Natural Hazards at Glenorchy

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Executive Summary

Glenorchy and its environs have a complex hazard setting. In fact, the sediments which Glenorchy is entirely located upon have been deposited as a result of hazardous debris and flood flows originating from the Buckler Burn. The community's exposure to the range of identified hazards, which include river and lake flooding, seismic hazards and mass movement, is defined by their nature, magnitude and frequency. This document identifies each hazard and the implications for the community based on current knowledge.

Flood hazards within the vicinity of Glenorchy vary in magnitude and nature. Inundation from high levels of Lake Wakatipu pose a risk to the community where these levels can remain for prolonged periods; usually days and sometimes weeks. High lake levels have been well documented and most recently impacted the community during November 1999.

Flood hazards derived from the Rees River include inundation, advancement of the delta and the lateral migration of channels towards the township or lagoon due to significant aggradation[1]. The Dart River, while not posing a direct risk to Glenorchy, does have secondary effects by contributing substantial flood flows into Lake Wakatipu resulting in higher lake levels for extended periods.

The Buckler Burn and Bible Stream flood hazards are typical of sediment-laden alluvial fan debris and flood flows. The Buckler Burn can aggrade significantly, as observed in November 1999, with significant potential to migrate laterally and possibly flow down the main road into the southern end of Glenorchy. The Bible Stream deposits debris and floodwaters towards parts of the township and has the potential to flood the eastern margins of the community.

Seismic hazards in the form of ground-shaking and liquefaction pose a risk to the community due to its proximity to the Alpine Fault and other regional faults, such as the Nevis-Cardrona Fault. During a large Alpine Fault earthquake (~M_w8.0)[2] Glenorchy may experience up to two minutes of ground shaking, liquefaction and/or lateral spread towards the lake. Also, waves generated by seismically-induced seiche (sloshing waves within the lake) have the potential to travel overland and into the township.

The isolation of the community due to rockfall or landslides on the Queenstown-Glenorchy Road is the most likely effect resulting from mass movements. In addition, landslide-induced waves in Lake Wakatipu may also impact Glenorchy. The most likely scenarios include a large landslide entering the lake from the valley sides, or a landslide event occurring beneath the lake

[1] Refer to glossary for definition

[2] An earthquake with an approximate magnitude of 8.0

surface. Both of these scenarios have the potential to generate large waves due to the displacement of water.

The frequency and magnitude of flood hazards is likely to increase due to predicted changes in rainfall patterns as a result of climate change. This will lead to an increase in the susceptibility and ultimately risk to the Glenorchy community. Additional intensification or development in hazard prone locations would amplify this risk further.

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1. Introduction

Located at the northern end of Lake Wakatipu, Glenorchy is a small township originally established by scheelite miners during the mid-to-late 19th century. While land uses within the region have included merino sheep farming and timber milling, more recently Glenorchy has become a gateway community to adventure tourism activities, such as high country tramping, kayaking and scenic sightseeing. The township is mainly comprised of residential and tourism-based operations as well as a primary school, Department of Conservation offices, and other community amenities (Figure 1.1).

Figure 1.1 Parts of Glenorchy from the air (left) and the Bible terrace (right). Newly formed and planned residential subdivisions can be seen in both photographs. Left photograph courtesy of GNS Science

Glenorchy's close proximity to popular attractions, such as the Routeburn track, and better accessibility, through improvements to the Queenstown-Glenorchy Road, has seen its residential population increase substantially over recent decades. The Queenstown-Lakes District Council (QLDC) projects that by the year 2029 the residential population of Glenorchy will have increased to 736 while peak-day population is estimated to double from 1,100 people in 2001 to 2,200 by 2029. Accordingly, the number of residential dwellings is also projected to increase from 170 in 2006 to 409 by 2029[3], as illustrated in Figure 1.2. The growing population of Glenorchy and associated development increases the level of human exposure to the surrounding hazards.

[3]Population and dwelling statistics sourced from: http://www.qldc.govt.nz

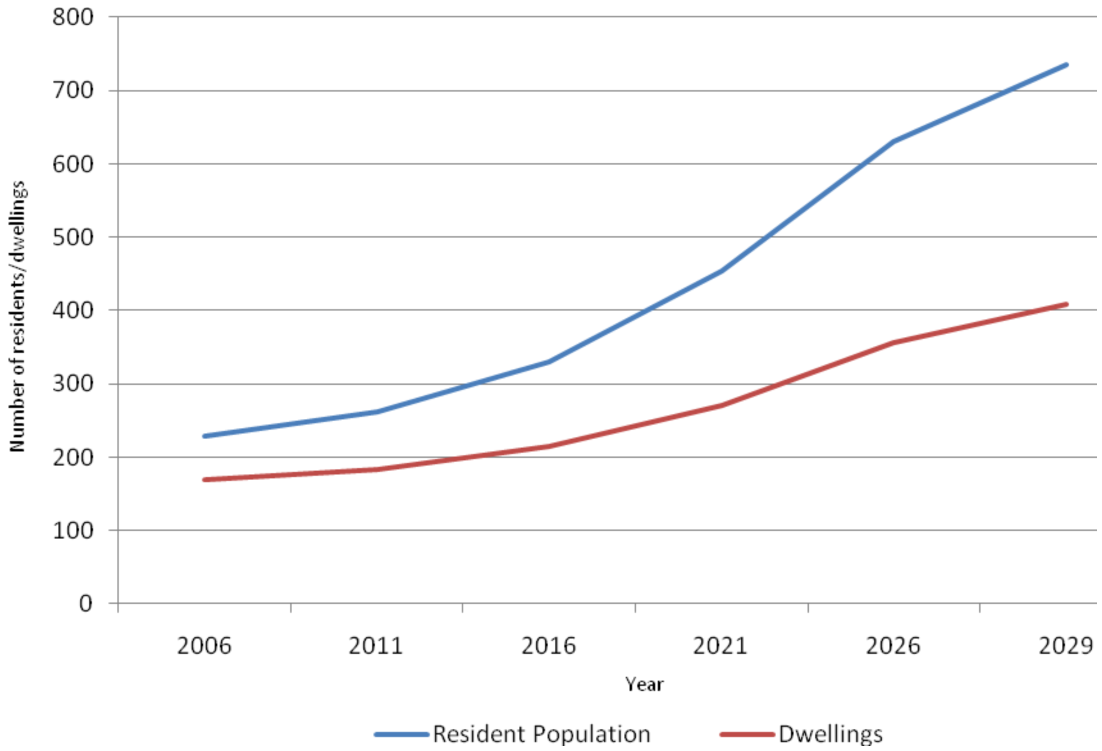

Figure 1.2 Projected resident/dwelling Growth for Glenorchy Source: ***www.qldc.govt.nz***

Glenorchy and its environs have a complex hazard setting, being exposed to inundation from high levels of Lake Wakatipu as well as debris flows and flooding from the Buckler Burn, Bible Stream and the Rees and Dart Rivers. Furthermore, mass movement and seismic hazards, generated by earthquakes, have the potential to affect not only the township but infrastructure and access routes that the community is dependent upon (Figure 1.3).

Glenorchy's remote location, in a geologically active alpine area, raises the community's risk profile due to the potential for isolation or direct impact from a number of natural hazards. Further intensification or spread of development onto the community's fringes will increase this risk, and this will be compounded by climate change. Therefore, Glenorchy's increasing population, coupled with the dynamic and changing nature of its surrounding environment, has prompted this study[4] to raise awareness of the community's vulnerability and surrounding hazardscape (Figure 1.4), and to inform decision-making in this regard.

[4]This study has been informed by and elaborates on a number of existing technical reports.

