and flooding, whereas terraced fans may have areas that lie well above present flood levels.

The Otago region spans a wide range of landscape settings. From the province's northwest margin in the Southern Alps, the wet mountain climate areas give way gradually to the semi-arid ranges and basins of Central Otago, which in turn grade out to the humid hills, valleys, terraces and plains of coastal Otago. These contrasts, plus the influences of geology, and of river, lake or coastal processes, are expressed in the character of the region's alluvial fans:

- In the wet mountains of northwest Otago (including Makarora and Glenorchy), the landscapes are young, precipitation is large and rates of erosion and fan-building are substantial. Fans are mostly aggradational, although other types are present, depending on the proximity of valley-floor rivers to the fan toes. There are many historic examples of damaging or destructive fan-flooding events.

- The ranges and basins of inland Otago encompass the selected assessment areas of Hawea, Wanaka, Luggate, Queenstown, Kingston and Kawarau (to the west), Cromwell and Alexandra (centre) and Roxburgh, Tapanui and Middlemarch (south and east). The landscapes are old and rates of erosion and fan-building are generally slow. All types of fans are present, with terraced fans particularly common close to the Clutha River. There are several historic examples of fan-flooding events.

- The hills, valleys and plains of coastal Otago (including the Oamaru assessment area) comprise a mix of old and young landscapes. Fans have built out onto terraces or into valleys, bays and harbours, and all types of fan are represented. Historic records of fan-flooding include instances where landslides in the catchments have sent damaging debris flows down onto the fans.

The report also outlines suggestions for how the supplementary mapping and other information could be used to guide enquiries into site-specific hazard issues.

1. INTRODUCTION

The Otago Regional Council (ORC) is leading a project to assess the nature and extent of hazards, and potential impacts on communities, associated with alluvial fans in Otago. The rationale behind the Otago Alluvial Fans Project is that by improving our knowledge of alluvial fans, their associated hazards may be able to be mitigated in an appropriate manner.

What is an alluvial fan? In technical terms, it is an accumulation of river or stream (alluvial) sediments that forms a sloping landform, shaped like an open fan or segment of a cone, concave side down. Alluvial fans typically form where streams emerge from hill country onto a valley floor (Fig. 1). A sediment-laden flood travels easily down a steep, narrow, stream gully, but as the flood emerges into flatter, more open, ground, the water loses power and its sediment load is deposited on the land surface. Over time, the accumulated sediments build a fan-shaped landform with its apex at the gully mouth. Alluvial fans form on all scales, from a few tens of metres to many kilometres across. People have long been drawn to smoothly-sloping, elevated positions near the bases of hills. Such locations offer broad views and commonly have a water supply from an adjacent stream. Few appreciate that many such locations lie on alluvial fans; even fewer realise that these are potentially hazardous places.

The most serious hazards associated with alluvial fans are fast-moving sediment-laden floods and debris flows. Such floods and flows may break out from existing stream channels and forge new, sometimes unexpected, paths. Sediment 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 damage productive land, crops or various types of infrastructure such as water supplies or roads. The nature and extent of alluvial fan hazards may be recognised and taken into account when planning new developments. For existing developments, such hazards may be able to be mitigated, but mitigation measures may be costly to implement and generally require ongoing maintenance.

In 2006, ORC commissioned a general review of the hazards associated with alluvial fans[1], led by Opus International Consultants Limited (Opus) and assisted by the Institute of Geological and Nuclear Sciences Limited (GNS Science). That report (Grindley *et al*. 2009) describes the nature of alluvial fans, the ways in which they form, the types of hazards that they pose to land use and human activity, and how such hazards may be mitigated. It includes a set of maps of alluvial fans in Otago, compiled largely from pre-existing data at a regional scale (i.e. details are omitted in favour of a broad picture), within a Geographic Information System (GIS) computer format.

Those maps show that alluvial fans comprise about 6% of the land area of the Otago Region. However, well over half of Otago is hilly to mountainous and sparsely populated. Most settlements and much of the intensively-cultivated land lie in the valleys and basins, which is also where the fans are concentrated. Consequently the 6% of land area comprising alluvial fans represents a significant portion of the more versatile land in Otago.

[1] In this report, the term 'alluvial fan' includes fans that have been formed by alluvial activity as well as fans that have been formed primarily by debris-flow activity.

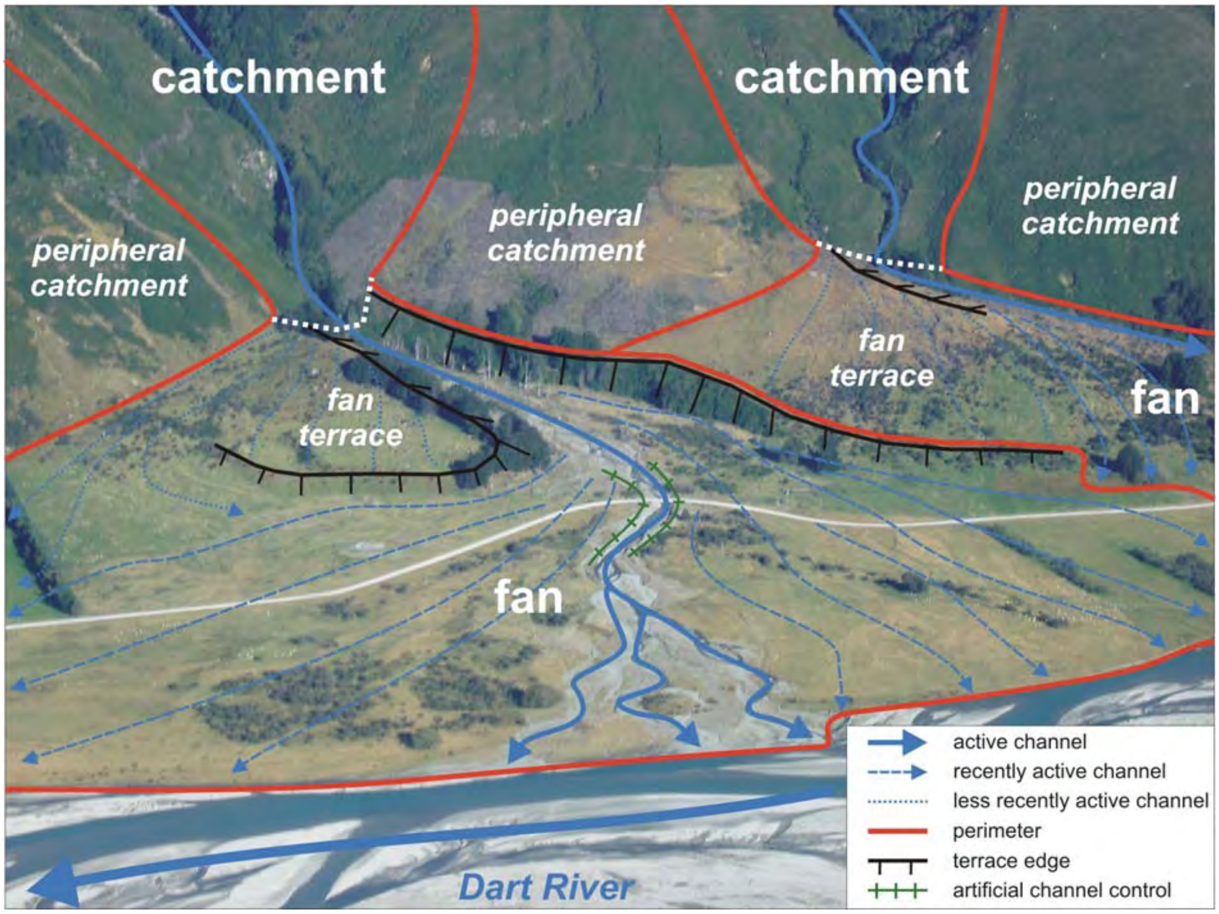

Figure 1: An example of an alluvial fan in Otago. This photo looks west towards the fan of Scott Creek (centre), on the western side of the Dart River, Lake Wakatipu catchment, near Glenorchy. The Routeburn Road crosses the fan. The annotations illustrate some of the types of features depicted on the maps accompanying this report (note that the Scott Creek area lies outside the coverage of these maps).

In 2008, ORC commissioned supplementary work, led by GNS Science and assisted by Opus. That work is described in this report. It comprised a more focused examination and new mapping of alluvial fans in specific areas, selected by ORC in consultation with territorial authorities; these are areas where additional information is considered likely to be most beneficial (Fig. 2). The aims of this work are to:

- provide a more in-depth picture of the nature and characteristics of alluvial fans in these areas, set within a regional perspective of alluvial fan active processes;
- develop methods for the mapping and classification of Otago's alluvial fans, drawing on geomorphologic (landform) evidence of flooding and sedimentation histories; and,
- produce an alluvial fan landform GIS data set for the investigation areas.

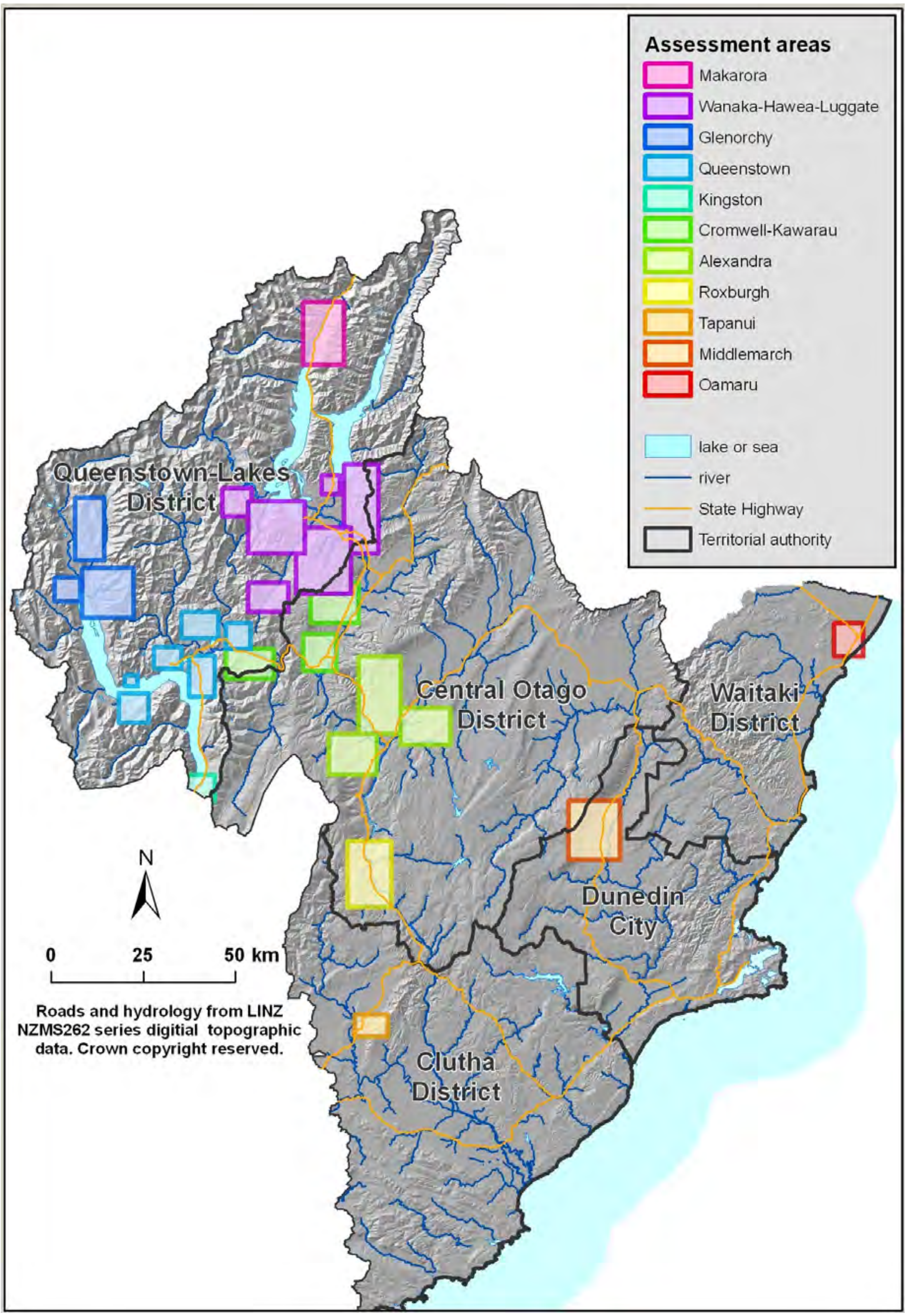

Figure 2: The Otago region, with locations of alluvial fan assessment areas presented in this report.

This report includes:

- an explanation of methods used here for mapping of alluvial fans and adjacent landform features, and description of the map categories (Section 2.1);
- an outline of a means of classifying and understanding the behaviour of alluvial fans (Section 2.2);
- description and discussion of selected examples of alluvial fans (Section 2.3);
- an overview of the characteristics of alluvial fans across Otago, drawing upon the examples of fans investigated in the selected investigation areas (Section 3);
- a glossary defining the technical terms used in this report (Appendix A);
- a description of the GIS map layers and attributes (Appendix B);
- a set of information sheets, accompanied by maps, that summarize the nature and characteristics of alluvial fans in each investigation area. Each information sheet includes comments on the nature of alluvial fan hazards in that area (Appendix C).

Despite its focus on particular areas, the work presented here is still of regional extent. It does not provide site-specific assessments of alluvial fan hazards, hazard zoning, nor does it quantify the expected frequencies of hazard occurrences. To do so would require site-focused engineering-based investigations. Consequently, the presentation and discussion of specific examples of alluvial fan features in this report are simply for illustrative purposes.

It is anticipated that the data sets accompanying this report will provide a foundation for the assessments of alluvial fan hazards. The data sets may also assist territorial authorities in the refinement of district plans and in guiding community and infrastructural developments.

2. MAPPING AND CLASSIFICATION OF ALLUVIAL FANS IN OTAGO

2.1 Mapping of alluvial fans

The regional overview report (Grindley *et al*. 2009), and accompanying alluvial fan map GIS data set (hereafter called the 1:50,000-scale fan GIS) presents an overall introduction to Otago's alluvial fans and their hazards. The 1:50,000-scale fan GIS relies mainly on existing geologic and geomorphologic (landform) maps, and classifies fans according to their activity and according to the types of floods that they are likely to experience:

- There are two classes of activity; active versus inactive. Active means that it is judged possible that such areas could be subject to flooding, sedimentation or erosion within the next 100 years or so;

- There are two main classes of flood type; debris-dominated versus floodwater-dominated. Debris-dominated means that debris flows and debris floods are expected to occur, whereas on floodwater-dominated areas, debris flows and debris floods are unlikely to occur. A third category of 'composite' (all modes of flood events are probable) was applied in some cases.

The primary purpose of the 1:50,000-scale fan GIS is to identify the regional distributions of alluvial fans and indicate some of their general characteristics. That data set highlights those areas of Otago that are mostly likely to be susceptible to some form of alluvial fan hazard.

An alluvial fan is a complex natural system whose overall behaviour depends on a variety of factors. A recent review of fan hazards in a New Zealand context (Davies & McSaveney 2008[2]) points out that an alluvial fan is an expression of the movement of sediment across a landscape. A fan is formed when some of that sediment accumulates. The stream that formed a fan plays an ongoing role in moving sediment from its catchment downhill to wherever that sediment may go. If one looks only at the fan area of a stream system, then one understands only about 1/3 of the system. The other components essential for understanding the system are what is occurring in the catchment upstream of the fan, and what is occurring at the downstream end of the fan.

This framework provides a basis for the work presented in this report. In each investigation area, new mapping was undertaken, involving examination and interpretation of aerial photographs and field-checking of selected locations. From this, we produced maps of landform features, compiled at approximately 1:10,000 scale (hereafter called the 1:10,000-scale fan GIS; see Appendix B). In addition to the fans themselves, the maps include the catchments upstream of the fans, as well as what lies at and just beyond the toes of the fans.

An important consideration was the selection of scientifically based, regionally applicable criteria for the fan mapping. For example, historic records of fan-flooding are extremely valuable information but their existence is not distributed uniformly - it depends on someone having left descriptions and illustrations of flood events, and such records being accessible. Furthermore, written historic records in New Zealand cover only a short period (generally

[2] This article is recommended reading for anyone interested in alluvial fan hazards

less than 150 years). Therefore, we sought to extract a longer and more uniform record of fan activity using a geologic approach (landforms, soils, etc). The different features that were mapped are described in Table 1 and in Appendix B and are shown on maps in Appendix C.

In summary, the three main components of fan systems (catchment, fan and fan toe) were mapped as follows:

- Catchments were subdivided according to a qualitative interpretation of the stability of slopes and the likelihood of sediment generation. Landform textures observed using aerial photos formed the main basis for interpretation;

- Fans were subdivided according to a qualitative interpretation of how recently the last episode of sedimentation or erosion had occurred on different parts of the fans. This interpretation was guided by how much a stream channel is cut down into its fan and by the maturity of soils formed on the fan. Because soils develop and evolve over time, the presence of an immature soil is a good indicator of recent sedimentation on that part of the fan. We consider that an immature soil indicates with some confidence that sedimentation has occurred within the past few hundred years (nominally less than about 300 years);

- Areas at and beyond the fan toes were mapped according to their origin and activity. Of greatest significance is whether there is an active riverbed or a wave-swept shoreline at the toe of a fan. River or wave erosion provides a means of removing sediment from a fan system and may limit further fan growth. This contrasts with less active landforms such as terraces, or other types of stabilised landforms, onto which fan sediments can extend, and build up.

Additional information gathered as part of the mapping (see Appendix B) included (i) the nature of the boundaries between different landforms; (ii) the nature and recentness of activity of stream channels on the fans; and (iii) points of information such as the depth of channels or presence of bouldery deposits.

The 1:50,000-scale fan GIS indicated areas that are possibly subject to debris flows, based mainly on proximity to the fan heads and the presence of ground slopes steeper than about 5°. We were not able to improve upon the information in the 1:50,000-scale fan GIS. A hummocky or irregular fan-surface texture is indicative of debris-flow deposits. However in work such as this, where aerial photographs are a major source of interpretation, areas that have urban landscaping, forest, or dense scrub do not yield information on ground surface texture. Because our mapping method is heavily reliant upon aerial photographs, we could not consistently differentiate areas where debris flows have occurred. Consequently, we did not include any specific delineation of debris-flow deposits in the 1:10,000-scale fan GIS.

However, in the data set we have shown (as data points) the observed locations of large bouldery deposits on the fans. Such deposits are good indicators of the past occurrence of debris flows because large boulders (e.g. >1 m diameter) are difficult to transport by flood water but are easily transported within debris flows. Delineation of areas where debris flows have occurred is best done by future, detailed, site-specific, ground-based inspection.

2.2 Classification of alluvial fans

The physical characteristics of alluvial fans and their settings in the landscape provide insights to the types of behaviour (and hazards) that can be expected. Figure 3 presents three block diagrams illustrating, in an idealised way, the concepts of aggradational, equilibrium and terraced fans. A description of each type of fan is provided in Table 2.

The dominant factor controlling the type of fan is the balance between: (i) the quantity of sediment delivered from a catchment; (ii) the quantity of sediment carried down a fan by its stream; and (iii) the quantity of sediment removed from the toe of a fan. The three main ways that sediment can be removed from a fan toe are: (a) transport down-valley by a river on the valley floor; (b) transport by wave action along a shoreline at the toe of a fan; or (c) human intervention, where sediment is physically removed from a fan.

A fan grows during episodic flood events, when aggradational conditions prevail, with rates of sediment supply that exceed the rates at which sediment is transported and removed from the fan. Sediment brought down from a catchment accumulates on the fan if there is no active, or sufficient, means of sediment being removed. An aggradational fan is susceptible to ongoing channel break-out across the fan, and will remain so until the sediment supply ceases, or a means of sediment removal, either natural or human, becomes established.

A fan is in a state of equilibrium when the sediment brought down from its catchment is able to be transported down the fan by its stream channel AND when there is an active means of sediment removal operating at the toe of the fan. Providing these factors remain in balance, equilibrium will persist, and a stream may remain in an approximately static position on its fan. However, in the natural environment, there is considerable independence in the processes of sediment supply, transport and removal, and equilibrium tends to be an exception rather than the rule. For example, increased landslide activity in a catchment, or migration of a river away from a fan toe are two independent factors, either of which would push an equilibrium fan towards aggradation.

A fan is in a state of degradation when the rate of sediment removal exceeds the rate of sediment supply. This commonly occurs where a fan toe is being cut away by erosion from a river or by waves. Removal of accumulated sediment causes the active stream channel to incise into its fan. Although an example of a degradational fan is not shown in Figure 3, degradational fans are described in Table 2.

A terraced fan is a product of repeated episodes of aggradation interspersed with periods of erosion of a fan toe and degradation of a fan stream. Terraced fans are prominent features of some large river valleys. The existence of a terraced fan does not, in itself, indicate whether the fan's active stream is in a state of aggradation, equilibrium or degradation. Any of these states prevail from time to time, depending on sediment supply, the stream's capacity to move that sediment and whether sediment can be removed from the fan toe.

There are no general trends in fan evolution. Some fans lie in parts of the landscape that are remote from any natural means of sediment removal. In this case, unless erosion ceases in their catchments such fans will remain aggradational for the foreseeable future under current geomorphic conditions. Other fans may repeatedly switch back and forth between aggradational and equilibrium conditions. Terraced fans have clearly experienced differing conditions through their histories. Alluvial fans are dynamic, naturally evolving features of the landscape. Understanding their function in the landscape as sediment transfer systems is an important step in minimising their hazards to human activities.

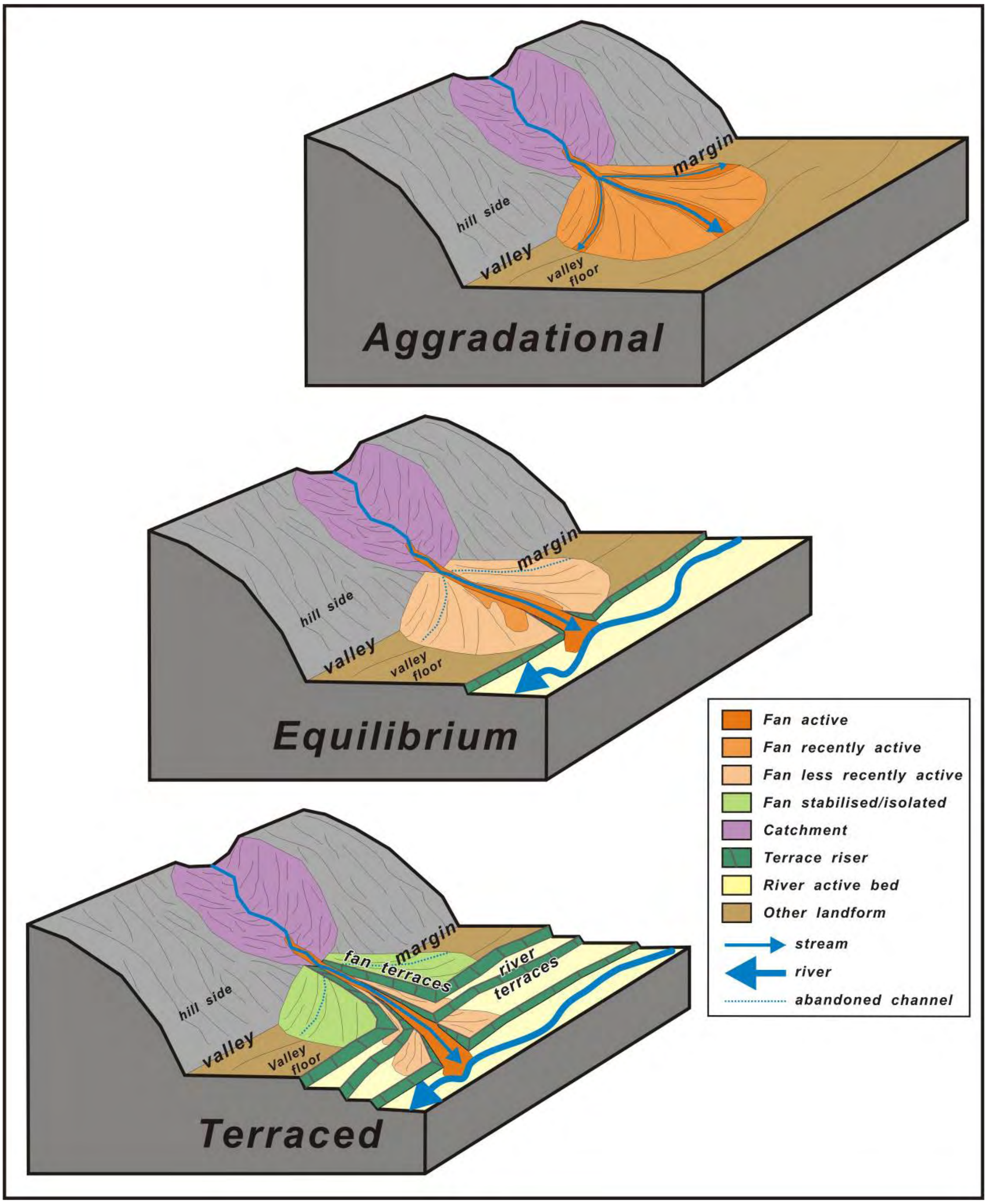

Figure 3: Concept diagrams illustrating three types of alluvial fan described in this investigation. The diagrams include examples of the distributions of fan-landform map units. These idealised diagrams do not depict any particular location in Otago. Differences in fan type depend largely on whether there is a mechanism for removing sediment from the fan system. The lower two diagrams show a river in this role; it could equally be a lake shore.

2.3 Selected examples of alluvial fans

In this section, we present and discuss some illustrative examples of alluvial fans in Otago. More comprehensive information on each of the assessment areas is given in Appendix C.

2.3.1 Fans at Makarora

Lying in a formerly glaciated valley at the head of Lake Wanaka, Makarora provides excellent examples of fans in the wetter, mountainous environment of northwestern Otago. Annual precipitation is about 2,000 mm per year (mm/yr) at the valley floor, increasing with altitude to more than 3,000 mm/yr at the alpine heads of the fan catchments (growOTAGO). A high frequency of high-intensity rain on steep, easily erodible slopes results in rapid rates of sediment delivery, by Otago standards (Otago Regional Council 2007). Although the Makarora valley is predominantly an aggradational environment because of progradation of the Makarora River delta into Lake Wanaka, local variations between aggradational and equilibrium conditions reflect migration of the Makarora River on its flood plain, and whether it is flowing close the toes of fans (Fig. 4). Recent debris flow activity at Pipson Creek can be attributed to a high rate of sediment supply from active landslides in its catchment. However, despite the active nature of the Makarora landscape, and numerous historic examples of fan flooding and sedimentation, not all parts of the fans have been active recently, as shown by the presence of mature soils in several areas on some of the fans.

2.3.2 Fans at Hawea Flat

The fans on the eastern side of the Hawea basin, at the foot of the Grandview range, are good examples of large fans formed in the sub-humid climate zone of western Central Otago. Annual precipitation is about 800 mm/yr at Lake Hawea and decreases southeast to 650 mm/yr at Hawea Flat; precipitation increases with altitude to more than 900 mm/yr at the heads of the fan catchments (growOTAGO). The majority of the fans are aggradational, because there are no natural means of sediment removal. However, the fans have extensive areas of mature soils, indicating that they are aggrading very slowly, with long intervals of inactivity over most of their area. This indicates that the total area of individual fans is very large compared with the volumes of sediment currently being supplied from their catchment, and may indicate that sediment supply has lessened in the recent geological past. In this regard, these fans have recently been behaving more like equilibrium fans, on account of the slow rates of sediment supply from the catchments.

A notable exception is Hospital Creek, which is actively aggrading and its stream is being controlled to try to maintain it in its present course. The present aggradation is a recent change, because it has left fresh, aggraded sediment, only about 1 m thick, resting on fan sediments with a mature brown soil profile (Fig. 5). This is an example of a change on a fan, perhaps due to increased gullying or minor landsliding in the catchment, which has resulted in an increase in sediment supply. There is nothing to preclude similar occurrences on other fans near Hawea Flat, or farther afield.

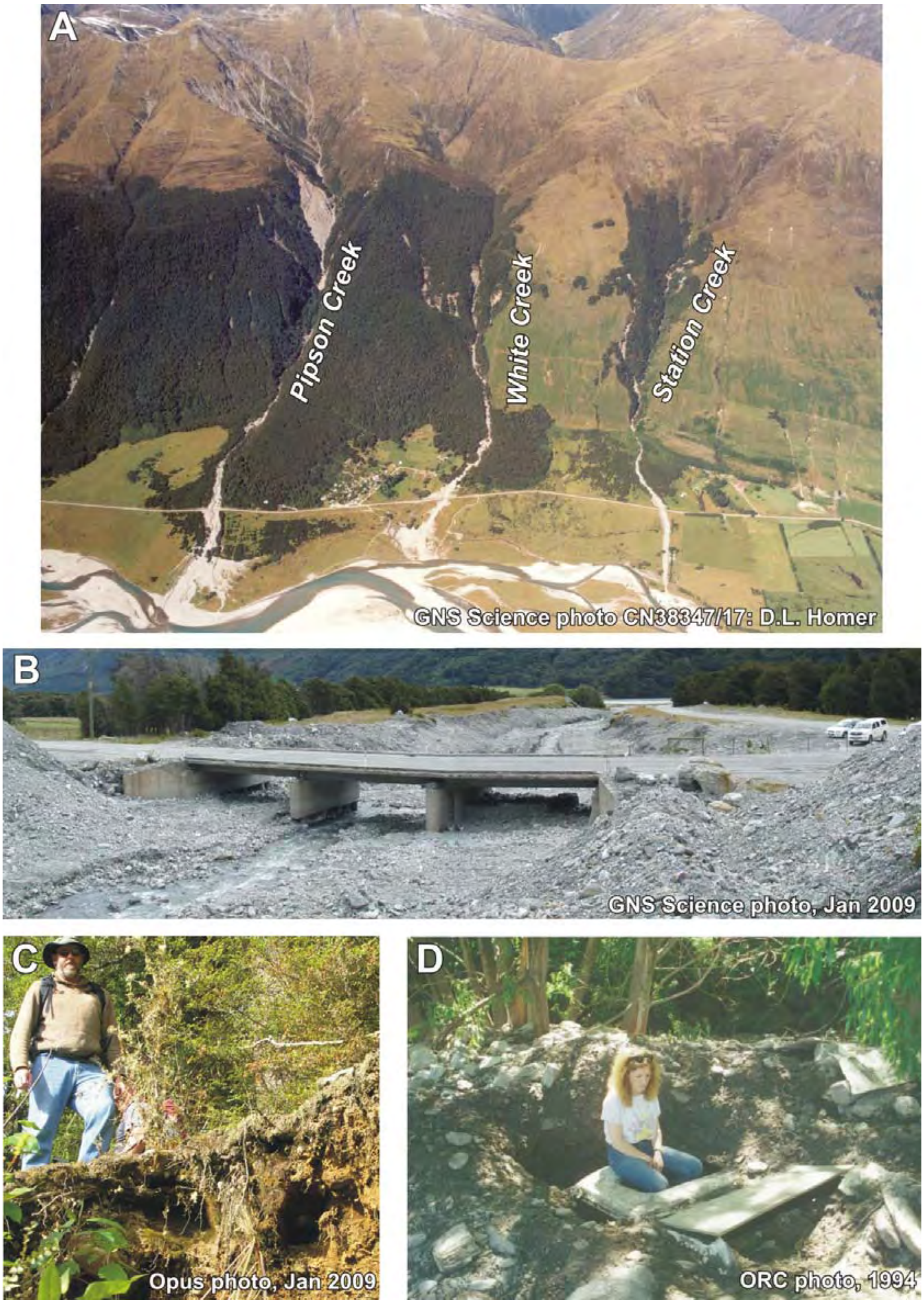

Figure 4: Features of fans at Makarora. (A) In this aerial view of Makarora, the 'fan active' beds of Pipson, White and Station creeks are easily identifiable by their bare sediment. The active bed of Makarora River (foreground) flows from left to right. (B) The 'fan active bed' of Pipson Creek at State Highway 6 is constrained within artificial embankments of gravel. (C) Mature brown-weathered soil on a 'fan less recently active' terrace surface on the north side of White Creek. (D) Aggradation at Wharf Creek during a high-intensity rainstorm in 1994 buried this car (shown with its sunroof exhumed).

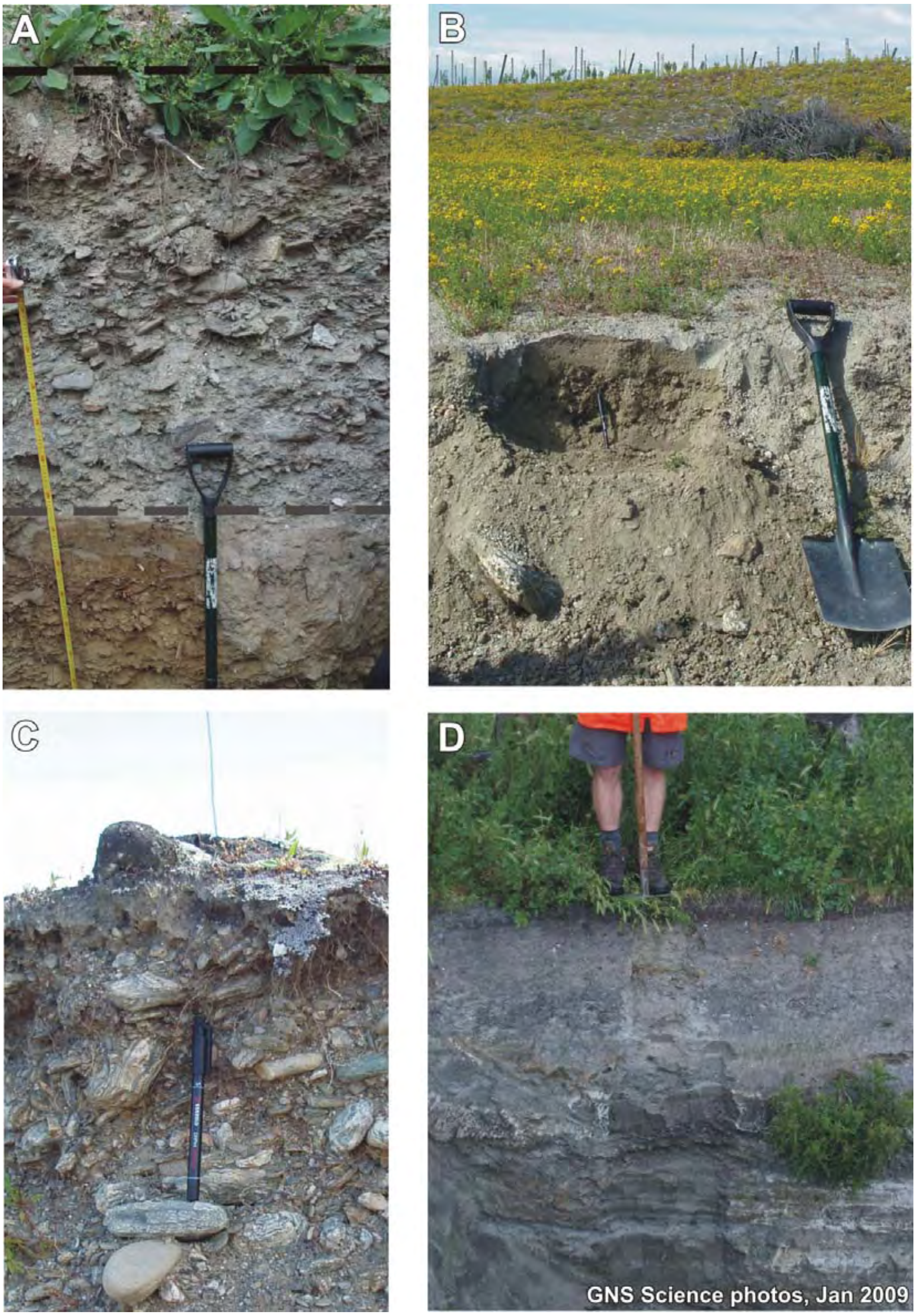

Figure 5: Examples of soil maturity. (A) At Hospital Creek, Hawea Flat, ‘fan less recently active’ sediments with a mature brown-weathered soil are buried (at the grey line) by grey ‘fan recently active’ sediments, on which an immature (raw) soil is developed (black line). (B-C) Differing soil maturities on fan terraces of Tinwald Burn, Cromwell; a mature light-brown soil on a ‘fan less recently active’ terrace (B) versus an immature (raw) grey soil on a ‘fan recently active’ terrace (C). (D) An immature soil profile developed on grey ‘fan recently active’ sediments at the foot of Coronet Peak, Queenstown.

2.3.3 Fans at Queenstown

Not all fans are large. Excellent examples of small fans from minor catchments draining mountain flanks occur in The Gorge area of Queenstown, also within the sub-humid climate zone of western Central Otago. Annual precipitation at Queenstown is a little more than 800 mm/yr, increasing with altitude to 1,500 mm/yr at the crest of Ben Lomond (growOTAGO). Figure 6 shows a forested catchment that drains into the Bodytown suburb of Queenstown on the eastern side of the Skyline Gondola. A small aggradational fan lies at the mouth of this catchment near Reavers Lane. The 'Reavers Lane fan' has been urbanised, and the gully draining its catchment is piped into the stormwater system via a culvert (Fig. 7). Despite there being no known historical record of a sediment-laden flood down this gully, the existence of a fan at the mouth of the gully is clear geomorphologic evidence that many sediment-laden floods have happened in the past.

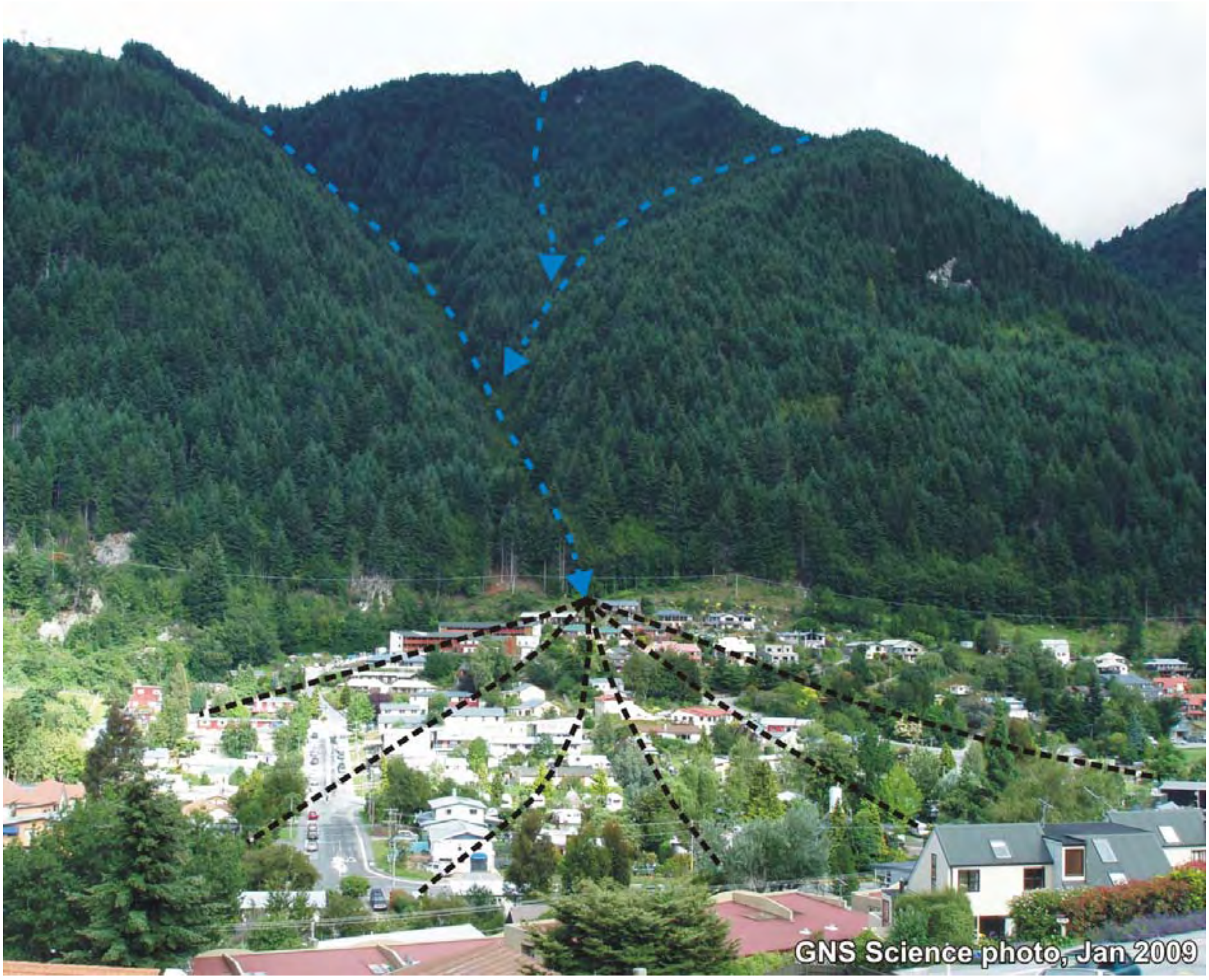

Figure 6: A fan in an urban area at Queenstown. This view looks northwest towards a forested catchment of about 46 hectares which drains (blue lines) from the eastern side of the Skyline Gondola (skyline, far left). The fan radiates out (black lines) from the mouth of the gully, near Reavers Lane.

This is an example of an aggradational fan that, within the period of European settlement, appears to have had little if any sediment supplied from its catchment, and thus its potential for sedimentation may not be less readily apparent.

 

Figure 7: Drainage reticulation at the head of the 'Reavers Lane fan' in Queenstown. LEFT: a view down the lowest reach of the gully that has formed the 'Reavers Lane fan', upon which the buildings are sited. The culvert that collects all drainage from the gully is to the left of centre. RIGHT: The grill-covered culvert is intended for water but not for gravel or boulders. (GNS Science photos, Jan 2009).

2.3.4 Fans in the Roxburgh area

Fans at Roxburgh are typical of those formed in the sub-humid to semi-arid environment of Central Otago. Annual precipitation is about 500 mm/yr at Roxburgh, and increases with altitude to more than 900 mm/yr at the heads of the fan catchments (growOTAGO).

The Roxburgh fans include good examples of the contrasts between aggradational, equilibrium and terraced fan types. This is a consequence of the somewhat sinuous course of the Clutha River along its valley floor. Aggradational fans are built onto terraces that lie remote from the river, whereas equilibrium fans descend with an even gradient to meet the river. Other fans have had their toes trimmed by the river, and so are terraced to varying degrees and flow in channels incised down to the river margin.

Figure 8 illustrates a fan that has a very small extent (6 ha) compared with the size of its catchment (140 ha). The Clutha River terrace onto which it is built is at least several thousand years old. This suggests that since the fan began to form, its catchment has produced only very small amounts of sediment. However, judging from the size of the artificial channel, this catchment is likely to have caused flooding and sedimentation problems on the fan in historic times.

There are contrasting types of artificial channels on the Roxburgh fans, as illustrated in Figure 9. The scale of these measures no doubt reflects the severity of historic floods at Roxburgh. Cowie (1957) recounts such an event at Slaughterhouse Creek on 9 November 1938:

> "*A cloud-burst occurred at Slaughterhouse Creek, near Roxburgh, at about 6pm in the evening. As is usual in occurrences of this nature the calamity took the form of a rainfall of extremely high intensity, though of comparatively short duration, on an area of limited extent. The locality consists of steep*

mountainous country intersected by gullies, and composed of friable schist soil and boulders. The deluge, racing down the steep gullies, brought thousands of tons of boulders and silt, depositing these on the flatter slopes occupied for the most part by orchards. Some idea of the force of the water can be gauged from the fact that one boulder, estimated at not less that twenty tons, was transported for at least ten chains and left on the top of the bank of a gully which before had been some 10 ft. to 15 ft. deep. The resultant damage consisted of a number of acres of orchard being buried under varying depths of boulders and silt, some two to three miles of privately owned irrigation races being either blocked with debris or washed out, and several chains of the Milton – Queenstown State Highway being covered with silt. Private damage to orchards amounted to £4,720, repairs to the creek £350, and damage to the highway £50.