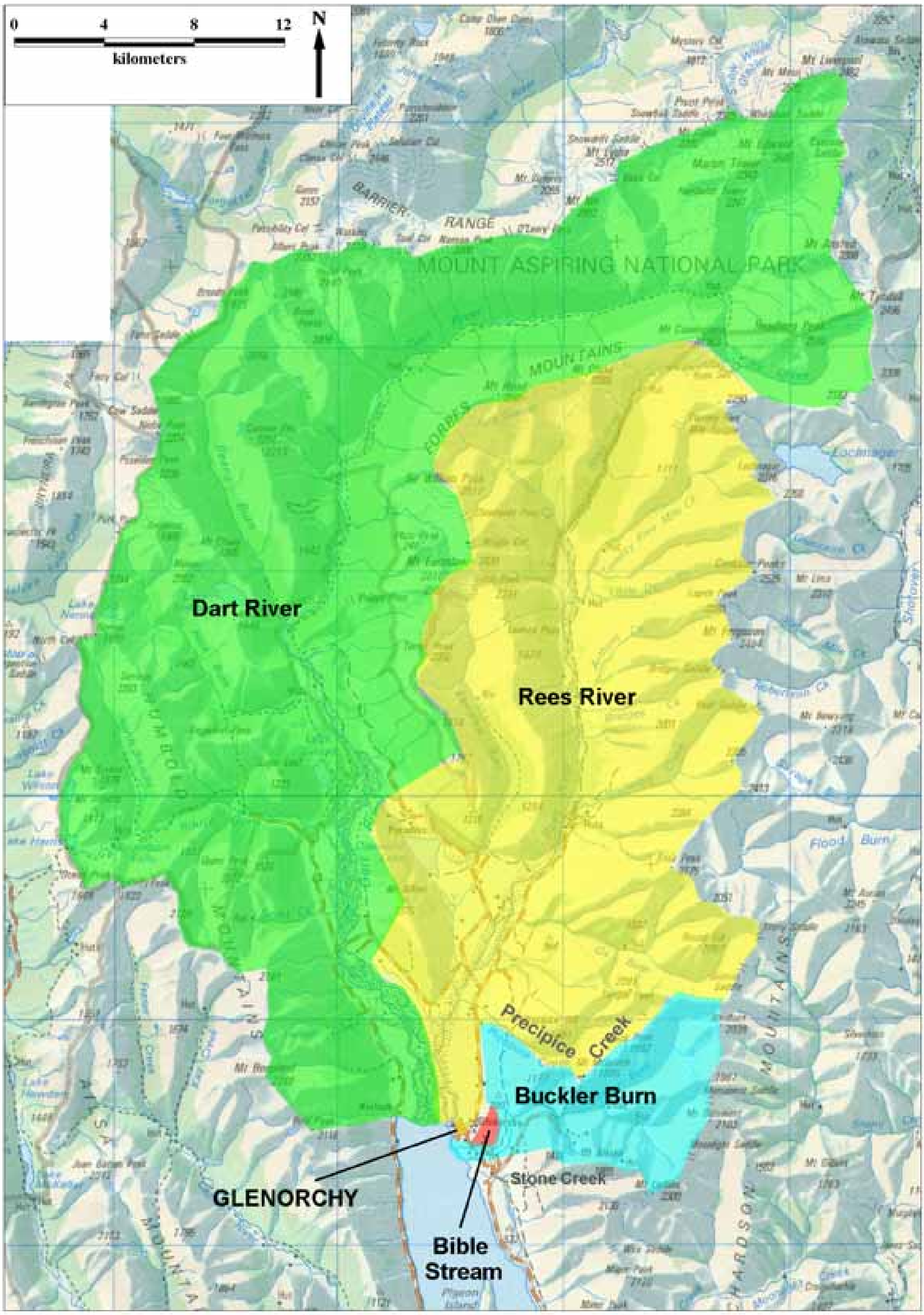

Figure 1.3 Map showing the location of Glenorchy and surrounding catchment areas

Figure 1.4 Glenorchy and its surrounding hazardscape (Background image courtesy of GNS Science)

2. Environment Setting

The head of Lake Wakatipu is part of a large basin carved out by the Dart glacier during the Pleistocene, about 12 – 15,000 years ago. This basin is typical of a previously-glaciated, U-shaped valley with a flat valley floor and gentle lower slopes which lead up to the steep peaks of the flanking mountain ranges. On either side of the Wakatipu basin lie the Richardson Mountains to the east and the Humboldt Mountains to the west (Figure 2.1), which rise to over 2000m above sea level. Mount Alfred/Ari is located in the centre of the valley floor and is flanked by the Dart River to the west, and Rees River to the east. The floor of the basin is 3.6km wide at the head of Lake Wakatipu expanding to 5.6km where the Dart and Rees valleys meet just south of Mt Alfred/Ari.

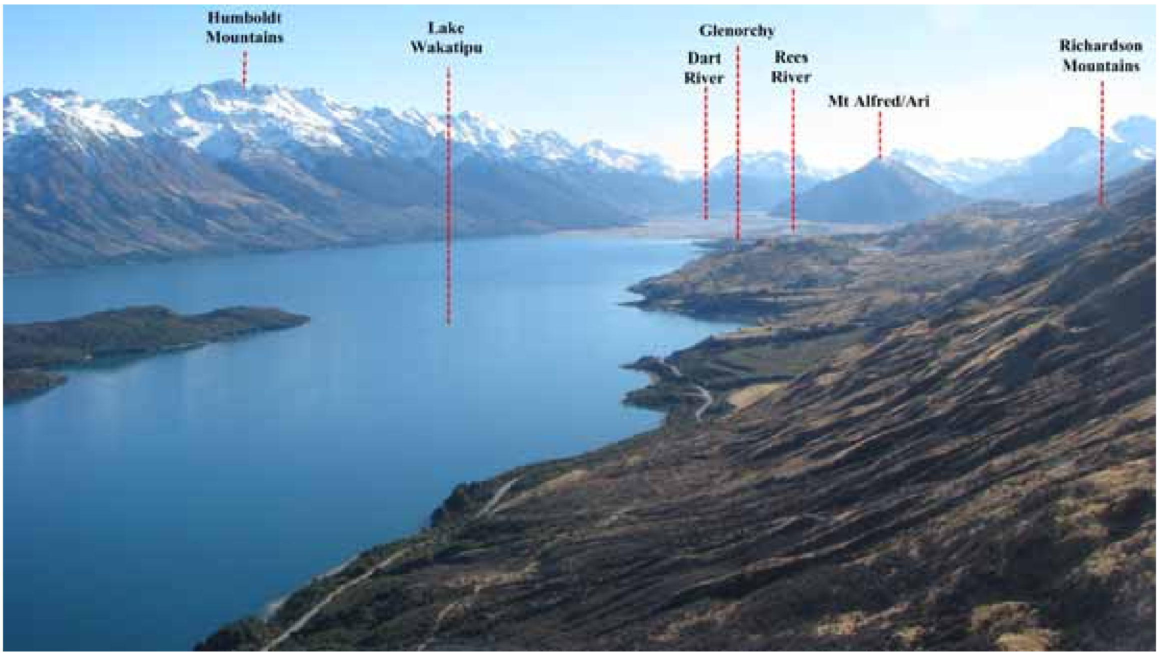

Figure 2.1 The Upper Wakatipu basin and mountain ranges

The braided floodplains of the Dart and Rees Rivers lie to the north of Glenorchy delivering large quantities of sediment and flow into Lake Wakatipu. These catchments are composed of highly erodible schist which is transported down valley by the rivers, and eventually deposited into the head of Lake Wakatipu. Sediment deposited into the lake has formed two deltas which have advanced 180-200 metres and 90-175 metres respectively since the late 19th century (URS, 2007b).

Following the retreat of the Wakatipu Glacier up the Dart and Rees valleys, numerous several of landforms were created from streams flowing from the Richardson and Humboldt Mountains. These features form the underlying geology and shape the surrounding environment of Glenorchy and consist of alluvial fans (Figure 2.2), terraces, deltas and lake shorelines, formed by the Buckler Burn, Stone and Precipice Creeks (Figure 1.3). The Bible Stream, located to the immediate southeast of Glenorchy, has developed an erosion gully into one of these post-glacial terraces.

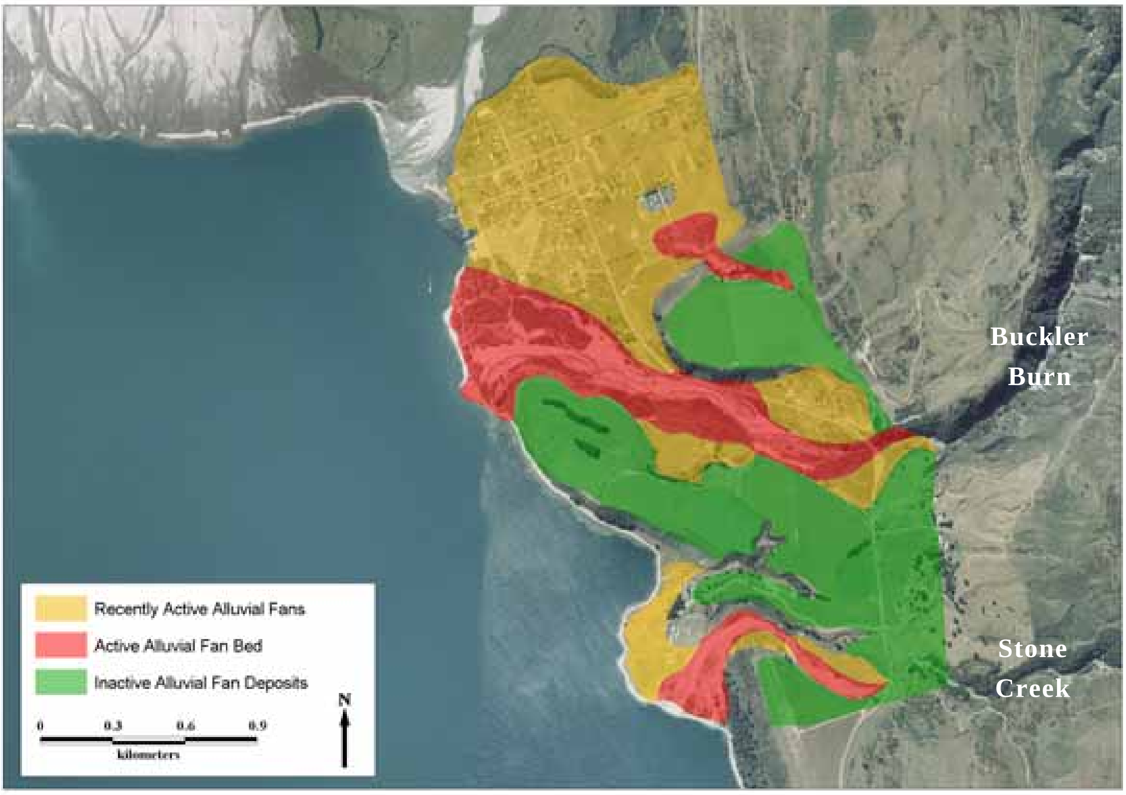

Figure 2.2 Alluvial fan deposits formed by the Buckler Burn and Stone Creek (Barrell et al, 2009). Note that Glenorchy is located on sediments initially deposited by the Buckler Burn

The Glenorchy community is situated on the lower slopes of the Richardson Mountains and is located entirely on an alluvial fan previously deposited by the Buckler Burn. This landform has been created by episodic debris and flood flows which have deposited sediment and debris across this area. These processes continue today, although have more recently been confined to the active Buckler Burn fan-delta.