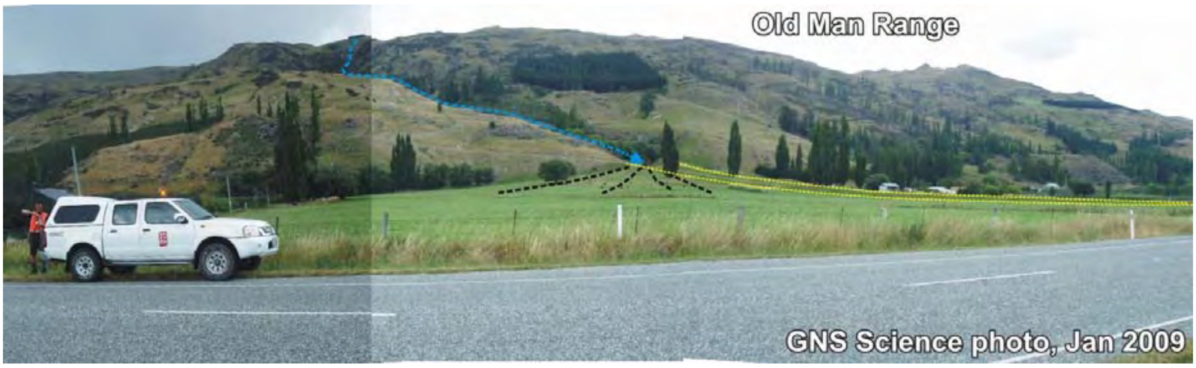

Figure 8: A small aggradational fan north of Roxburgh. ABOVE: The fan radiates out (black lines) from moderate-sized catchment (blue arrow) onto an abandoned terrace of the Clutha River. Embankments (yellow) create an artificial channel for floodwater and sediment that extends out across the river terrace. BELOW: A view up the artificial channel (GNS Science photos).

Figure 9: Different types of artificial channel at Roxburgh. LEFT: A steep concrete-lined channel conveys Reservoir Creek down its equilibrium to slightly terraced fan in the Roxburgh urban area (Opus photo, Jan 2009). RIGHT: Gravel embankments up to 4 m high constrain the course of Slaughterhouse Creek on the centre of its equilibrium to aggradational fan, north of Roxburgh. The gradient of its channel is much less than that of Reservoir Creek, and the Slaughterhouse Creek channel therefore has a correspondingly lesser ability to transport coarse sediment such as gravel or boulders (GNS Science photo, Jan 2009).

3. REGIONAL SYNTHESIS

The Otago region spans a wide range of landscape settings. From the province's northwest margin in the Southern Alps, the wet mountain climates of the Makarora and Glenorchy areas give way gradually to the semi-arid ranges and basins of Central Otago, which in turn grade out to the humid hills, valleys, terraces and plains of coastal Otago.

These contrasts in climate and topography, plus the influences of geology, and of river, lake or coastal processes, are expressed in the character of the region's alluvial fans.

3.1 The wet mountains of northwest Otago

This part of the Otago region, including the Makarora and Glenorchy areas, has landscapes whose overall shapes reflect the actions of Ice Age glaciers. This region has a large annual precipitation, and prolonged high-intensity rainstorms associated with northwesterly wind flows are a significant feature of the precipitation regime. The landscapes are geologically young and are evolving rapidly, with high rates of erosion and sedimentation (Otago Regional Council 2007, 2008). Alluvial and debris fans are predominantly aggradational in character. However, depending on where the fans lie in the present landscape, some are in equilibrium if their sediment is being removed from their toes, while others that lie close to valley-floor rivers may be terraced. Rates of sediment generation from catchments are relatively large on account of the mountainous topography and abundant precipitation. On aggradational fans, the rates of fan-building are large by Otago standards. There are many historic examples of damaging or destructive fan-flooding events in this part of Otago (e.g.

McSaveney 1995; McSaveney & Glassey 2002; Otago Regional Council 2007; Grindley *et al*. 2009).

3.2 The ranges and basins of inland Otago

This part of the Otago region has, at its margins, humid climates that grade inward to semi-arid climates. It includes on its western fringe the Hawea, Wanaka, Luggate, Queenstown, Kingston and Kawarau areas. The centre includes the Cromwell and Alexandra areas, while the Roxburgh, Tapanui and Middlemarch areas lie towards the southern and eastern fringes of inland Otago. The origins of the inland Otago landscapes are tectonic; the ranges have been uplifted by faulting or folding over a long period of geologic time, while the basins are the areas of little or no tectonic uplift. As the ranges have risen, the river systems have developed their somewhat tortuous paths through the lowest-lying parts of the basins. The main elements of the landscapes are ancient, and the relatively dry climates mean that rates of erosion and sedimentation are generally less than occur farther northwest.

Erosion of the ranges has fed sediment down into the basins. In areas remote from rivers, large fans have formed (Turnbull 2000; Forsyth 2001; Turnbull & Allibone 2003). Although many of these are aggradational, many also have widespread areas of mature soil, indicating that rates of fan-building aggradation are currently slow (e.g. fans at the margin of the Grandview range between Hawea and Luggate, and near Middlemarch). Over geologic time-scales (many thousands of years), factors such as climate shifts (e.g. glacial/interglacial cycles) and episodic large earthquakes on the faults that run along the basin-range margins may have led to periods of more rapid fan-building (Litchfield & Lian 2004). However, as found at Hospital Creek near Hawea Flat, increased aggradation may result from natural dynamics in a catchment, due to factors such as increased gullying or minor landsliding.

Close to rivers or lake shores, equilibrium or terraced fans are common, such as around lakes Wakatipu and Wanaka, the Queenstown area, the Cardrona and Kawarau valleys, Cromwell, Alexandra, Roxburgh and Tapanui. Some of these fans have had a very long history of evolution, such as the Waikerikeri fan near Alexandra, and have extensive fan terraces that are isolated far above currently active parts of the fans. Historic examples of fan flooding and sedimentation, for example at Roxburgh, are associated with intense rainstorm events.

3.3 The hills, valleys and plains of coastal Otago

Relatively subdued topography characterises the humid coastal fringe of Otago. Although elements of the landscape include tectonic basins and ranges like those of inland Otago, the overall geologic setting is one of very slow uplift, erosion of hills and terracing or infilling of valleys, in conjunction with cycles of glacial/interglacial sea level changes. Some parts of the landscape have ancient origins, such as the 10-million year old Dunedin Volcano, which has been so dissected by valley erosion and the formation of Otago Harbour that it is barely recognisable as the remains of a volcano.

Gullied hill terrain, in places with extensive landslides, has provided a source of sediment for fans that have built out onto terraces or into valleys, bays and harbours (Bishop & Turnbull 1996; Barrell *et al*. 1998). All types of fan are represented in coastal Otago, for instance around the Lower Taieri Plain, there are many terraced fans southwest of Mosgiel, but predominantly aggradational fans northeast of Mosgiel. A feature of some fans, for example around Dunedin and near Oamaru, is that their sediments are almost entirely of silt or clay, derived from the erosion of loess or weathered volcanic or sedimentary rocks in their catchments. There are historic examples of shallow landslides in catchments that have been remobilised into silty debris flows that have spilled out onto the fans, with damaging consequences (Stewart 1996).

3.4 Hazard considerations

The methodology for mapping fans presented in this report is intended to be a scientific means of extracting a longer record of alluvial fan flooding and sedimentation activity than is available from historic information. We suggest that this provides a useful starting point for the assessment of hazards posed by any particular fan. The method of classifying fans, into aggradational, equilibrium, degradational or terraced types, provides a means of gaining insight to the past behaviour of fans. Considering fans in the context of being one part of a natural sediment transport system, which includes the characteristics of the catchment as well as the processes operating at the toe of a fan, is anticipated to be useful for the assessment, mitigation or avoidance of alluvial fan hazards in Otago.

Table 3 sets out some of the implications for hazards associated with the alluvial fan map categories. It shows the relationship between the 1:50,000-scale fan GIS (as described by Grindley *et* al. 2009) classification and the 1:10,000-scale fan GIS classification described here. The last column of this table presents some suggestions for how the information in the 1:10,000-scale fan GIS could be used to guide enquiries into site-specific hazard issues.

4. CONCLUSIONS

Based on the examination of alluvial fans in selected areas of Otago, and the collation, field-checking and production of a GIS map of landforms relevant to alluvial fans, we draw the following conclusions.

1. Alluvial fans are an expression of the natural means by which streams transfer sediment from their catchments out into the wider landscape. Fans are a place of temporary sediment accumulation.

2. The maturity of soils on fan landforms provides a basis for assessing how recently that landform has been affected by fan flooding and sedimentation activity.

3. Soils are a source of information that can be applied uniformly to a fan or to sets of fans that is independent of historic records, and extends further into the past than written records.

4. The landscape setting and physical features of the fan provide insights to the past behaviour of fans. Conditions in the catchments and at the toes of fans are important factors in the behaviour of fans.

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TABLES

Table 1: 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)

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).

NAME	UNIT_CODE	DEFINITION
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 2: Fan stability classification – including type of fan, nature of slopes in the catchment, and conditions at the fan toe

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 3: Fan landform types & boundaries in relation to hazard issues, the Grindley *et al*. 2009 report classification, and hazard assessment considerations.

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.

APPENDICES

APPENDIX A: GLOSSARY

Aggradation	The accumulation, or build-up, of sediment on a surface, leading to a rise in the ground level.
Alluvium	A deposit formed by the action of rivers or streams.
Alluvial	Of, or pertaining to, rivers or streams. 'Fluvial' is another word that means the same thing.
Bedrock	The rock that forms the general geologic foundation, or undermass, at any particular location.
Break-out	Break-out is the switching of a stream channel to a new course. Break-out may involve re-occupation of a previously abandoned channel, or the formation of a new channel. Channel break-out or switching is also known as avulsion.
Catchment	The area from which a surface or subsurface water system derives its water.
Channel	A river or stream flow-path, either natural or artificial. In this report, we distinguish between three types of natural channel: - active channels (currently carry water, or have carried water during floods within the last 20 years or so); - recently active channels (interpreted to have carried stream flood-water within the last 300 years or so), and; - less recently active channels (interpreted to have been free of stream flood-water for at least the last 300 years).
Debris	Loose unconsolidated material, can include silt, sand gravel, boulders and vegetation.
Debris flood	A debris flood is a very rapid (up to ~5 m/s), surging flow of water, heavily charged with sediment. Debris floods are more fluid than debris flows. Debris floods and debris flows may occur during the same flood.
Debris flow	A flow comprising a slurry of water and debris. Debris flows typically form within steep, narrow stream channels during high-intensity rainstorms, and travel downstream rapidly (e.g. between 15 and 30 km/h). A small to medium-size landslide into a flooded stream may commonly result in a debris flow. A debris flow is generally classified as a type of landslide. Debris flows are highly charged with sediment and have a consistency like wet concrete. Debris flows can pick up and carry all manner of material, including trees and huge boulders. Because of their high velocity, high density and ability to carry large volumes of material, debris flows are the most dangerous and destructive process associated with fans.
Degradation	The removal, or erosion, of sediment on a surface, leading to a decrease in ground level. Also see incision.

Delta	A landform of broadly triangular extent, or alternatively lobe-like, formed where a river or stream flows into a body of standing water, such as a sea or lake. Sand and gravel cannot be transported by still water, so progressively accumulates at the shoreline, and in the near-offshore, to create the delta.
Embankment	A human-constructed bank of natural material (typically gravel); in this report, the focus is on embankments used as part of flood protection measures.
Equilibrium	A condition where a system is operating under a natural balance. An example of a stream in equilibrium is where the supply of sediment matches the ability of the stream to transport that sediment. Under ideal equilibrium conditions, a stream will neither aggrade nor degrade.
Erosion	The wearing away of land surface materials, especially rocks, sediments, and soils, by the action of water, wind, or a glacier. Usually erosion also involves the transport of eroded material from one place to another.
Fan	A gently to steeply sloping landform, shaped like an open fan or a segment of a cone, associated with river or stream deposits. An alluvial fan is constructed from deposits laid down by flowing water. A debris-flow fan is a special type of alluvial fan, where the deposits have been laid down by debris-flow events. Fans form where a valley, channel or gully meets an area that is unconfined, or less confined. A typical location is where mountain or hill terrain meets a valley floor. In technical terms, a fan is formed where the sediment transport capacity of a stream decreases because of factors such as increase in channel width, or reduction in channel gradient.
Fan head	The farthest upstream point on a fan. Also known as the fan apex.
Fan terrace	A terrace formed on an alluvial fan. See definition of terrace below.
Fan toe	The downstream margin of a fan.
Fault	A fracture within the Earth's crust along which movement (e.g. upwards or sideways) has occurred. A fault movement commonly occurs in a sudden burst once the strain has built up to a critical level; an earthquake results from the vibrations associated with a sudden fault movement.
Geology	The scientific study of the solid matter (e.g. rocks, sediments, soil) that constitutes the Earth, particularly the composition, structure, physical properties, history, and the processes that shape Earth's components.
Geomorphology	The scientific study of the nature of the Earth's surface, and in particular the characteristics, origins and evolution of landforms.
GIS	A geographic information system (GIS) is a computerized means of collating, storing, viewing, editing and analyzing geographical

	information. A key feature is that all information is tied to its specific geographic location (‘spatially-referenced’).
growOTAGO	Grow Otago is an online database, including comprehensive maps, of the Otago region's climate and soils, administered by Otago Regional Council.
Ice Ages	A general term for periods of globally cooler climate that have affected the Earth in regular cycles over the past 2.5 million years or so. Between each Ice Age (or ‘glaciation’) there has been a period of warmer climate (‘interglaciation’), such as exists today. On average, an Ice Age has happened at least once every 100,000 years, which means that there have been more than 25 Ice Ages in the Earth’s recent history. Despite the name, Ice Ages were not periods when ice was everywhere, but was only in places, such as mountain ranges and continental areas in high latitudes (e.g. northern North America and Northern Europe), which got cool enough to support the growth of glaciers and ice sheets. In New Zealand, it is estimated that during the most recent Ice Age, which spanned from about 30,000 years ago until 18,000 years ago, average annual temperatures were only about 5° cooler than today. This was sufficient to push treelines and snowlines about 700 m lower than they are today, and allowed glaciers to fill all the main valleys of the Southern Alps.
Incise	Cut down into. A stream channel that has been eroded down below the general level of a fan is said to be incised. The process is called incision. Also known as entrenchment.
Inundated	To be covered or flooded.
Landform	A recognizable feature of the Earth's surface. Landforms have characteristic shapes and may include large features such as plains, plateaus, mountains, and valleys, as well as smaller features such as terraces, alluvial fans and gullies.
Lithology	The nature or composition of a rock.
Loess	A silt deposit formed from wind-blown dust.
Moraine	An accumulation of material deposited by a glacier. The ground surface of a moraine commonly has an irregular or hummocky form.
Orthophoto	An orthophoto is an aerial photograph, or montage of aerial photographs, that have been geometrically corrected (‘orthorectified’) for topographic relief, camera lens distortion and camera tilt. These corrections mean that the scale of the orthophoto is uniform, and it is in effect a scaled map.
Outwash deposit	Gravelly river sediment deposited by meltwater downstream of a glacier.
Precipitation	Any form of water, such as rain, snow, sleet, or hail, which falls to the Earth's surface.

Qualitative	Relating to or involving comparisons based on qualities (e.g. surface appearance), rather than measurable quantities.
Quantitative	Relating to or involving measurable quantities (e.g. amount or size), rather than comparison of relative qualities.
River Environment Classification (REC)	River Environment Classification is a system that classifies New Zealand's rivers, or parts of rivers, using a scheme of six hierarchical levels. In this report, we make use of the 'stream order' part of the classification. A stream order of 1 denotes the smallest size of stream, with progressively larger streams attracting larger numbers. The largest-order stream examined in this investigation is Luggate Creek, which has a stream order of 5.
Runoff	That proportion of precipitation that flows on the ground surface.
Schist	A metamorphic rock typically composed of flaky parallel layers. It is the product of the alteration, under heat and pressure, of a pre-existing rock. In Otago, the schist is largely derived from former sandstone or mudstone rocks. Otago schist commonly has well-defined light- and dark-coloured layers, in varying proportions. In places where it is not so metamorphosed, it is termed semi-schist and has a parallel flakiness, but lacks well defined layers.
Sea level	The average level of the sea's surface in relation to the land. By definition it represents an elevation of 0 m. Sea level is linked to global 'Ice Age' glaciation/interglaciation cycles. During an Ice Age, so much water becomes 'locked' up in ice sheets that form on Europe and North America that the level of the sea drops. At the culmination of the last Ice Age, about 18,000 years ago, sea level was at least 120 m lower than it is now. As Northern Hemisphere ice sheets melted, sea level rose, stabilising at about its present level about 7,000 years ago. The last time the sea was as high as it is now was during the last interglacial period, about 120,000 years ago. At lowest sea level during the last Ice Age, the shoreline was at the outer edge of the continental shelf, between about 30 and 40 km east of the modern Otago coast. Changing sea levels have had major effects on landscapes of Otago's coastal fringes, and on the near-coastal reaches of rivers and streams.
Sediment	Fragmented material, typically derived from rock or soil, that is transported and deposited by water, ice, or wind, or which is derived from biologic sources (e.g. peat or guano). Fragmental sediment is commonly classified according to the size of fragments (grain-size, or 'texture'); gravel grains are larger than 2 mm, sand grains are between 2 mm and 0.06 mm, silt grains are between 0.06 and 0.004 mm, and clay is finer than 0.004 mm. "Mud" consists mostly of silt, but also commonly includes some sand or clay. Sedimentary rocks consist of consolidated sediment (e.g. sandstone).
Sedimentation	The deposition of sediment.

Soil	The top layer of the Earth's surface. Soils are produced by physical, chemical or biological alteration of the parent material (rock or sediment) forming the Earth's surface at any particular location. Soils commonly consist of rock and mineral particles mixed with organic matter. Other common definitions of soil (e.g. 'engineering soil' = unconsolidated material) are not used in this report.
Soil – immature	A soil that displays minimal alteration or disruption of the original parent material. Typically there is little if any weathering of the parent material, little disturbance by plant roots or burrowing soil organisms and little accumulated organic matter. In terms of the New Zealand Soil Classification System (Hewitt 1993), soils described in this report as 'immature' includes Raw Soils and the youngest of Recent Soils. These features are interpreted to indicate that not much time has elapsed since the soil began to form; in this report, such soils are inferred to be younger than about 300 years.
Soil - mature	A soil that displays notable alteration or disruption of the original parent material. Typically there is some weathering of the parent material, disturbance by plant roots or burrowing soil organisms and accumulated organic matter. In terms of the New Zealand Soil Classification System (Hewitt 1993), soils described in this report as 'mature' include Brown soils, Gley soils (excluding Recent Gley), Pallic soils and Semiarid soils (including Immature Semiarid). These features are interpreted to indicate that some time has elapsed since the soil began to form; in this report, such soils are inferred to be older than about 300 years.
Tectonic	Describes the disruption (e.g. faulting or folding) of rocks in response to stresses within the Earth's crust.
Terrace	A flat or gently sloping bench. Typically refers to former river or stream floodplains that now stand some distance above the present floodplain, as a result of incision of the river or stream system.
Terrace riser	The slope that separates two terrace levels from one another, or that separates a terrace from a modern floodplain.
Training (river)	Refers here to any artificial measures that attempt to control a watercourse. These may include embankments, but could include measures like steel cables, rows of trees, etc.

APPENDIX B: OTAGO ALLUVIAL FANS PROJECT – OUTLINE OF GIS DATA

Updated regional 1:50,000 data set

Alluvial fans across Otago were identified and mapped at a regional level during 2006-07 (Grindley *et al.* 2009). A polygon data set of these fans (**orc_fans_v4FINAL0707.shp**) was provided to the Otago Regional Council (ORC). The data set includes published and some unpublished observations, mostly made or collated at 1:50 000-scale. 2197 alluvial fans were identified, and although numerous small fans were included, it was not possible to guarantee that all fans smaller than ~0.1 km^2 were included. Fans were classified according to their activity (active/inactive), which indicated places where “there may be a hazard to look for”, and an indication as to the most likely nature of that hazard (debris-dominated, composite, floodwater-dominated). ORC, in consultation with the territorial authorities of Otago, used the data set to identify and prioritize areas for more detailed investigation.

A 2009 version (**orc_fans_v5UPDATED0309.shp**) has been produced with a new attribute tagging those areas where there has been further investigation and more detailed maps and GIS data are available. This revised 1:50,000 data set is suitable for regional-scale assessments and contains the most comprehensive data currently available for use outside the detailed assessment areas.

New 1:10,000 data set for selected areas (2009)

A new 1:10,000 GIS data set has been produced for selected areas (see Figure 2 of report text), comprising a folio of five separate GIS layers. 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 Datum1949). All contain metadata on the data source, scale of capture and/or estimated precision. 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.

The new (2009) layers are:

orc_fans_landform_type_poly0309.shp — a polygon shapefile depicting types of landforms in the assessment areas. Subdivided into different types of catchment, fan, river, or other landforms.

orc_fans_landform_boundary_line0309.shp — a line shapefile depicting the nature of boundaries between different landform

	types, or places where there are relevant geomorphological features that are best represented with a line at the scale of capture (for example a fault or a river trim line).
orc_fans_channel_type0309.shp	a line shapefile of river and stream channels derived from NZMS260 series *river_line* and boundaries of *river_poly* digital data sets (LINZ Crown copyright reserved), complemented with additional mapping of channels from aerial photographs or field observations. Classified within the areas of landform mapping as active, recently active, less recently active or artificial.
orc_fans_data_point0309.shp	a point shapefile of localities where field and/or aerial photo observations have been made. Includes information such as depth of channel incision, size of sediment carried in the stream, and places where soil has been examined. The method of data capture (digitising or field GPS) is used to define location accuracy.
orc_fans_cover_type0309.shp	a polygon shapefile derived by compiling landcover information from the NZMS 260 series digital data sets (LINZ Crown copyright reserved) *forest*, *native*, *exotic*, *scrub*, *shingle*, *sand*, *mud*, *scree*, *sediment*, *river_poly*, *lake*, *snow*, *ice* and *residential_area*.

Table 1 (report text) summarizes the content of the main data layers and their attributes. The methodology adopted to develop these layers included:

- stereoscopic interpretation of geomorphology using Otago Regional Council colour aerial photos (taken between 1996-98, printed at 1:25,000 and 1:33,000 scales). For the most part these photographs provided an indication of alluvial fan flooding activity within the 10 years prior to photography.

- collation of fan and catchment interpretations onto orthorectified colour photo base maps at 1:10,000 scale. These 0.6 m resolution photographs, taken during 2005-06, are the most recent detailed regional-extent photographic record of fan activity. Catchments at Glenorchy and Luggate were mapped at 1:15,000 and 1:25,000 scales due to their large extents;

- o digitising of linework and point observations using ArcMap;
- o field checking of selected parts of the investigation areas. The work includes examination of landforms, soil types, channel depths and riser heights, coarseness of fan sediment, etc. Refinement of fan mapping and classification produced from aerial photo interpretation. Discussions with available local residents to gain further insight to stream behaviour and flood histories. Location and collection of field data points by 12 channel Garmin GPS (horizontal precision ± 10m or better);
- o extraction of hydrologic (stream and river) line data from NZMS260 topo dataset (LINZ, Crown Copyright Reserved). Editing where necessary and classification based on aerial photo interpretation and field observation. Extraction of land cover and vegetation information from NZMS260 digital data sets (LINZ, Crown Copyright Reserved). Merging these data into new landcover polygon shapefiles.
- o finalisation of data sets, plotting, hard-copy review and checking of digitising and data attribution;

APPENDIX C: OTAGO ALLUVIAL FANS PROJECT – SUMMARY ASSESSMENTS AND MAPS FOR THE INVESTIGATION AREAS

This appendix contains:

(1) Summary tables listing characteristics for selected fans in each of the investigation areas (Table C1) and an explanation of codes used in that table (Table C2).

(2) A summary information sheet for each fan assessment area, accompanied by maps for each area derived from the 1:10,000-scale fan GIS data set. Assessment areas are presented in the following order:

(1) Makarora; accompanied by two map sheets (north and south)

(2) Hawea (west); accompanied by one map sheet

(3) Hawea (Grandview); accompanied by one map sheet

(4) Luggate (Grandview); accompanied by two map sheets (north and south)

(5) Luggate (township); accompanied by one map sheet

(6) Wanaka (township); accompanied by one map sheet

(7) Wanaka (Glendhu Bay); accompanied by one map sheet

(8) Wanaka (Treble Cone); accompanied by one map sheet

(9) Wanaka (Cardrona); accompanied by one map sheet

(10) Glenorchy (Kinloch); accompanied by one map sheet

(11) Glenorchy (Earnslaw); accompanied by one map sheet

(12) Glenorchy (township); accompanied by two map sheets (Precipice Creek and Glenorchy)

(13) Queenstown (Walter Peak); accompanied by one map sheet

(14) Queenstown (Bobs Cove); accompanied by one map sheet

(15) Queenstown (township); accompanied by one map sheet

(16) Queenstown (Coronet Peak); accompanied by one map sheet

(17) Queenstown (Crown Terrace); accompanied by one map sheet

(18) Queenstown (Remarkables); accompanied by two map sheets (north and

south)

(19) Kingston; accompanied by one map sheet

(20) Kawarau (Gibbston); accompanied by one map sheet

(21) Cromwell (Mt Pisa); accompanied by one map sheet

(22) Cromwell (Lowburn-Ripponvale); accompanied by one map sheet

(23) Alexandra (Waikerikeri); accompanied by two map sheets (north and south)

(24) Alexandra (Galloway); accompanied by one map sheet

(25) Alexandra (Omeo Creek); accompanied by one map sheet

(26) Roxburgh; accompanied by two map sheets (north and south)

(27) Tapanui; accompanied by one map sheet

(28) Middlemarch; accompanied by two map sheets (north and south)

(29) Oamaru; accompanied by one map sheet

TABLE C1: Summary of characteristics of individual fans examined in this investigation

Name	Location	Catch _type	Catch_ order	Catch _relief	Catch_vege	Catch_ geol	Fan_type	Fan_ proc	Fan_toe	Fan_vege	Fan_infra	Comment
Johns Creek	Hawea-Grandview	pos	2	1000	grass	schist	equi	all	squo	grass	10 houses, unsealed road	
Grandview Creek	Hawea-Grandview	pos	3	1000	grass	schist	equi	all	squo	grass	10 houses, unsealed roads	
Drakes Creek	Hawea-Grandview	pos	2	600	grass	schist	equi	all	pagg	grass		
Cameron Gully	Hawea-Grandview	pos	2	700	grass	schist	equi	all	pagg	grass		
Hospital Creek	Hawea-Grandview	pru	2	900	grass	schist	agg	all	pagg	grass	10 houses	
Hawea Motorcamp	Hawea-west	pru	1	900	grass, scrub	semi-schist	equi	all	squo	grass	Motorcamp	
Grayburn North	Hawea-west	pru	2	900	grass, scrub	semi-schist	agg	all	pagg	grass	house, golf course, SH6	
Grayburn	Hawea-west	pru	1	700	grass, scrub	semi-schist	agg	all	pagg	grass	house, burst dam, SH6	
Grayburn South	Hawea-west	pos	1	400	grass, scrub	semi-schist	equi	all	pagg	grass	SH6	
Brady Creek	Makarora	pru	3	1500	forest, grass, bare	schist	agg	deb	pdeg	forest, grass	SH6	
Sawmill Creek	Makarora	pos	1	900	forest, grass, bare	schist	agg	deb	pagg	forest, grass	SH6	
Unnamed	Makarora	pos	2	1400	forest, grass, bare	schist	agg	deb	pagg	forest, grass	SH6	
Pipson Creek	Makarora	pru	2	1580	forest, grass, bare	schist	agg	deb	pdeg	forest, grass	SH6, Makarora village, campground, Visitor Centre	
White Creek	Makarora	pos	2	1500	forest, grass, bare	schist	agg	deb	squo	forest, grass	SH6, up to 10 houses	
Station Creek	Makarora	pos	2	1400	forest, grass, bare	schist	agg	deb	pdeg	forest, grass	SH6, Houses	
Ewings Creek	Makarora	pos	1	1200	forest, grass	schist	agg	deb	pagg	grass	SH6	
Unnamed	Makarora	pos	2	1300	forest, grass, bare	schist	agg	deb	pagg	grass	SH6	
Boggy Creek	Makarora	pru	2	1200	forest, grass, bare	schist	agg	deb	pagg	grass	SH6	
Cemetery Creek	Makarora	pru	2	1100	grass, bare	schist	agg	deb	pagg	grass	SH6	
Flaxmill Creek	Makarora	pos	2	1400	forest, grass, bare	schist	agg	deb	pagg	grass	Makarora South	
Lagoon Creek	Hawea-Grandview	pos	3	800	grass, scrub	semi-schist	agg	all	squo	grass	farm house	
Glenfoyle Road	Hawea-Grandview	pos	2	700	grass, scrub	semi-schist	agg	all	squo	grass	SH8A, farm house	
Trig Burn	Hawea-Grandview	pos	3	700	grass, scrub	semi-schist	deg	all	pdeg	grass	SH8A, farm houses	
Deep Gully	Hawea-Grandview	pos	2	600	grass, scrub	semi-schist	deg	all	pdeg	grass	SH8A	
Dead Horse Creek	Hawea-Luggate	pos	3	1100	grass, scrub	schist	equi	all	squo	grass	outskirts of Luggate, SH8	
Luggate Creek	Hawea-Luggate	pos	5	1600	grass	schist	equi	all	squo	grass, urban	parts of Luggate town, SH8	
"Stoney Creek"	Wanaka	pru	2	900	grass	schist	equi	com	squo	grass, urban	part of Wanaka township	
Waterfall Creek	Wanaka	pru	3	1200	grass, scrub	schist	equi	com	squo	grass	Wanaka-Mt Aspiring Road, farm house	
"Roys Peak fan"	Wanaka	pos	2	1100	grass, scrub	schist	agg	com	squo	grass	Wanaka-Mt Aspiring Road, farm houses	
Damper Bay	Wanaka	pou	1	500	grass	schist	agg	com	squo	grass	Wanaka-Mt Aspiring Road	

Name	Location	Catch_type	Catch_order	Catch_relief	Catch_vege	Catch_geol	Fan_type	Fan_proc	Fan_toe	Fan_vege	Fan_infra	Comment
Tuohys Gully	Cardrona	pou	3	750	grass, scrub	schist	tced	all	squo	grass	farm buildings and houses	
Pringles Creek	Cardrona	pou	2	1350	grass	schist	tced	com	squo	grass	Crown Range Road, lifestyle subdivision	
Little Meg	Cardrona	pou	2	1200	grass	schist	tced	com	squo	grass	Crown Range Road, farm house	
Glendhu Bay	Wanaka-Glendhu	pos			grass	schist	agg	all	squo	grass		
Alpha Burn northeast	Wanaka-Glendhu	pru	1	1050	grass	schist	agg	all	pagg	grass		
Alpha Burn	Wanaka-Glendhu	pru	2	950	grass	schist	agg	all	pagg	grass	house	
Alpha Burn southwest	Wanaka-Glendhu	pru	3	1150	grass	schist	agg	all	pagg	grass		
Twin Falls southeast	Wanaka-Treble Cone	pru	2	1300	grass	schist	agg	deb	pagg	grass		
Twin Falls	Wanaka-Treble Cone	pru	2	1400	grass	schist	agg	deb	pagg	grass	road	
Treble Cone Road south	Wanaka-Treble Cone	pru	2	1400	grass	schist	agg	deb	pagg	grass	skifield road	
Treble Cone Road north	Wanaka-Treble Cone	pru	3	1550	grass	schist	agg	deb	pagg	grass	road	
Cattle Flat	Wanaka-Treble Cone	pru	2	900	grass	schist	agg	deb	pagg	grass	house	
Eastbourne	Queenstown-Crown Tce	pos	1	600	grass	schist	deg	all	pdeg	grass	road	
Swift Burn	Queenstown-Crown Tce	pos	2	460	grass	schist	deg	com	pdeg	grass	road, houses	
Royal Burn	Queenstown-Crown Tce	pru	2	950	grass	schist	agg	all	squo	grass	road, houses	
McMullen Creek	Queenstown - Coronet	pru	2	1000	grass	schist	agg	com	pagg	grass		
Station Creek	Queenstown – Coronet	pru	2	1170	grass	schist	agg	com	pagg	grass	road, houses	
Gibbston Vineyard	Kawarau	pos	1	1140	grass	schist	tced	all	pdeg	grass, hort	SH6, buildings	
Franks Creek	Kawarau	pru	2	960	grass	schist	tced	all	pdeg	grass, hort	SH6, buildings	
Gibbston Back Road fan complex	Kawarau	pru	2	800	grass	schist	tced	all	pdeg	grass, hort	SH6, buildings	
Horn Creek	Queenstown	pru	1	1340	forest, grass	schist	agg	deb	pagg	urban	populated urban area	
Reavers Lane	Queenstown	pru	1	700	forest	schist	agg	deb	pagg	urban	populated urban area	
One Mile Creek	Queenstown	pru	3	1470	forest, grass	schist	tced	all	squo	urban	road	
Two Mile Creek	Queenstown	pru	1	1120	forest, grass	schist	tced	all	squo	scrub, urban	road	
Glacier Burn	Glenorchy West	pru	2	1960	forest, grass, bare	schist	agg	deb	pagg	forest, grass	road	
Woodbine	Glenorchy West	pru	2	1800	forest, grass, bare	schist	agg	deb	pagg	forest, grass	road, house	
Gorge Creek	Glenorchy West	pru	1	1620	forest, grass, bare	schist	agg	com	pagg	forest, grass	road, houses	
Mick Creek	Glenorchy West	pru	2	1600	forest, grass, bare	schist	agg	deb	squo	forest	Road	
Precipice Creek	Glenorchy East	pru	3	1740	forest, grass, bare	schist	agg	all	pagg	grass, bare	road, houses	

Name	Location	Catch _type	Catch_ order	Catch _relief	Catch_vege	Catch_ geol	Fan_type	Fan_ proc	Fan_toe	Fan_vege	Fan_infra	Comment
Buckler Burn	Glenorchy East	pru	4	1900	forest, grass, bare	schist	agg	all	pagg	bare, urban, grass	populated urban area	
Little Stony Creek	Glenorchy South	pru	2	1590	grass, bare, scrub, forest	schist	agg	deb	pagg	grass	Power	
Little Stony Creek south	Glenorchy South	pou	2	1600	bare, grass, scrub	schist	tced	deb	pagg	grass	Power	
Earnslaw Burn	Glenorchy North	pru	3	2450	forest, grass, bare	schist	agg	all	pagg	grass	Road	
"Cemetery Creek"	Kingston	pru, pou	2	1040	grass, bare	schist	agg	deb	pagg	grass	town, SH6	
"Jetty Creek N"	Kingston	pru	1	920	grass, scrub	schist	equi	deb	squo	grass		
"Jetty Creek S"	Kingston	pru	1	760	grass, scrub	schist	agg	deb	pagg	grass		
"Skifield Rd fan"	Remarkables	pos	2	1200	grass, bare, scrub	schist	equi	com	squo	grass, hort	SH6, farm buildings	
"Remarkables Station homestead fan"	Remarkables	pos	2	1500	grass, bare	schist	equi	com	squo	grass, scrub	SH6, farm buildings	
"Jacks Point fan"	Remarkables	pos	2	1500	grass, bare	schist	equi	com	squo	grass, scrub	SH6, farm buildings, lifestyle subdivision, golf course	
Tinwald Burn	Cromwell North	pos	3	1500	grass, bare, scrub	schist	tced	all	pagg	grass, hort	SH6, farm buildings	Aggradation into Lake Dunstan.
Amisfield Burn	Cromwell North	pos	3	1200	grass, bare, scrub	schist	tced	all	pagg	grass, hort	SH6, farm buildings	Aggradation into Lake Dunstan.
Burn Cottage Road	Cromwell South	pou	3	700	grass, scrub	schist	tced	all	pagg	grass, hort	SH6, farm buildings and houses	Aggradation into Lake Dunstan.
Ripponvale	Cromwell South	pos	1	400	grass, scrub	schist	agg	all	squo	grass, hort	roads, lifestyle subdivision and farm buildings	
Waikerikeri Creek	Alexandra	pos	4	1200	grass, scrub	schist	tced	all	squo	grass	roads, lifestyle subdivisions and farm buildings	
Scrubby Gully	Alexandra	pos	4	950	grass, scrub	schist	tced	all	squo	grass	SH85, farm buildings	McArthur Gully is head waters of Scrubby Gully.
Dip Creek	Alexandra	pos	4	400	grass	schist	equi	all	pagg	grass	roads, farm houses	
Omeo Creek	Alexandra	pos	4	1400	grass	schist	tced	all	squo	grass	roads, farm houses	
Coal Creek Flat	Roxburgh	pos	1	600	grass	schist	agg	all	pagg	grass	farm buildings	
Slaughterhouse Creek	Roxburgh	pou	2	750	grass, scrub	schist	agg	com	squo	grass, hort	SH8, farm buildings	Artificial levee channel.
"Mitchell Creek"	Roxburgh	pou	2	800	grass, scrub	schist	equi	com	squo	grass, hort	SH8, lifestyle subdivision	
Reservoir Creek (town creek)	Roxburgh	pou	2	800	grass, scrub	schist	equi	com	squo	urban	SH8, approx 30 dwellings	Artificial concrete channel.
"Golf course"	Roxburgh	pou	2	1000	grass, scrub	schist	tced	com	squo	grass, urban	SH8, <10 dwellings	Toe trimmed by Clutha.
Black Jacks Creek	Roxburgh	pos	3	1050	grass, scrub	schist	tced	com	squo	Grass	SH8	Toe trimmed by Clutha.
Stevenson Creek	Roxburgh	pou	2	1000	grass, scrub	schist	equi	com	squo	grass, hort	SH8, <10 dwellings	
Langlea Road	Roxburgh	pou	1, 2	600	grass, scrub	schist	agg	all	squo	Grass	road, SH8, <10 dwellings	
Whisky Gully	Tapanui	pou	2	600	forest, grass, scrub	semi-schist, greywacke	equi	all	squo	Grass	roads, farm houses, part of Tapanui urban area	
Rock Creek	Middlemarch	pou	1, 2	700	grass, scrub	schist	equi-tced	com	squo	Grass	roads, farm houses	
Six Mile Creek	Middlemarch	pou	3	1000	grass, scrub	schist	equi-tced	com	squo	Grass	roads, farm houses	

TABLE C2: Description of the categories of individual fan characteristics

Category	Data type	Description	Attributes
Name	Text string, 48 characters	Fan Identifier	Unique identifier name, common to Landform_type_poly GIS layer
Location	Text string, 56 characters	Location description	
Catch_type	Text string, 24 characters	Overall catchment slope stability conditions	Restricted List, select from presently unstable (pru), potentially unstable (pou), potentially stable (pos): see Fan Stability Classification (Table 2, text)
Catch_order	Number, 1 digit	Stream order value at fan head (from River Environment Classification; Snelder *et al*. 2004))	Restricted List, select from 1, 2, 3, 4 or 5. 1 = smallest, 5 = largest
Catch_relief	Number, 4 digit	Elevation change, fan head to catchment head in metres, to nearest 20 m	Values read off from topographic map contours
Catch_vege	Text string, 24 characters	Predominant landcover type(s)	Restricted List, select up to three from bare, grass, scrub, forest, hort(iculture)
Catch _geol	Text string, 48 characters	Predominant geologic material type(s)	Restricted List, select up to three from schist, greywacke, sedimentary rock, Quaternary deposits
Fan_type	Text string, 28 characters	Present-day fan behaviour type	Restricted List, select from aggradational (agg), episodically-aggradational (epi-agg), equilibrium (equi), degradational (deg), terraced (tced): see Fan Stability Classification (Table 2, text)
Fan_process	Text string, 28 characters	Dominant processes observed on the fan	Restricted List, select from dominant processes of alluvial (all), composite (com) or debris (deb)
Fan_toe	Text string, 24 characters	Presence of factors that could produce medium-term changes in fan behaviour	Restricted List, select from potential aggradation (pagg), status quo (squo) or potential degradation (pdeg): see Fan Stability Classification (Table 2, text)
Fan_vege	Text string, 24 characters	Predominant landcover type(s)	Restricted List, select up to three from bare, grass, scrub, forest, hort(iculture), urban
Fan_infra	Text string, 56 characters	Description of main types of existing infrastructure on the fan	Include buildings, road types, utility corridors (e.g. water, power)

OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

MAKARORA area – summary assessment

A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies on the east side of the Makarora River, between the head of Lake Wanaka to the south, and Brady Creek to the north. It is bordered to the east by the crest of the McKerrow Range. The fan areas include the villages of Makarora and Makarora South.

The Makarora valley is cut in ancient schist bedrock. The valley was occupied by glaciers during the last Ice Age; the oldest parts of the landscape date from the retreat of the ice, which began about 18,000 years ago. Eroding schist rock in the catchments has fed sediment onto alluvial fans that border the Makarora River. The sediment carried by the Makarora River to Lake Wanaka is 'trapped' in a delta and the river is progressively building out into the lake. Farther upstream sediment must also build up in order for the river to maintain its grade. As a result, river and stream sediments are slowly filling in the valley floor, and the landscape, geologically speaking, is very young. Many of the catchments contain areas of landslides and erosion that contribute abundant sediment to the fans. Pipson Creek is a notable example.

Makarora's large annual precipitation (about 2,000 mm/yr at the valley floor, increasing with altitude to more than 3,000 mm/yr in the McKerrow Range - growOTAGO), results in a high rate of fan-building activity.

LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation:	Oct 2008
Field Check:	Jan 2009
Revisions:	

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: There are many historic examples of major flooding and extensive sedimentation on most of these fans, including Flaxmill Creek, Cemetery Creek and Pipson Creek. On extensive parts of the fans, the soils are immature. These poorly-developed soils indicate that flood sedimentation has occurred within the past few hundred years. Parts of some fans have mature forest and mature soils, indicating that they have been free of fan sedimentation for at least several hundred years.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture with some areas of native forest and scrub. Pastoral farming and large-holding residential.

B3. EXISTING INFRASTRUCTURE: Small townships, motor camp, Department of Conservation visitor centre, State Highway 6, farm buildings.

B4. EXISTING CONTROL WORKS: River-training embankments along most of the major stream channels. Ongoing sediment extraction programmes, particularly at Pipson Creek.

B5. TYPES OF FAN: Predominantly aggradational fans. Debris flows have occurred historically on some parts of some of the fans.

B6. CONDITIONS AT TOES OF FANS: Some fan streams are actively trimmed by the Makarora River (e.g. Pipson Creek), others are building onto abandoned river terraces. Sediment build-up is expected to continue, unless sediment is removed mechanically.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Localised areas of active landsliding and gully erosion, notably in the Pipson Creek catchment. Some extensive areas of creeping or dormant landslides, notably in Flaxmill Creek and Boggy Creek catchments.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grassland, forest, and areas of bare ground, particularly near the crest of the McKerrow Range.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 900 m and 1,500 m.

D. Additional information

D1. EXISTING REPORTS: A comprehensive report that includes details of historic fan flood events, prepared by Otago Regional Council, 'Natural Hazards at Makarora' can be accessed at www.orc.govt.nz.

D2. ILLUSTRATIONS

Cemetery Creek alluvial fan: breakout and deposition of gravelly sediment across paddocks and the highway after a major rainstorm in 1994 (*Otago Regional Council photo*).