Figure 2.3 shows a Digital Elevation Model (DEM) of the underlying topography of Glenorchy with 1 metre contours representing the shape of the land[5]. The contour information shows that the parts of the township located beside the main road are higher than the fringes which is a consequence of the alluvial fan deposition processes. Towards the east of the township (centre-left

[5] Contour information used to generate the DEM derived from aerial photography flown in 1998; supplied by QLDC

of image) the land is lower where floodwaters that originate from the Bible Stream pond during flood events[6]. Flow is trapped at this location, particularly when the lake and/or wetland are at high levels. It is these parts of Glenorchy that are being progressively developed, whereas previously development has taken place on higher parts of the fan. The steep Bible Stream alluvial fan is represented by the very close contours located where the stream exits the Bible Terrace face (Figure 2.3).

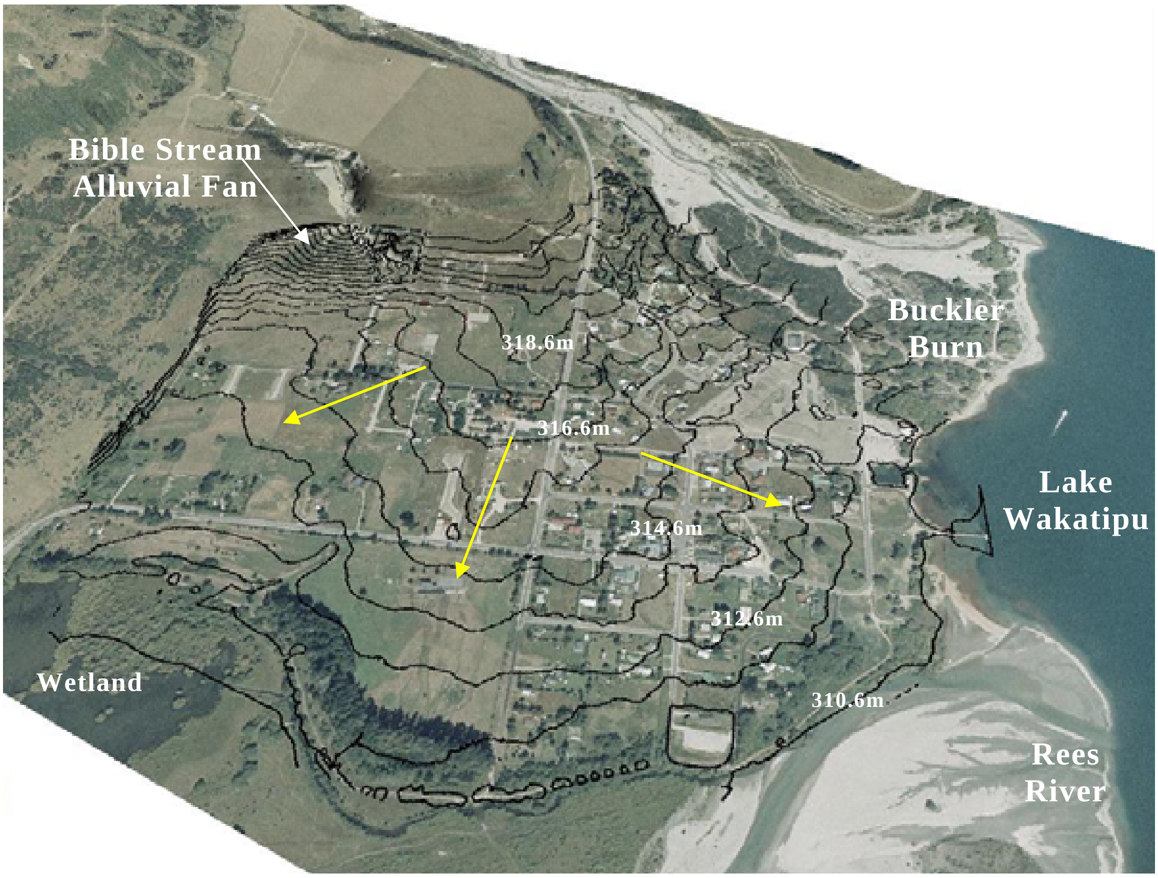

Figure 2.3 Digital Elevation Model and contour information representing the underlying topography of Glenorchy; yellow arrows depict the slope of the land. Note that Lake Wakatipu in November 1999 peaked at 312.78m

[6] Flooding from the Bible Stream is discussed later in Section 3.6

3. Flood Hazard

Flood hazards, in the form of river flooding and lake inundation, pose a threat to the Glenorchy community due to the resulting impact on people, property and infrastructure. Inundation from high lake levels, as seen in the November 1999 flood event, is a risk due to the lake remaining at high levels for prolonged periods, usually days to weeks. Additionally, flooding from the Rees River, the Buckler Burn and the Bible Stream all have associated flood hazards that may affect Glenorchy (Figure 1.4).

The frequency and magnitude of flood events is closely related to the rainfall events from which they are derived. Annual rainfall in the western part of the South Island generally exhibited an upward trend during the 20th century, with annual rainfall at Queenstown (which is about 30km from Glenorchy) increasing by approximately 160mm between 1901 and 2003 (Mojzisek, 2005). The rate of increase appeared to accelerate during the latter part of the century.

In the Glenorchy area, the longest rainfall record is for the Earnslaw gauge (Figure 3.1) in the Rees River catchment (Figure 3.2). Between 1950 and 2000, average annual rainfall increased by more than 500mm at this site. Mojzisek (2005) agrees with these findings where a significant upward trend in total precipitation, rain days, consecutive wet days and number of very wet days in the vicinity of Glenorchy have been identified (Appendix 1). Since the turn of the century however, annual rainfall totals in north-western Otago have generally declined again, and this trend has also been evident at the Earnslaw gauge.

There is moderate confidence that average annual rainfall in the north-west of Otago is projected to increase by approximately 12%, with a range of -2 to 34% (MfE, 2008). Heavy rainfall events are also projected to become more frequent, and may become more intense[7].

[7] Note that these projections may change into the future, as our understanding of the effects of a warmer climate improves.

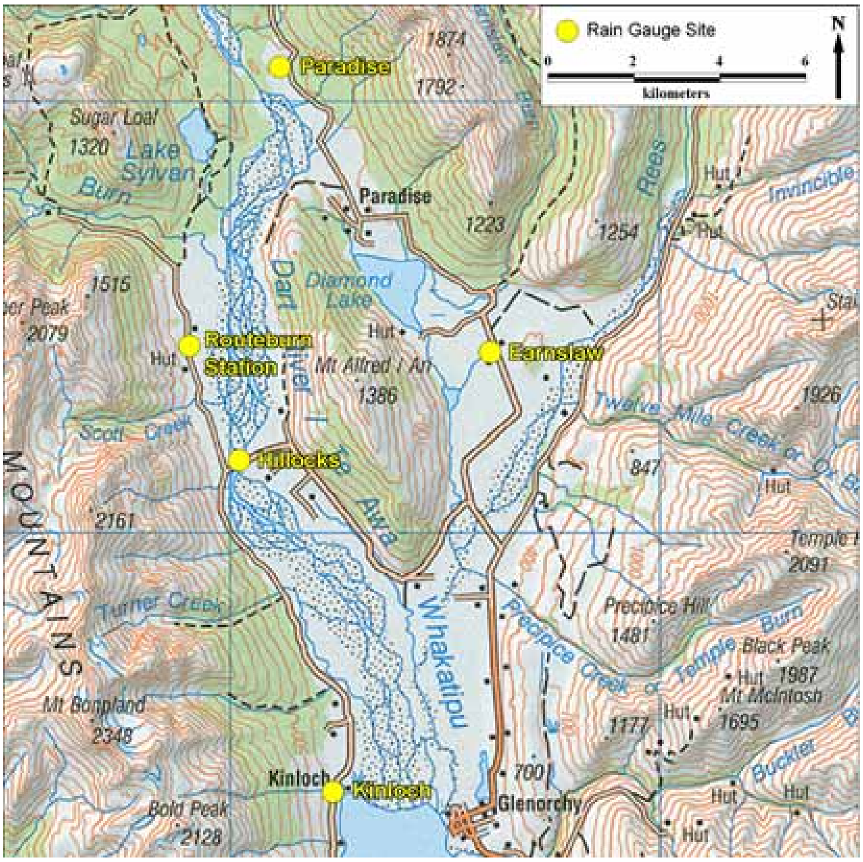

Figure 3.1 Rain gauge sites within the vicinity of Glenorchy

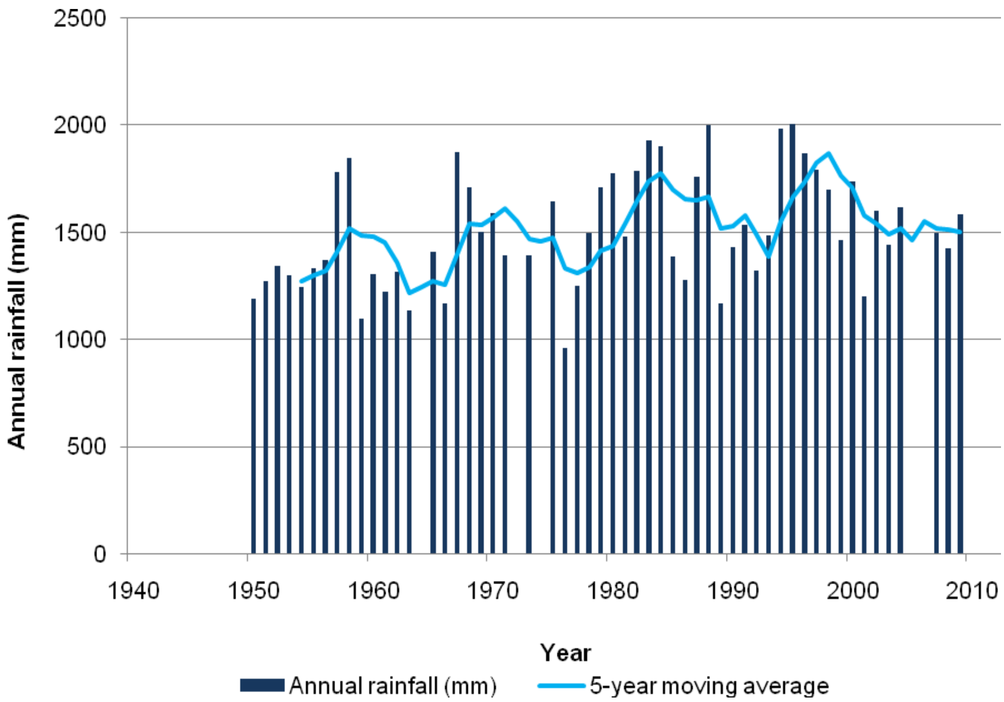

Figure 3.2 Annual rainfall totals for the Rees at Earnslaw gauge, 1950-2009. Missing record in: 1964, 1972, 1974, 2005 and 2006

3.1 Lake Wakatipu flooding

Lake Wakatipu is New Zealand's third-largest lake with a surface area of 293 km^2 and a total catchment area of 3,067 km^2. Depths at the head of the lake between Kinloch and Glenorchy are generally less than 50m due to the development of the Rees/Dart Delta. However the lake does, in places, reach depths greater than 300m.

The primary hazard associated with Lake Wakatipu, that directly impacts Glenorchy, is prolonged inundation from high lake levels, particularly in the townships lower lying areas (Figure 3.3). The level of Lake Wakatipu has been observed to vary through a range of nearly 3.9m with a mean level of approximately 310 metres above sea level (masl). The flood of November 1999 was the highest lake level on record at 312.77 masl (URS, 2003) with the second highest level being recorded in September 1878 at 312.60 masl (Figure 3.4). The maximum extents of lake inundation from the November 1999 event are presented in Figure 3.5 (URS, 2007a).

Figure 3.3 The lower margins of Glenorchy showing lake inundation on 19 November 1999

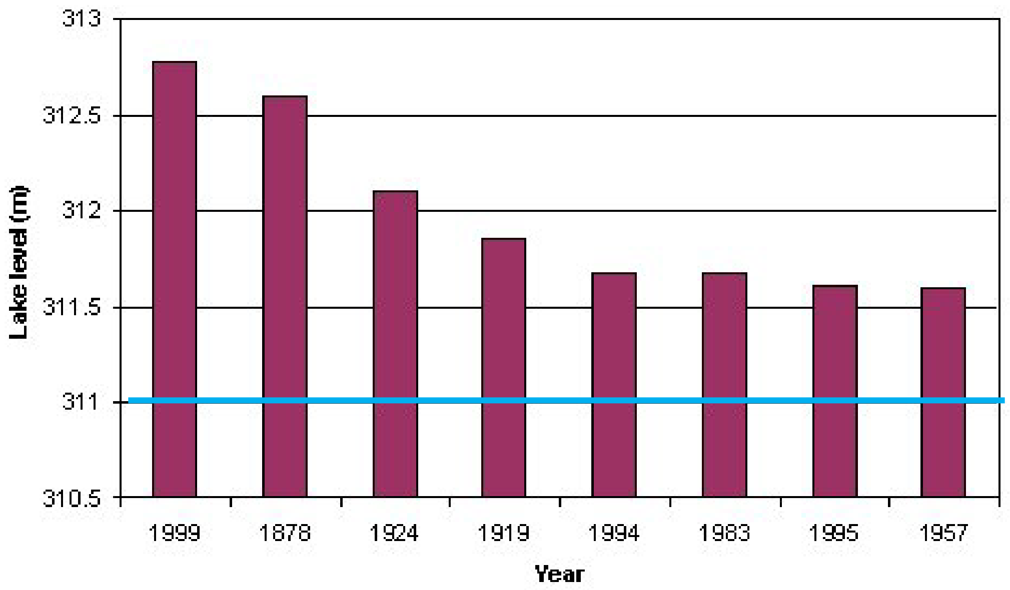

Figure 3.4 Highest recorded levels of Lake Wakatipu 1878-2007. Lower parts of Glenorchy are inundated at about 311m represented by the blue line (refer Figure 2.3)

Figure 3.5 Maximum level of Lake Wakatipu in Glenorchy; November 1999 (URS, 2007a)

The main cause of high lake levels in Lake Wakatipu is the natural imbalance between the capacity of the lake outlet (Kawarau River) and the magnitude of inflows during heavy rainfall events. Due to the location of the Shotover River confluence near the lake outlet, outflow from the lake can be further impeded by flood and sediment flows (QLDC/ORC, 2006). These conditions, in association with a succession of frontal weather systems, can provide circumstances where the lake may stay at high levels for prolonged periods. (Barnett & MacMurray, 2006).

Contour information (Figure 2.3) shows that lower lying parts of Glenorchy begin to be inundated when the lake level reaches approximately 311m. Historically this level has been exceeded on numerous occasions which is reflected in Table 3.1. Between 1963 and 2009, the level of Lake Wakatipu exceeded 311m for a total of 158 days. Of these days, the lake exceeded 312m for the equivalent of one week.

Table 3.1 Number of days Lake Wakatipu has exceeded 311.0m between 1963 and 2009

Lake Level	Number of Days
>312.0	7
>311.5	27
>311.0	124
Total	**158**

Rainfall has a strong influence on the level of Lake Wakatipu, due to the cumulative effect of successive events resulting in higher average lake level (Figure 3.6). If average rainfall was to increase, the ‘normal’ range of Lake Wakatipu would also be expected to increase, due to greater runoff and higher river flows in turn, increasing Glenorchy’s risk of flooding.

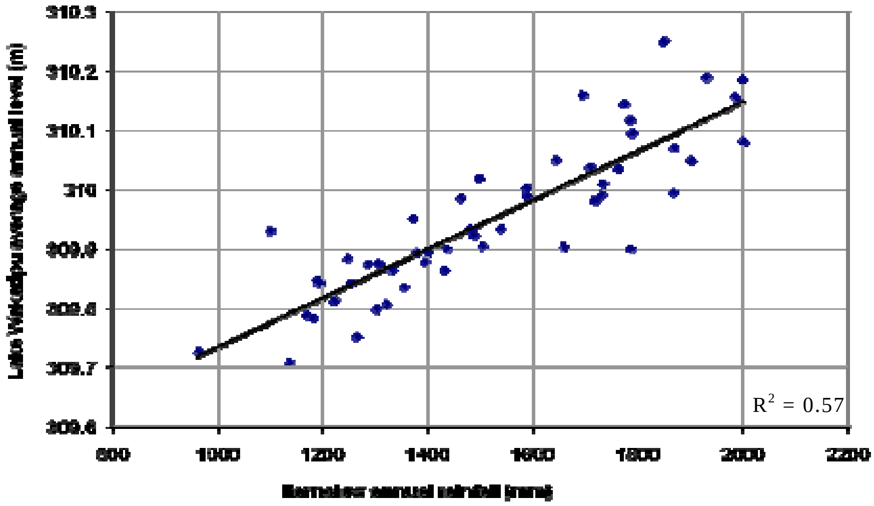

Figure 3.6 The relationship between average annual rainfall at the Earnslaw gauge and the average annual level of Lake Wakatipu, 1963 to 2009.