Pipson Creek fan at the highway bridge. Large gravel embankments, constructed from debris that has choked the channel, currently direct the active channel straight down the fan to the Makarora River (*GNS Science photo, Jan 2009*)

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
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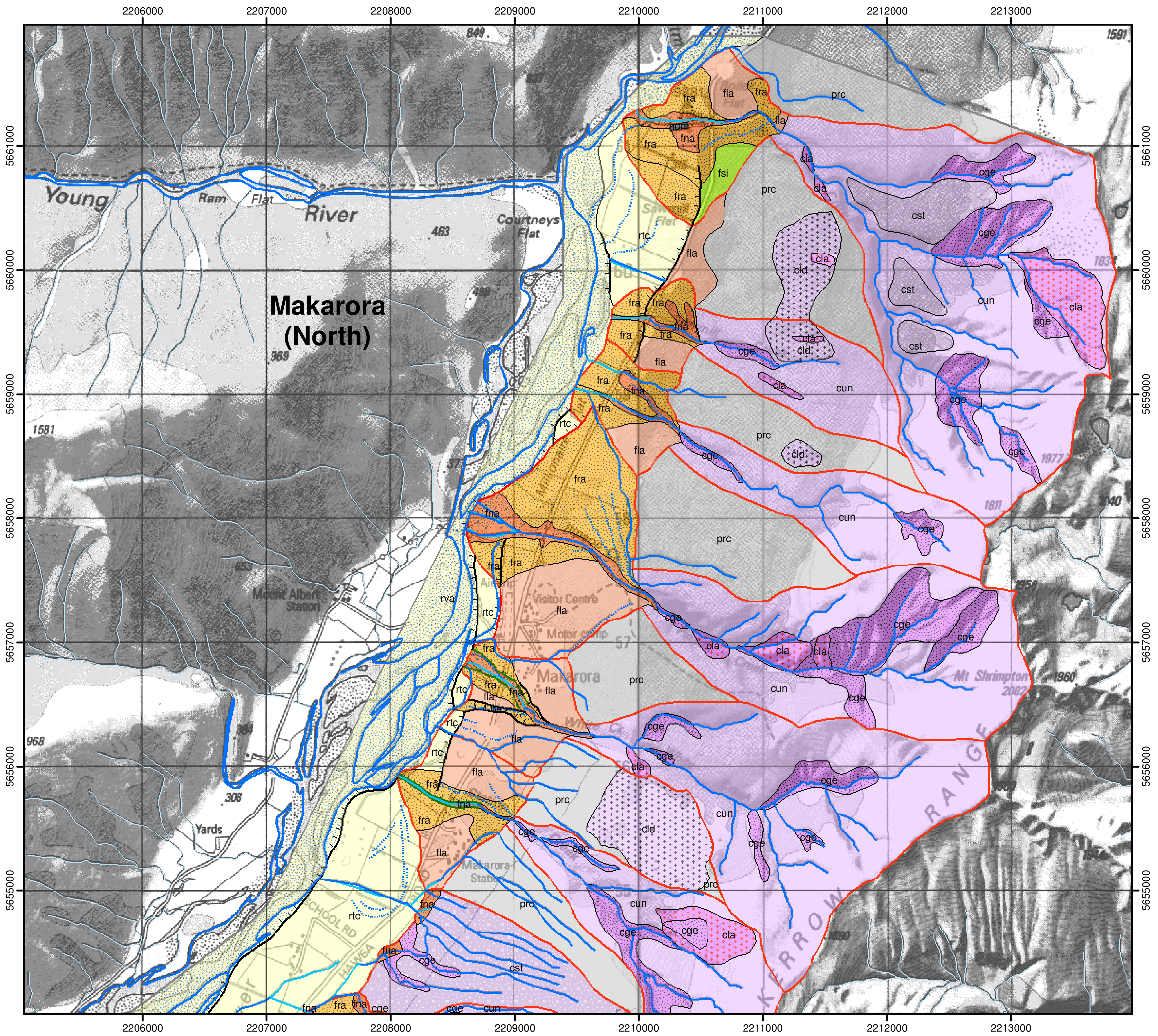

Alluvial Fans Map Legend

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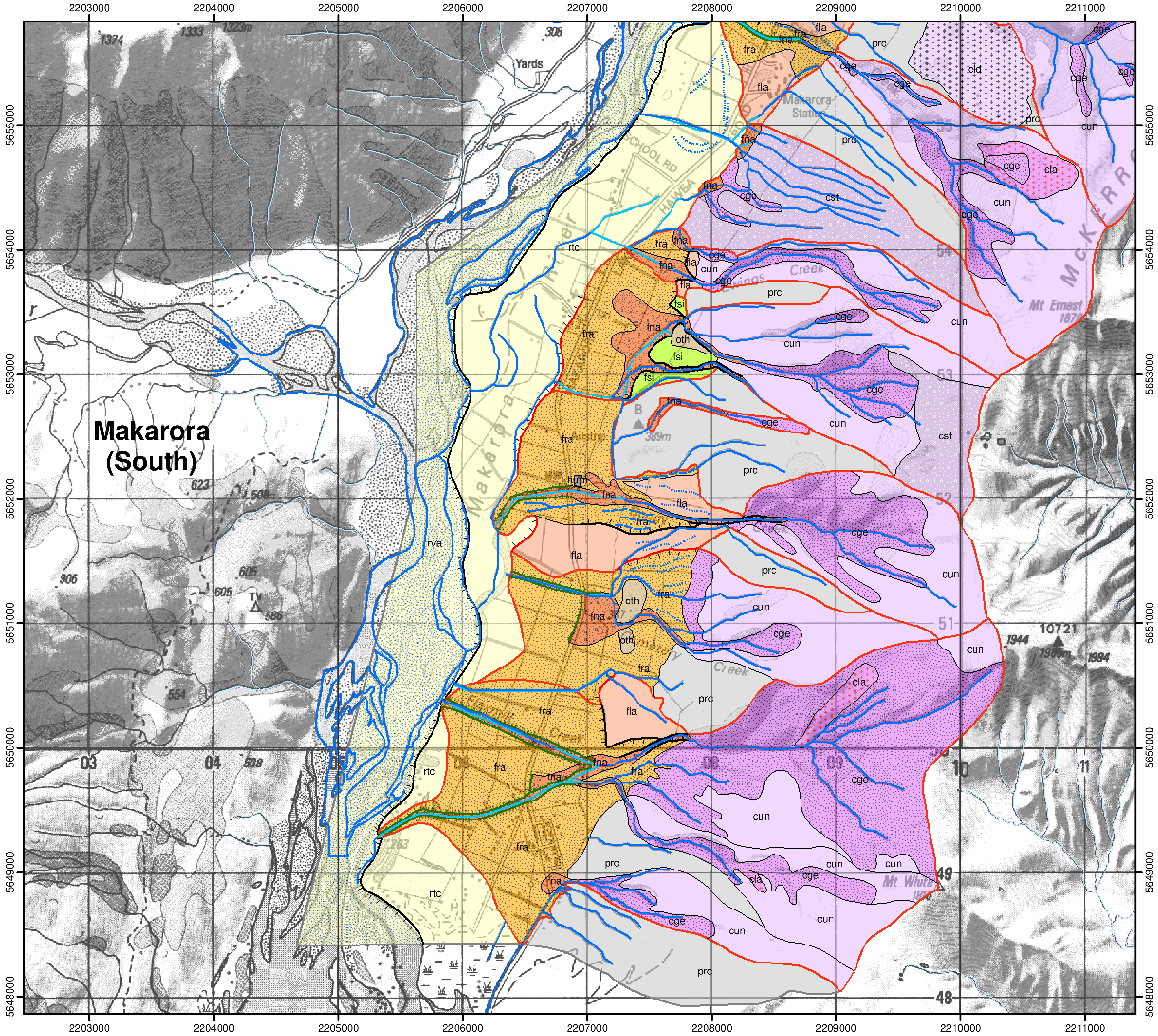


OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

HAWEA (west) area – summary assessment

A. Extent and nature of the assessment area

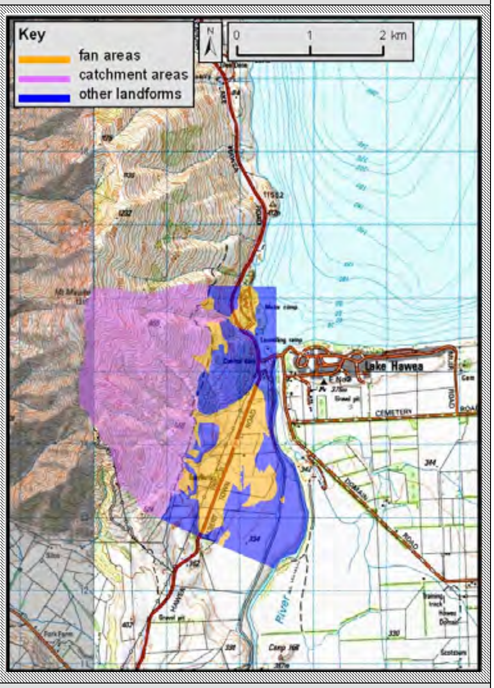
DESCRIPTION:

The assessment area lies to the west of the Lake Hawea outlet, under the eastern flank of Mt Maude. The fan area includes the Lake Hawea camping ground.

Ranges either side of the Hawea Basin are formed in ancient semi-schist bedrock. This tectonic basin was occupied repeatedly by glaciers during Ice Ages. Glaciers scoured and shaped the flanks of the ranges and left extensive areas of moraine and glacial outwash river terraces in the basin. Ice retreated from Lake Hawea most recently about 18,000 years ago; most of the landforms date from about that time. The landscape, geologically speaking, is young.

Eroding bedrock in the fan catchments has fed sediment onto small alluvial fans that have built out onto terraces of the Hawea River.

Annual precipitation at Hawea (west) is about 800 mm/yr at the valley floor, increasing with altitude to more than 1,000 mm/yr at the catchment heads (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS260 series.
Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Most parts of the fans have mature soils, indicating that there has been little or no sediment-laden flooding on these areas within at least the past few hundred years, except close to present stream channels. Recent failure of a small water-supply dam in the gully north of Grayburn homestead caused scouring (to a depth of 2 m) and accompanying sedimentation of the stream channel at the highway.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture with some areas of forest and scrub. Pastoral farming, some large-holding residential, minor commercial and recreational.

B3. EXISTING INFRASTRUCTURE: Lake Hawea Holiday Park, Lake Hawea Motors, golf course, State Highway 6.

B4. EXISTING CONTROL WORKS: Minor channel control of active streams. At the highway, a large road-fill embankment has been constructed across the Holiday Park fan stream channel, and appears to have isolated the fan from its catchment.

B5. TYPES OF FAN: Aggradational to equilibrium fans. Predominant processes appear to have been flooding and sedimentation rather than debris flows.

B6. CONDITIONS AT TOES OF FANS: All fans are built on Hawea River terraces, except the northernmost which abuts Lake Hawea as a delta. Any sediment brought down by the streams is likely to build up in their channels, and possibly spread onto the fans, unless sediment is removed mechanically.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Extensive areas of gullied terrain with some landslide terrain, some of which are active and others that appear dormant.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass with large areas of regenerating scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 900 m in the north, decreasing to 400 m in the south.

D. Additional information

D1. EXISTING REPORTS: none known.

D2. ILLUSTRATIONS:

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

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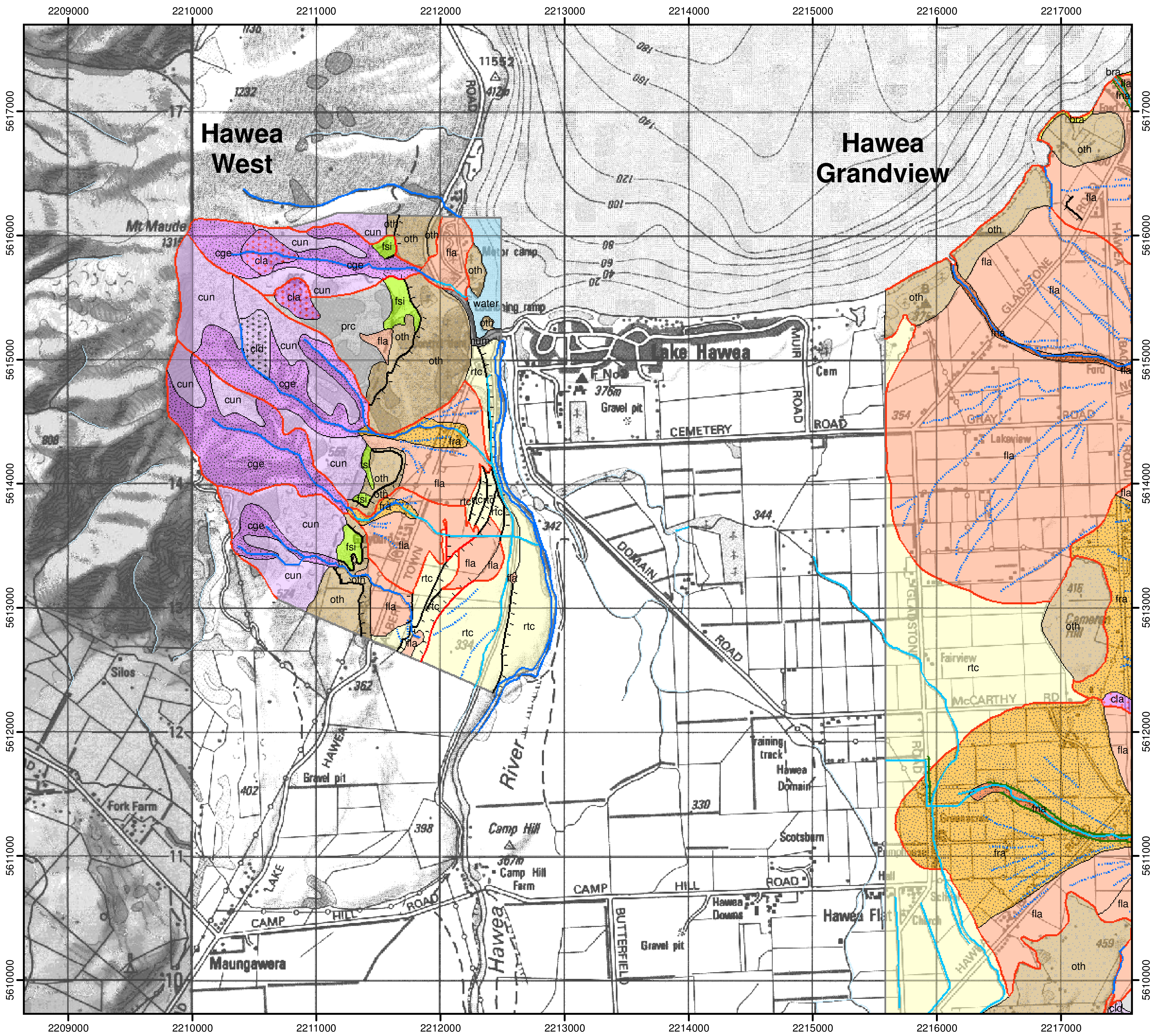


OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

HAWEA (Grandview) area – summary assessment

A. Extent and nature of the assessment area

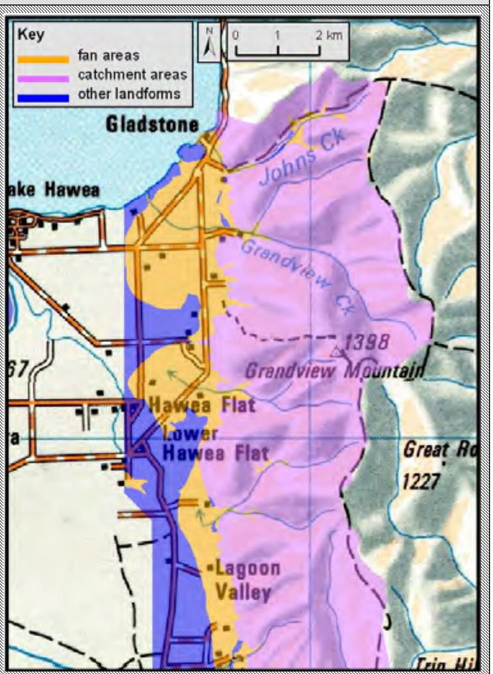
DESCRIPTION:

The assessment area lies on the east side of the Hawea basin, on the western flank of the Grandview range. It extends from Johns Creek on the shore of Lake Hawea, south to the Lagoon Valley area.

Ranges either side of the Hawea Basin are formed in ancient semi-schist bedrock. This tectonic basin was occupied repeatedly by glaciers during Ice Ages. Glaciers scoured and shaped the flanks of the ranges and left extensive areas of moraine and glacial outwash river plains and terraces in the basin. Ice retreated from Lake Hawea most recently about 18,000 years ago; most of the landforms date from about that time. The landscape, geologically speaking, is young.

Eroding bedrock in the fan catchments has fed sediment onto large alluvial fans that have built out onto the glacial outwash plain that extended down-valley from the moraines enclosing Lake Hawea.

Annual precipitation of about 800 mm/yr at Lake Hawea decreases southeast to 650 mm/yr at Hawea Flat and to less than 600 mm/yr near Luggate. Precipitation increases with altitude to more than 900 mm/yr at the heads of the catchments in the Grandview range (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Most parts of the fans have mature soils, indicating that there has been little or no sediment-laden flooding within at least the past few hundred years, except close to the present stream channels.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture. Pastoral farming, residential at Johns Creek (Gladstone).

B3. EXISTING INFRASTRUCTURE: minor roads, small village at Gladstone, farm buildings.

B4. EXISTING CONTROL WORKS: Localised channel control of active streams. Larger embankments, sediment-retention structures and sediment extraction at Hospital Creek.

B5. TYPES OF FAN: Equilibrium to aggradational fans. Predominant processes are flooding and sedimentation rather than debris flows.

B6. CONDITIONS AT TOES OF FANS: All fans are built out onto extensive Ice Age river plains or moraines. Except for Johns Creek and Grandview Creek, which drain into Lake Hawea, any sediment brought down by the streams is likely to build up in the stream channels or on the fans, unless sediment is removed mechanically. Conditions at the mouths of Johns and Grandview creeks vary depending on the level of the lake. Lake level is controlled for hydro-electric purposes and varies by up to 7 m seasonally. A major flood when the lake is low is likely to cause degradation and incision of their lower reaches; floods at times of high lake level may result in sediment build-up in their lower reaches.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Extensive areas of gullied terrain with some landslide terrain, some of which are active, while others appear dormant.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass with minor areas of regenerating scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is up to 1,000 m in the north, decreasing to 800 m in the south.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

The active channel of Hospital Creek, downstream of Hawea Back Rd, is contained between artificial embankments. The accumulating gravelly sediment is episodically bulldozed to contribute to the embankments; some is stockpiled. This is one of the few sites of active sediment build-up in the assessment area (*Opus photo, Jan 2009*).

At the downstream end of the constrained active channel of Hospital Creek, floods have deposited gravel on the alluvial fan surface. Upstream, the active gravel bed between the embankments now stands 1 – 2 m above the surrounding farmland. If an embankment were to fail, a gravel flood like this would break out onto presently stable land (*Opus photo, Jan 2009*).

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

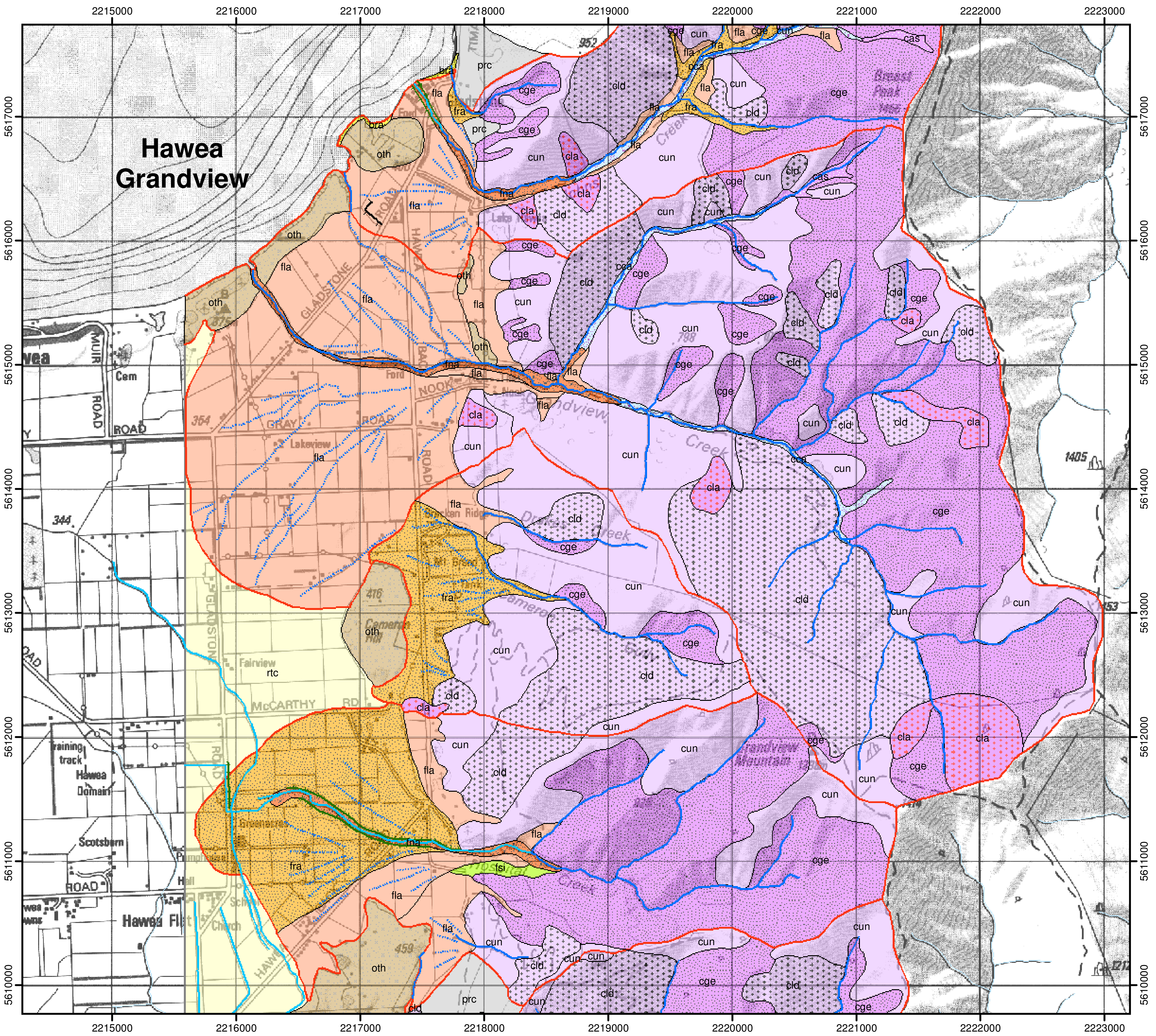
- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

0 0.5 1 2 Km



OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

LUGGATE (Grandview) area – summary assessment

A. Extent and nature of the assessment area

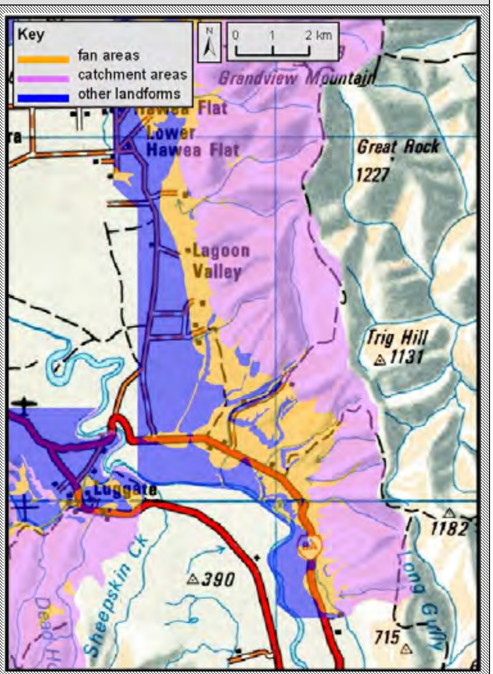
DESCRIPTION:

The assessment area lies on the east side of the Upper Clutha valley, at the western edge of the Grandview range. It extends from Lagoon Valley south to Long Gully farm.

The Grandview range is formed in ancient semi-schist bedrock. The upper Clutha valley is a tectonic basin that was occupied repeatedly by glaciers during earlier Ice Ages, but not during the most recent ones. Ice has scoured and shaped the lower flank of the Grandview range and left patches of moraines, glacial lake beds and glacial outwash river gravel terraces in the valley.

Eroding bedrock in the catchments has fed sediment onto alluvial fans that have built out onto the glacial outwash terraces. Episodes of fan building have been interrupted by periods of river gravel build-up, and subsequent erosion, by the Clutha River in response to Ice Age advances and retreats of glaciers farther upstream. Landforms in the assessment area cover a wider range of ages than occur farther upstream in areas more recently affected by Ice Age glaciers.

Annual precipitation is a little less than 600 mm/yr in the valley floor, but increases with altitude to an estimated 800 mm/yr at the catchment heads (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Most parts of the fans have mature soils, indicating that there has been little or no sedimentation within at least the past few hundred years, except close to the present stream channels.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture. Pastoral farming.

B3. EXISTING INFRASTRUCTURE: State Highway 8A, farm buildings, minor roads, minor large-holding residential.

B4. EXISTING CONTROL WORKS: None known, other than bridges and culverts.

B5. TYPES OF FAN: Includes aggradational fans and degradational fans. Predominant processes are flooding and sedimentation rather than debris flows.

B6. CONDITIONS AT TOES OF FANS: All fans are built out onto glacial outwash gravel terraces of the Clutha River. Fans such as those near McKay Road and Glenfoyle Road are built onto an extensive river terrace. Their fan toes do not reach the Clutha River cliff, so the fans are aggrading (e.g. Crook Burn). Any sediment brought down by these streams is likely to accumulate in the stream channels and possibly onto the fan surfaces. Those fans farther southeast (e.g. Trig Burn and Deep Gully) are built across narrower river terraces that lie closer to the high, eroded bank of the Clutha. As a result, most of these fans are degradational, having been incised by their stream channels, which naturally confines any surface flow into an active gully that increase in depth towards the river. Sediment brought down by the streams is transported naturally to the Clutha River. There is more potential for sediment to build up, and perhaps break out from the stream channels near the heads of the fans, where the streams are barely incised, if at all. Southeast of Sandy Point, the Clutha River channel lies further from the foot of Grandview range. As a result, the fans here are aggradational, similar to those near Glenfoyle and McKay roads.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Some areas of gullied terrain with minor landslide terrain. Gullies and landslides are more extensive in Crook Burn catchment.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass with minor areas of regenerating scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between 600 and 700 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

At Lagoon Valley, an abandoned glacial outwash channel (blue line) has been choked by alluvial fans radiating out (grey lines) from the catchments draining the Grandview range (distance). Because there is no longer any through-drainage (from left to right) down the old outwash channel, the sediment that the streams bring down from the catchments is not carried away, and will continue to build up on these fans (*GNS Science photo, Jan 2009*).

View of the terraced northern margin of the Clutha valley northwest from Sandy Point farm, beside SH 8a (far left). The large alluvial fan of Crook Burn (left distance) radiates out (orange lines) onto a wide abandoned terrace of the Clutha River. This fan is in an aggradational state, with Crook Burn only slightly incised into its fan. In contrast, the fan of Trig Burn (foreground, radiating grey lines) has formed where the Clutha River terrace is narrower, and river-bank erosion of the Clutha has trimmed the toe of the fan. This has caused Trig Burn incise a gully (blue arrow) that gets progressively deeper towards the river (out of sight behind the photographer). Trig Burn fan is currently in an equilibrium to degradational state (*GNS Science photo, Jan 2009*).

D3. COMMENTS:

Alluvial Fans Map Legend

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- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
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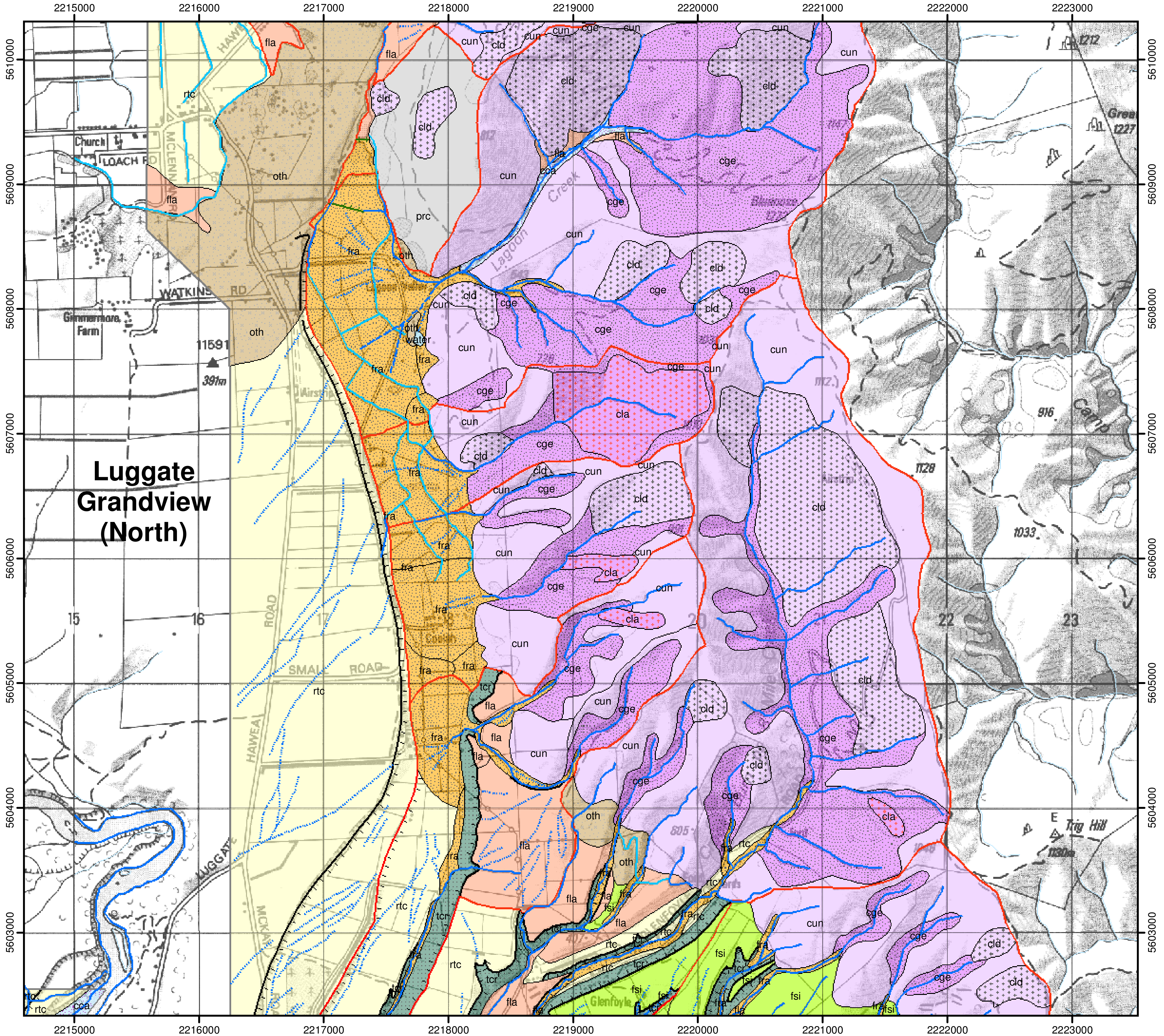
0 0.5 1 2 Km



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Base Map LINZ NZMS 260 series
(Crown copyright reserved)

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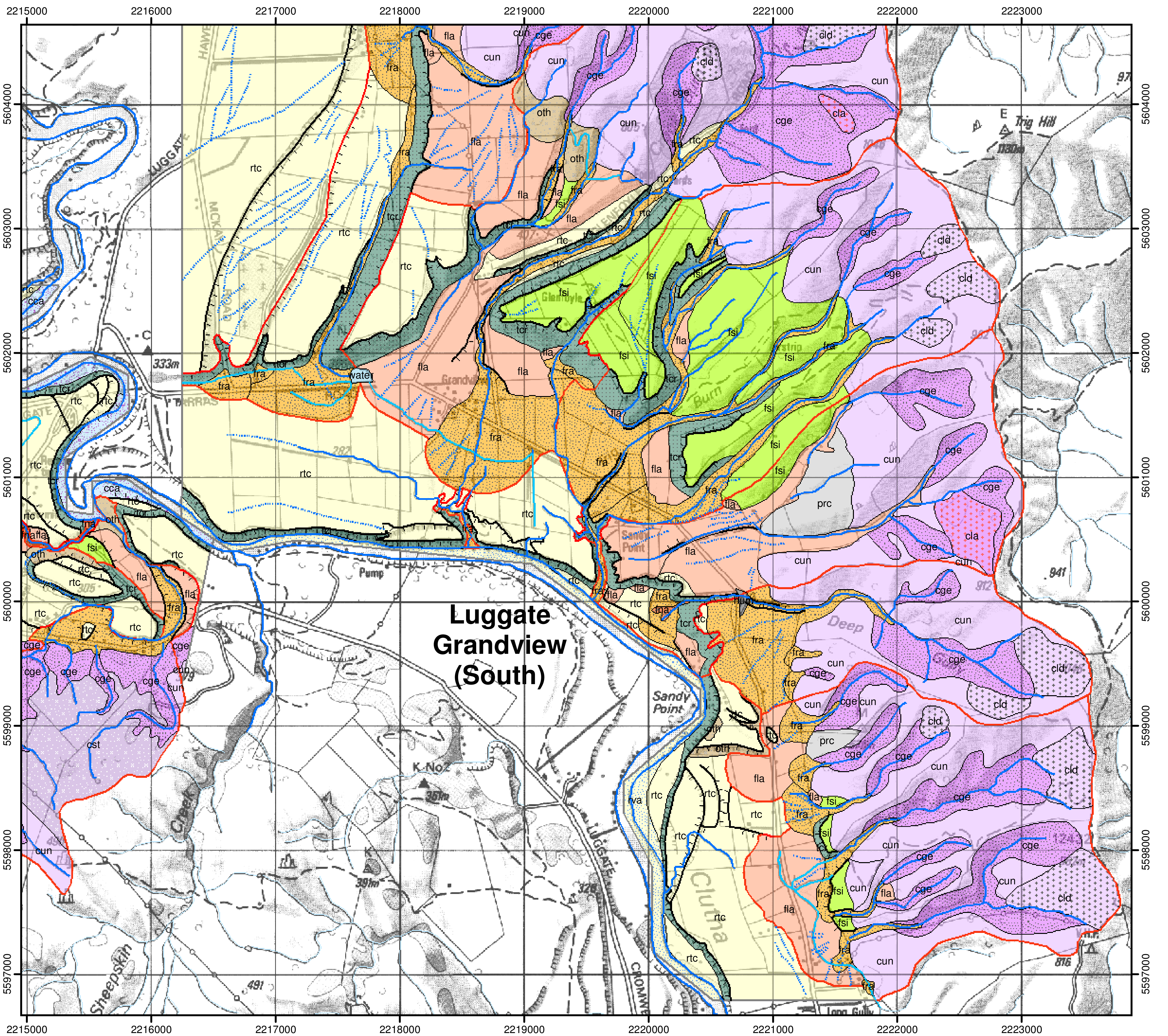


OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

LUGGATE (township) area – summary assessment

A. Extent and nature of the assessment area

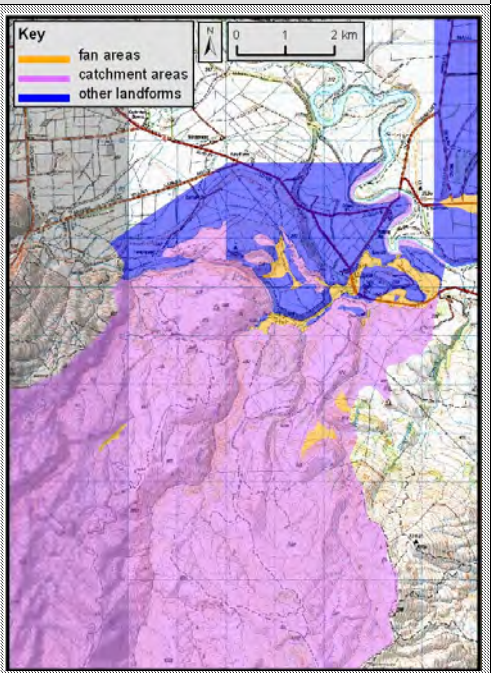
DESCRIPTION:

The assessment area lies southwest of the upper Clutha River at the town of Luggate, at the northern margin of the Pisa Range. It includes the town and its outskirts, in the vicinity of Luggate Creek and Dead Horse Creek.

The Pisa Range is formed in ancient schist bedrock. The upper Clutha valley is a tectonic basin that was occupied repeatedly by glaciers during earlier Ice Ages, but not during the most recent ones. Ice, and meltwater draining from ice, has scoured and shaped the lower flank of the Pisa Range and left patches of moraines, glacial lake beds and glacial outwash river gravel terraces in the valley.

Eroding schist rock in the catchments has fed sediment onto alluvial fans that have built out onto the glacial outwash terraces. The main Clutha terrace at Luggate town was formed during the most recent Ice Age. After the retreat of ice from lakes Wanaka and Hawea about 18,000 years ago, the Clutha River has eroded down into its gravel deposits, and gradually cut a flight of progressively lower river terraces. Luggate Creek and Dead Horse Creek have built small alluvial fans across the flight of Clutha terraces. Luggate Creek has a large catchment (about 120 square kilometres – almost half the size of the Cardrona River catchment) and thus is capable of producing large flood events.

Annual precipitation is a little less than 600 mm/yr at the valley floor, but increases with altitude to more than 1,000 mm/yr at the catchment heads (growOTAGO).



Inset: Extent of Luggate Creek catchment

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

LOCATION MAP

Base maps from LINZ NZMS260 and 262 series. Crown copyright reserved.

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: The Luggate Creek fan is confined to the immediate vicinity of its stream bed. The stream is only slightly incised, suggesting that the fan surfaces are likely to have been affected by flooding and minor sedimentation in the past few hundred years. Similarly, much of the Dead Horse Creek fan is not incised by its stream, and the fan surface is judged to have been susceptible to flooding in the past few hundred years. In its lower reaches, terraces of Dead Horse Creek fan are judged to be high enough above stream level to have been free of flooding or sedimentation for at least the past few hundred years.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture. Pastoral farming and urban.

B3. EXISTING INFRASTRUCTURE: State Highway 6, parts of Luggate township.

B4. EXISTING CONTROL WORKS: Embankments up to 1 m high are constructed on the northern side of Luggate Creek through the built-up area of the town. No control works were noted at Dead Horse Creek.

B5. TYPES OF FAN: Equilibrium. Predominant processes are flooding and minor sedimentation.

B6. CONDITIONS AT TOES OF FANS: Luggate Creek appears to have an almost perfect equilibrium profile down its fan. The lack of significant fan accumulation suggests that Luggate Creek's channel is able to transport its sediment load to the Clutha River with minimal deposition in transit. Dead Horse Creek appears similar, although over time has laid a greater extent of fan sediments than has Luggate Creek. If there is any sudden increase in sediment supply from either catchment (e.g. due to activation of a sediment source such as a landslide), either fan could conceivably change to an aggradational state.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Areas of gullied terrain and some areas of landslide occur in both catchments.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass with minor areas of regenerating scrub, particularly in the lower reaches of the catchments.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 1,100 m (Dead Horse Creek) and 1,600 m (Luggate Creek).

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

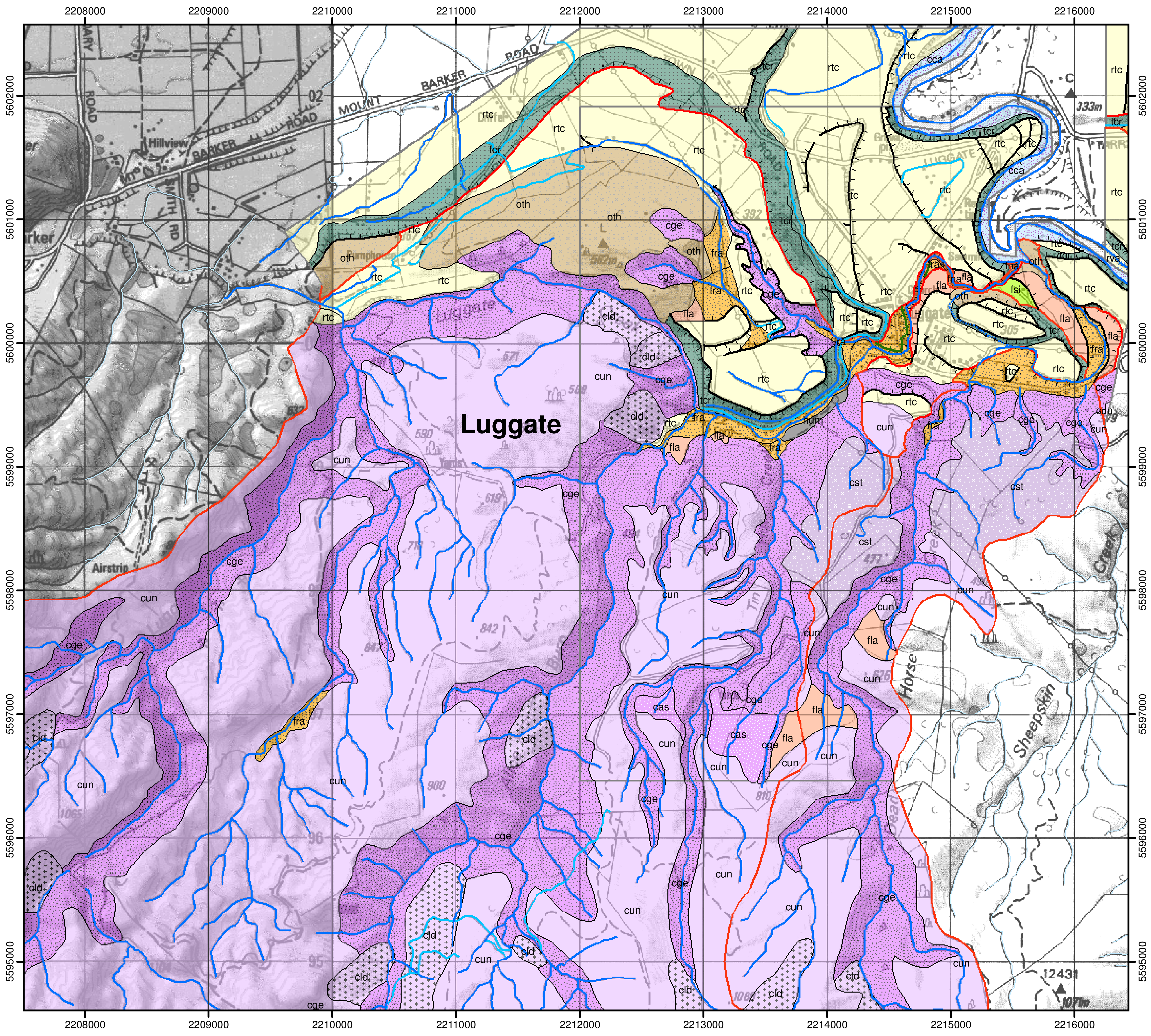
- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

0 0.5 1 2 Km



OTAGO REGIONAL COUNCIL ALLUVIAL FAN HAZARDS

WANAKA (township) area – summary assessment

A. Extent and nature of the assessment area

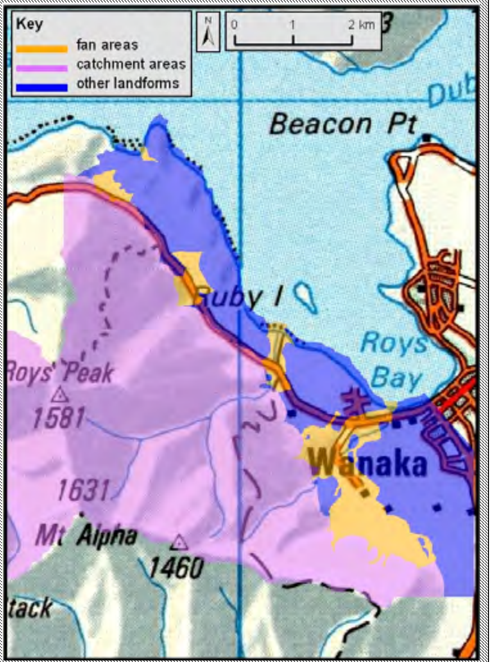
DESCRIPTION:

The assessment area lies southwest of Lake Wanaka, on the northeast flanks of Roys Peak and Mt Alpha, and includes part of Wanaka township. The main streams are Stoney Creek (local name) and Waterfall Creek.

The ranges and hills are formed in ancient schist bedrock. The valley floor was occupied repeatedly by glaciers during Ice Ages. Glaciers scoured and shaped the flanks of the schist ranges, as well as the sides and tops of isolated schist hills such as Mt Iron. The glaciers left extensive areas of moraine and river-gravel terraces in the Wanaka area. Ice retreated from the Wanaka area most recently about 18,000 years ago, and the lake formed in the trough left by the glacier. Most landforms in the assessment area date from around that time; the landscape, geologically speaking, is young.

Eroding schist rock in the catchments has fed sediment onto small alluvial fans that have built out onto the moraines and river terraces. After the retreat of ice, Lake Wanaka initially stood about 20 m higher than it does now. Wave-cut cliffs, beach ridges, and alluvial fans that formed at the '20 m lake level', are common around the lake. As lake levels fell (due to incision of the Clutha River), many streams cut valleys into their fans, leaving abandoned fan terraces flanking some of the modern streams.

Annual precipitation in Wanaka is about 700 mm/yr, increasing with altitude to about 1,250 mm/yr at the heads of the catchments (growOTAGO).



LOCATION MAP

Base maps from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Floods in Stoney Creek in 1999 and 2004 spread sediment-laden floodwater out of its channel; flood protection work has subsequently been carried out (ORC brochure, see below). That part of the assessment area close to Wanaka is undergoing urban development. Associated landscaping and earthworks have modified the natural landform, and tended to obscure the evidence for recent sedimentation activity. The mapped extent of the Stoney Creek fan is a best estimate; outer limits of the fan are probably accurate to only 50 or 100 m.

Elsewhere in the assessment area, the degree of incision by streams and freshness of channel form has guided the interpretation of which areas have been affected most recently by fan activity.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture. Pastoral farming, large-holding residential and urban.

B3. EXISTING INFRASTRUCTURE: Wanaka-Aspiring Road, parts of Wanaka township.

B4. EXISTING CONTROL WORKS: Within the Wanaka urban area, Stoney Creek flows in an engineered channel with debris traps. No other significant control works are known.

B5. TYPES OF FAN: Equilibrium to aggradational. Predominant processes are flooding and sedimentation. Debris-flows are possible at Waterfall Creek, especially near the head of the fan.

B6. CONDITIONS AT TOES OF FANS: Stoney Creek meets Lake Wanaka in a sheltered bay. Wave action is unlikely to remove sediment from the toe of the fan. Sediment brought down the creek is likely to accumulate in the lowest reaches of its channel. Waterfall Creek meets Lake Wanaka on a more exposed shoreline, and the toe of the fan is slightly cliffed by wave erosion. This is essentially an equilibrium state; in the short- to medium-term, sediment that comes down Waterfall Creek is likely to be carried away by long-shore drift.

Other fans north of Waterfall Creek do not have well-defined stream channels. Any sediment that comes down from their catchments is likely to build up on their fans.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: There are extensive areas of gullied terrain and landslides in most of the catchments.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass with minor areas of regenerating scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 500 m (Damper Bay) and 1,200 m (Waterfall Creek).

D. Additional information

D1. EXISTING REPORTS: Otago Regional Council has more information available, such as ‘Stoney Creek Flood Protection’ brochure, May 2005, available at www.orc.govt.nz.

D2. ILLUSTRATIONS:

	
Stoney Creek, downstream of Studholme Rd, following a major rainstorm in 2004. LEFT: Sediment-laden water overflowed the channel, depositing sand and gravel on the surface of the alluvial fan, beyond the confines of the channel. RIGHT: During the flood, sediment-laden water spilled from the channel and built up behind fences, partly burying them (*Otago Regional Council photos*).	
	
Stoney Creek, looking upstream from Old Station Avenue. Landscaping disguises the engineered nature of the channel. It has been widened, deepened and its floor armoured with large boulders to prevent erosion (*Opus photo, Jan 2009*).	At the head of its fan, Waterfall Creek descends a very narrow and steep channel from its catchment. The Waterfall Creek catchment is several times larger than that of Stoney Creek, so would be expected to produce a flood several times larger than could occur in Stoney Creek. Blockage of the channel by a small landslide movement could generate debris flows (*Opus photo, Jan 2009*)

The head of Waterfall Creek fan, looking northeast. The photo above was taken from the paddock (right). The alluvial fan radiates out (grey lines) to the right. At the fan head (foreground), Waterfall Creek (blue arrow) is incised less than 2 m, but the incision increases rapidly downstream; under the two trees (centre), the incision is about 5 m. A small build-up of sediment could be enough to allow Waterfall Creek to break out onto its fan and spread debris sediment out towards the right, in the opposite direction to its present channel (*Opus photo, Jan 2009*).

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

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- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
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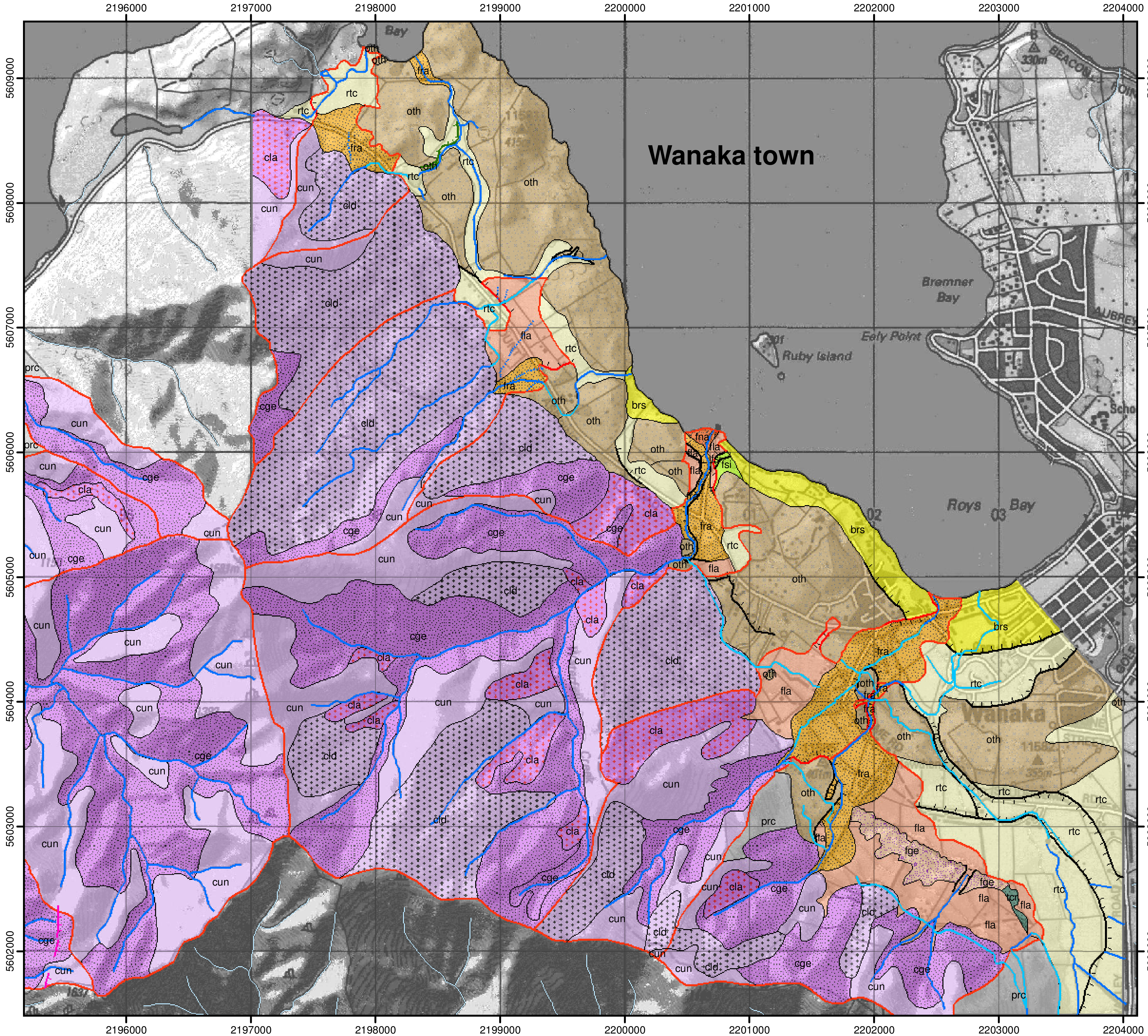


OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

WANAKA (Glendhu Bay) area – summary assessment

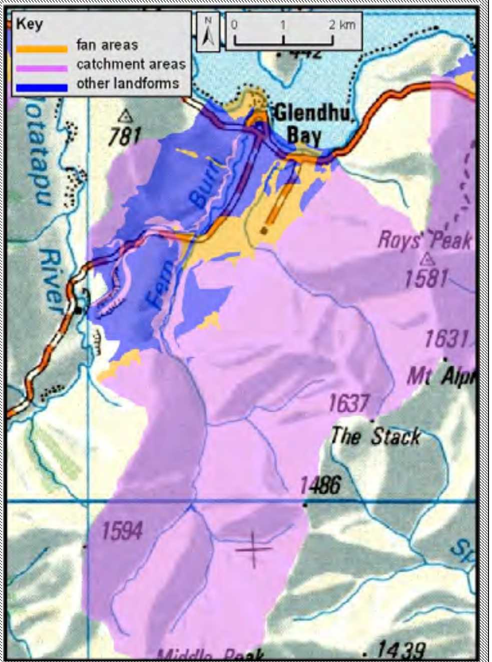
A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies on the southwest side of Lake Wanaka, at Glendhu Bay. The main streams are Alpha Burn and the much larger Fern Burn.

The ranges and hills are formed in ancient schist bedrock. The valley floor has been occupied repeatedly by glaciers during Ice Ages. Glaciers scoured and shaped the schist ranges, as well as the numerous isolated schist hills and ridges. Ice retreated from the Wanaka area most recently about 18,000 years ago. Lake Wanaka formed in the trough left behind by the glacier. The lake initially stood about 20 m higher than it does now. Floods of river sediment brought down by Fern Burn built an extensive fan-delta terrace, at the '20 m lake level'. As lake levels fell (due to incision of the Clutha River), Fern Burn and Alpha Burn cut valleys into this terrace, and both streams have built deltas out into the progressively lowering lake. Eroding schist rock in the catchments on the south margin of the 20-m terrace, including Alpha Burn, has fed sediment onto small fans that have built out onto the terrace. The landscape, geologically speaking, is young.

Annual precipitation at Glendhu Bay is about 850 mm/yr, increasing with altitude to about 1,250 mm/yr at the heads of the catchments (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Immature soils on most parts of the fans near Alpha Burn suggest that there has been sediment-laden flooding within the past few hundred years. Close to the stream mouths, their deltas are also likely to have been subject to episodic flooding and sedimentation.

The owner of Alpha Burn Station has a photograph of the Alpha Burn Station homestead taken about 1913, showing fresh fan-flooding sediment spread across the fan just south of the homestead.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture with minor scrub and some streamside trees. Pastoral farming, motor camp.

B3. EXISTING INFRASTRUCTURE: Wanaka-Aspiring Road, motor camp, farm buildings.

B4. EXISTING CONTROL WORKS: Minor training of stream channels; no other significant flood control works are known. Some streams are tapped for domestic water supply, stock water and irrigation.

B5. TYPES OF FAN: Aggradational. Predominant processes are flooding and sedimentation. Alpha Burn (main stream) may be close to equilibrium, with a channel graded to the lake, and redistribution of much of its sediment by wave action and along-shore drift of sediment.

B6. CONDITIONS AT TOES OF FANS: The fans of the Alpha Burn tributaries are built out on the 20-m terrace. Sediment brought down from the catchments is likely to accumulate on the fans. Where the streams enter Lake Wanaka, sandy and gravelly sediment contributes to the growth of their deltas. Wave action redistributes some sediment along the shore but the Fern Burn delta has shown significant historical growth. There is potential for channel break-out in the camp ground near the stream mouths, especially if floods in the streams occur when the lake is high.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: There are extensive areas of gullied terrain, and a few landslides, in most of the catchments. A landslide has activated on the south side of the Alpha Burn catchment during the past few years, and has the potential to supply considerable quantities of debris to the fan. An active fault is recognised in the Fern Burn catchment (www.gns.cri.nz – Active Faults Database).

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass with minor areas of regenerating scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 950 and 1,150 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
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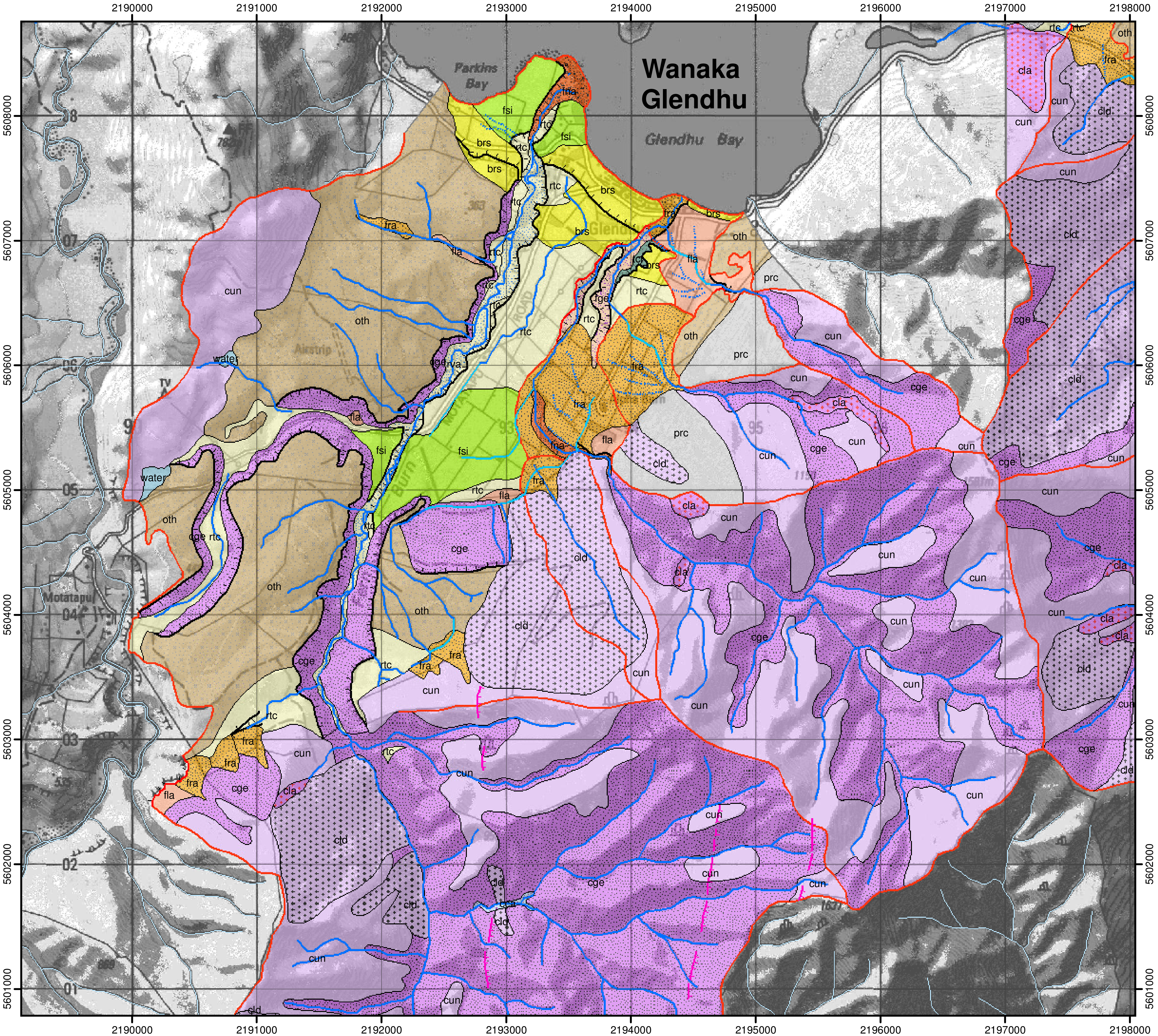


OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

WANAKA (Treble Cone) area – summary assessment

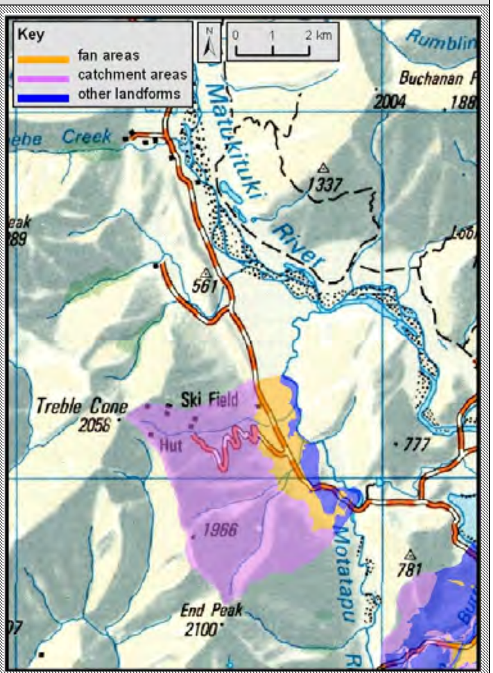
A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies in the lower Matukituki – Motatapu valleys, at the eastern margin of the Harris Mountains, below Treble Cone.

The ranges and hills are formed in ancient schist bedrock, and have repeatedly been over-run by glaciers during Ice Ages. Ice retreated from this area most recently about 18,000 years ago. Glacier-scoured valley sides and ice-smoothed hills and ridges dominate the landscape. Eroding schist bedrock has fed sediment onto alluvial fans that have built out onto the valley floors. Lake Wanaka is a 'trap' for all the sediments carried by the rivers. The Matukituki River is progressively building out a delta into the lake. As the delta has built out, the river has in effect become longer, and its bed level has had to rise in order to maintain its gradient. The valley floors are slowly filling up with river and alluvial fan sediment. The landscape, geologically speaking, is very young.

Annual precipitation at the valley floor is about 1,200 mm/yr and increases with altitude to between 2,000 and 3,000 mm/yr at the heads of the fan catchments (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: The streams are flowing on the surfaces of their fans. Most parts of the fans are likely to have been affected by flooding and sedimentation within the past few hundred years. Historic flood sedimentation has affected the road.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture with minor scrub. Pastoral farming.

B3. EXISTING INFRASTRUCTURE: Wanaka-Aspiring Road, skifield road, farm buildings.

B4. EXISTING CONTROL WORKS: Training works on most active streams.

B5. TYPES OF FAN: Aggradational. Predominant processes are extensive flooding and sedimentation, with evidence that debris flows have affected the upper parts of the fans.

B6. CONDITIONS AT TOES OF FANS: The Motatapu River flows along the toes of the Twin Falls, Treble Cone Road and Cattle Flat fans. The river transports the fan-toe sediments down-valley and at the present time may be these fans in a state of equilibrium.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Landslide areas are extensive throughout the catchments, as is gullied terrain.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass, with rare areas of scrub and forest in gullies.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 900 m and 1,550 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
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- rtc - river terrace
- rva - river active bed
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LANDFORM BOUNDARY

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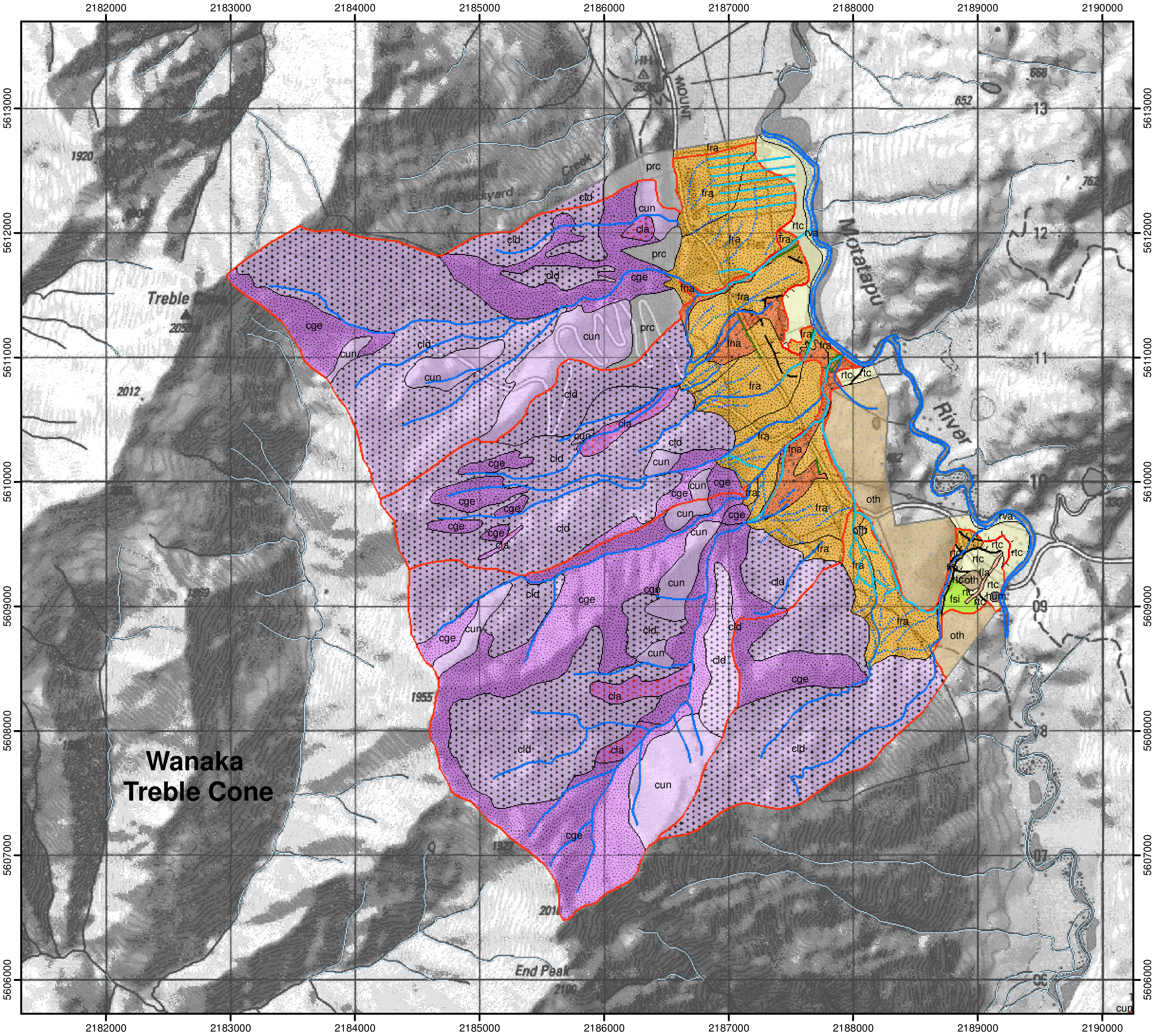
CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

0 0.5 1 2 Km



OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

WANAKA (Cardrona) area – summary assessment

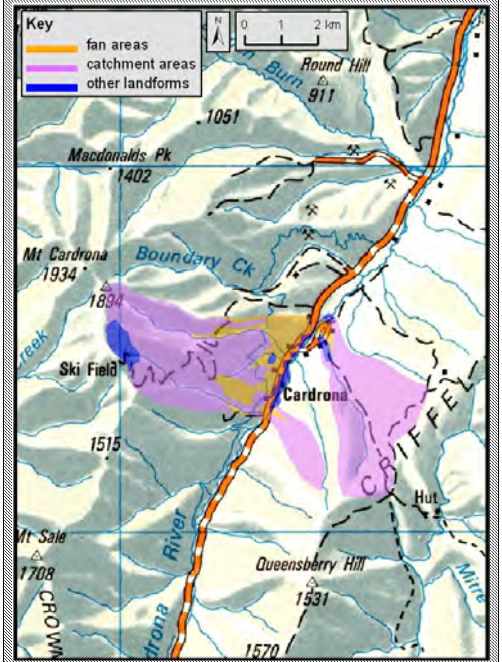
A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies in the Cardrona valley, near Cardrona village. It is flanked to the northwest by the Crown Range and to the southeast by the Criffel Range. The main streams draining from the northwest are Little Meg, Pongs and Pringles Creek, with Tuohys Gully draining from Criffel Range.

The ranges are formed in ancient schist bedrock. Glaciers did not reach into the Cardrona valley during the last few Ice Ages but ice near Wanaka did, at times, temporarily blocked the northeast end of the valley. This resulted in large thicknesses of river sediments building up in the Cardrona valley. Much of this sediment was washed down valley after the ice retreated, but some remains beneath high terraces at the valley margins. The landscape contains many elements that are older than the landforms near Wanaka. Main features include flights of river and fan terraces, as well as eroded and gullied schist slopes at the valley margins. Eroding rock in the catchments has fed sediment onto fans that have built out into the valley.

Annual precipitation at the valley floor is about 700 mm/yr, increasing with altitude to more than 1,000 mm/yr at the heads of the fan catchments (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series.
Crown copyright reserved.

Aerial Photo Interpretation:	Oct 2008
Field Check:	Jan 2009
Revisions:	

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Those parts of the fans close to present stream levels are judged likely to have been affected by flooding and sedimentation within the past few hundred years. These areas are of limited extent. More common are fan terraces that are well above stream levels, and are judged likely to have been unaffected by stream activity for many thousands of years.

There has been extensive modification of the valley floors due to mining activity (include large-scale dredging). This greatly reduces the certainty with which the pre-mining natural landscape can be identified and described.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture with minor scrub. Pastoral farming, some large-holding residential, minor residential and commercial.

B3. EXISTING INFRASTRUCTURE: Cardrona Valley Road, two skifield roads, hotel, houses, hostel, farm buildings.

B4. EXISTING CONTROL WORKS: Few if any stream channels leading out onto the valley floor are unmodified, as a result of past mining disruption.

B5. TYPES OF FAN: Terraced. Predominant processes are flooding and sedimentation on the lowest lying parts of the fans; Large boulders on higher terraces of the Little Meg and Pringles Creek fans suggest that in times past, debris flows may have emanated from their catchments.

B6. CONDITIONS AT TOES OF FANS: The valley floor has been modified greatly by the effects of gold mining, and little can be said of what the natural state of the valley was prior to the mid-19th century. Pringles and Pongs creeks drain into man-made channels that carry water to the Cardrona River, which currently lies on the southeast side of its valley floor. The Cardrona River lies closer to the toe of the Little Meg fan; this stream may currently be in a state of equilibrium. The lower end of Tuohys Gully fan has built out across a Cardrona River terrace, but there was much 19th century gold mining in its valley; it is possible that this part of its fan may be very young and formed by mining tailings. Regardless of its origin, the present stream channel is only slightly incised into its fan; sediment brought down by the Tuohys Gully stream may possibly accumulate in its channel, or spread onto its fan.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Landslide areas and/or gullied terrain are common.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass, with some areas of scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 750 m (Tuohys Gully) and 1,350 m (Pringles Creek).

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

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Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
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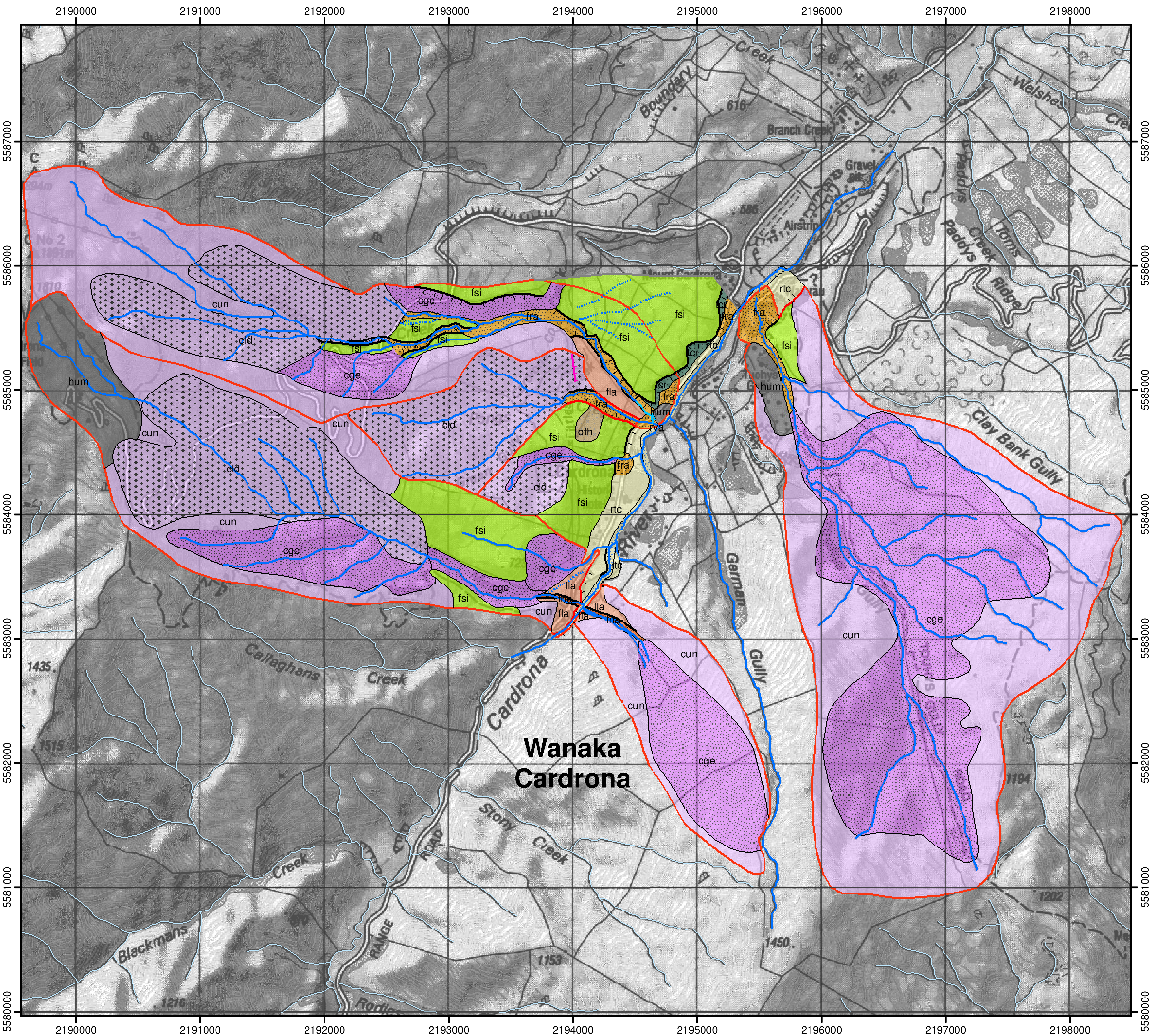


OTAGO REGIONAL COUNCIL ALLUVIAL FAN HAZARDS

GLENORCHY (Kinloch) area – summary assessment

A. Extent and nature of the assessment area

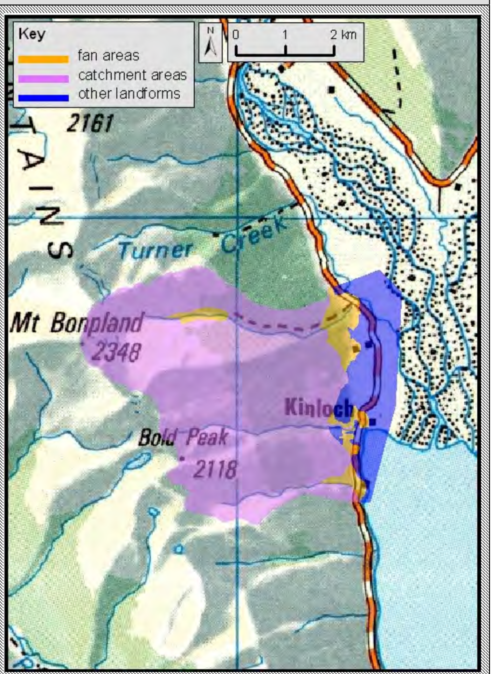
DESCRIPTION:

The assessment area includes the village of Kinloch on the western side of the head of Lake Wakatipu, at the foot of the Humboldt Mountains. The main named streams are, from north to south, Glacier Burn, Gorge Creek and Mick Creek.

The ranges and hills are formed in ancient schist bedrock, and have been occupied repeatedly by glaciers during Ice Ages. The oldest parts of the landscape date from the most recent retreat of the ice, about 18,000 years ago. Glacier-scoured valley sides with remnants of moraine dominate the landscape. Eroding schist rock in the catchments has fed sediment into the rivers and streams. Lake Wakatipu 'traps' all sediment from its inflowing rivers and streams. The Dart and Rees rivers are building out into the lake, and their valley floors are slowly filling up with sandy and gravelly sediment. The landscape, geologically speaking, is very young.

After the ice retreated, Lake Wakatipu formed and initially stood about 50 m higher than it does now. Wave-cut cliffs, beach ridges, and alluvial fan-deltas graded to the higher lake level, are common around the lake. As lake level fell (due to incision of the Kawarau valley), streams, such as Glacier Burn, cut valleys down into their fan-deltas, leaving abandoned fan terraces flanking the modern streams. Glacier Burn and Gorge Creek are building alluvial fans out into the Dart valley, while Mick Creek is continuing to build a fan-delta into the lake.

Annual precipitation at Kinloch is about 1,500 mm/yr, increasing with altitude to more than 3,000 mm/yr at the heads of the catchments (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Those parts of the fans at or close to the levels of the active stream beds are judged likely, from their setting, and by immaturity of their soils, to have been subject to flooding and sedimentation within the past few hundred years.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Native forest and grass. Land-use includes farming and large-holding residential.

B3. EXISTING INFRASTRUCTURE: Routeburn – Kinloch Road and Greenstone Station Road, houses, farm buildings.

B4. EXISTING CONTROL WORKS: Embankments confine the lower reaches of Glacier Burn. The creek south of Glacier Burn near Woodbine Station also has embankments, and sediment is regularly excavated out of the channel by the landowner.

B5. TYPES OF FAN: Aggradational, with some terraced older parts of fans. The predominant processes are flooding and sedimentation, with debris flows in the channels near the heads of the fans.

B6. CONDITIONS AT TOES OF FANS: Formerly, erosion by wave action, before the Dart River had advanced to its current down-valley position and displaced the lake from the assessment area, and more recently, river action, would have removed sediment from the fan toes, maintaining the fans in or close to equilibrium.

At present, the toes of all fans are building out, either onto the Dart valley floor or into Lake Wakatipu. Sediment from these streams will continue to build their fans or deltas, unless sediment is removed mechanically. Mick Creek meets an exposed part of the lake shore, and wave action redistributes some sediment by along-shore drift.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Some areas of gully erosion and some landslides.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Native forest in the valley floor and lower slopes, progressively giving way to grass and bare rock or ice at higher altitudes.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans ranges from 1,600 m to 1,960 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

In Glacier Burn, recent sediment aggradation during sediment-laden floods and debris flows has killed trees beside the stream channel. A small artificial embankment of gravel lies in the foreground *(Opus photo).*

Near the toe of its fan, the active channel of Glacier Burn is trained between gravel embankments *(Opus photo).*

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
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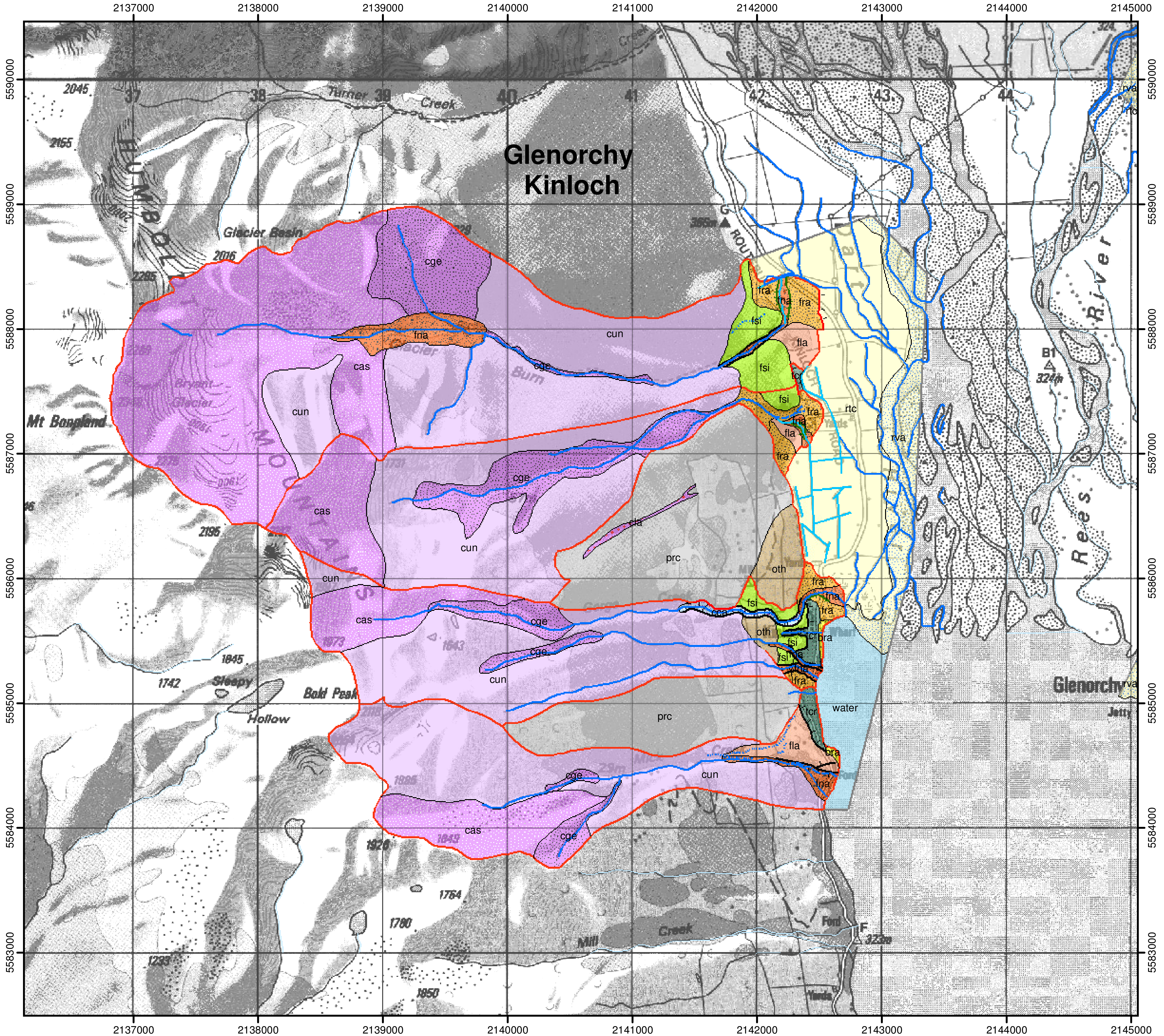


OTAGO REGIONAL COUNCIL ALLUVIAL FAN HAZARDS

GLENORCHY (Earnslaw) area – summary assessment

A. Extent and nature of the assessment area

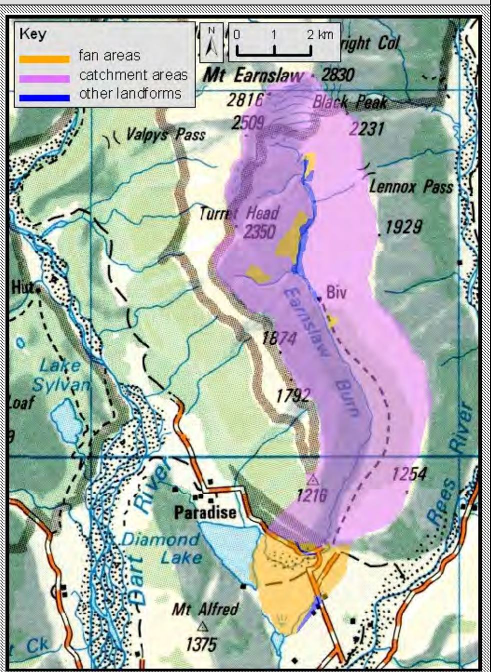
DESCRIPTION:

The assessment area lies between Diamond Lake and Rees River in the headwaters of the Lake Wakatipu valley. It comprises the fan of Earnslaw Burn.

The ranges and hills are formed in ancient schist bedrock, and have repeatedly been over-run by glacier ice during Ice Ages. The oldest parts of the landscape date from the most recent retreat of the ice that began after 18,000 years ago. Ice-scoured ranges and ice-smoothed ridges and hills, such as Mt Alfred, dominate the landscape. Eroding bedrock in the catchments has fed sediment into the rivers and streams. Lake Wakatipu ‘traps’ inflowing sediment. As the Dart and Rees Rivers slowly build a delta into the lake, their valley floors are rising as sandy and gravelly sediment is deposited over their flood plains. The landscape, geologically speaking, is very young.

When Lake Wakatipu formed, it initially stood about 50 m higher than it is now and extended up-valley to at least the Paradise area. Broad terraces east of the Earnslaw Burn fan are remnants of fans constructed by the Rees River and Earnslaw Burn at about the’50 m lake level’. As the lake dropped (due to incision of the Kawarau valley), rivers and streams built fans out to progressively lower levels. Diamond Lake is a ‘fan-dammed’ lake, ponded between the overlapping fans of River Jordan (near Paradise) and Earnslaw Burn.

Annual precipitation at Diamond Lake is about 1,700 mm/yr, increasing with altitude to more than 3,000 mm/yr in the Earnslaw Burn catchment (growOTAGO).



Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

LOCATION MAP

Base map from LINZ NZMS262 series.

B. Nature of the alluvial fan

B1. EVIDENCE OF PAST ACTIVITY: Earnslaw Burn is flowing on the surface of its fan. Aerial photographs show areas of bare sediment deposited in paddocks during flood break-outs from the present floodplain. Most of the Earnslaw Burn fan is judged likely, from its lack of freeboard from the present stream, and by immaturity of soils, to have been affected by flooding and sedimentation within the past few hundred years. Historic floods have spread out onto parts of the fan. Terrace surfaces to the east have mature soils and have been free of flood sedimentation for probably thousands of years.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass and minor scrub, with swamp vegetation near Diamond Lake. Land-use is pastoral farming.

B3. EXISTING INFRASTRUCTURE: Glenorchy – Paradise Road.

B4. EXISTING CONTROL WORKS: Embankments confine Earnslaw Burn upstream of and alongside Glenorchy – Paradise Road.

B5. TYPE OF FAN: Aggradational, with terraced older parts of the fan to the east. The predominant active processes are flooding and sedimentation.

B6. CONDITIONS AT TOE OF FAN: The toe of the Earnslaw Burn fan will continue to build into Diamond Lake. All sediment brought down by the river will continue to accumulate on the fan, and in Diamond Lake, unless it is removed mechanically.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Some areas of gullied terrain, but few landslides. Glaciers persist in the head of the catchment.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Native forest in the valley floor and lower slopes, progressively giving way to grassland, bare rock or perrenial snow at higher altitudes.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the top of the catchment to the head of the fan is 2,450 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

Earnslaw Burn is a sizable river draining into Diamond Lake, visible in mid-centre to the west-northwest. The grassed low-lying parts of its fan away from the present active bed have raw soils, indicating that the river has occupied its fan surface within the past few hundred years *(GNS Science photo).*

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

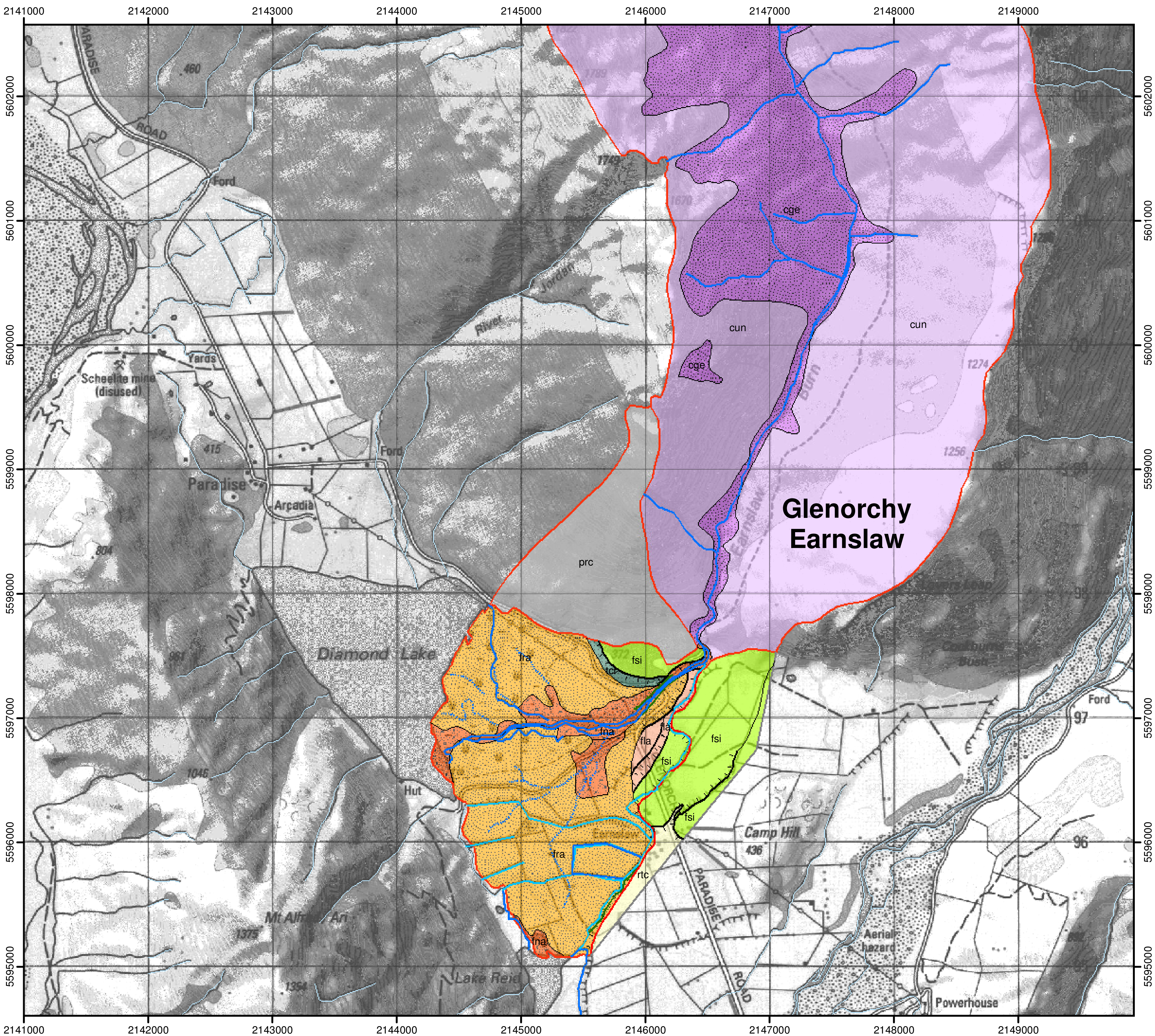
- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

0 0.5 1 2 Km



OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

GLENORCHY (township) area – summary assessment

A. Extent and nature of the assessment area

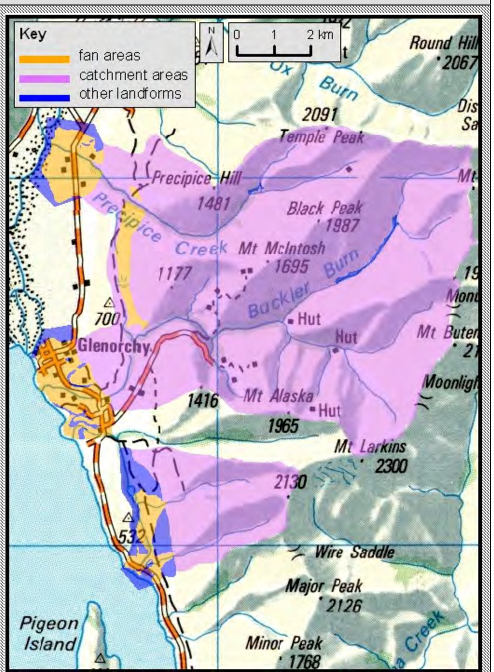
DESCRIPTION:

The assessment area includes the town of Glenorchy on the eastern side of the head of Lake Wakatipu. The main streams are, from north to south, Precipice Creek, Buckler Burn and Little Stony Creek.