3.2 River deltas at the head of Lake Wakatipu

Sediment deposited into the head of Lake Wakatipu has formed deltas from the Dart and Rees Rivers and the Buckler Burn. Since the late 19th century both the Dart and Rees deltas have advanced 180-200m and 90-175m respectively (URS, 2007b). Investigating the formation of this delta complex, as well as others within the Otago region, is part of a PhD studentship at the University of Canterbury being funded by the Otago Regional Council, which is expected to completed in 2011. Figure 3.7 shows some of the initial results from this investigation where lake shorelines have been mapped from aerial photography between 1937 and 2007.

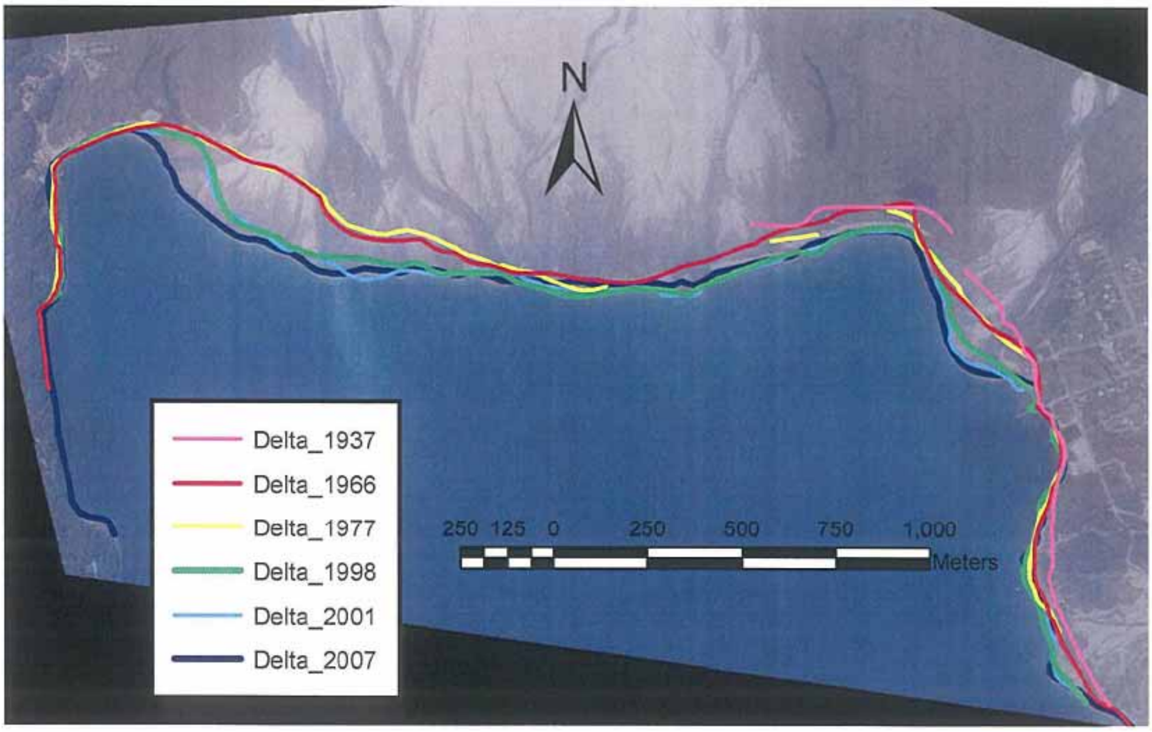

Figure 3.7 Lake shoreline advances 1937-2007 (M. Wild, 2007)

The Rees River delta is 575m wide and almost reaches to the current position of the Glenorchy jetty. Observations of delta growth began in the late 19th century. By the mid-1930's it had advanced significantly, necessitating the original Glenorchy jetty being moved 220m south to its current position in deeper water. Figure 3.7 shows how the delta has progressively advanced between measured years, establishing a new river bed directly adjacent to Glenorchy. This allows the Rees River to laterally migrate towards lower lying land on the margins of the township. In addition, the Buckler Burn delta advanced approximately 215m into Lake Wakatipu from 1864 to 2001, with more recent growth primarily being along the southern sector of the delta (URS, 2007b).

These deltas will continue to advance into the lake and contribute to higher river bed levels, as a result of the large amounts of sediment being supplied from the river catchments. As these features advance further they are expected to combine into one large delta complex, raising river bed levels adjacent to Glenorchy and possibly causing lateral migration of the Rees River towards the township. This effectively increases Glenorchy's risk exposure to flood hazards from the Rees River.

3.3 Dart River erosion and flooding

The Dart River floodplain and fairway are typical of a large braided river. The Dart fairway has migrated across the valley floor while recycling floodplain deposits and eroding in-channel sediment bars and islands. The position of large braid channels on the true right of the Dart fairway has caused erosion of agricultural land just north of Kinloch. The erosion of this land is a natural process that occurs as the channel migrates.

Direct risk to the Glenorchy community by the Dart River is relatively low due to its location on the western side of the Rees-Dart valley. However, secondary effects from the Dart River include the contribution of substantial flood flows into Lake Wakatipu, resulting in higher lake levels.

3.4 Rees River flooding

The Rees River fairway varies between 160m and 400m wide while occupying the eastern 1.7km of the Dart/Rees Rivers floodplain. Figure 3.8 shows the position of the main Rees channel at the Lake/Glenorchy confluence in 1989 and 2006. These images represent the dynamic, changing nature of the Rees River system over a relatively short period.

In 1989 most of the flow in this section of the river is located in the western branch (A) of the Rees. However, during this 17-year period, significant changes in channel position upstream of the confluence have diverted the majority of this flow into the eastern branch, placing it directly adjacent to Glenorchy (B). Having the majority of flow located adjacent to Glenorchy increases the community's susceptibility to Rees River erosion and flood hazards. In response to this shift in location, the Glenorchy-Rees floodbank was constructed in 2000 to mitigate the effects of flooding and to train the Rees away from Glenorchy (URS, 2007b). Substantial growth of the Rees Delta (C) into Lake Wakatipu during this period is also evident (Figure 3.8). Channel form and delta growth between these years are likely to have been influenced by large flood events in 1994, 1995 and 1999.

Figure 3.8 The Rees River and Glenorchy in 1989 (left) and 2006 (right)

The Rees River system is an extremely dynamic braided river with the potential to change significantly over relatively short periods. Otago Regional Council (2008) discussed the morphology and sedimentation characteristics of the Rees River and found:

- Channel form and development within the Rees River is indicative of a high sediment yield, braided river system
- The redistribution of sediments from upper to lower catchments may be activated by large flood events, such as November 1999
- Upper and mid cross sections on the Rees River have experienced significant aggradation between surveyed periods.

URS (2007b) note that if this sediment migrates downstream it is likely to increase the potential for the Rees River to shift its channel and flow directly into the Glenorchy wetland/lagoon area; and/or cause further aggradation at the Lake Wakatipu confluence.

Cross-section information indicates that this is a likely scenario as the bed of the Rees River is already higher than some lower-lying parts of Glenorchy. Figure 3.9 shows a cross-section of the Rees River bed that has been joined to the DEM of the township (Figure 2.3 and Figure 3.10). The black dotted line represents 311m[8] and indicates that a large part of the Rees River bed lies above or at similar levels to parts of Glenorchy. As the delta continues to advance and grow, it is anticipated that the Rees River bed levels will rise accordingly, consequently increasing Glenorchy's risk.

[8] As noted in Section 3.1, 311m is the point at which low lying parts of Glenorchy become inundated by the lake. Therefore, this level indicates that the Rees River bed level is elevated above these lower margins of the township.

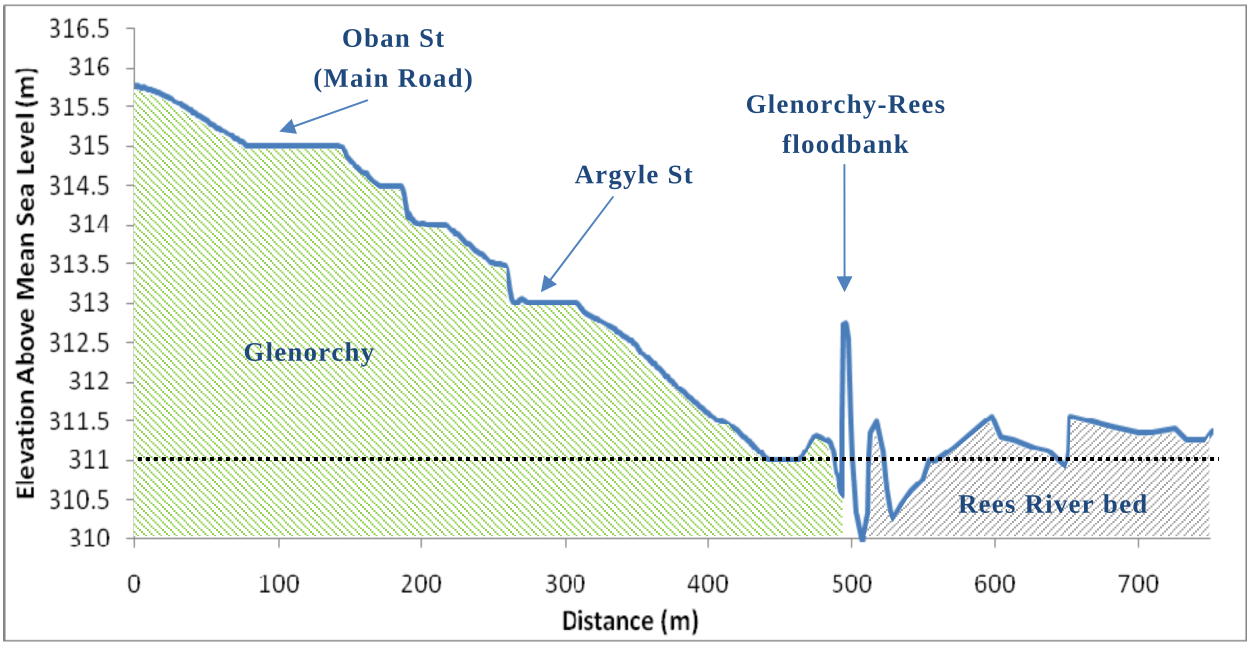

Figure 3.9 Cross-section of the Rees River, surveyed in December 2006, and Glenorchy showing the elevation of the river bed with respect to the township