The ranges and hills are formed in ancient schist bedrock, and have repeatedly been over-run by glaciers during Ice Ages. The oldest parts of the landscape date from the most recent retreat of the ice that began about 18,000 years ago. Eroding schist rock in the catchments has fed sediment onto alluvial fans that have built out from the valley margins. Glacier-scoured valley sides with remnants of moraine dominate the landscape. Eroding schist rock in the catchments has fed sediment into the rivers and streams. Lake Wakatipu 'traps' the sediments of its inflowing rivers and streams. The Dart and Rees rivers are slowly building out into the lake, and their valley floors are slowly filling up with sandy and gravelly sediment. The landscape, geologically speaking, is very young.

The retreat of ice allowed Lake Wakatipu to form. Initially, the lake stood about 50 m higher than it does now. Wave-cut cliffs, beach ridges, and alluvial fan-deltas that built out to the higher lake level, are common around the lake. As lake levels fell due to incision of the Kawarau valley, streams, such as Buckler Burn, cut valleys down into their fan-deltas, leaving abandoned fan terraces flanking the modern streams. Buckler Burn and Little Stony Creek are continuing to build fan-deltas into the lake, while Precipice Creek has built an alluvial fan out into the Rees valley.

Annual precipitation at Glenorchy is about 1,500 mm/yr, increasing with altitude to between 2,000 and 3,000 mm/yr at the heads of the catchments (growOTAGO).



Aerial Photo Interpretation:	Oct 2008
Field Check:	Jan 2009
Revisions:	

LOCATION MAP

Base map from LINZ NZMS262 series.
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B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Historic flooding from the Buckler Burn has affected Glenorchy. Extensive parts of the fans at or close to the modern streams are judged likely, from their setting, and by immaturity of soils, to have been subject to flooding and sedimentation within the past few hundred years, with historic flood sedimentation also reported.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture and minor scrub, some stream-side trees. Land-use includes farming, Glenorchy urban area, and some large-holding residential.

B3. EXISTING INFRASTRUCTURE: Glenorchy – Queenstown Road and Glenorchy – Paradise Road, Glenorchy township, some large-holding subdivisions.

B4. EXISTING CONTROL WORKS: Embankments confine Buckler Burn alongside Glenorchy. Embankments also constrain the lower part of the course of Precipice Creek.

B5. TYPES OF FAN: Aggradational, with some terraced older parts of fans. The predominant processes are flooding and sedimentation on the Precipice Creek and Buckler Burn fans, and the Little Stony Creek delta. The upper part of Little Stony fan is subject to debris flows.

B6. CONDITIONS AT TOES OF FANS: The toes of all fans are building out, either onto the Rees valley floor or into Lake Wakatipu. Sediment from these streams will continue to build their fans or deltas. Little Stony Creek meets an exposed part of the lake shore, and wave action is likely to continue to redistribute its sediment by along-shore drift, keeping the delta in a state approaching equilibrium.

Buckler Burn at present drains to a wave-exposed shore, and wave action causes some long-shore redistribution of the stream sediment. The Buckler Burn delta is increasingly being encroached upon by the Rees-Dart delta, and the potential for wave-induced redistribution of fan sediment is diminishing.

Much of the sediment brought down Precipice Creek is taken away down-valley by the Rees River.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Extensive areas of gully erosion and some landslides.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass, with some native forest and scrub particularly near the valley floors, and some bare rock in the catchment heads.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans ranges from about 1,600 m to 1,900 m.

D. Additional information

D1. EXISTING REPORTS: Otago Regional Council report 'Channel morphology and sedimentation in the Rees River', available from www.orc.govt.nz

D2. ILLUSTRATIONS:

A view northwest across Glenorchy from the Bible Terrace. Buckler Burn (far left) has constructed a broad fan out to the north (orange lines) against part of the delta of the Rees River floodplain (centre middle distance). A small fan radiates out (orange lines, lower right) from a gully draining off the Bible Terrace. This terrace is an abandoned fan-delta of Buckler Burn, constructed at the '50 m lake level' *(GNS Science photo).*

Looking west from on top of the ’50 m lake level’ fan-delta of Precipice Creek. After the lake level fell, the creek cut a set of terraces into its fan delta. The present creek bed (blue arrow) has built a large aggradational fan (centre middle distance) out into the Rees valley floor. The Rees River runs from right to centre *(GNS Science photo).*

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
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- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
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- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
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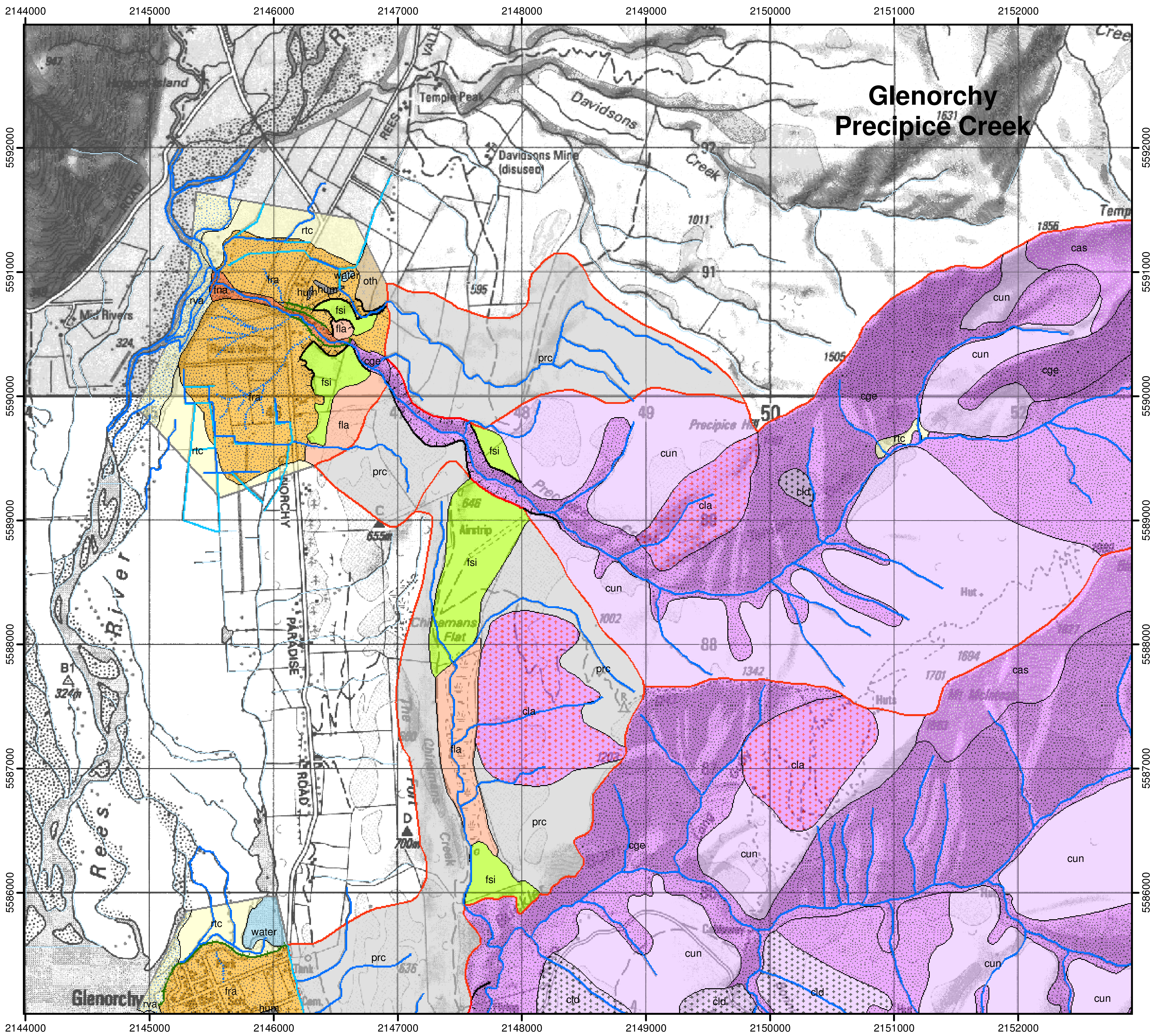

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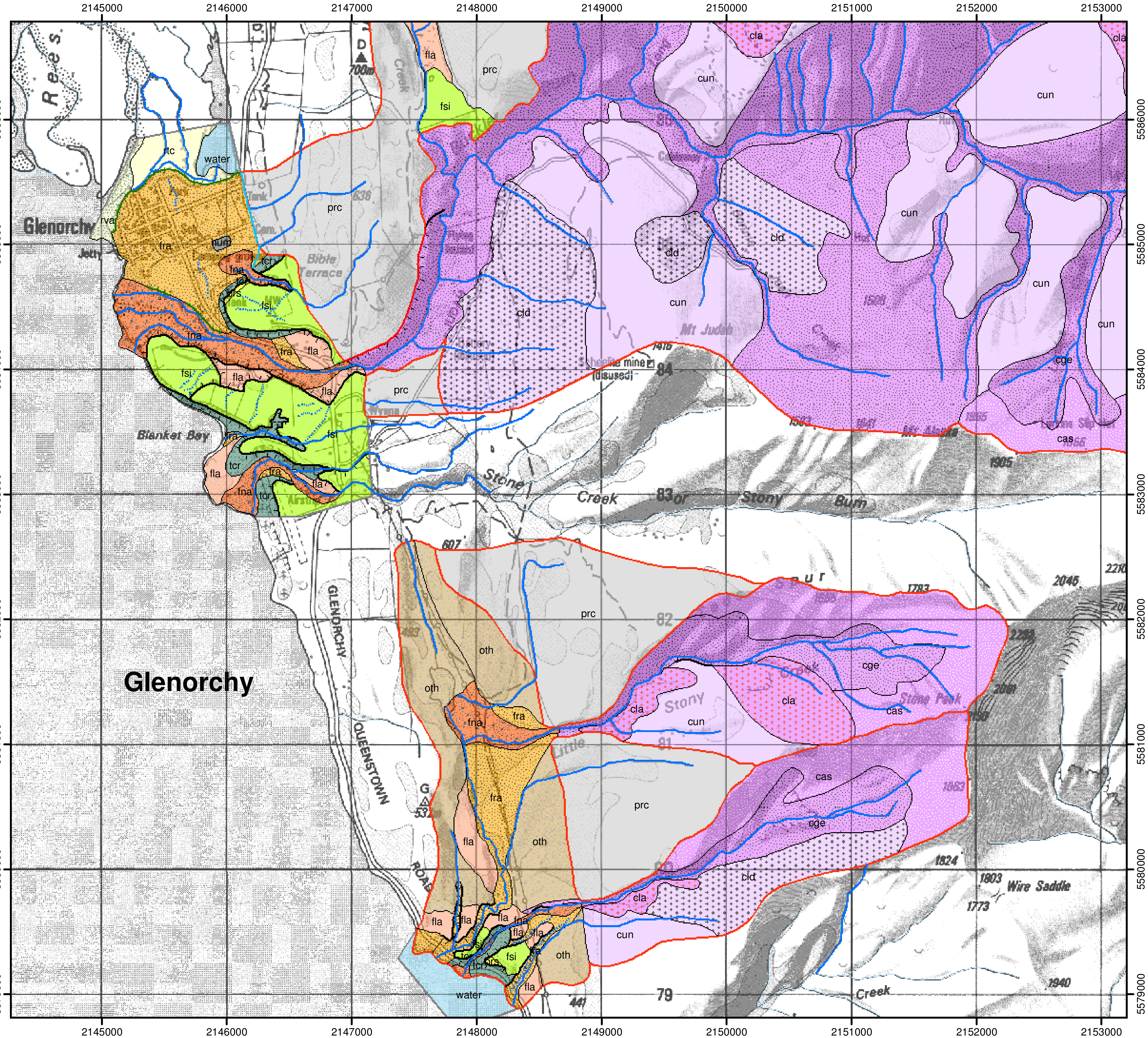

OTAGO REGIONAL COUNCIL ALLUVIAL FAN HAZARDS

QUEENSTOWN (Walter Peak) area – summary assessment

A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies near Walter Peak on the southwestern shore of Lake Wakatipu, along the northern flanks of a ridge extending from Afton Peak east to Walter Peak.

The ranges and valley sides are formed in ancient schist bedrock. The Lake Wakatipu valley was occupied repeatedly by glaciers during Ice Ages. Glaciers scoured the flanks of the ranges and the sides and tops of ice-smoothed schist hills and ridges near the valley floor, and left localised areas of moraine. Ice retreated most recently about 18,000 years ago. Eroding schist rock in the catchments has fed sediment onto alluvial fans that have built out from the valley margins. The retreat of ice allowed Lake Wakatipu to form. Initially, the lake stood about 50 m higher than it does now. Wave-cut cliffs, beach ridges, and alluvial fan-deltas that built out to the higher lake level, are common around the lake. As lake levels fell, due to incision of the Kawarau valley, many streams cut valleys down into their fan-deltas, leaving abandoned fan terraces flanking some of the modern streams. The landscape, geologically speaking, is young.

Annual precipitation at Walter Peak homestead is about 900 mm/yr, increasing with altitude to about 2,000 mm/yr at the crest of Walter Peak (growOTAGO).

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Historic floods and debris flows occurred close to Walter Peak homestead buildings at Beach Bay (eastern end of study area) in 1999 and in 2002 (GNS Science Client Report, see below). Elsewhere, the streams crossing the upper to mid parts of the fans are barely, if at all, incised into the fans. It is likely that these parts of the fans have been subject to fan activity within the past few hundred years.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass, some scrub and minor exotic forest. Land-use includes pastoral farming and tourism.

B3. EXISTING INFRASTRUCTURE: Minor roads, buildings, tourist amenities.

B4. EXISTING CONTROL WORKS: Debris-flow protection embankments upslope of the buildings at Beach Bay. A stand of exotic trees also provides some mitigation against debris flows.

B5. TYPES OF FAN: Aggradational fans near Beach Bay. Farther west, the streams of the fans drain into gullies that are incised into the beach/fan-delta complexes that formed at the ’50 m lake level’. These streams appear to be aggradational near their heads, and in equilibrium in their mid to lower reaches.

B6. CONDITIONS AT TOES OF FANS: In the eastern part of the assessment area, the fans either grade onto older landforms, or into the sheltered shore of Beach Bay. There is no natural mechanism for transporting sediment away from the toes of these fans, and sediment that comes down from the catchments will accumulate on the fans, unless it is removed mechanically.

Farther west, the lowest reaches of the fans meet a wave-swept shoreline and it is likely that wave action provides along-shore redistribution of the sediment brought down by the streams. This is probably maintaining the lower to mid reaches of these fans in an approximate state of equilibrium, under current rates of sediment delivery from the catchments.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Some areas of gullied terrain and landslides.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass, minor scrub and some bare rock, especially in the eastern part of the assessment area. Some forest in the gully and lower valley slopes in the gully called Mick O’Dea on the topographic map.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 1,100 m and 1,300 m.

D. Additional information

D1. EXISTING REPORTS: GNS Science Client Report 2002/127 (confidential to client; enquire with owners of the Walter Peak property).

D2. ILLUSTRATIONS:

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
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- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
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- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
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Base Map LINZ NZMS 260 series
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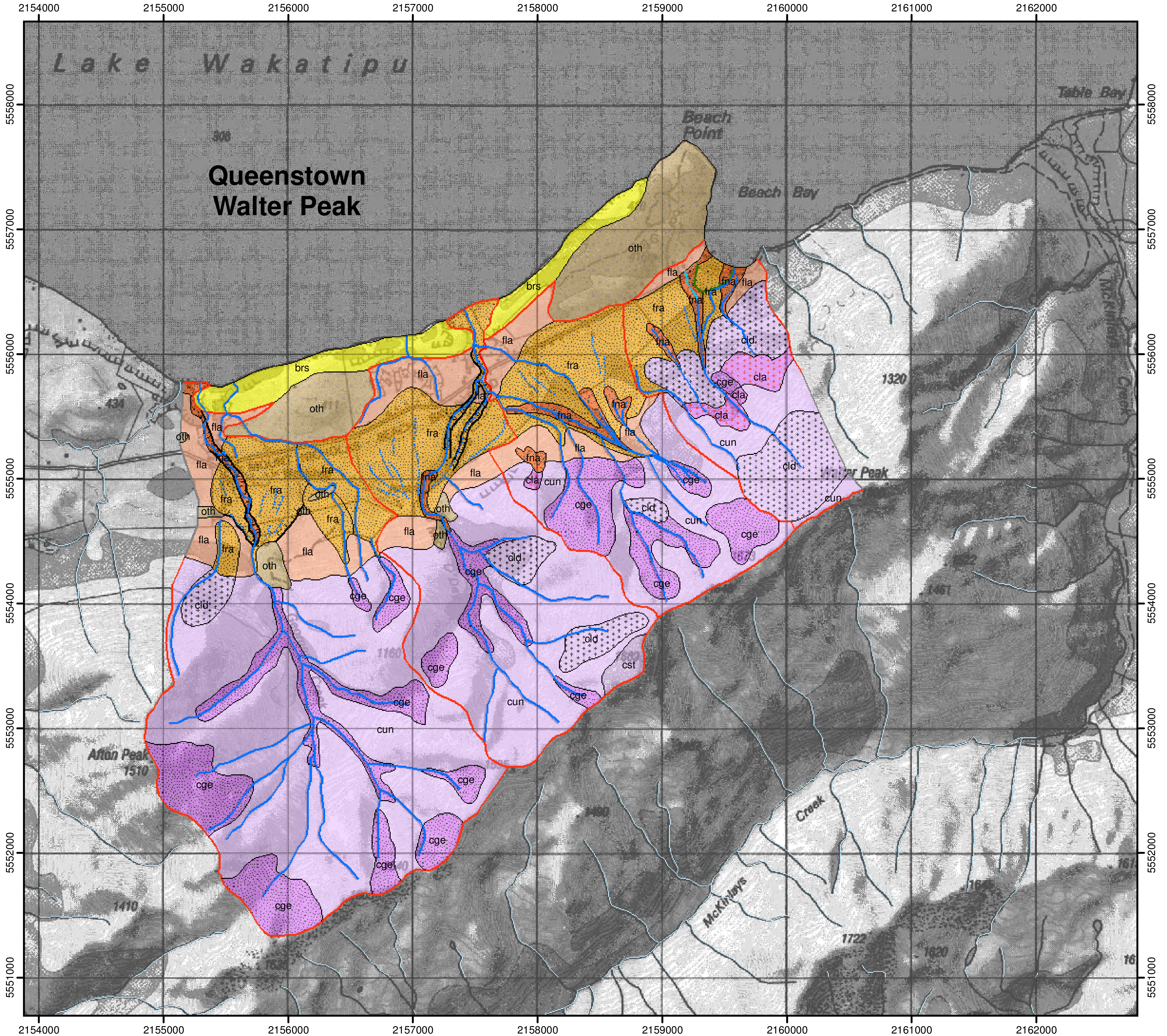


OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

QUEENSTOWN (Bobs Cove) area – summary assessment

A. Extent and nature of the assessment area

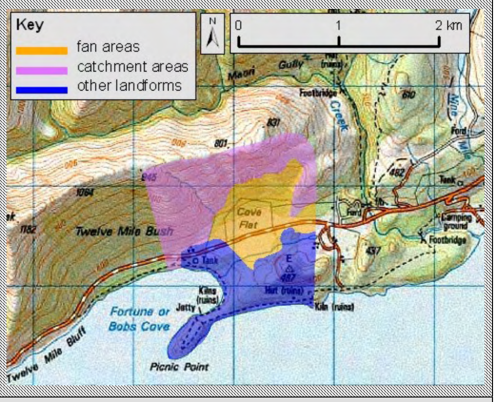
DESCRIPTION:

The assessment area lies at Bobs Cove, on the northern shore of Lake Wakatipu, about 12 km west of Queenstown.

The ranges and valleys are formed in ancient schist bedrock, with minor sedimentary rock. An active fault (Moonlight Fault) lies close to Bobs Cove. The Lake Wakatipu valley was occupied repeatedly, and scoured out, by glaciers during Ice Ages. Scattered remnants of moraine are plastered on the glacier-scoured bedrock. Ice retreated most recently about 18,000 years ago. The retreat of ice allowed Lake Wakatipu to form. Initially, the lake stood about 50 m higher than it does now. Wave-cut cliffs, beach ridges, and alluvial fan-deltas that built out to the higher lake level, are common around the lake. As lake levels fell, due to incision of the Kawarau valley, many streams cut valleys down into their fan-deltas, leaving abandoned fan terraces flanking some of the modern streams, such as Twelve Mile Creek. The landscape, geologically speaking, is young.

Eroding schist rock in the face of the ridge north of Bobs Cove has fed sediment onto small, steep alluvial fans that have built out onto a '50 m lake level' fan-delta and beach ridge complex immediately east of Bobs Cove.

Annual precipitation at Bobs Cove is between 800 and 900 mm/yr, increasing with altitude to more than 1,250 mm/yr at the crest of the ridge east of Jessie Peak (growOTAGO).



Aerial Photo Interpretation:	Oct 2008
Field Check:	Jan 2009
Revisions:	

LOCATION MAP

Base maps from LINZ NZMS262 and 260 series. Crown copyright reserved.

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Forest and scrub cover the mid to upper parts of the fan areas, making assessment of recent activity more difficult. Areas close to, and down-slope of, channels on the mid-slope are likely to have been subject to fan activity within the past few hundred years. Areas away from the channels have mature soils and have been active less recently.

Contouring for subdivision development has destroyed much evidence of fan activity on the lower part of the fan.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture, native forest & scrub. Large-holding residential adjoining conservation land (Mt Crichton Scenic Reserve and Bobs Cove – Twelve Mile Delta recreation reserves).

B3. EXISTING INFRASTRUCTURE: Glenorchy – Queenstown Road, large-holding subdivision.

B4. EXISTING CONTROL WORKS: Downstream parts of well-defined channels on the fans have been widened and armoured as part of subdivision development.

B5. TYPE OF FAN: Aggradational. The predominant process is debris flow on the mid- to upper parts of the fans, with flooding and sedimentation nearer the fan toes.

B6. CONDITIONS AT TOE OF FAN: The toe of the fan apron is constructed part-way out onto an old fan-delta terrace. There is no longer any drainage down this fan-delta landform that could move or redistribute sediment. Any sediment brought down onto the fans will build up on the fans, especially towards their lower parts, unless sediment is removed mechanically.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Steep slopes, gullied in places.

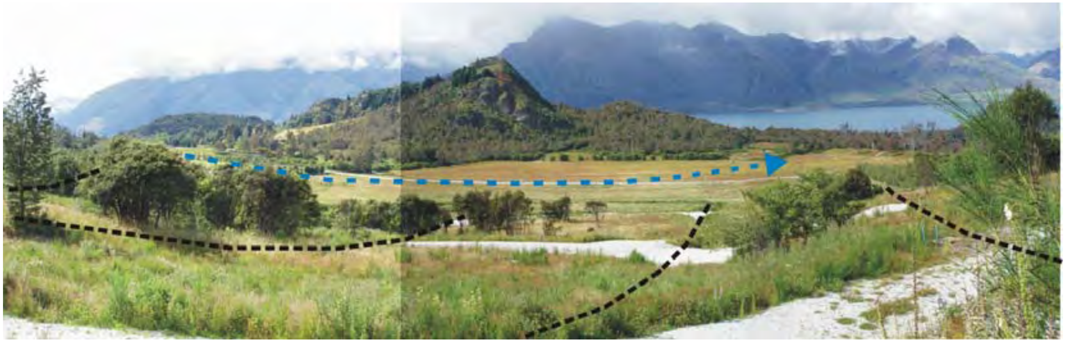
C2. EXISTING TYPES OF VEGETATION/LAND-USE: Native forest and scrub. Part of Mt Crichton Scenic Reserve.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the top of the catchment to the heads of the fans is about 350 m.

D. Additional information

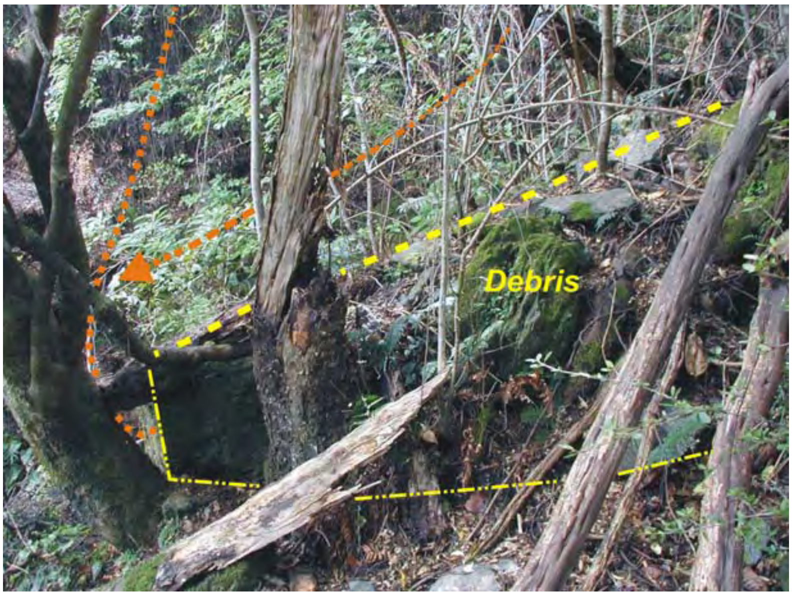
D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:



An apron of small, steep, fans (foreground, with black lines illustrating directions of fall) have accumulated at the foot of a ridge facing the Bobs Cove area (centre). The fan sediments have built onto the edge of an abandoned fan-delta. The fan-delta was constructed by an overflow of sediments that had built out (blue line) from the Twelve Mile Stream catchment, when Lake Wakatipu stood at its '50 m level'. View is to the south (*GNS Science photo*).

A 2-m deep channel with steep sides (orange dots) on the mid-part of the Bobs Cove fan complex, with the orange arrow indicating the channel axis and flow direction *(GNS Science photo).*



A view side-on into the channel shown above (orange dots = channel sides, arrow = channel axis and flow direction). Above the edge of the channel, bouldery debris (heavy yellow line shows top of debris, thin line indicates base of debris) has piled up against the upstream margin of trees. This is interpreted to be a spill-over of sediment from a debris flow that has come down the channel *(GNS Science photo).*

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

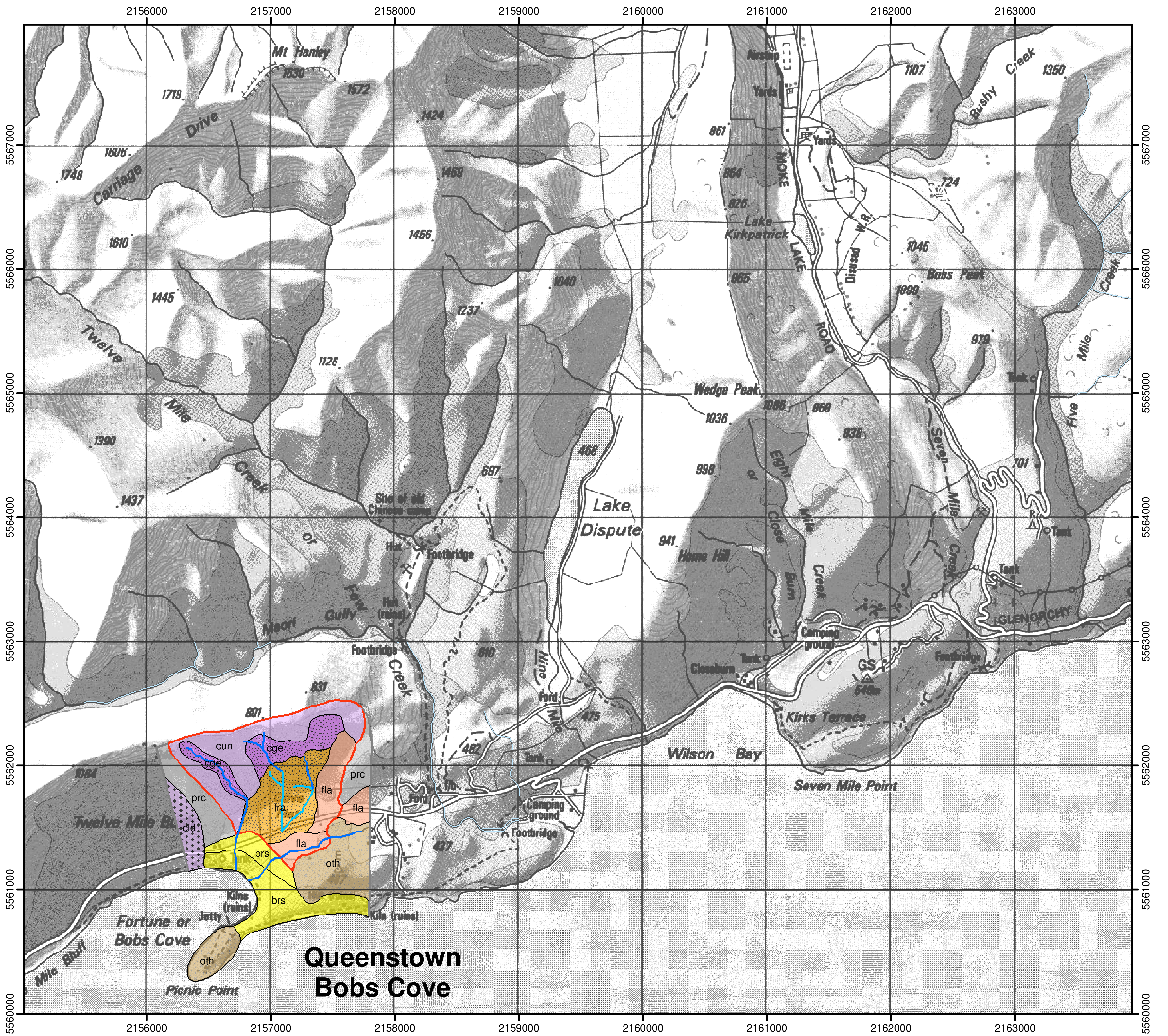
- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

0 0.5 1 2 Km



OTAGO REGIONAL COUNCIL ALLUVIAL FAN HAZARDS

QUEENSTOWN (township) area – summary assessment

A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies at Queenstown, on the flanks of Ben Lomond and Queenstown Hill. The main named streams are Horn Creek, and One Mile and Two Mile creeks. (Note that Horn Creek is the correct spelling; it is often known as Horne Creek).

The ranges and valleys are formed in ancient schist bedrock. The Lake Wakatipu valley, including the Queenstown area, was occupied repeatedly by glaciers during Ice Ages. Glaciers scoured the flanks of the ranges and the sides and tops of isolated hills such as Queenstown Hill. The Gorge is an abandoned conduit for ice and meltwater that formerly flowed east towards Arrowtown. The glacier left many areas of moraine in the Queenstown area.

Ice retreated most recently about 18,000 years ago, allowing Lake Wakatipu to form. Eroding schist rock in the catchments has fed sediment onto alluvial fans that have built out from the valley margins. Initially, the lake stood about 50 m higher than it does now. Wave-cut cliffs, beach ridges, and alluvial fan-deltas that built out to the higher lake level, are common around the lake. As lake levels fell (due to incision of the Kawarau valley), many streams cut valleys down into their fan-deltas, leaving abandoned fan terraces flanking some of the modern streams. The landscape, geologically speaking, is young.

Annual precipitation at Queenstown is a little more than 800 mm/yr, increasing with altitude to about 1,500 mm/yr at the crest of Ben Lomond (growOTAGO).

LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Modification to the landscape during urban development has obscured much of the evidence of past activity on the fans. Fan terraces left stranded by the fall in lake level, such as One Mile and Two Mile creeks near Fernhill, have probably been isolated from fan activity for thousands of years). The lowest lying parts of fans, close to present stream levels, are likely to have been subject to flooding and sedimentation activity within the past few hundred years.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Predominantly urban.

B3. EXISTING INFRASTRUCTURE: Roads, dwellings, apartment buildings, tourist accommodation, urban amenities.

B4. EXISTING CONTROL WORKS: All streams have artificially modified courses, and minor watercourses are reticulated into the stormwater system. Flood control measures have been constructed on Horn Creek.

B5. TYPES OF FAN: West of central Queenstown, the main fans are terraced. Fans in the Horn Creek catchment are aggradational. Predominant processes at the heads of fans from steep catchments are debris flow, while flooding and sedimentation predominate on lower-gradient fans.

B6. CONDITIONS AT TOES OF FANS: One Mile Creek and Two Mile Creek enter the lake directly from deeply incised valleys cut into their terraced, '50 m lake level' fans. They have constructed small deltas, now heavily modified, out into the lake. Sandy and gravelly sediment brought down by these streams will contribute to the growth of their deltas, although wave action may help redistribute the sediment along the shore and reduce the rate of sediment build-up. There may be potential for channel break-out near the stream mouths, especially if floods in the streams occur when the lake is high.

In the Horn Creek catchment, small fans built at the mouths of steep gullies are aggradational. Any sediment brought down by the streams in such gullies (e.g. Reavers Lane; see below) is likely to build up in stream channels, and spread onto the fan.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Many areas of landslide or gullied terrain.

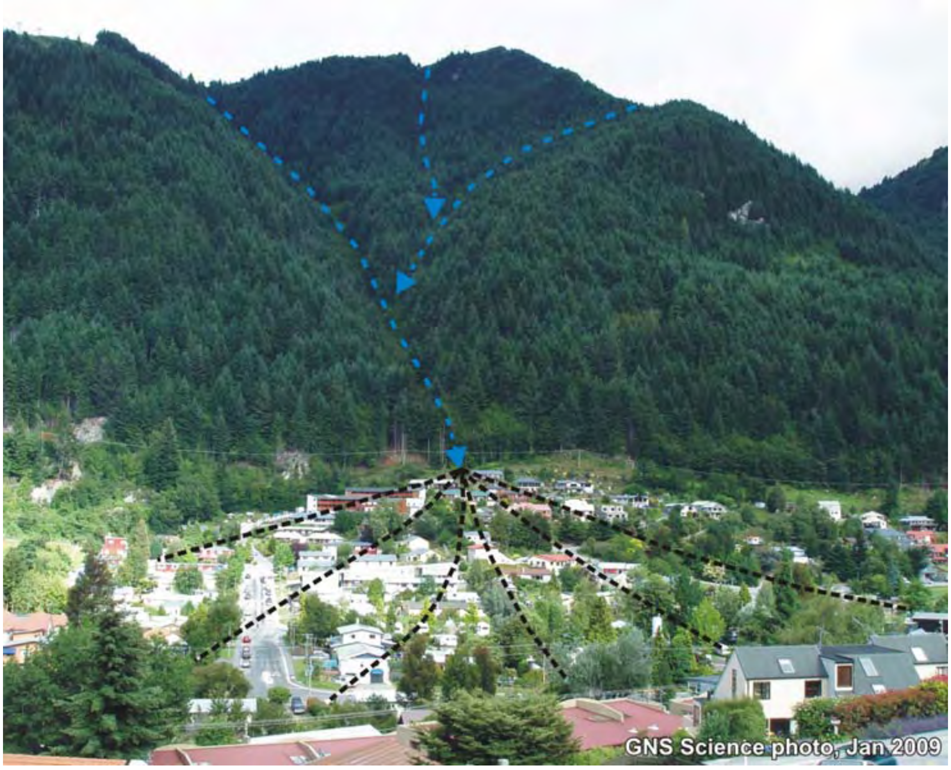
C2. EXISTING TYPES OF VEGETATION/LAND-USE: Forest (mainly exotic), scrub, grass, minor bare rocky outcrops.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 700 m (Reavers Lane) and 1,320 m (Horn Creek).

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:



A forested catchment, with an area of about 46 hectares, drains into the Bodytown suburb of Queenstown on the eastern side of the Skyline Gondola (skyline, far left). Sediment brought down by the gully draining this catchment (blue line) has accumulated in a fan that radiates out from the gully mouth (black lines), at Reavers Lane. View is to the west-northwest. *(GNS Science photo)*.

The Reavers Lane fan, looking east-northeast. At the head of the fan, where the blue line marking the gully meets the radiating black lines illustrating the directions of fall on the fan, a culvert transfers the drainage from the gully into the stormwater system (see photos below). *(GNS Science photo)*.

	
A view down the lowest reach of the gully that has formed the Reavers Lane fan, upon which the buildings are sited. The culvert that collects drainage from the gully is to the left of centre (neighbouring photo) (*GNS Science photo)*.	The culvert at the head of the Reavers Lane fan has a grill and narrow-diameter pipe intended for water, but not for coarse sediment (i.e. gravel or boulders) *(GNS Science photo)*.

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
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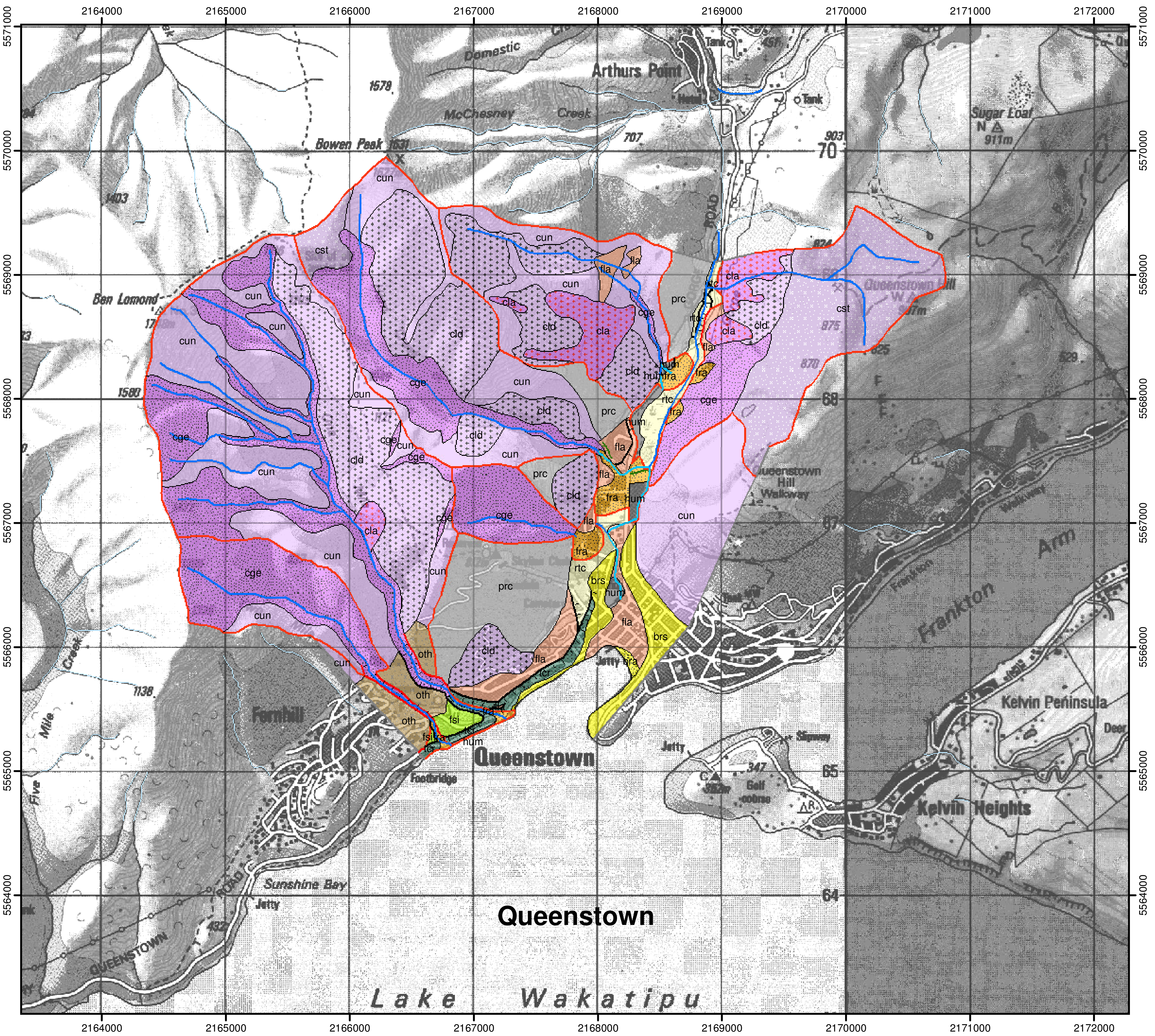


OTAGO REGIONAL COUNCIL ALLUVIAL FAN HAZARDS

QUEENSTOWN (Coronet Peak) area – summary assessment

A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies in the Queenstown-Arrowtown basin, west of Arrowtown on the southern flank of Coronet Peak.

The ranges and basin floor are formed in ancient schist bedrock. The Queenstown-Arrowtown basin was occupied repeatedly by glaciers during Ice Ages. Glaciers scoured the flanks of the ranges, as well as the sides and tops of isolated schist hills such as Slope Hill. The southern flank of Coronet Peak has been affected in its entirety by landslide movements, giving its slopes a distinctive irregular hummocky texture.

A broad valley carved in bedrock along the foot of Coronet Peak carried large volumes of meltwater, including much of the Shotover River's flow, when ice extended into the basin during the last Ice Age, which ended about 18,000 years ago. River terraces in this meltwater valley date from around that time. Since then, gullies draining the Coronet Peak landslide have fed schist sediment onto alluvial fans that have built out into the meltwater valley. The landscape, geologically speaking, is dominated by last Ice Age landforms, with only the fans, and perhaps some landslide slopes, providing younger elements.

Annual precipitation at the valley floor is a little less than 900 mm/yr, increasing with altitude to about 1,500 mm/yr at the crest of Coronet Peak (growOtAGO).

LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation:	Oct 2008
Field Check:	Jan 2009
Revisions:	

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Most parts of the fans have immature soils, indicating that they have been affected by flooding or sedimentation within the past few hundred years. This is especially evident in the vicinity of Station Creek and McMullan Creek.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture. Pastoral farming.