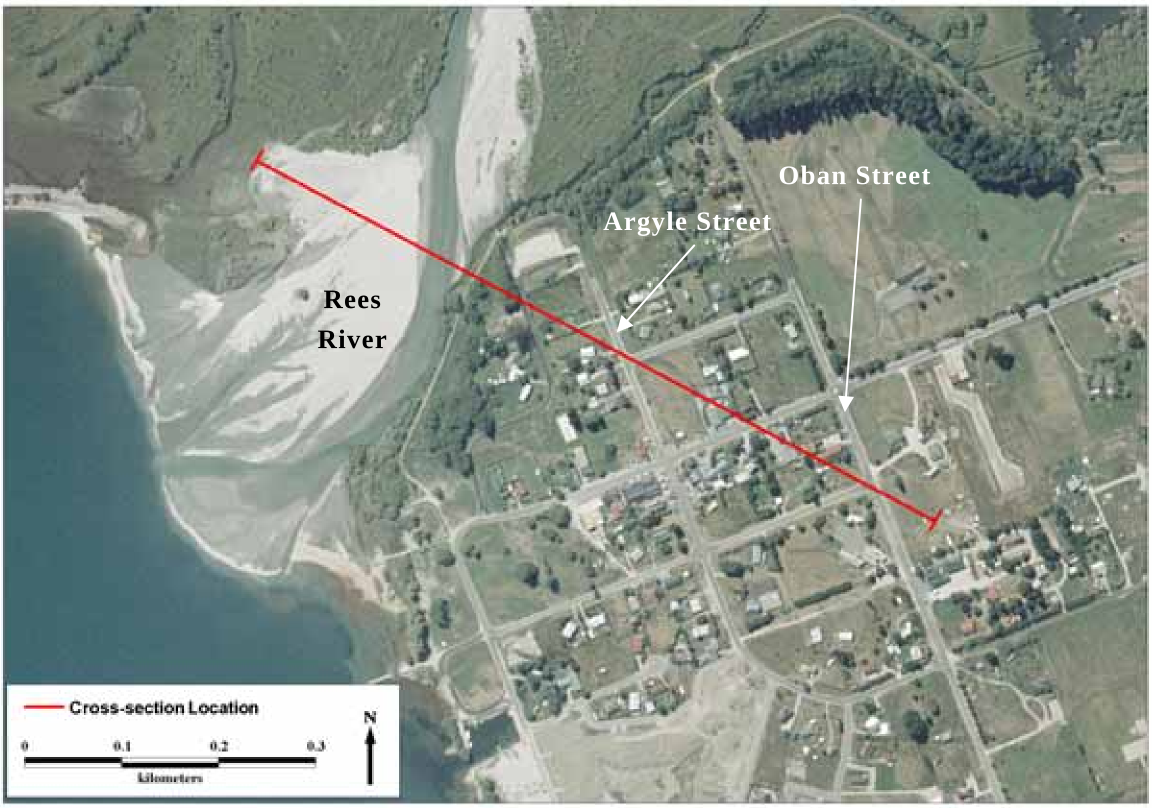

Figure 3.10 Location of cross-section represented in Figure 3.9

3.5 Buckler Burn flooding and landslide dam

The Buckler Burn drains the eastern slopes of the Richardson Mountains with the length of the catchment extending 16 km down to Lake Wakatipu, and is located to the south-southeast of Glenorchy. The lower 6.5km of the catchment is a narrow gorge about 400m wide at the top, and 150-200m deep, cut in the base of a valley fan (Figure 2.2). Upstream of the Glenorchy-Queenstown Road bridge the gorge is cut down into schist with the last 1.8km incised into old lake and gravel deposits (Figure 3.11). Hazards that have potential risk for Glenorchy, resulting from the Buckler Burn, include the possible avulsion of the channel due to aggradation and/or a large debris/flood flow sourced from the breach of a natural dam in the upper catchment.

Figure 3.11 The lower Buckler Burn floodplain incised into old alluvial terraces seen at a higher level on the left and right of the image

3.5.1 Buckler Burn aggradation/avulsion

During the 1999 flood event, the point where the Buckler Burn is closest to the Glenorchy-Queenstown Road aggraded significantly. Figure 3.12 shows that a large volume of sediment was deposited over the Buckler Burn fan-delta during this event and overtopped the road embankment on the true right of the channel.

Figure 3.12 Lower Buckler Burn aggradation following the 1999 flood event

Modelling for a $170m^3/s$ flow event[9] in the Buckler Burn showed that flood levels are still contained within the current channel and floodplain limits[10] (Figure 3.13). URS (2007a) note that flooding is contained within the existing floodplain. However, if bed levels continued to aggrade without intervention there would be significant risk of the existing bank protection being overtopped and floodwaters flowing down the main road into Glenorchy (URS, 2007a). This is a natural process that has formed the sediments on which Glenorchy is now located.

[9] $170m^3/s$ peak flow is assessed as having a 1:100 year return period (URS, 2007a). This flow is chosen to be representative of effects during a “flood”.

[10] Flood modelling of the Buckler Burn used cross-section information surveyed in December 2006, and therefore flood hazard extents are mapped based on bed levels at that time. These extents represent one scenario therefore should be regarded as indicative. The dynamic and variable nature of Buckler Burn flood/debris hazards means they are very difficult to model accurately.

Figure 3.13 Buckler Burn flood extent for a 170m^3/s peak flood event (URS, 2007a)

3.5.2 Buckler Burn landslide dam

Geologically, recent large-scale mass movement and slope instability in the upper catchment of the Buckler Burn (Figure 3.14) has led to the formation of a landslide dam at about 1,000 masl (Figure 3.15). This feature has been the subject of investigations undertaken by the Otago Regional Council since 2004. Opus (2004a) note that there is potential for ongoing landslide activity at this location and in turn, potential for this feature to become larger. An inspection undertaken in 2009 revealed that no water was impounded at that time (Figure 3.15). However it is important to note that dam formation and impoundment is largely dependent on the frequency and magnitude of rainfall events and snow-melt. Should the dam re-form and subsequently fail, large quantities of water, sediment and/or debris may flow down the Buckler Burn gorge causing aggradation on the fan-delta. This scenario could result in the Buckler Burn leaving its channel and flowing down the main road towards Glenorchy.

Figure 3.14 Large landslides in the upper Buckler Burn catchment on the true left of the channel (right image) and true right of the channel (left image). Depending on the nature of the Buckler Burn channel and quantity of sediment brought down by these slides, the channel can dam at this location

Figure 3.15 The Buckler Burn Landslide Dam in 2004 (top), looking upstream and in 2009 (bottom), looking downstream

3.6 Bible Stream flooding

The Bible Stream drains from a 40 hectare catchment at the southern end of Forts Ridge. The stream has formed an erosion gully in the terrace of the remnant Buckler Burn fan-delta. At the gully's mouth a small alluvial fan (Figure 2.2), covering about 4 hectares, has formed with most of the fan surface experiencing some overland flow and associated deposition since the 1930's (URS, 2007b). The fan extends across much of the land southeast of Glenorchy down to the eastern end of Shiel St, where sediment was deposited in the November 1999 flood event (Figure 3.16 and Figure 3.17). In 2000, the Bible Stream diversion was built to control water and sediment discharge onto properties located near the Bible Stream outlet and flowpath.

Figure 3.16 Sedimentation resulting from the November 1999 flood event across the Bible Stream alluvial fan

Figure 3.17 Sedimentation resulting from the November 1999 flood event across the Bible Stream alluvial fan

3.6.1 Bible Stream diversion

Two informal structures-a dam embankment created at the terraces lower margins (Figure 3.18) and a small diversion channel -divert flow away from Glenorchy and into the Rees River wetland. This feature has a storage capacity estimated to be less than a few hundred cubic metres when full. The structure discharges directly into the diversion channel and does not have an engineered spillway therefore, excessive flows in the catchment are likely to overtop this feature with flows re-entering the historic flow paths towards Glenorchy (URS, 2007b)

Figure 3.18 The Bible Stream Gully (left) and associated dam embankment (right)

Flood assessment for the Bible Stream catchment was undertaken for two hypothetical scenarios[11] (Figure 3.19). These were a breach scenario at the dam embankment and a less likely scenario where the diversion channel coped with flows and no overtopping occurred. Figure 3.19 shows the ponding areas associated with each scenario, with most of the flow being directed into the depression located to the east of Glenorchy (Figure 2.3).