B3. EXISTING INFRASTRUCTURE: Malaghans Road, farm houses and farm buildings.

B4. EXISTING CONTROL WORKS: None known.

B5. TYPES OF FAN: Aggradational. Predominant processes are flooding and sedimentation, with debris flows possible on upper parts of some fans.	
B6. CONDITIONS AT TOES OF FANS: The toes of the fans extend partway across a broad terraced valley landscape. There has been no through-drainage to the east (towards the Arrow River) of any consequence since the Ice Age. Consequently, there is no natural means of transporting sediment away from the fans. Sediment brought down by the streams is likely to build up on the fans, unless it is removed mechanically.	
C. Nature of the fan catchments	
C1. CHARACTER OF SLOPES: Landslide areas, gullied in places.	
C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass, with some areas of scrub and minor forest in gullies.	
C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 350 m (Arrowtown end) and 1,170 m (Coronet Peak).	
D. Additional information	
D1. EXISTING REPORTS: None known.	
D2. ILLUSTRATIONS:	
D3. COMMENTS:	

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

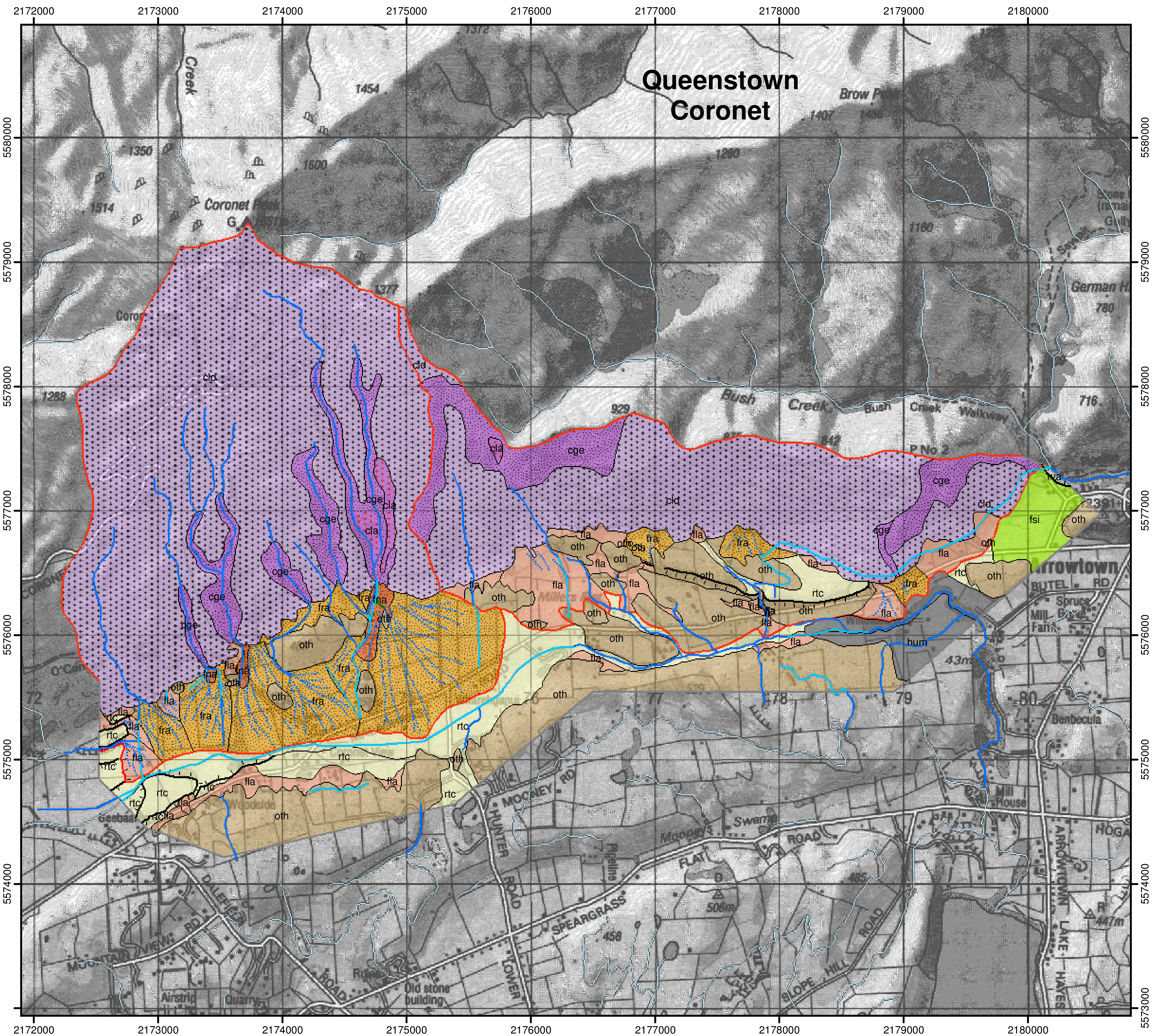
- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

0 0.5 1 2 Km



OTAGO REGIONAL COUNCIL ALLUVIAL FAN HAZARDS

QUEENSTOWN (Crown Terrace) area – summary assessment

A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies on the Crown Terrace, at the eastern end of the Queenstown-Arrowtown basin. It is flanked to the east by the Crown Range and to the west by a steep terrace edge descending to the basin floor and Arrow River.

The range, terrace edge and basin margins are formed in ancient schist bedrock. The Queenstown-Arrowtown basin was occupied repeatedly by glaciers during Ice Ages. Glaciers scoured and shaped the flanks of the ranges, as well as the sides and tops of isolated schist hills such as Morven Hill. Although ice did not extend up onto the Crown Terrace during the last Ice Age, the western side of the terrace has scattered remnants of moraine formed during earlier Ice Ages. Eroding bedrock in the Crown Range has fed sediment onto alluvial fans that have built up on the inner (Crown Range) side of the terrace. Because neither ice nor meltwater drainage overtopped the Crown Terrace during the last Ice Age, it is likely that these alluvial fans have been evolving through at least the last 70,000 years. The landscape, geologically speaking, is a mix of old and young landforms.

Annual precipitation on the Crown Terrace is a little more than 800 mm/yr, increasing with altitude to about 1,200 mm/yr at the heads of the fan catchments (growOTAGO).

LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation:	Oct 2008
Field Check:	Jan 2009
Revisions:	

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Most parts of the fans have mature soils, indicating that there has been little sediment-laden flooding within at least the past few hundred years, except close to the present stream channels. Towards the southeast some reaches of the streams are incised deeply into their fans, and are now flanked by fan terraces that have long been isolated from fan flooding and sedimentation.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture with minor scrub and stream-side trees in gullies. Pastoral farming, some large-holding residential.

B3. EXISTING INFRASTRUCTURE: Crown Range Road, minor roads, houses, farm buildings.

B4. EXISTING CONTROL WORKS: some minor control of stream channels.

B5. TYPES OF FAN: Aggradational to degradational. Predominant processes are flooding and sedimentation, with debris flows possible on upper parts of the fans.

B6. CONDITIONS AT TOES OF FANS: The main streams are graded to incised channels that flow over the western edge of the Crown Terrace. It is likely that under present conditions, the streams are in equilibrium, with sediment brought down by the streams being transported across the terrace and on down to the floor of the basin. Factors that could alter such equilibrium include increased sediment delivery from the catchments (e.g. due to activation of landslides), or obstruction of their incised channels close to the western edge of the terrace, either by natural factors, such as vegetation growth or landslides, or by human modifications.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Landslide areas and/or gullied terrain are common.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass, with some areas of scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 460 m to 950 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

Aerial view looking north across the Crown Terrace. Alluvial fans have built out across the terrace from catchments in the Crown Range (right background). The main streams have cut deep gullies over the western lip of the Crown Terrace (left to right foreground). As a result, some parts of the fans are now isolated above the levels of fan flooding or sedimentation activity, whereas other parts near the heads of the fans (distance) show signs of more recent fan activity. *(GNS Science photo; D.L. Homer)*.

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

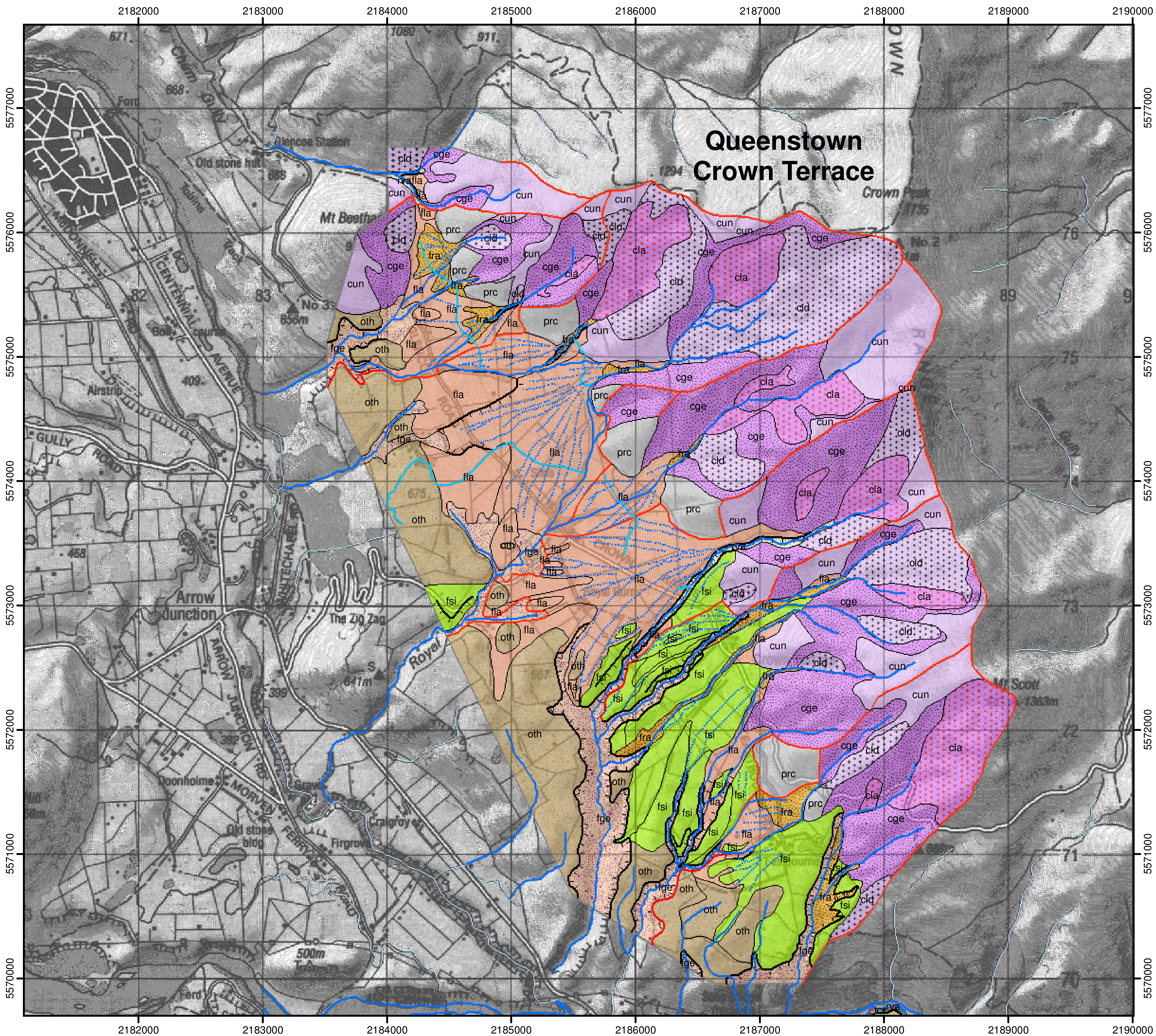
- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

0 0.5 1 2 Km



OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

QUEENSTOWN (Remarkables) area – summary assessment

A. Extent and nature of the assessment area

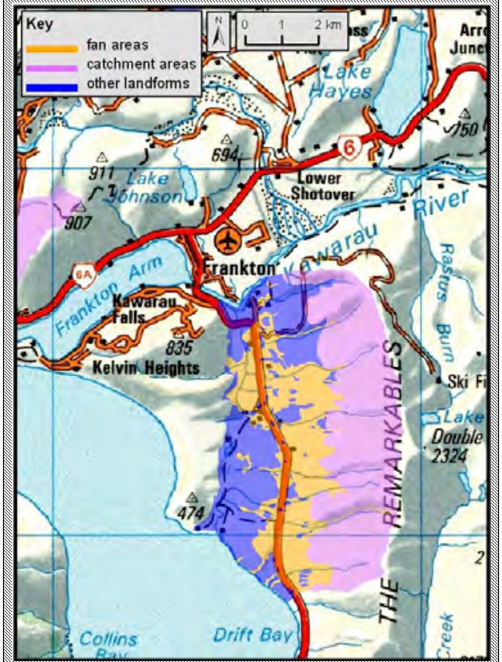
DESCRIPTION:

The assessment area lies to the east of Lake Wakatipu, on the western flank of The Remarkables range.

The ranges and valleys are formed in ancient schist bedrock. The Lake Wakatipu valley, including the Queenstown area, was occupied repeatedly by glaciers during Ice Ages. Glaciers scoured the flanks of the ranges and the sides and tops of isolated hills such as Peninsula Hill at Kelvin Heights. The glacier left many areas of moraine on the lower flanks of The Remarkables.

Ice abandoned the area recently about 18,000 years ago, allowing Lake Wakatipu to form. Most landforms in the assessment area date from around that time; the landscape, geologically speaking, is young. Eroding schist rock in the catchments has fed sediment onto alluvial fans that have built out from the valley margins. At first, Lake Wakatipu stood about 50 m higher than it does now. Wave-cut cliffs, beach ridges, and alluvial fan-deltas (including the Shotover delta) that built out to the higher lake level are common around the lake. As lake levels fell (due to incision of the Kawarau valley), many streams cut valleys down into their fan-deltas, leaving abandoned fan terraces flanking some of the modern streams.

Annual precipitation at the foot of The Remarkables of about 700 mm/yr increases with altitude to about 1,500 mm/yr at the crest of the range (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series.
Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: The lowest-lying parts of fans, close to present stream levels, commonly have immature soils and are likely to have been subject to fan activity within the past few hundred years. Historically, several of the larger streams have deposited gravelly sediment across the highway during floods, with aggradation upstream of the highway embankments.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass and scrub. Pastoral farming and some horticulture; large-holding residential; recent subdivisions.

B3. EXISTING INFRASTRUCTURE: SH 6, minor roads, houses, farm buildings, subdivisions, tourist amenities.

B4. EXISTING CONTROL WORKS: Minor embankment and channelization work along some stream courses.

B5. TYPES OF FAN: Aggradational fans close to the lower slopes of The Remarkables, or where fans are built onto lake or river terraces. Where fans have overtopped irregular moraine topography, or their lower reaches drain to gullies that are incised into the beach/fan-delta complexes that formed at the '50 m lake level', they are generally equilibrium fans. Predominant processes near the heads of fans include debris flow, with flooding and sedimentation predominant on mid- to lower parts of fans.

B6. CONDITIONS AT TOES OF FANS: The fans are built onto a variety of older landforms and toe conditions vary widely. Fans in the northern and the southern parts of the assessment area have active streams that feed into gullies. This facilitates the transport of their sediment either to the Kawarau River or to the lake shore. On other fans, there is no natural agency that can redistribute their sediment. Sediment from their catchments will accumulate on the fans, unless it is removed mechanically.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Many areas of gullied terrain with some landslides.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass, minor scrub, some bare rock.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 1,200 and 1,500 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

An aggradational fan on the uphill side of State Highway 6. The stream is barely incised into its fan surface and soils are immature, indicating that sedimentation has occurred on the fan surface within the past few hundred years. Behind the photographer, the toe of the aggradational fan passes down-slope into gullies incised into the '50 m lake level' terrace *(GNS Science photo)*.

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

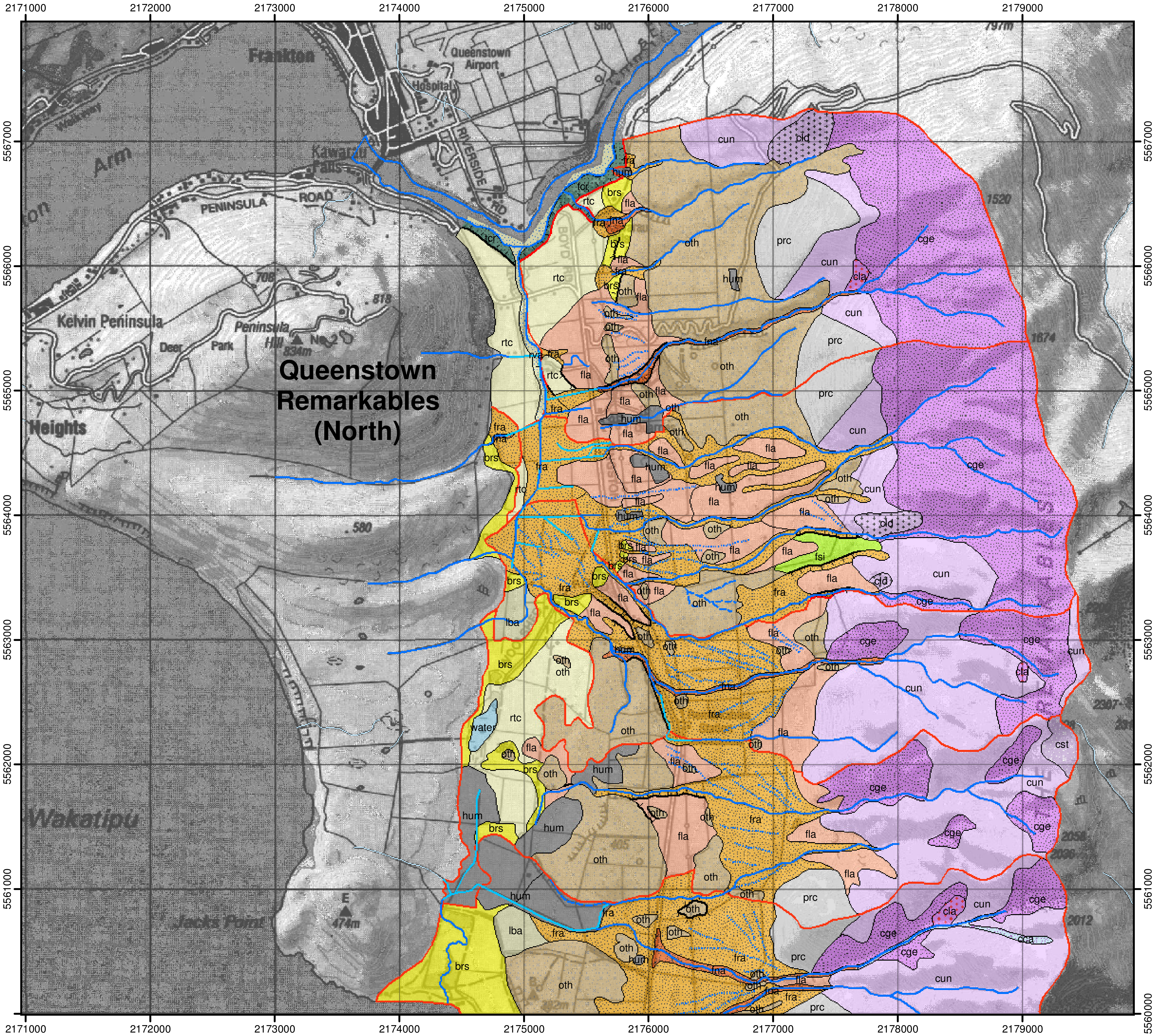
- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

0 0.5 1 2 Km



OTAGO REGIONAL COUNCIL ALLUVIAL FAN HAZARDS

KINGSTON area – summary assessment

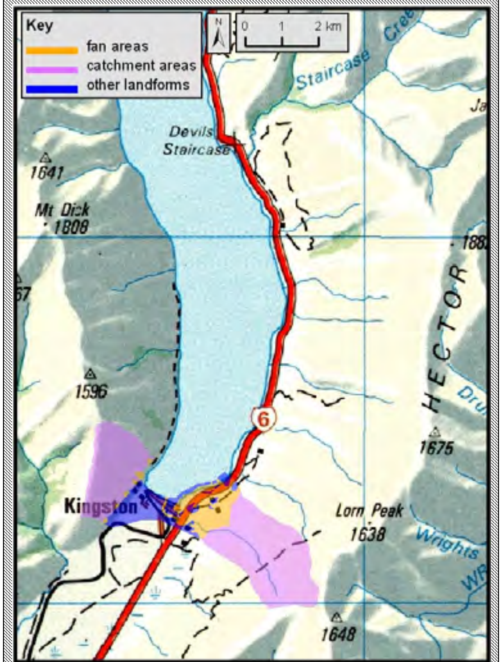
A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies at the southern end of Lake Wakatipu. The Hector Mountains lie to the east, with the foothills of the Eyre Mountains to the west.

The ranges and valleys are formed in ancient schist bedrock. The Lake Wakatipu valley was occupied repeatedly by glaciers during Ice Ages. The glacier scoured the flanks of the ranges on either side of the lake. The maximum extent of ice during the Last Ice Age lay just south of Kingston, and is marked by terminal moraines as well as outwash plains that extend down-valley. Ice retreated most recently about 18,000 years ago, allowing Lake Wakatipu to form. Eroding schist rock in the catchments has fed sediment onto alluvial fans that have built out from the valley margins. At first, the lake stood about 50 m higher than it does now. Wave-cut cliffs, beach ridges, and alluvial fan-deltas graded to the higher lake level, are common around the lake. As lake levels fell (due to incision of the Kawarau valley), many streams cut valleys down into their fan-deltas, leaving abandoned fan terraces flanking some of the modern streams. Lake beach deposits dominate the landscape in Kingston township. The main fan drains from near Lorn Peak, and several small fans are formed at the mouths of steep gullies draining the flank of the ridge west of Kingston. The landscape, geologically speaking, is young.

Annual precipitation at Kingston is about 900 mm/yr increasing with altitude to about 1,500 mm/yr at the crests of the ranges (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation:	Oct 2008
Field Check:	Jan 2009
Revisions:	

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: The lowest-lying parts of fans, close to present stream levels, commonly have immature soils and are likely to have been subject to fan activity within the past few hundred years.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass and minor scrub. Pastoral farming and minor residential.

B3. EXISTING INFRASTRUCTURE: SH 6, minor roads, houses, farm buildings.

B4. EXISTING CONTROL WORKS: Minor embankments and channelization along some stream courses.

B5. TYPES OF FAN: East of Kingston, the fans are aggradational close to the foot of the Hector Mountains. Farther down-slope, the fans drain into gullies that are incised into the beach/fan-delta complexes that formed at the '50 m lake level'. From the heads of these gullies, down to the lake shore, these parts of the fan system generally appear to be equilibrium fans, under present conditions. Predominant processes near the heads of fans include debris flow, with flooding and sedimentation a feature of mid- to lower parts of fans. The small fans west of Kingston are aggradational.

B6. CONDITIONS AT TOES OF FANS: Streams draining to wave-exposed parts of the lake shore may have their sediments redistributed by along-shore drift. Elsewhere, sediments brought down from the catchments will accumulate in stream channels and spread onto fans, unless removed mechanically.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Many areas of gullied terrain with some landslides.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass, some scrub and regenerating forest, minor bare rock.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 760 and 1,040 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

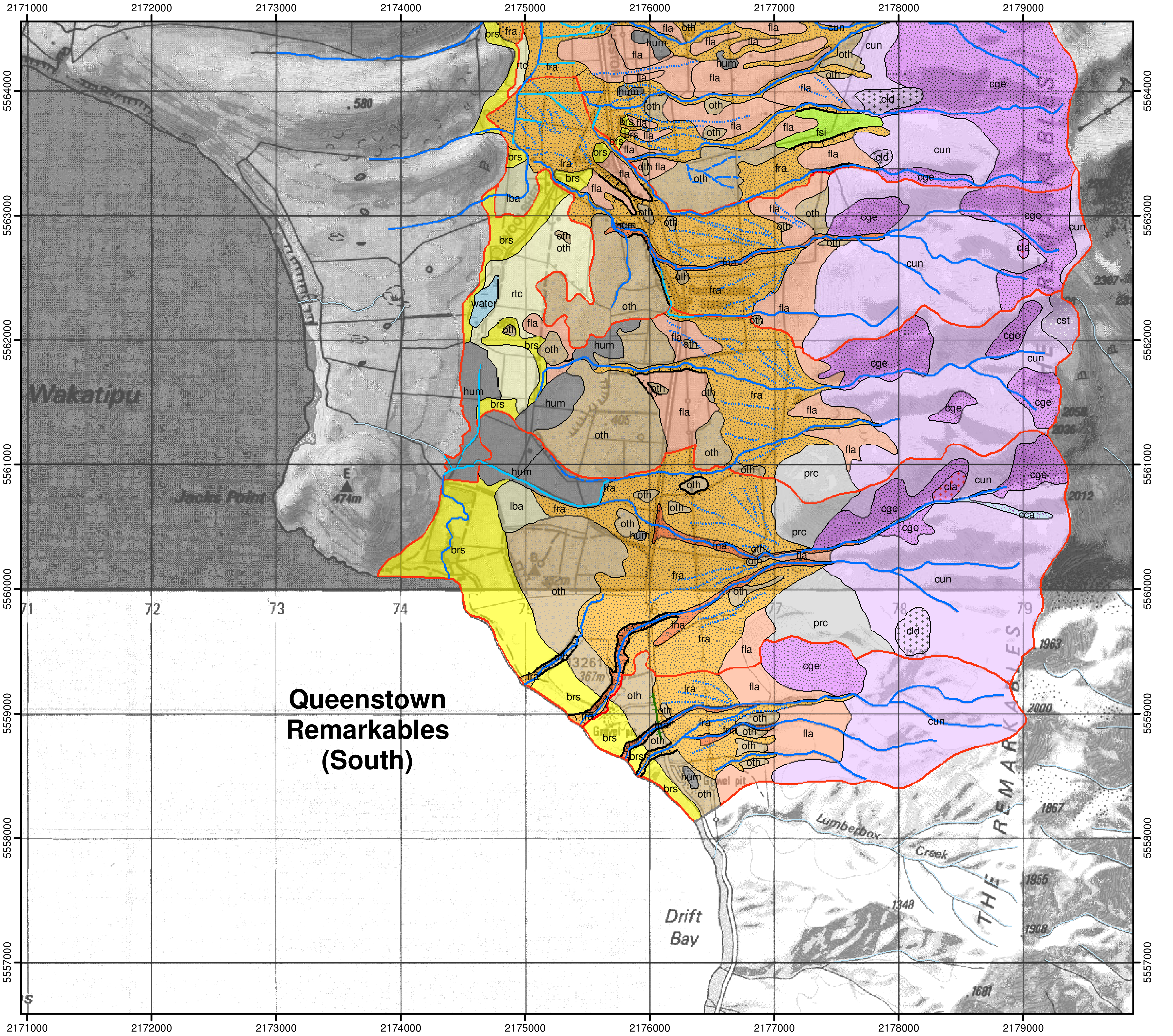
- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

0 0.5 1 2 Km



Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
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- cst - catchment long stabilised
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LANDFORM BOUNDARY

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CHANNEL TYPE

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- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
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Base Map LINZ NZMS 260 series
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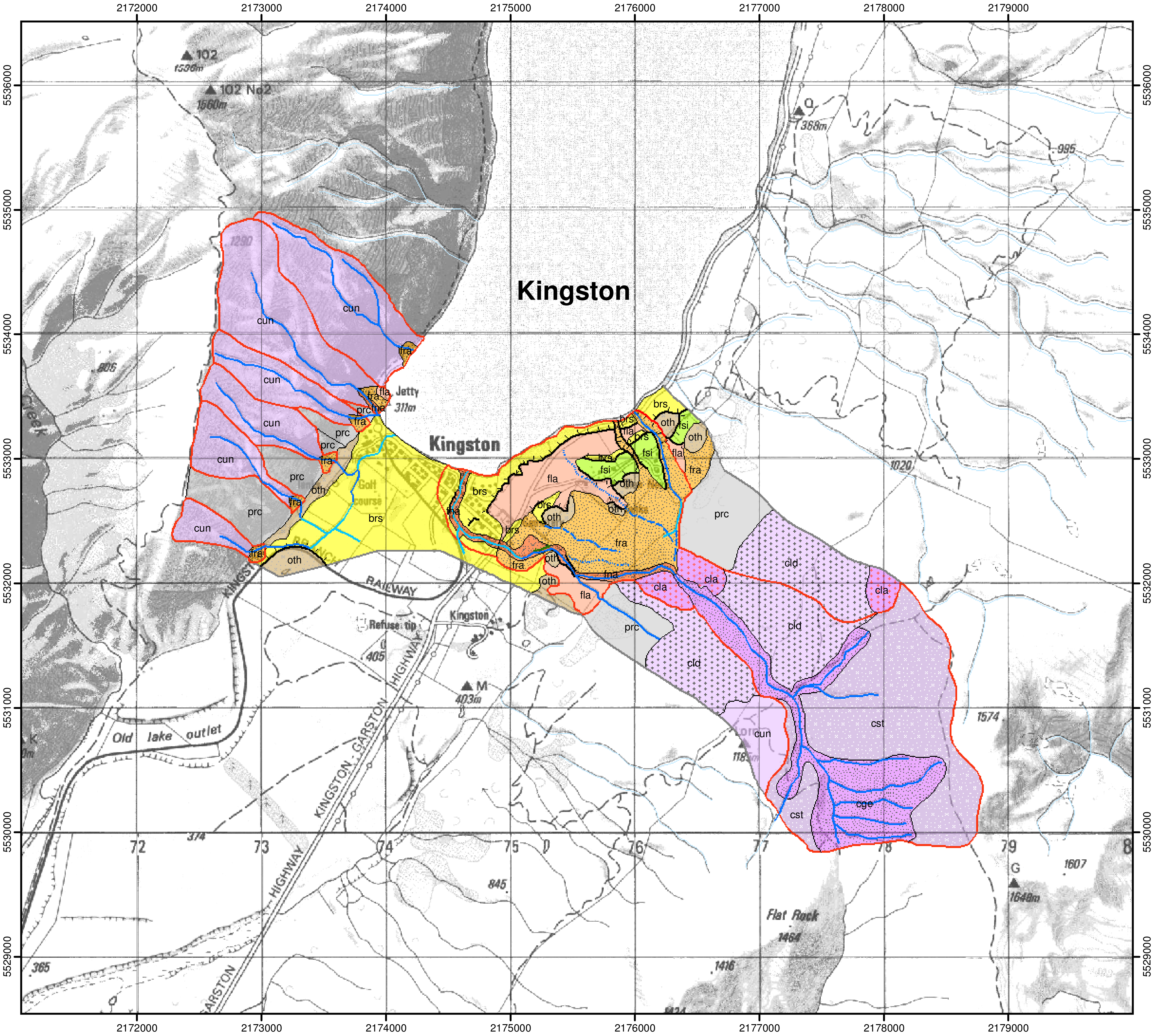


OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

KAWARAU (Gibbston) area – summary assessment

A. Extent and nature of the assessment area

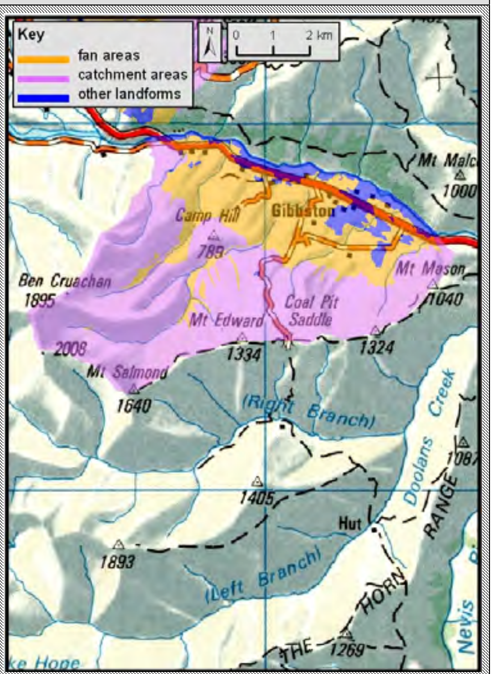
DESCRIPTION:

The assessment area lies on the southern side of Gibbston basin of the Kawarau valley, between Kawarau Bridge to the west and Nevis Bluff to the east.

The basin and flanking ranges are formed in ancient schist bedrock. West of Gibbston, the Queenstown-Arrowtown basin was occupied repeatedly by glaciers during Ice Ages. Ice may have extended into Gibbston at such times, but not during the last Ice Age, which ended about 18,000 years ago. Instead, the major control on the Gibbston landscape has been the episodic build-up, and subsequent erosion of Kawarau river gravel in response to advances and retreats of glaciers farther up-valley. This has produced a series of river-eroded schist benches and outwash gravel terraces.

Eroding bedrock in the ranges flanking the Gibbston basin has fed sediment onto alluvial fans that have built out onto the glacial outwash terraces or schist benches. Episodes of fan building have been interrupted by aggradation or degradation of Kawarau river gravel in the valley. Landforms in the assessment area cover a wider range of ages than occur farther upstream in areas more recently affected by Ice Age glaciers.

Annual precipitation at Gibbston is slightly more than 600 mm/yr, increasing with altitude to more than 1,000 mm/yr at the heads of the fan catchments (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series.
Crown copyright reserved.

Aerial Photo Interpretation:	Oct 2008
Field Check:	Jan 2009
Revisions:	

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Those parts of the fans where the stream channel is barely incised, if at all, into the fan surface are judged likely to have experienced flooding and sedimentation within the past few hundred years. West of Toms Creek, near Gibbston Vineyard, a fan at the mouth of a gully whose headwaters were sluiced during the 19th century gold rush was probably formed from sluice tailings and may have been inactive since mining stopped.

Towards the southwest at the foot of the range, most reaches of the streams are incised deeply into their fans, and are now flanked by terraces that have long been isolated from fan flooding and sedimentation.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Grape vines, pasture, stream-side trees and scrub in stream valleys. Land-use includes extensive horticulture, some pastoral farming and large-holding residential.

B3. EXISTING INFRASTRUCTURE: State Highway 6, minor roads, houses, farm buildings, vineyards.

B4. EXISTING CONTROL WORKS: Minor embankments and channelization along streams.

B5. TYPES OF FAN: Terraced. Lower parts of fans on the valley floor terrace may in part be aggradational, or in equilibrium where the fans grade to gullies incised at the river cliff down to the Kawarau river. Predominant processes are flooding and sedimentation.

B6. CONDITIONS AT TOES OF FANS: The main streams are graded to incised channels that flow over the eastern edge of the terraces, into the rock gorge of the Kawarau River. It is likely that under present conditions, these streams are in equilibrium, with sediment brought down by the streams being transported across the terrace and on down to the river. Factors that could alter such equilibrium include increased sediment delivery from the catchments (e.g. due to activation of landslides), or obstruction of their incised channels close to the eastern edge of the terrace, either by natural factors, such as vegetation growth or landslides, or by human modifications. Some small fans extend only part-way across the terraces, and their toes are probably aggradational. Any sediment that is brought down onto these fans is likely to build up, unless removed mechanically.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Extensive areas of gullied terrain and large landslide areas in the largest catchments.

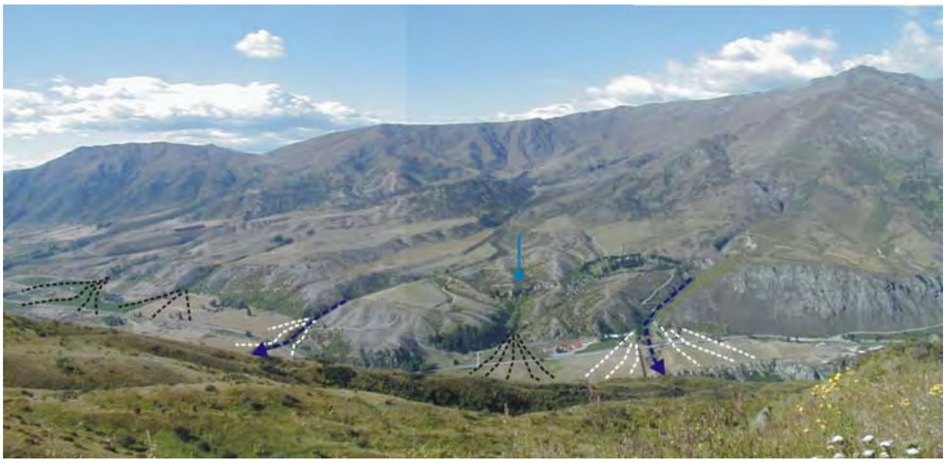
C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass, with some areas of scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the terraced fan complexes is between about 700 m and 1150 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:



The terraced fan landscape of Gibbston basin, seen from the Crown Range Road. Small fans radiating out (black lines) from the mouths of creeks draining the fan terraces are aggradational, with no well-defined stream channels. Any sediment brought down from their catchments will accumulate on their surfaces, in the absence of human intervention. Gold sluicings (blue arrow) probably contributed to construction of the small fan in the centre. Larger streams (dark blue) draining from the range behind have built fans (white lines) out across the river terrace. The streams then cut gullies over the terrace margin (almost obscured from view, in the foreground), down to the Kawarau River. As a result the streams have cut down into their fan surfaces. Under present conditions, these streams are probably in equilibrium, with channel depths and gradients that are sufficient to transport their sediment to the Kawarau River *(GNS Science photo)*.

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

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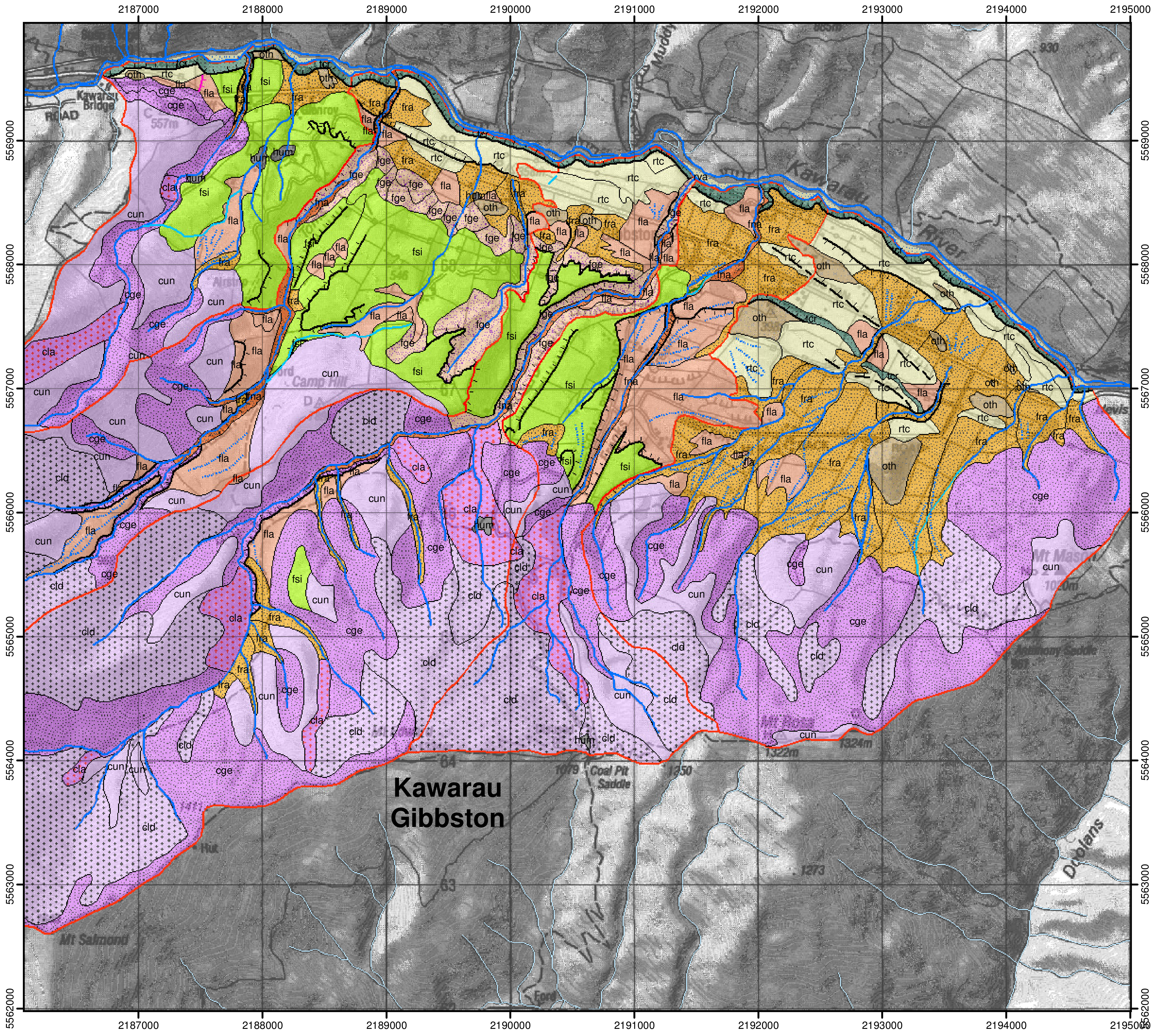


OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

CROMWELL (Mt Pisa) area – summary assessment

A. Extent and nature of the assessment area

DESCRIPTION:

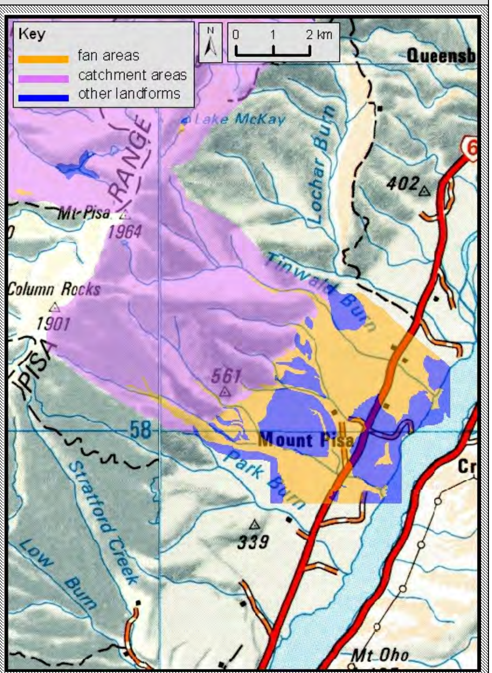
The assessment area lies in the Upper Clutha valley, west of Lake Dunstan at the foot of the Pisa Range, between Amisfield Burn in the south and Lochar Burn in the north.

The Pisa Range is formed in ancient schist bedrock. The upper Clutha valley is a tectonic basin. It was occupied repeatedly by glaciers during earlier Ice Ages, which scoured and shaped the lower flanks of the ranges and deposited moraines and glacial lake beds. More recent Ice Ages saw ice was confined to the Wanaka-Hawea basin, and outwash river gravel deposition and erosion processes have dominated this sector of the Clutha valley.

Eroding bedrock in the catchments has fed sediment onto alluvial fans that have built out onto Clutha River terraces. The valley-floor landscape is dominated by sequences of terraces and fans. These landforms span a wider range of ages than occur farther upstream in areas more recently affected by Ice Age glaciers.

The most recent change in the landscape is artificial Lake Dunstan, which now acts as a trap for sandy and gravelly sediment that used to be carried away by the Clutha River.

Annual precipitation at valley-floor level is about 450 mm/yr, increasing with altitude to more than 1,000 mm/yr at the heads of the fan catchments (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Amisfield Burn and Tinwald Burn flow in narrow valleys incised into their fans; the floors of these valleys have immature soils and have been subject to flooding and sedimentation within the past few hundred years. Aggradation has occurred historically at the SH6 bridge across Amisfield Burn. The stream draining the unnamed catchment between Amisfield and Tinwald Burns flows on the surface of its fan; it is judged likely that flooding and minor sedimentation has occurred on its fan within the past few hundred years.

There are extensive areas of fan terraces that lie well above modern stream levels and have long been isolated from alluvial fan flooding and sedimentation.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Grape vines, pasture, stream-side trees and scrub in stream valleys. Land-use includes extensive horticulture, pastoral farming.

The terraced fan of Tinwald Burn at SH6, with the Pisa Range in the background. The first terrace above the active channel has raw soils, indicating that it has been subject to flood sedimentation within the past few hundred years. The next terrace up (to right, with pine trees) has mature soils indicating that it has been free of flooding and sedimentation for a much longer period, probably several thousands of years. The high terrace behind the vehicle is isolated far above the modern stream level, and has been free of fan activity for a very long time, probably many thousands of years. Although there is no prospect of it being re-occupied by fan activity, the edges of this terrace, or of other terraces, are not necessarily immune to being eaten away by erosion from the active stream channel *(GNS Science photo)*.
D3. COMMENTS:

B3. EXISTING INFRASTRUCTURE: State Highway 6, minor roads, houses, farm buildings, vineyards.

B4. EXISTING CONTROL WORKS: Minor channelisation of streams.

B5. TYPES OF FAN: Generally terraced, although the incised valleys of streams may be in equilibrium and graded to the Clutha River/Lake Dunstan. The fan of the unnamed catchment between Amisfield and Tinwald burns is aggradational. Predominant processes are flooding and sedimentation.

B6. CONDITIONS AT TOES OF FANS: The creation of Lake Dunstan has put a stop to down-valley transfer of sediment reaching the mouths of Amisfield and Tinwald burns. Aggradation of their lower reaches as fan-deltas is an inevitable consequence, unless sediment is removed mechanically. Any sediment brought down from the unnamed catchment between these two valleys is likely to build up on the fan of that catchment, unless the sediment is removed mechanically.

Factors that could alter the presumed equilibrium of the active channels of Amisfield Burn and Tinwald Burn include increased sediment delivery from the catchments (e.g. due to activation of landslides), or obstruction of their incised channels by natural factors or human modifications.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Some areas of gullied terrain and some landslides. At high altitudes, there is extensive stabilised, relict topography dating from the last Ice Age, when a cap of glaciers formed on the crest of the Pisa Range.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass, with some areas of scrub, minor bare rock at higher altitudes.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the terraced fan complexes is between about 1,200 m and 1,500 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

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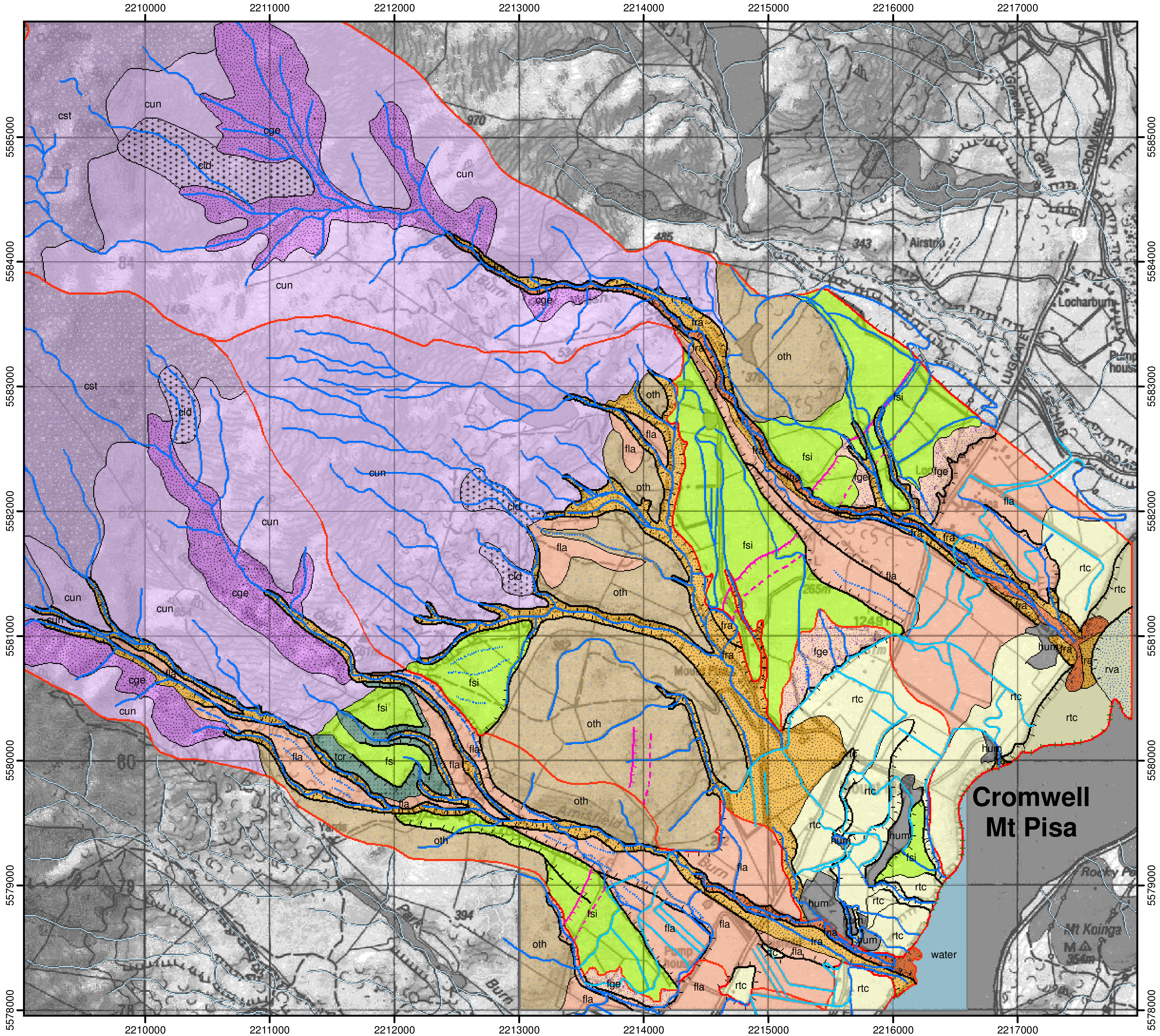


OTAGO REGIONAL COUNCIL ALLUVIAL FAN HAZARDS

CROMWELL (Lowburn-Ripponvale) area – summary assessment

A. Extent and nature of the assessment area

DESCRIPTION:

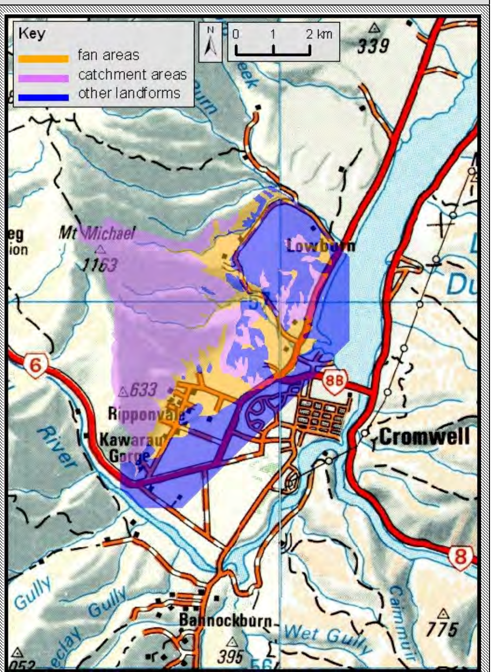
The assessment area lies in the Upper Clutha valley, west of Cromwell, at the foot of the Pisa Range between Lowburn and the Kawarau River.

The Pisa Range is formed in ancient schist bedrock. The Clutha valley at Cromwell is a tectonic basin which, although beyond the reaches of Ice Age glaciers, has undergone repeated periods of river gravel build-up, and subsequent erosion, by the Clutha and Kawarau rivers, in response to Ice Age advances and retreats of glaciers farther upstream.

Eroding bedrock in the catchments has fed sediment onto alluvial fans that have built out onto Clutha or Kawarau river terraces. The valley-floor landscape is dominated by sequences of terraces and fans at the valley margins. These landforms span a wider range of ages than occurs farther upstream in areas more recently affected by Ice Age glaciers.

The most recent change in the landscape is artificial Lake Dunstan, which acts as a trap for sandy and gravelly sediment that used to be carried away by the Clutha and Kawarau rivers.

Annual precipitation at valley-floor level is a little less than 450 mm/yr, increasing with altitude to between 550 and 750 mm/yr at the heads of the fan catchments (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series.
Crown copyright reserved.

Aerial Photo Interpretation:	Oct 2008
Field Check:	Jan 2009
Revisions:	

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: The assessment area has been much disturbed by land-use activities, including effects of gold mining and more recently intensive horticulture. Around Ripponvale, there are no well-defined stream channels, and therefore the streams that issue from the catchments presumably flow on the surfaces of their fans. However, the soils appear to generally be mature. From available information, it was not possible as part of this work to define the extents of flooding or sedimentation activity of the past few hundred years in the Ripponvale area. Towards Lowburn, the streams are generally incised into the their fans, and it is judged likely that flooding and sedimentation during the past few hundred years has been in and close to the present stream channels.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Orchards, grape vines, pasture, stream-side trees and scrub in stream valleys. Land-use includes intensive horticulture, pastoral farming, large-holding residential.

B3. EXISTING INFRASTRUCTURE: State Highway 6, minor roads, houses, farm buildings, orchards, vineyards, many associated irrigation dams, water races.

B4. EXISTING CONTROL WORKS: Minor channelization of streams.

B5. TYPES OF FAN: To the northeast, fans are terraced (e.g. Burn Cottage Road valley). The incised valleys of streams may be in equilibrium and graded to the Clutha River/Lake Dunstan. To the southwest (Ripponvale area), fans are aggradational. Predominant processes are flooding and sedimentation.

B6. CONDITIONS AT TOES OF FANS: The creation of Lake Dunstan has put a stop to down-valley transfer of sediment reaching beyond the mouth of 'Burn Cottage Road' stream. Any sandy or gravelly sediment brought down this stream will build up in the lower reaches of this channel, unless it is removed mechanically. Any sediment brought down from the catchments behind the Ripponvale area will build up on the fan of that catchment, unless removed mechanically.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Some areas of gullied terrain and some landslides.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass with some scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 400 m and 700 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
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- cla - catchment landslide active
- cld - catchment landslide creeping
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- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
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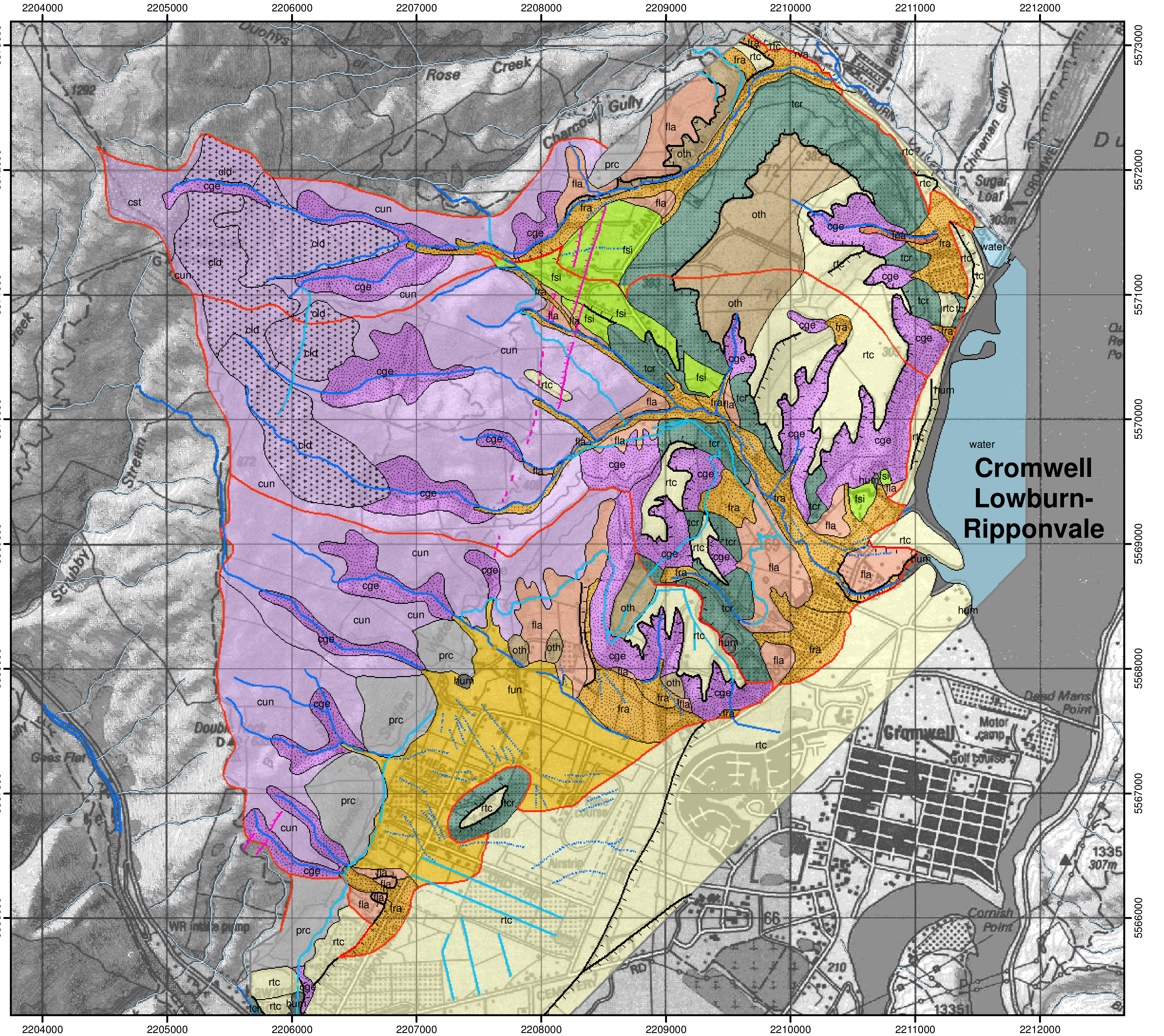


OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

ALEXANDRA (Waikerikeri) area – summary assessment

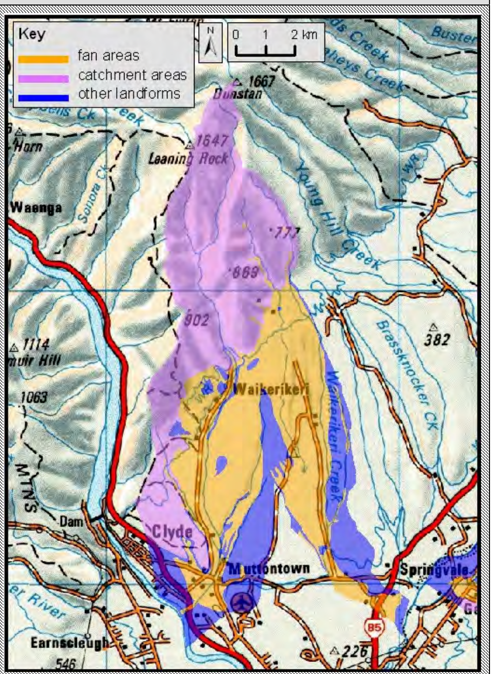
A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies in the Manuherikia basin, between Clyde and Springvale. The main streams are Waikerikeri Creek and Scrubby Gully, both of which drain the southern margin of the Dunstan Mountains.

The Dunstan Mountains are formed in a tectonically-uplifted block of ancient schist bedrock. Most of the landscape in the fan sector of the assessment area is formed in younger sedimentary rocks that lie on top of the schist. Eroding bedrock in the catchments has fed sediment onto alluvial fans that have built out from the Dunstan Mountains. A gullied, terraced complex of fans merges southward with river gravel terraces of the Clutha River. The Alexandra area lies well outside the extents of Ice Age glaciers, but the Clutha valley has undergone periods of river gravel build-up, and subsequent erosion, in response to Ice Age advances and retreats of glaciers farther upstream. Landforms near Alexandra span a wide range of ages; the highest river and fan terraces are hundreds of thousands of years old.

Annual precipitation at Muttontown is a little more than 400 mm/yr, increasing with altitude to between 600 and 750 mm/yr at the heads of the fan catchments (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series.
Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Only the floors of valleys close to modern stream levels are judged likely to have experienced flooding and sedimentation within the past few hundred years. Near Waikerikeri, the valley floor includes some sizable (up to 2 ha) fans downstream of gullies that were sites of gold-rush sluicing. These fans are probably relict features formed as a result of mining in the mid- to late 1800s.

There are vast areas of fan terraces that lie well above modern stream levels and have long been isolated from alluvial fan flooding and sedimentation.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture, minor scrub and stream-side trees, some orchards and grape vines. Land-use is predominantly pastoral farming with some horticulture and large-holding residential.

B3. EXISTING INFRASTRUCTURE: State Highway 85, Springvale Road, minor roads, houses, farm buildings, some orchards and vineyards, many associated irrigation dams, water races.

B4. EXISTING CONTROL WORKS: Minor channelization of streams.

B5. TYPES OF FAN: Terraced. The incised valleys, such as Waikerikeri Creek and Scrubby Gully, may be in equilibrium, graded to the Clutha River (Scrubby Gully drains to the Manuherikia River). Predominant processes are flooding and minor sedimentation.

B6. CONDITIONS AT TOES OF FANS: Waikerikeri Creek has cut a deep gully into its lower fan, graded to the incised Clutha River. Despite the slowing of river flow due to artificial Lake Roxburgh farther downstream, the Clutha River is probably able to carry away any sediment delivered by Waikerikeri Creek. This process helps maintain a state of equilibrium for fan activity in the lower reaches of Waikerikeri Creek. Similar circumstances prevail where Scrubby Gully meets the Manuherikia River.

Due to the great length of the stream valleys, and dry climate, were there to be any future increases in the amounts of sandy or gravelly sediment brought down from the stream catchments, it is likely that the sediment would be slow to migrate downstream, and may build up within the stream valleys. The fans formed downstream of gold-rush sluicings are good examples. Such sediment build-ups could spread onto nearby parts of the lowest-lying fan terraces, unless sediment is removed mechanically.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Some areas of gullied terrain and some landslides.

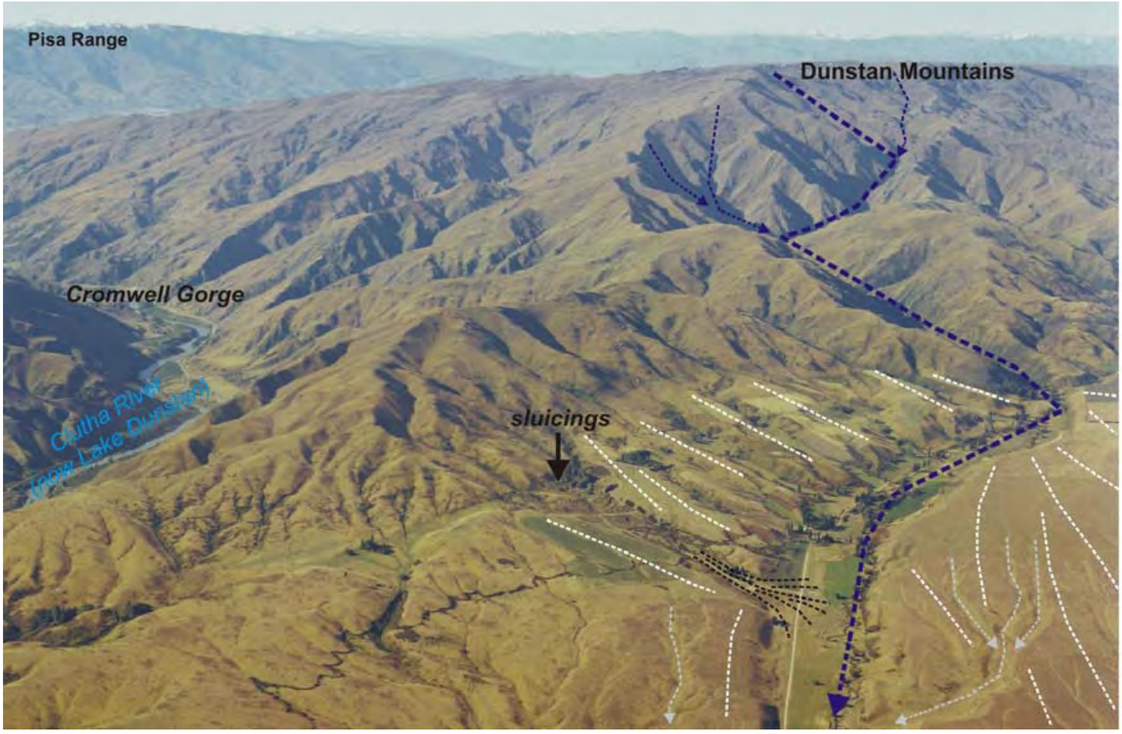
C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass with some scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the terraced fan complexes is between about 950 m and 1,200 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:



Far back in the past, Waikerikeri Creek and its tributaries built a large alluvial fan (white lines) out into the Manuherikia basin. More recently, the creek has incised a valley (navy blue arrow) into its fan, leaving older parts of the fan isolated far above present stream levels. Rainfall runoff has had sufficient time to incise substantial gullies (grey arrows) on the older fan terraces. A fan (black lines) built into Waikerikeri valley probably formed during the gold rush due to sluicing upstream *(GNS Science photo; D.L. Homer)*.

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

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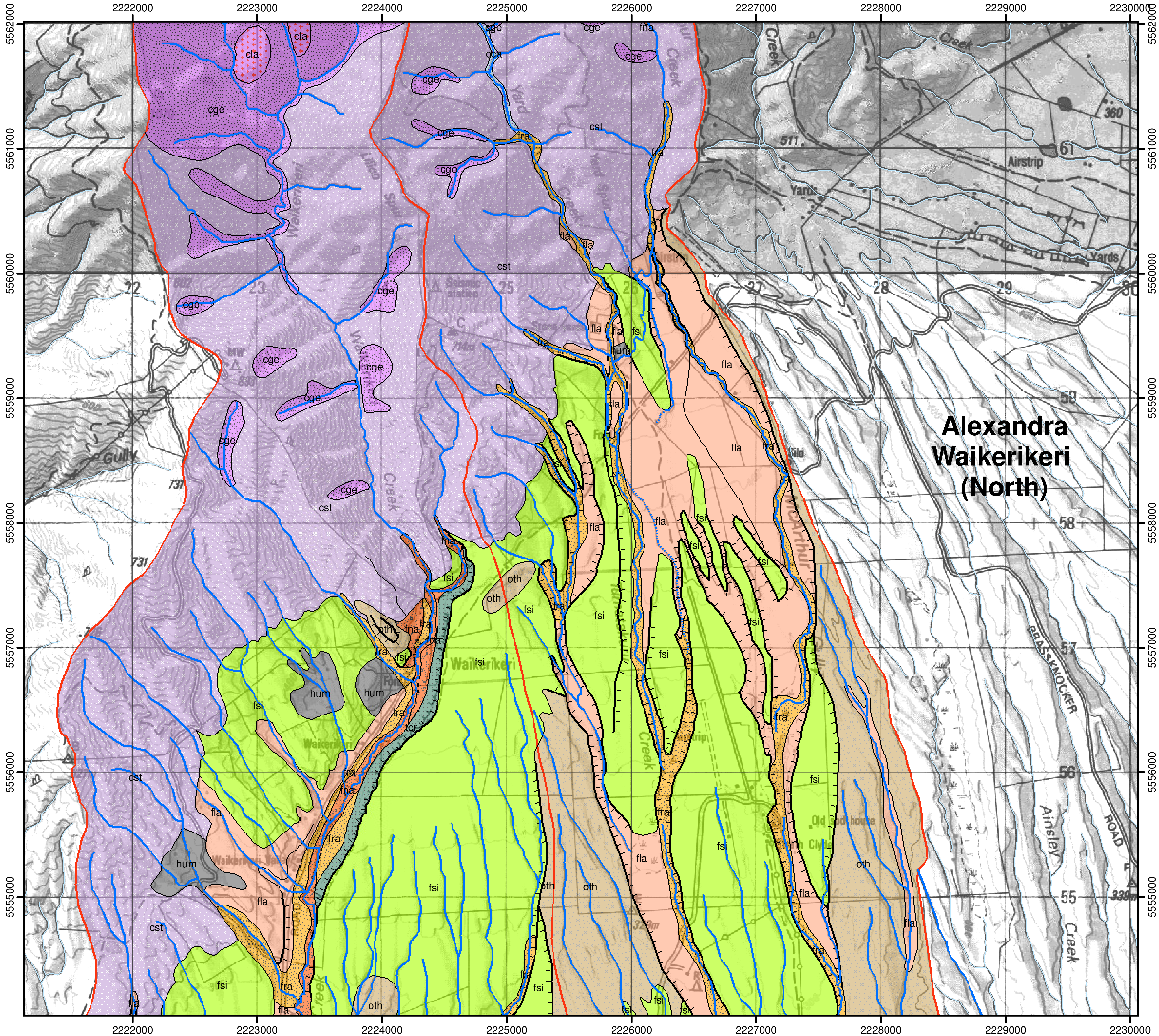

Alluvial Fans Map Legend

LANDFORM TYPE

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- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
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- water

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CHANNEL TYPE

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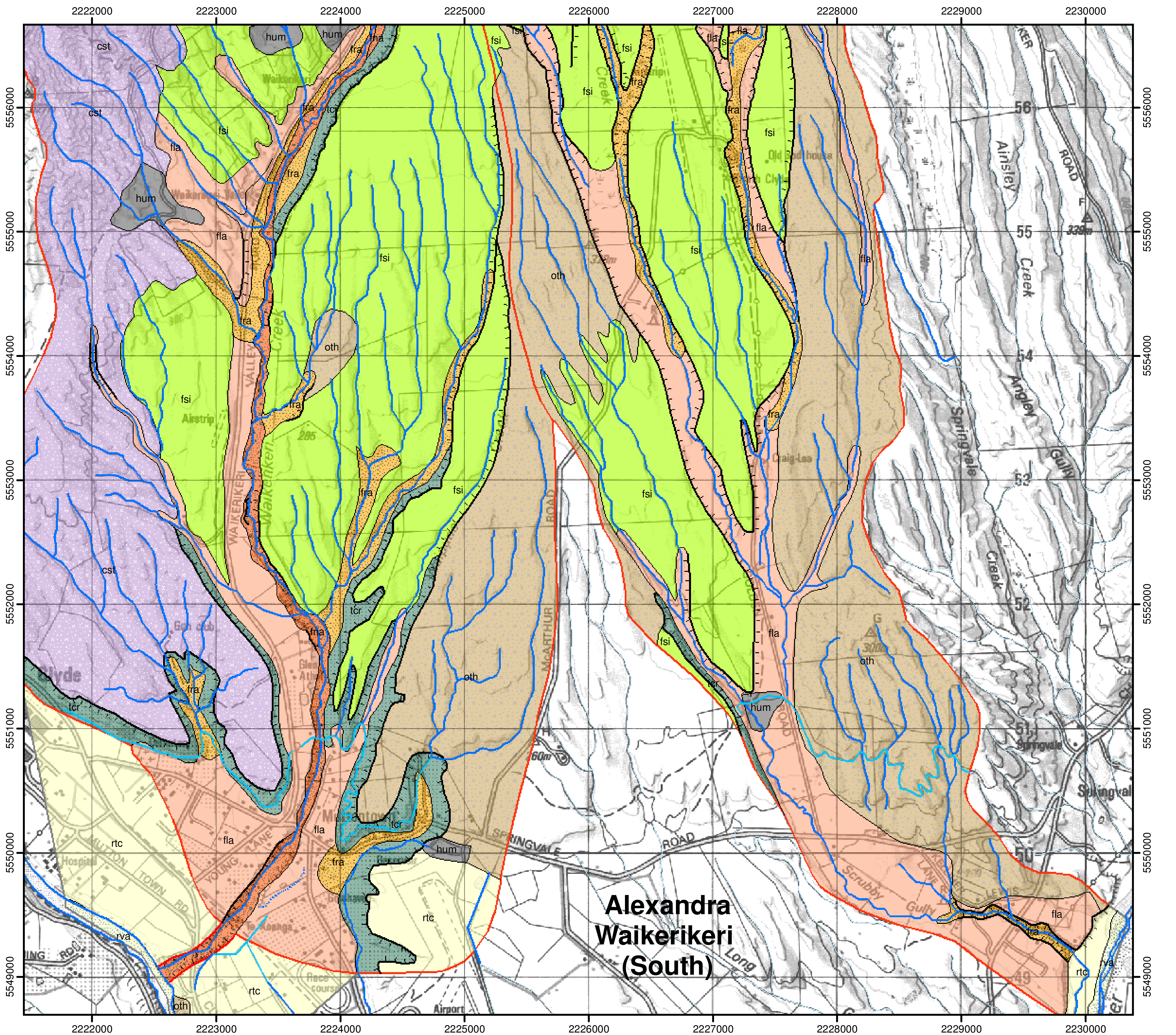


OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

ALEXANDRA (Galloway) area – summary assessment

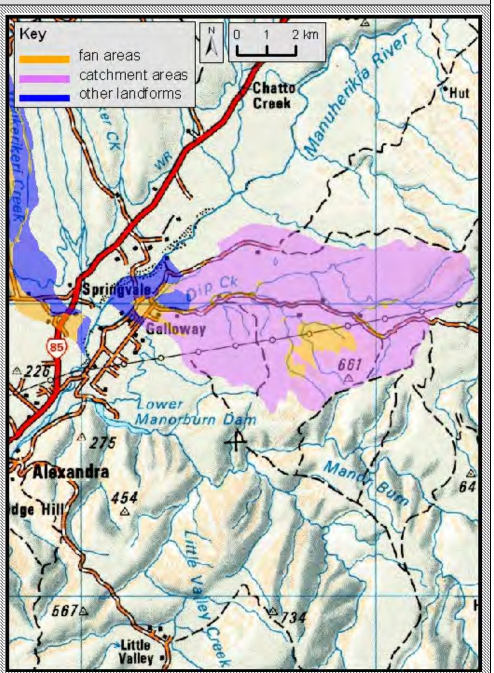
A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area comprises the Dip Creek catchment and fan near Galloway, in the Manuherikia basin. The catchment drains the northern flank of the Crawford Hills.

The catchment is formed in ancient schist bedrock. Eroding bedrock in the catchment has fed sediment onto alluvial fans constructed within the catchment, and also where the stream emerges into the Manuherikia valley.

Annual precipitation at Galloway is a little less than 400 mm/yr, increasing with altitude to a little more than 500 mm/yr at the crest of Crawford Hills (growOTAGO). This is one of the driest parts of New Zealand. The combination of low precipitation and low topographic relief contributes to a slow rate of fan-building activity, by Otago standards.



LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Only the floors of valleys close to modern stream levels are judged likely to have experienced flooding and sedimentation within the past few hundred years.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture, minor stream-side trees. Land-use is predominantly pastoral farming. Extensive areas of ground disturbed by historic gold-mining near the toe of the fan.

B3. EXISTING INFRASTRUCTURE: minor roads, houses, farm buildings.

B4. EXISTING CONTROL WORKS: Minor channelization of streams.

B5. TYPE OF FAN: Equilibrium to aggradational. Minor areas of terraced fan within the mid- to upper part of the catchment. Predominant processes are flooding and minor sedimentation.

B6. CONDITIONS AT TOE OF FAN: The Dip Creek fan formerly extended part-way out onto an abandoned low-level terrace of the Manuherikia River. It is likely that this fan was in an aggradational condition at the time of European settlement. Extensive dredging for gold was carried out on the abandoned Manuherikia river terrace, and the lowermost part of the Dip Creek fan was destroyed as part of the dredging. The fan now terminates against irregular dredge tailings. Any sediment brought down from the Dip Creek catchment will accumulate on its fan, unless that sediment is removed mechanically.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Minor areas of gullied terrain.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass with some scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the top of the catchment to the head of the fan at Galloway is about 400 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

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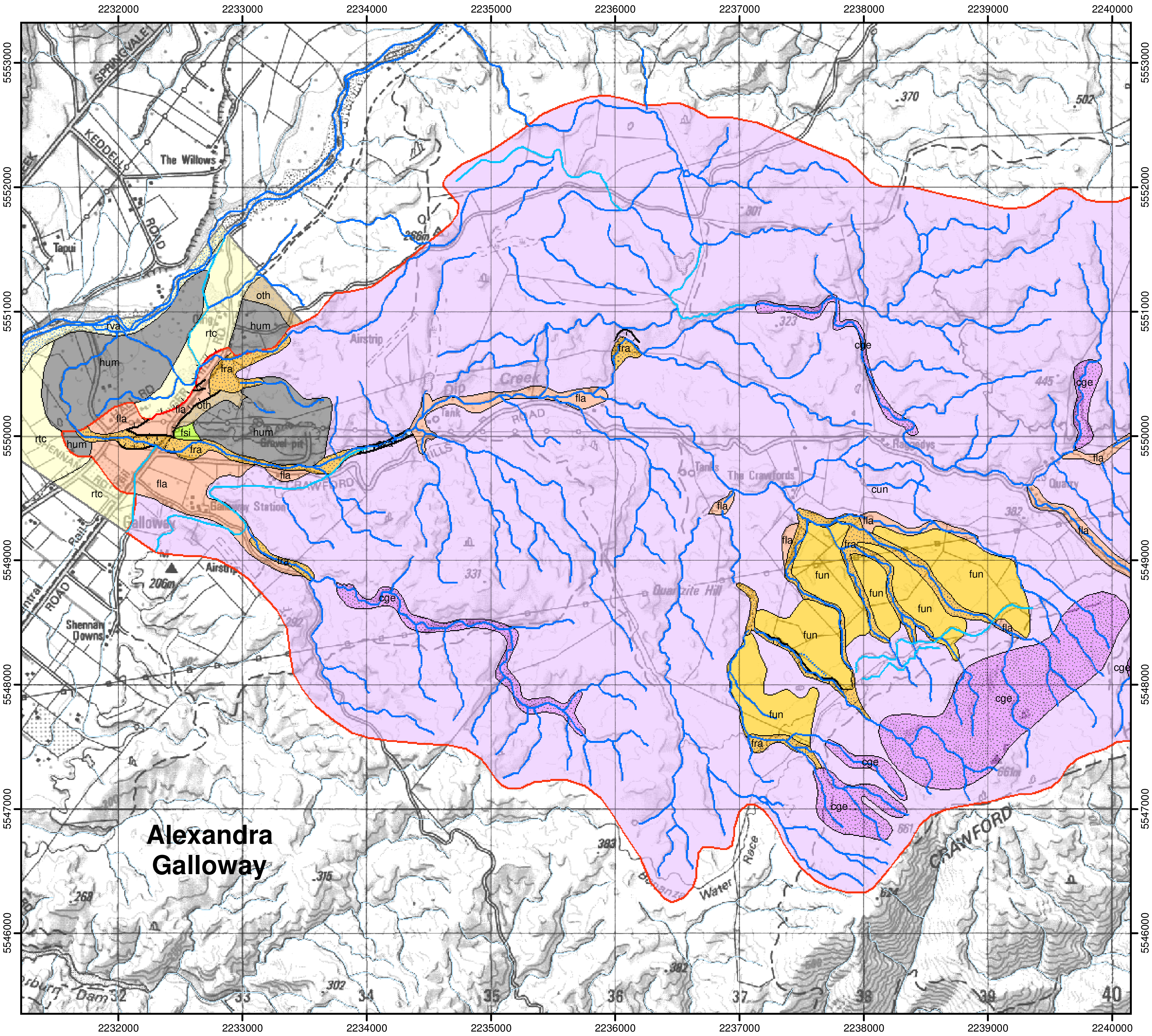


OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

ALEXANDRA (Omeo Creek) area – summary assessment

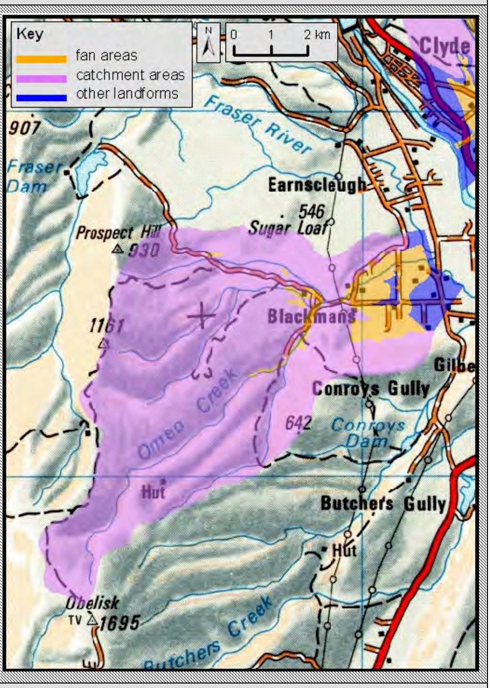
A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies in the southwestern corner of the Alexandra basin, and comprises the catchment and fan of Omeo Creek. The catchment drains the Obelisk Range, and the fan is built out onto the Fraser River plain.

The Obelisk Range is formed in a tectonically uplifted block of ancient schist bedrock. Eroding bedrock in the catchments has fed sediment onto the Omeo alluvial fan. The Alexandra area lies well outside the extents of Ice Age glaciers, but the Clutha valley has undergone periods of river gravel build-up, and subsequent erosion, in response to Ice Age advances and retreats of glaciers farther upstream. Episodes of fan building have been interrupted by periods when the Fraser or the Clutha rivers eroded the toe of the fan and carried fan sediment away down-valley. Landforms in the assessment area span a wide range of ages.

Annual precipitation at Blackmans is between 400 and 450 mm/yr, increasing with altitude to between 900 and 1,000 mm/yr at Obelisk (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series.
Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: The floors of the valley and of gullies close to modern stream levels, and the toe area of the fan where it is built out towards the Fraser River, are judged likely to have experienced flooding and sedimentation within the past few hundred years.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Orchards, pasture, and stream-side trees. Land-use includes horticulture, pastoral farming and some large-holding residential.

B3. EXISTING INFRASTRUCTURE: minor roads, houses, farm buildings, orchards and irrigation dams.

B4. EXISTING CONTROL WORKS: Minor channelization of streams.

B5. TYPES OF FAN: Terraced. Predominant processes are flooding and sedimentation.

B6. CONDITIONS AT TOE OF FAN: The fan from Omeo Creek extends out to the Fraser River. Any sediment reaching the fan toe is likely to be carried away downstream by the Fraser River, maintaining a general state of equilibrium. On its fan, Omeo Creek is confined to a narrow channel, and any increases in its sediment load may cause aggradation of this channel, and possible break-out onto its fan, unless sediment is removed mechanically.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Some areas of gullied terrain and some landslides.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass with some scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the top of the catchment to the head of the terraced fan complex is about 1,400 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

At Hawley Road, Omeo Creek flows (from right to left) in a narrow 2 m deep, tree-lined channel. The straightness of the channel suggests that it is an engineered ditch, formed as part of the early agricultural development of the valley. Immature soils on the valley floor indicate that prior to its channelization, Omeo Creek flowed unconfined on the valley floor. In the left distance is the rise up to an abandoned terrace of the Omeo fan, isolated far above the level of recent fan activity *(GNS Science photo)*.

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

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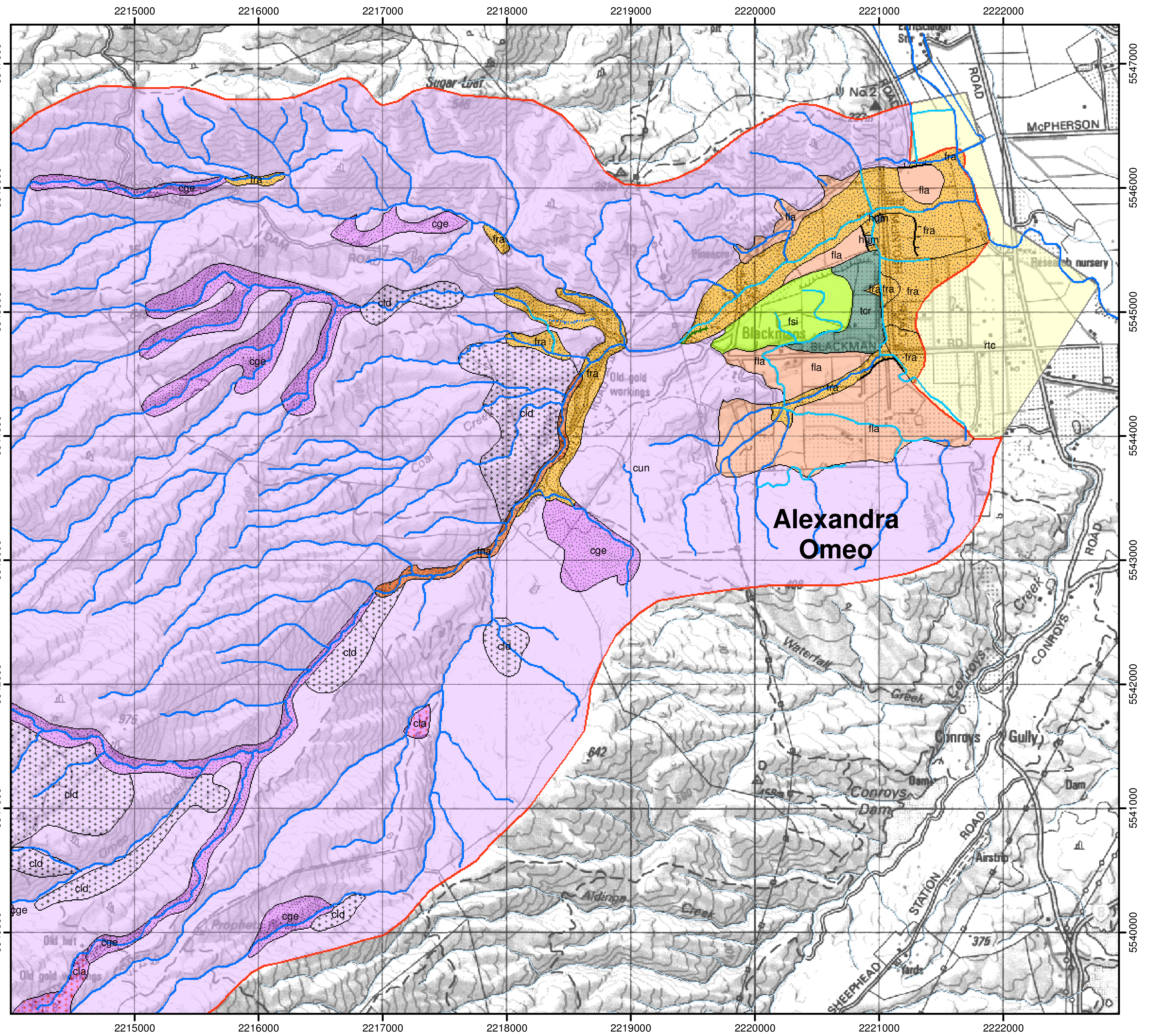


OTAGO REGIONAL COUNCIL ALLUVIAL FAN HAZARDS

ROXBURGH area – summary assessment

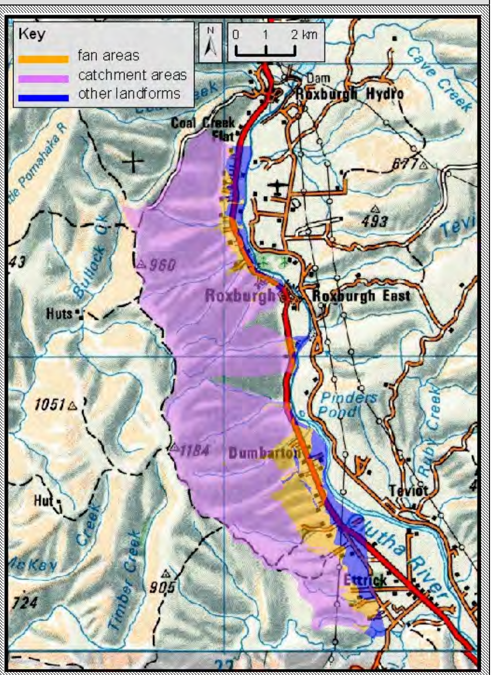
A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies on the eastern flank of the Old Man Range, west of the Clutha River, from Coal Creek Flat south as far as Benger Burn near Ettrick. It includes Roxburgh township and the Dumbarton area.

The Old Man Range is formed in a tectonically uplifted block of ancient schist bedrock. Eroding bedrock in the catchments has fed sediment onto alluvial fans that have built out onto terraces of the Clutha River. The Roxburgh area lies well outside the extents of Ice Age glaciers, but the Clutha valley has undergone periods of river gravel build-up, and subsequent erosion, in response to Ice Age advances and retreats of glaciers farther upstream. Episodes of fan building have been interrupted by periods when the Clutha River eroded the toes of the fans and carried fan sediment away down-valley. Landforms in the assessment area span a wide range of ages.