This assessment indicated that floodwater, under a breach scenario, would flow north-west towards Glenorchy. As floodwaters reach the limits of the Bible Stream debris fan, velocities would reduce and water would start to flow north-east towards the depression on the township's eastern margin, shown by blue arrows in Figure 3.19 (URS, 2007a). These inundation and flow characteristics were observed in the November 1999 flood event and are evident in Figure 3.17.

Figure 3.19 Bible Stream flood extents both assessed scenarios (left – no breach, right – dam breach) (URS, 2007a)

[11] Flood and debris flows derived from the Bible Stream are very unpredictable and characteristic of variable alluvial fan hazards. Therefore, the flood extents represented in Figure 3.19 should be regarded as indicative, as flood and debris flows may occur outside these extents, depending on the nature of that event and the effects of surface features such as buildings, fences and drains.

4. Earthquakes and Seismicity

Earthquakes occurring locally or regionally present a hazard to the Glenorchy community. Seismic risk, or the risk due to earthquakes, depends on the magnitude, frequency and nature of the earthquake, its distance from the subject area; and the susceptibility of the underlying ground to seismic shaking. Seismic activity affecting the Glenorchy area is most likely to originate on the Alpine Fault. Seismic activity can generate both direct and indirect hazards which may impact Glenorchy, including fault movements, liquefaction, mass movement and lake seiche.

4.1 Fault movements

The Alpine Fault (Figure 4.1) is located along the western edge of the Southern Alps and has the capability to generate very large earthquakes (~M_w8.0) relatively frequently (estimated every 200-300 years). It passes within 55km of the Glenorchy community and has the potential to create approximately 2 minutes of immediate ground shaking in the township during a M_w8.0 event. Opus (2004b) note that an event of this size will have a Modified Mercalli intensity of MMVIII (Appendix 2) which indicates:

- people are alarmed and approach panic
- motor vehicle steering is greatly affected
- old buildings are heavily damaged, some collapse
- houses not secured to foundations may move
- unreinforced domestic chimneys are damaged and many are brought down

Located 45km east of Glenorchy is the Nevis-Cardrona fault system (Figure 4.1). Estimated to have a return period of 5,000-10,000 years for a M_w7.1 event, this structure is the closest significant active fault system to the Glenorchy community. While the recurrence intervals of some faults have been calculated, seismic risk also exists from potentially active faults that have either not been identified or studied to great extents.

All recorded earthquakes, greater than magnitude 3.0, located in the vicinity of Glenorchy, are shown in Figure 4.2. Earthquakes located in the immediate Glenorchy area are generally shallow (<40km depth) and have a magnitude less than M_w5.0. Hazards associated with these earthquakes includes surface rupture and liquefaction (URS, 2007b). The evidence for surface rupture is minimal in the immediate Glenorchy district due to the absence of identified active fault traces. However, the possibility of liquefaction due to ground shaking is prevalent.

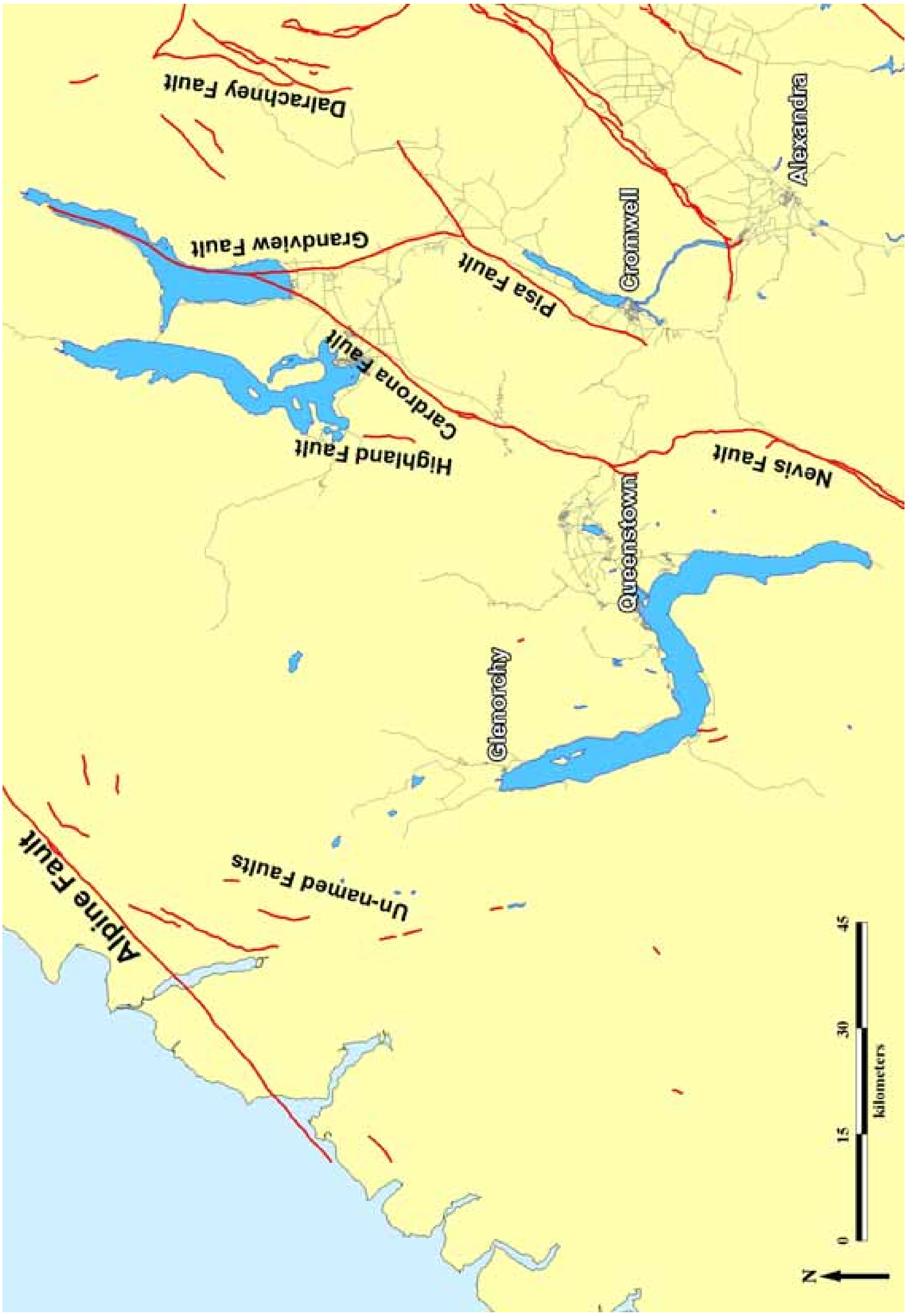

Figure 4.1 Location of known active faults in the Queenstown-Lakes District (Opus, 2004b)