Annual precipitation at the valley floor is about 500 mm/yr at Roxburgh, increasing southward to about 600/ mm/yr at Ettrick. Precipitation also increases with altitude, and is more than 900 mm/yr at Mt Benger, the highest point at the heads of the fan catchments (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: North of Roxburgh, the fans are built onto river terraces and the streams are barely incised into their fans. Lack of incision coupled with immaturity of soils indicates that most parts of these fans have experienced flood sedimentation within the past few hundred years. Localised break-out of water and sediment from the streams has occurred historically in this area. Further south, the fans descend with an even gradient to the Clutha River, or the river is trimming their toes. Their streams flow in valleys incised into the fans, or on a well-established course on the fan surface. The degree of incision and amount of soil maturity indicates that only those parts of the fan close to the present streams have been subject to flood sedimentation within the past few hundred years.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture, orchards, minor scrub and stream-side trees. Land-use is predominantly pastoral farming or horticulture, with some large-holding residential.

B3. EXISTING INFRASTRUCTURE: State Highway 8, minor roads, parts of Roxburgh township, houses, farm buildings, orchards and associated irrigation dams.

B4. EXISTING CONTROL WORKS: Most streams are channelized, such as the concrete channel of Reservoir Creek (Roxburgh township). Some have training embankments, such as the gravel levees confining Slaughterhouse Creek.

B5. TYPES OF FAN: Range from aggradational (e.g. fans north of Slaughterhouse Creek), equilibrium (e.g. Slaughterhouse Creek, Reservoir Creek, Stevenson Creek (Dumbarton), to terraced (e.g. fan at Roxburgh golf club, Black Jacks Creek). Around Dumbarton, there are extensive areas of high fan terraces that were built onto an old, high terrace of the Clutha River. These fan terraces have long been isolated from fan sedimentation.

Predominant processes are flooding and sedimentation. In addition, debris flows may occur near the heads of the fans or within incised channels.

B6. CONDITIONS AT TOES OF FANS: Conditions vary depending on the proximity of the Clutha River channel to each fan. North of Roxburgh, the river is on the eastern side of its valley floor, and the fans are building out onto an extensive river terrace. Any sediment brought down from these fan catchments will accumulate on the fans, unless removed mechanically.

From Slaughterhouse Creek southwards, the Clutha River lies closer to the western side of its valley, and has partly trimmed the toes of the fans, causing the lower reaches of the stream channels to incise slightly into their fans. Under present conditions these streams are in approximate equilibrium, and providing their channels are wide enough and steep enough to transport the sediment delivered from their catchments, the Clutha River will maintain their equilibrium by carrying the sediment away down-valley. Disruption of this equilibrium could occur through an increase in sediment load of a stream or by migration of the active channel of the Clutha River. Either of these scenarios could occur as a result of natural or human activity.

South from Dumbarton, the Clutha River migrates away to the eastern side of its valley, and an extensive river terrace widens out towards Ettrick. In this area, fans are built out onto this terrace, and are in aggradational states. Any sediment that comes down from their catchments will accumulate on the fans, unless removed mechanically. However, in this area, the sizes and heights of the catchments decrease southward, and commensurately, the rates of fan building progressively diminish. This explains why these fans are much smaller than those at Dumbarton, despite all these fans having begun to form at the same time, when the Clutha River abandoned the river terrace on which the fans lie.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: North from Dumbarton, many areas of gullied terrain and some landslide areas. At Dumbarton, extensive landslide areas in the catchments. South from Dumbarton, few areas of either gullied terrain or landslides.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass with some scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is about 1,000 m in the centre of the assessment area, progressively decreasing both north and south to about 600 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

North of Roxburgh township, the character and behaviour of alluvial fans depends on where they lie in relation to the Clutha River. In the foreground, the river flows close to the foot of the hill and the fans (white lines) extend to the water's edge. Sediment brought down from the fan catchments is delivered to the river, and from there carried away down-valley. This allows the fans to exist in a state of equilibrium – whatever sediment comes down their streams is taken away naturally by the river. In places the river has cut away at the toes of the fans, forcing the stream flowing down the fan to incise a valley, which grades to the river's edge, creating a terraced fan.

In the distance, a wide river terrace occupies the valley floor. Aggradational fans (black lines) are building out onto this terrace, but have not yet extended all the way out to where the river is. Sandy and gravelly sediment brought down from these catchments will build up on these fans unless it is removed mechanically *(GNS Science photo)*.

West of State Highway 8, near Coal Creek Flat north of Roxburgh, a classic aggradational fan (black lines) radiates out from the mouth of moderate-sized catchment (blue arrow), onto an abandoned terrace of the Clutha River (fore- and mid-ground). The fan has no well-defined stream channel on it. Ever since the Clutha River abandoned this river terrace, there has been no natural means of removing the sediment brought down from the fan catchment. Large embankments of gravel (yellow) create an artificial channel for the stream, extending from the mouth of the catchment (see below) *(GNS Science photo)*.

Looking up the artificial channel seen in the photo above. The fan is very small (6 ha) for the size of its catchment (140 ha). The most likely explanation for this is that there have been few areas of active erosion (i.e. places where sediment is produced) in this catchment since the fan began to form. The construction of this substantial channel was presumably motivated by flooding problems associated with this catchment. This channel is likely to be effective for conveying floodwater, but its gradient is too gentle to allow transport of gravel. Any gravel or sand brought down from the catchment will accumulate in this channel, and would need to be removed mechanically in order to maintain the channel's floodwater-carrying capacity *(GNS Science photo)*.

A steep concrete-lined channel conveys Reservoir Creek though the Roxburgh urban area. The Reservoir Creek fan is graded to the Clutha River. It is essentially in equilibrium, though the Clutha River has trimmed the toe of the fan. The house is built on the fan terrace at the top of the river-trimmed terrace riser (O*pus photo)*.

	Gravel embankments up to 4 m high constrain the course of Slaughterhouse Creek on the centre of its fan, above State Highway 8. This fan is in an equilibrium to aggradational state. Its channel gradient is far less than that of Reservoir Creek. This reduces its capacity to carry gravelly sediment. Such sediment is likely to build up in this channel, and require manual removal *(GNS Science photo)*.
	At Stevenson Creek, Dumbarton, sediment has aggraded upstream of the State Highway 8 bridge, and historically has spread across the road during floods. Gravel from the stream channel has been formed into rough bunds either side of the channel. Stevenson Creek is an equilibrium fan graded to the Clutha River. The stream flows in a shallow channel on the surface of its fan, and immature soils occur only close to its present channel. This suggests that the stream channel width and gradient are about right for transporting the sediment carried during floods in this stream, and has been so for the past many hundreds of years. The sediment build-up illustrated here is therefore at odds with the long-term behaviour of this stream, and may possibly be attributable to human activities related to the highway *(GNS Science photo)*.

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
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- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
(Crown copyright reserved)

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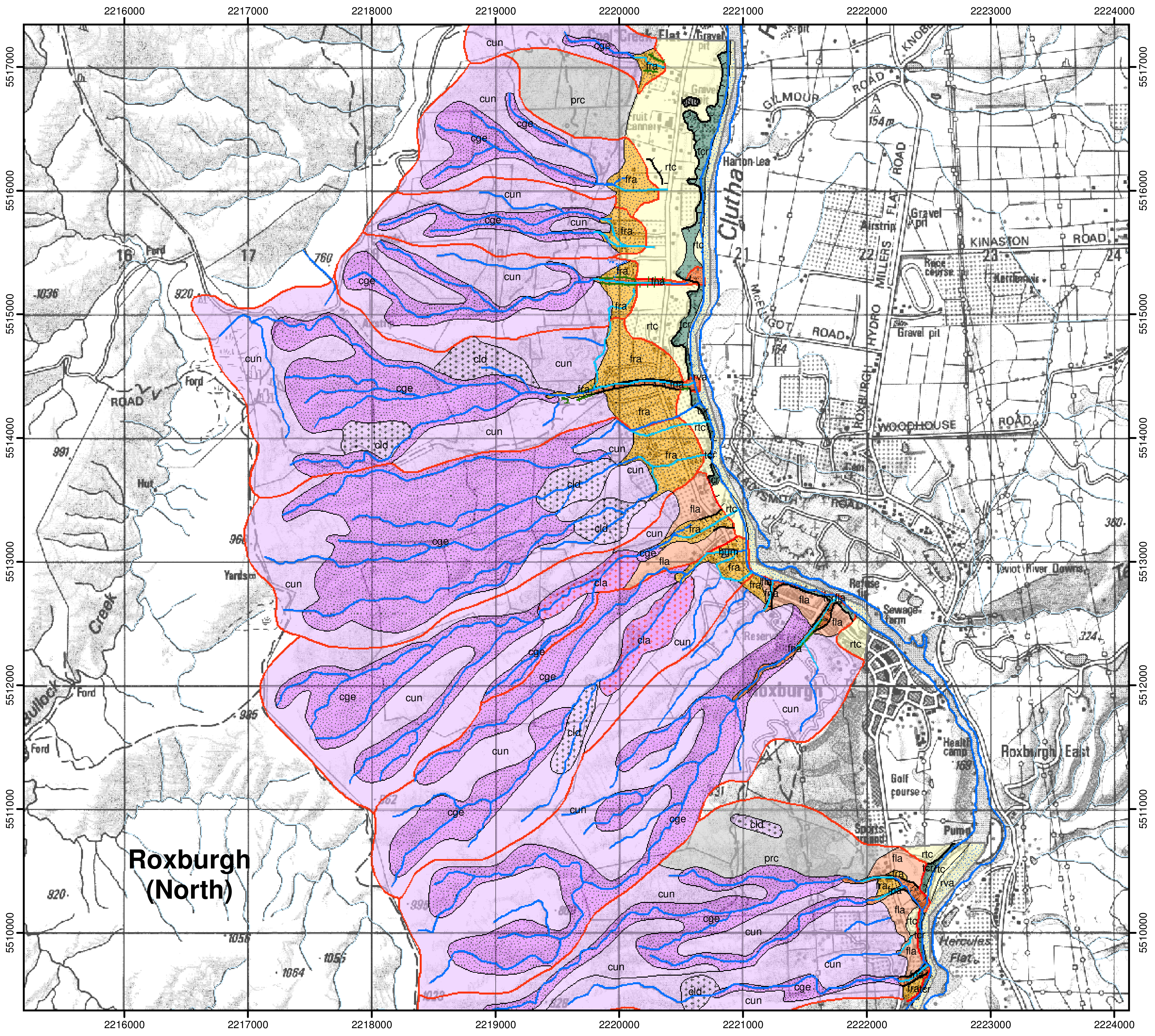

Alluvial Fans Map Legend

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CHANNEL TYPE

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- artificial
- recently active
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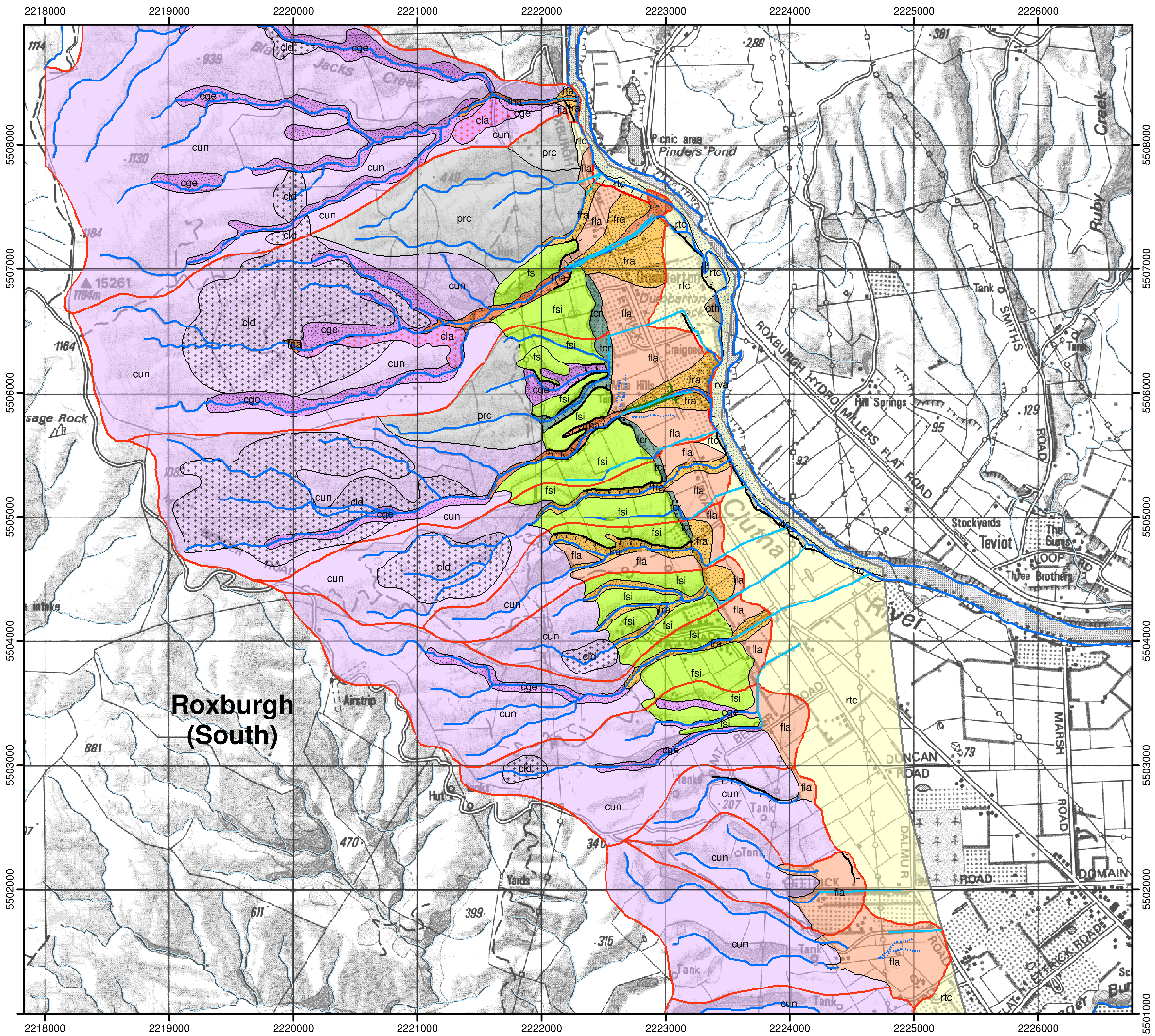


OTAGO REGIONAL COUNCIL
ALLUVIAL FAN HAZARDS

TAPANUI area – summary assessment

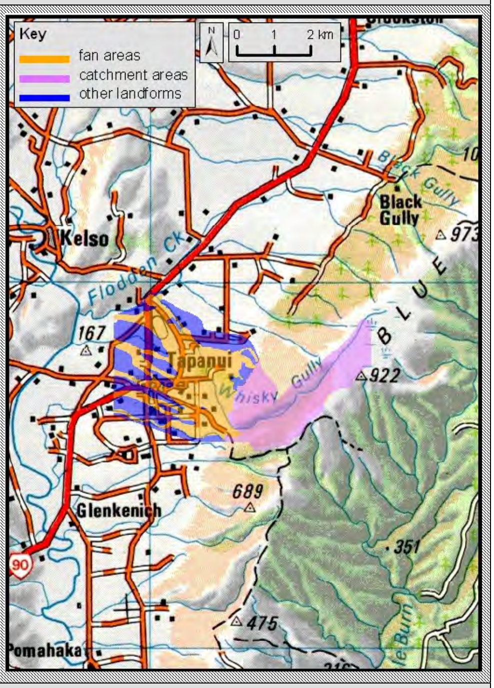
A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies at the northwestern margin of the Blue Mountains. It comprises Tapanui township and its immediate outskirts, on the eastern side of the valley of the Pomahaka River and Flodden Creek.

The Blue Mountains are formed in a tectonically uplifted ancient greywacke and semi-schist bedrock. The landscape of the valley is dominated by low hills and ridges dissected by broad gullies. Eroding bedrock in the Whisky Creek catchment has fed sediment onto an alluvial fan that has built out into the valley. Parts of the toe of the fan have spread down valleys within the hill-and-ridge landscape. Landforms in the assessment area span a wide range of ages.

Annual precipitation at Tapanui is between 900 and 1,000 mm/yr, increasing with altitude to more than 1,200 mm/yr at the head of the Whisky Gully catchment (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fan

B1. EVIDENCE OF PAST ACTIVITY: Whisky Gully is incised into the head of its fan, and now flows along the northern margin of its fan. The fan surface has mature soils, indicating that there has been little or no flooding or sedimentation within at least the past few hundred years, except close to the present stream channels. Although the floors of the main gullies could experience surface flooding in extreme rainstorms, the central to southern parts of the fan have long been isolated from alluvial fan flooding and sedimentation.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture, minor scrub and stream-side trees, minor exotic forestry. Land-use is predominantly pastoral farming, the Tapanui urban area and some large-holding residential.

B3. EXISTING INFRASTRUCTURE: roads, parts of Tapanui township, houses and farm buildings.

B4. EXISTING CONTROL WORKS: Adjacent to the old sawmill in Cameron Road, Whisky Gully flows in an artificial channel.

B5. TYPE OF FAN: The majority of the fan surface was formed at a time in the past when the fan was in an aggradational condition. It is presently in an equilibrium condition. Predominant processes are flooding and sedimentation.

B6. CONDITIONS AT TOE OF FAN: The narrow zone of immature soils alongside the active stream indicates that under present conditions, the sediment delivered from the catchment is being transported down the fan, with no net accumulation. Presumably, Flodden Creek has been able to carry away whatever sediment is brought down Whisky Gully.

Factors that could change the equilibrium condition include an increase is sediment from the catchment, due for instance to landslide movement, or human intervention in the stream channel that reduces its capacity to transport sediment.

C. Nature of the fan catchment

C1. CHARACTER OF SLOPES: Minor areas of gullied terrain.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Forest, scrub, grass.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the top of the catchment to the head of the fan is about 600 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

- fna - fan active bed
- fra - fan recently active
- fla - fan less recently active
- fge - fan gully erosion
- fun - fan undifferentiated
- fsi - fan stabilised isolated
- tcr - terrace riser
- cca - catchment channel active
- cge - catchment gully erosion
- cas - catchment active scree
- cla - catchment landslide active
- cld - catchment landslide creeping
- cst - catchment long stabilised
- cun - catchment undifferentiated
- prc - catchment peripheral
- bra - beach ridge active
- brs - beach ridge stabilised
- rtc - river terrace
- rva - river active bed
- lba - lake bed abandoned
- hum - human modified
- oth - other
- water

LANDFORM BOUNDARY

- contact
- map border
- terrace edge
- artificial
- fault scarp base
- fault scarp crest
- perimeter
- artificial perimeter
- terrace perimeter

CHANNEL TYPE

- active
- artificial
- recently active
- less recently active
- unclassified

Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
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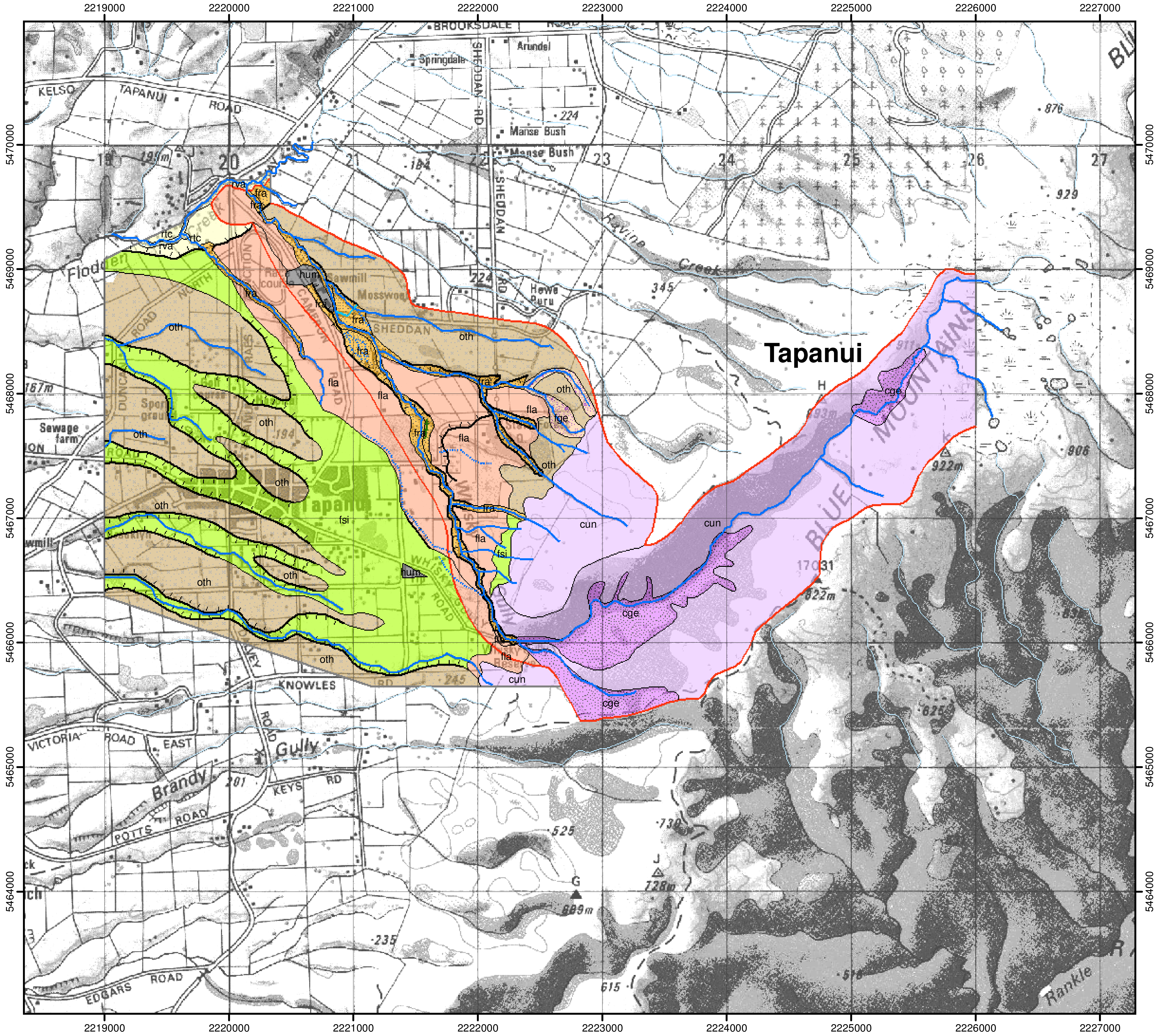
0 0.5 1 2 Km



OTAGO REGIONAL COUNCIL ALLUVIAL FAN HAZARDS

MIDDLEMARCH area – summary assessment

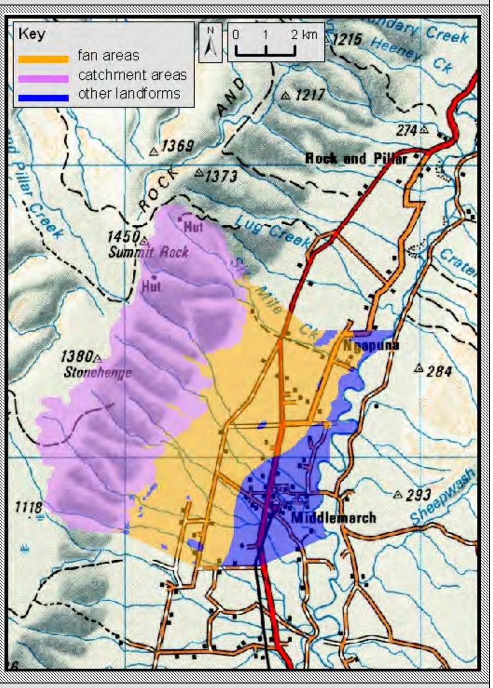
A. Extent and nature of the assessment area

DESCRIPTION:

The assessment area lies on the southeastern flank of the Rock and Pillar Range, on the west side of the Strath Taieri plain of the Taieri River. It includes Middlemarch township.

The Rock and Pillar Range is formed in a tectonically uplifted block of ancient schist bedrock. The landscape of the Strath Taieri is dominated by river terraces, with a few rocky outcrops of schist protruding from the plain. Eroding bedrock in the catchments has fed sediment onto a series of overlapping alluvial fans that have built out onto the river terraces. The fans merge almost imperceptibly with the river terraces and it is difficult to be sure where the fans end and the terraces start. Landforms in the assessment area span a wide range of ages.

Annual precipitation at Middlemarch is a little more than 500 mm/yr, increasing with altitude to more than 1,200 mm/yr at the heads of the catchments (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation:	Oct 2008
Field Check:	Jan 2009
Revisions:	

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: Most parts of the fans have mature soils, indicating that there has been little or no flooding or sedimentation within at least the past few hundred years, except close to the present stream channels.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture, minor scrub and stream-side trees. Land-use is pastoral farming.

B3. EXISTING INFRASTRUCTURE: State Highway 87, minor roads, houses and farm buildings. Middlemarch township is on river terraces, just outside the fan areas.

B4. EXISTING CONTROL WORKS: minor channelization of some streams.

B5. TYPES OF FAN: The majority of the fan surfaces were formed at a time in the past when the fans were in an aggradational condition. They are presently in an equilibrium condition, with streams incised at the fan heads (giving the fan heads a terraced appearance), and flowing on the fan surfaces towards the toe areas. Predominant processes are flooding and sedimentation, although debris flows were a prominent feature of some of the fans when they were last in an aggradational condition, judging by the large boulders on parts of the fan surfaces.

B6. CONDITIONS AT TOES OF FANS: Only the Six Mile Creek fan is built out as far as the Taieri River. This is the only fan whose sediment can be carried away from the fan. The other fans terminate on abandoned river terraces. Consequently, any sediment that comes down from their catchments will accumulate on the fans. The very limited extent of immature soils indicates that not much sediment has come down these stream systems in the recent past. This means that the streams are, in effect, in equilibrium, but would become aggradational if sediment supplies increased.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Many areas of landslide terrain and some gullied terrain.

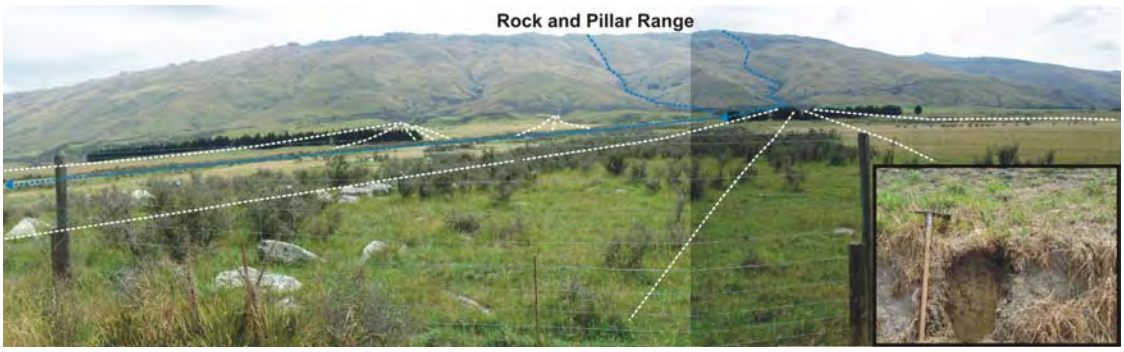
C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass and minor scrub.

C3. TOPOGRAPHIC RELIEF: Total elevation change from the tops of the catchments to the heads of the fans is between about 600 m and 1,000 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:



Looking northwest from McKinnon Road, the large fan radiating out (white lines) from the catchment of Dewar Stream (blue arrows) in places has a bouldery surface (left). Boulders of this size so far out from the catchment suggest that in times past, debris flows have been generated from this catchment and have spread down the fan. Extensive boulder fields also occur on the fan of Six Mile Creek, whose catchment is visible at far right), indicating that debris flows have also been a feature of the Six Mile Creek area. Right of centre, smaller fans radiate out from the March Creek catchment.

Most parts of these fans have mature soils. An example of a mature yellow-brown soil profile developed in a silty sediment is shown in the inset. This photo is from a site on the Dewar Stream fan about 1 km north of the photo panorama location. This degree of soil development indicates that it has been some time (at least several hundred years) since sediment was deposited at this location. The widespread mature soils on the fans of the Middlemarch area indicate that the fans are not actively growing at the present time, and recent activity has been limited to areas close to the present stream channels. The reason(s) for the differences in behaviour over time is not known. Perhaps episodes of fan-building occurred during times of cooler Ice Age climates, or coincided with episodes of landslide activation in the catchments *(GNS Science photos)*.

D3. COMMENTS:

Alluvial Fans Map Legend

LANDFORM TYPE

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- fra - fan recently active
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LANDFORM BOUNDARY

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CHANNEL TYPE

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- recently active
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Drawn from ArcMap GIS dataset
Geodetic Datum NZMG 1949
Base Map LINZ NZMS 260 series
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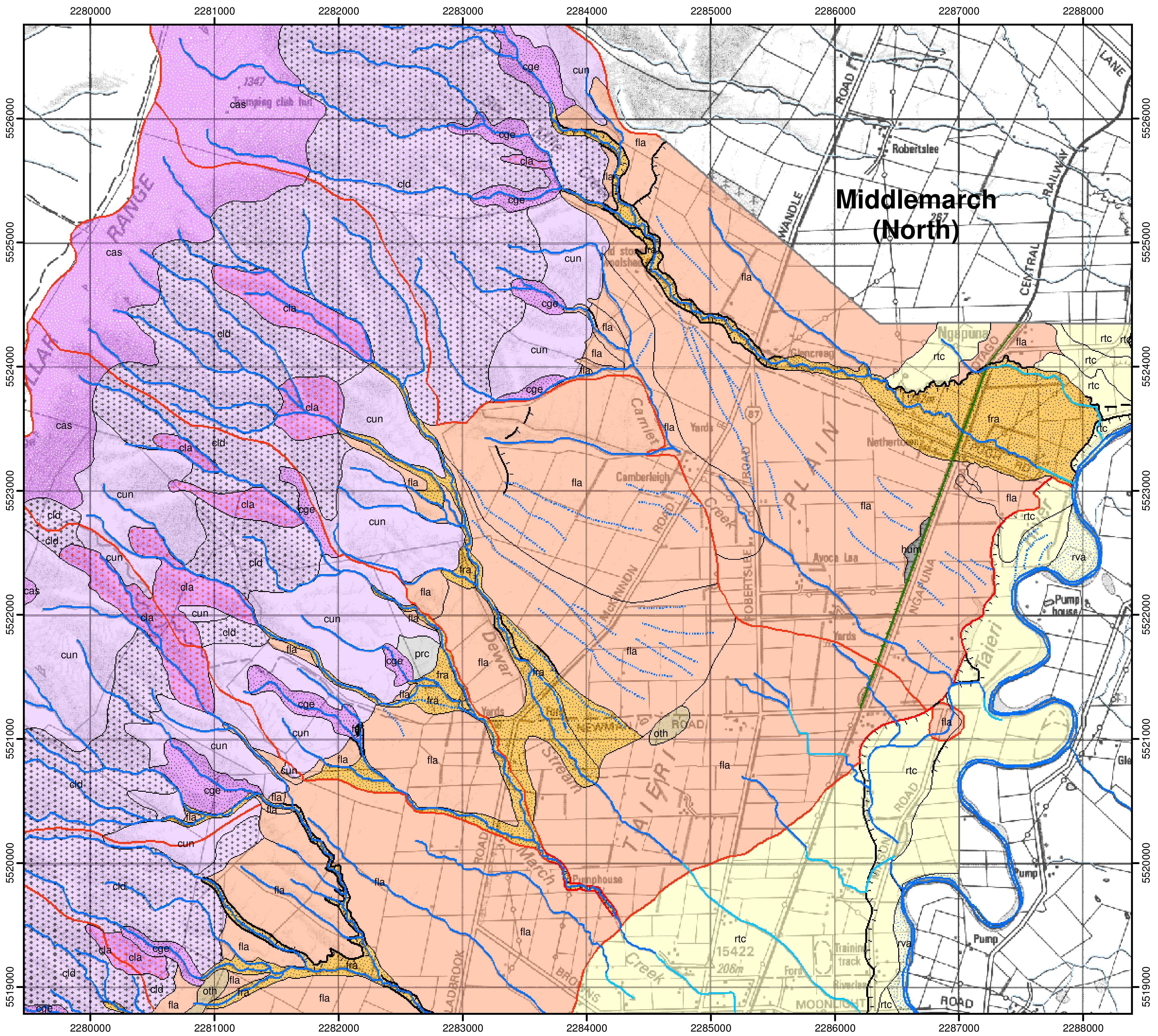

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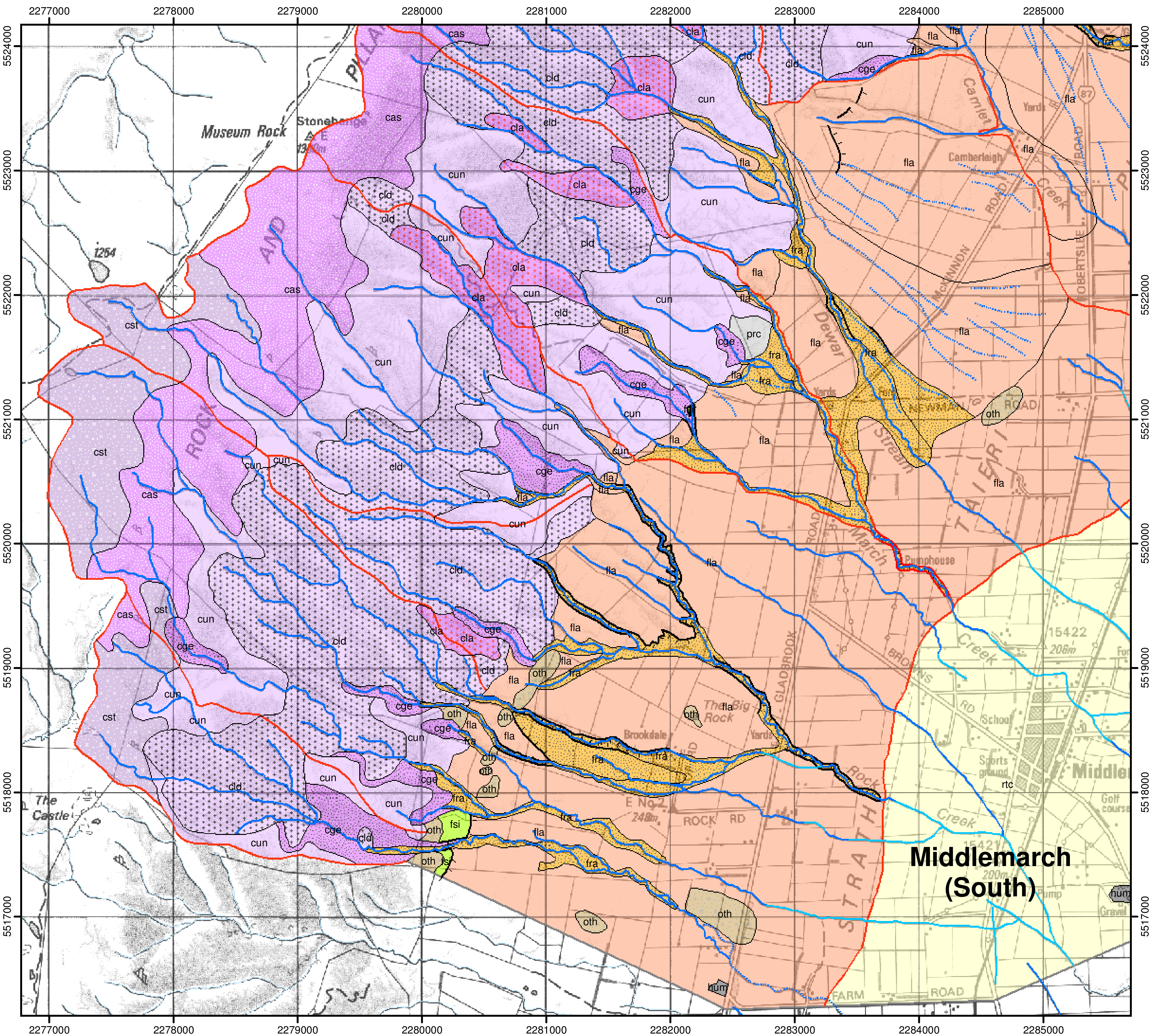


OTAGO REGIONAL COUNCIL ALLUVIAL FAN HAZARDS

OAMARU area – summary assessment

A. Extent and nature of the assessment area

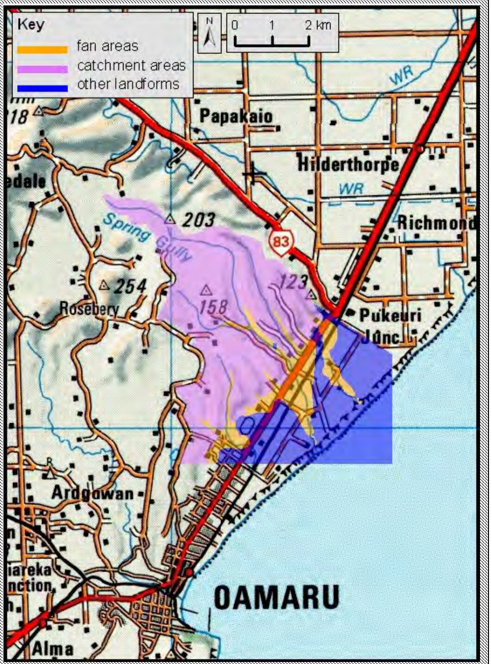
DESCRIPTION:

The assessment area comprises the high terrace and coastal plain north of Oamaru. It includes the northernmost parts of Oamaru township and its outskirts. The largest stream is Landon Creek.

The high terrace is formed on ancient sedimentary rocks, including sandstone and limestone, and very old river gravel. The terrace is dissected by a network of valleys and gullies. In many parts of the catchments there is a mantle of yellow windblown silt (loess) up to several metres thick. The southeast margin of the terrace is an ancient sea cliff. During the last Ice Age, when sea levels were much lower than present, the Waitaki River built a vast fan of river gravel, part of which forms the Waitaki plains. These plains extended southwest of Pukeuri around the front of the old sea cliff and down to Oamaru.

After the Waitaki River abandoned the Waitaki plains and became confined to its present channel near Glenavy, erosion in the catchments of the valleys draining the high terrace fed sediment onto small alluvial fans that built out onto the margin of the Waitaki plains. Following the last Ice Age, which ended about 18,000 years ago, the sea reached its present level about 7,000 years ago, and waves began eroding the edge of the Waitaki plains. The landward migration of the sea cliff is affecting the behaviour of streams draining the larger fans.

Annual precipitation at Oamaru is about 500 mm/yr (growOTAGO).



LOCATION MAP

Base map from LINZ NZMS262 series. Crown copyright reserved.

Aerial Photo Interpretation: Oct 2008

Field Check: Jan 2009

Revisions:

B. Nature of the alluvial fans

B1. EVIDENCE OF PAST ACTIVITY: In most places, the streams are barely, if at all, incised into their fans. It is judged likely that most parts of their surfaces have been subject to flooding and possibly minor sedimentation within the past few hundred years.

B2. EXISTING TYPES OF VEGETATION/LAND-USE: Pasture and stream-side trees. Land-use includes pastoral farming, large-holding residential and urban.

B3. EXISTING INFRASTRUCTURE: State Highway 1, parts of Oamaru township, minor roads, houses and farm buildings. The Oamaru urban effluent-to-land farm lies just beyond the fan areas.

B4. EXISTING CONTROL WORKS: Minor channelization of most streams. There is a dam on Landon Creek 1 km upstream of the highway; its age and purpose are not known.

B5. TYPES OF FAN: Aggradational to equilibrium. The sediments in the fans are largely silty, as they are derived from the erosion of loess in the catchments. Predominant processes are flooding and minor sedimentation.

B6. CONDITIONS AT TOES OF FANS: The largest stream, Landon Creek, has a slot channel several metres deep down its fan. The stream then descends a deep gully cut in the coastal cliff to the beach. Whether this channel on its fan is natural or engineered is not known. The stream appears to be in approximate equilibrium across its fan. The dam on the creek is currently acting as a trap for sediment. The other fans are built out onto the Waitaki plain. Most do not have well-defined channels, and their flows are diverted to ditches or stormwater reticulation. Any sandy or gravelly sediment that comes down from the catchments is likely to build up in their channels, or spread onto their fans, unless removed mechanically.

C. Nature of the fan catchments

C1. CHARACTER OF SLOPES: Extensive gullied terrain on the valley sides.

C2. EXISTING TYPES OF VEGETATION/LAND-USE: Grass and minor scrub.

C3. TOPOGRAPHIC RELIEF: Maximum elevation change from the tops of the catchments to the heads of the fans is about 200 m.

D. Additional information

D1. EXISTING REPORTS: None known.

D2. ILLUSTRATIONS:

D3. COMMENTS:

Alluvial Fans Map Legend

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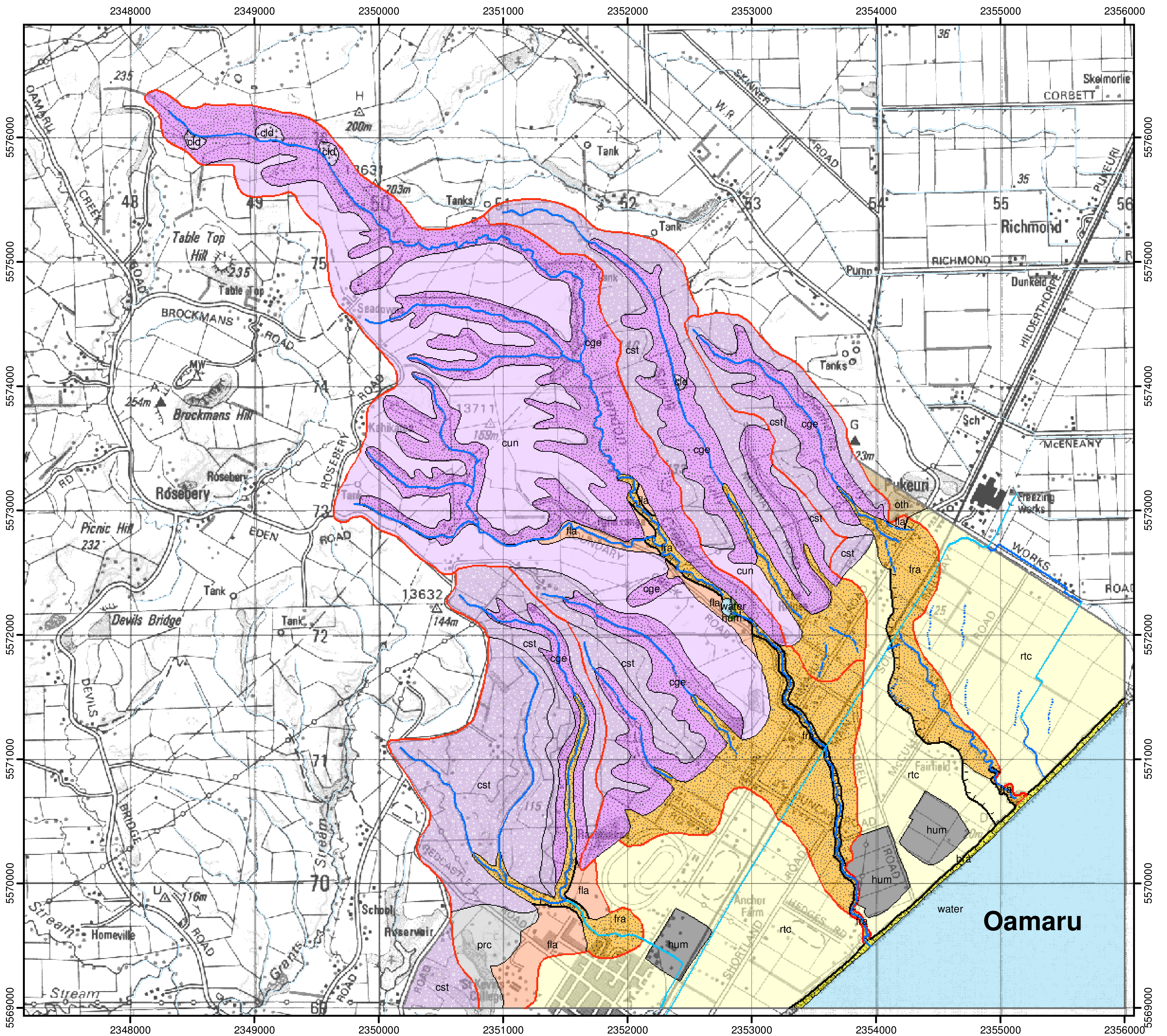

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Dunedin
New Zealand
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F +64-3-477 5232

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Wairakei
Private Bag 2000, Taupo
New Zealand
T +64-7-374 8211
F +64-7-374 8199

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Lower Hutt
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F +64-4-570 4657