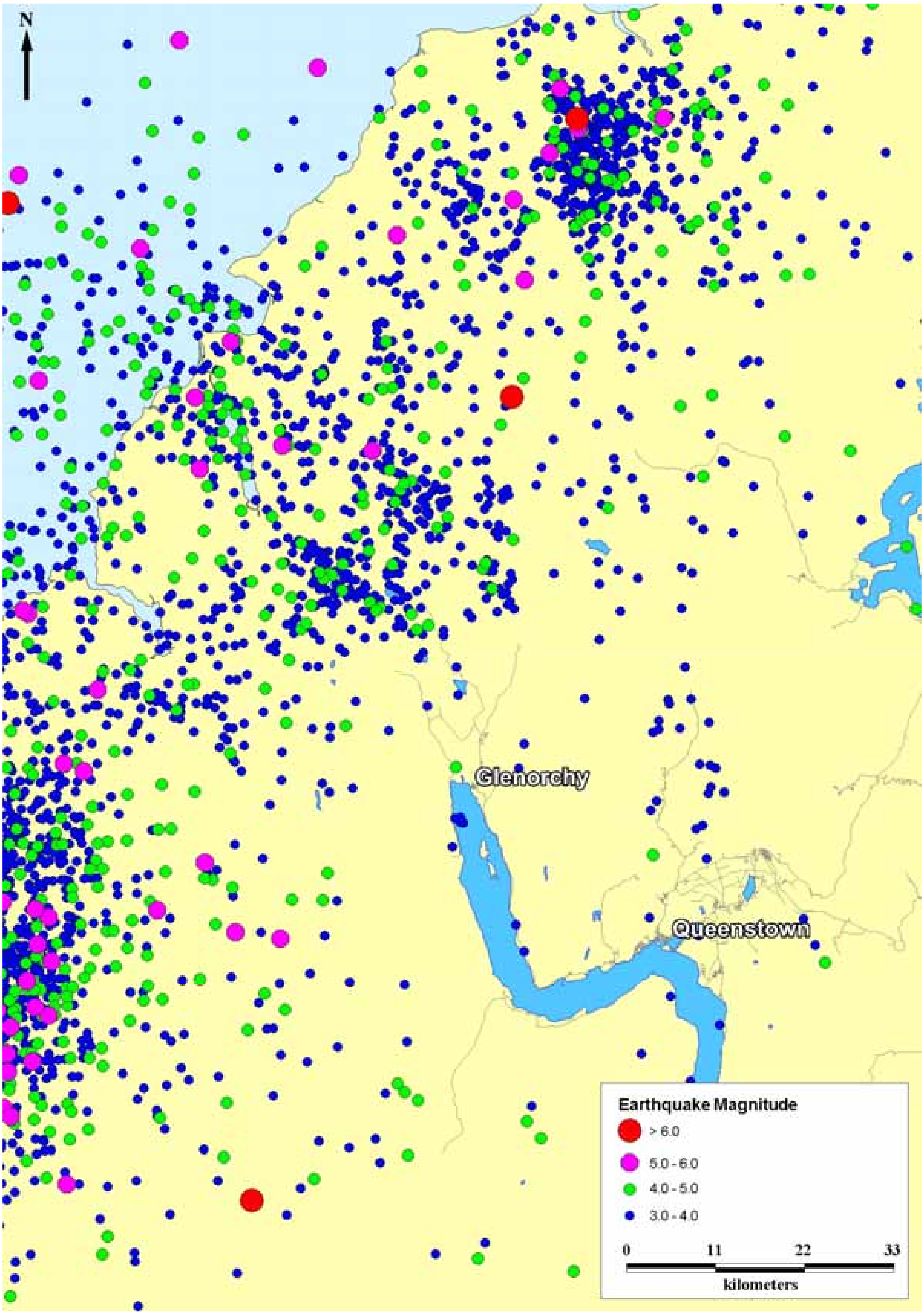

Figure 4.2 **All recorded earthquakes greater than magnitude 3.0 in the vicinity of Glenorchy. Data courtesy of GNS Science www.geonet.org.nz**

4.2 Liquefaction

Another risk faced by the Glenorchy community associated with earthquakes is the liquefaction of soils due to seismic shaking (Figure 4.3). Liquefaction occurs when sediments and soils are shaken, often by earthquakes, and lose their ability to stay cohesive. As the sediments are shaken they act like a fluid or shaken jelly, causing deformation, settlement and sometimes lateral spread toward water bodies.

Historical records and studies[12] of liquefaction in New Zealand suggest that the magnitude of shaking felt in Glenorchy, from a M_w8.0 Alpine Fault event, would cause soils to settle and liquefy (URS, 2007b). This could cause damage to older building structures, infrastructure (including roads and underground pipes), as well as moderate ground damage. Changes in topography due to ground settlement may also alter or change existing drainage patterns. Additionally, Glenorchy's position adjacent to the edge of Lake Wakatipu means that it may experience lateral spreading where sediments move laterally towards the lake.

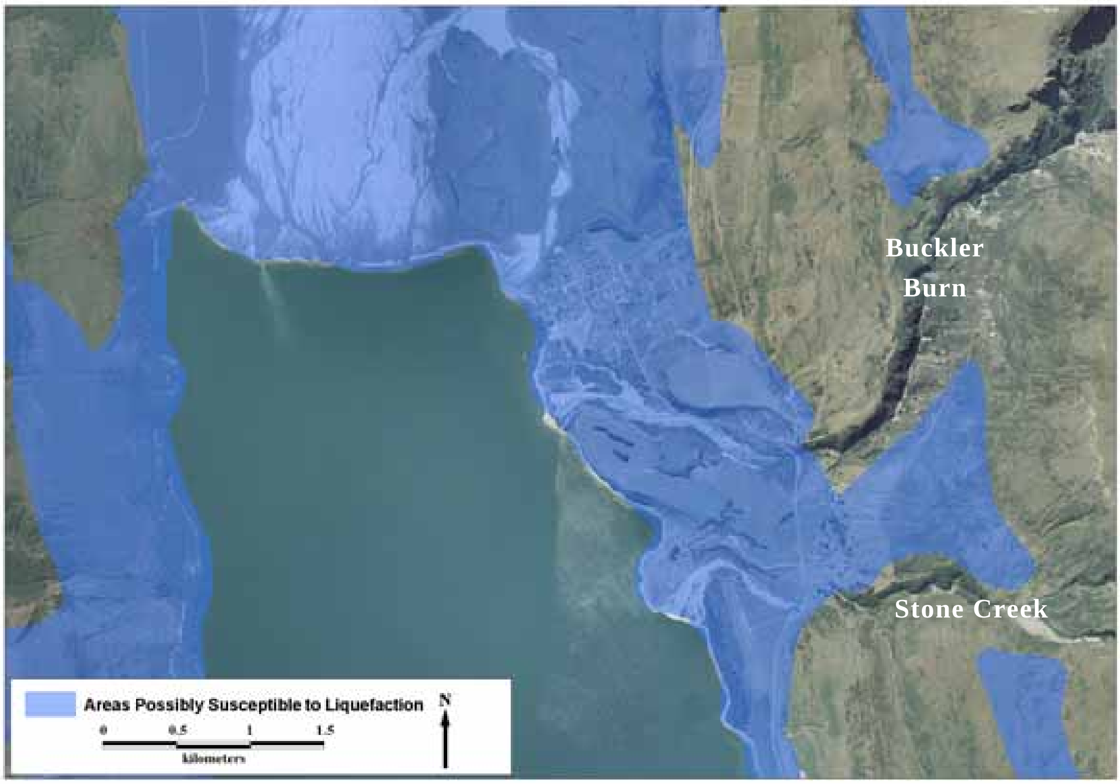

Figure 4.3 Areas possibly susceptible to liquefaction within the vicinity of Glenorchy (Opus, 2004b)

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[12] As noted in Opus (2004b)

4.3 Lake seiche

Seiches are generally defined as a standing wave in a closed body of water such as a lake or bay, however they can be best described as the sloshing of water in an enclosed basin/lake. Lake Wakatipu, like many large lakes, has its own natural seiche, which oscillates depending on meteorological and astronomical variations. While the natural seiche does not pose a significant hazard to existing communities, the distinction between this natural oscillation and seismic induced seiche is important.

Opus (2004b) note that there are worldwide historical records of seismic seiches comprising up to 3.7m high waves in lakes caused by Modified Mercalli VI intensities of seismic shaking and increasing wave heights with greater intensity. As mentioned in section 4.1, Glenorchy may experience seismic intensities associated with a MMVIII event, indicating that a significant seiche hazard may exist.

5. Mass Movement

Mass movements in the form of landslides and rock falls are not significant in the immediate Glenorchy area (URS, 2007b). Rather, large schist landslides and road-cutting failures along the Queenstown-Glenorchy Road have the potential to isolate the community. Mass movement-induced waves, from failure either under the lake surface or directly into the lake, could also affect the community.

5.1 Local mass movement

Strong seismic shaking is a common trigger of slope failure. Slope failure scenarios that could affect the wider Glenorchy area resulting from strong earthquake shaking include:

- Reactivation of the rock slope failure that resulted in a landslide dam on the Buckler Burn (refer Section 3.5.2)
- New rock slope failure resulting in a landslide dam on Buckler Burn or Precipice Creek
- Reactivation of the rock slope failure above Glenorchy-Paradise Road north of Glenorchy
- Toppling of a section of the steep cliffs cut in fan materials adjacent to Buckler Burn
- Slope failure of road cuttings of the Queenstown-Glenorchy Road preventing road access to Glenorchy. This is the most likely slope failure scenario that could affect Glenorchy (URS, 2007b)

5.2 Mass movement induced waves

Not a lot of information exists regarding the likelihood or risk posed from mass movement induced waves affecting impacting the communities adjacent to Lake Wakatipu. However, based on the size of the lake and geomorphology of the adjacent slopes, this hazard is recognised to pose a risk to low-lying areas on its margins (Figure 2.3).

The likelihood of such an event occurring is considered more likely as a result of strong seismic shaking. Two main scenarios are considered for the generation of a large wave resulting from mass movement:

- A large landslide failure enters the lake sourced from the adjacent slopes, displacing large amounts of water
- A submarine landslide failure, occurring under the lake surface, displaces a large amount of water.

6. Residual Risk

This document has outlined and discussed a number of known natural hazards to which Glenorchy is susceptible. It has been demonstrated that the hazardscape within which Glenorchy resides is dynamic, and subject to rapid change.

The frequency and magnitude of flood hazards is likely to increase due to predicted changes in rainfall patterns as a result of climate change. This will lead to an increase in the susceptibility-and ultimately risk-to the Glenorchy community. Additional intensification or development in hazard prone locations would amplify this risk further.

7. Glossary

Aggradation: To raise the grade or level of the river bed primarily by depositing sediment accumulations.

Alluvial fan: Landforms which develop where a steep gully emerges from its confines onto a flatter valley floor, or at other sites where sediment accumulates in response to changes in stream gradient and/or width.

Avulsion: The abandonment of a river channel and the establishment of a new channel at a lower elevation on its floodplain as a result of floodplain/channel *aggradation.*

Braided river: A river characterised by a network of interconnected converging and diverging channels resembling the strands of a braid.

Delta: A fan-shaped alluvial deposit at a river or stream mouth formed by the deposition of successive layers of sediment.

Digital elevation model: A computer representation of the land surface and landforms of specific area.

Fairway: The active channel margins of a braided river system where channels migrate laterally during periods of high flow.

Lateral migration: The process whereby channels move sideways across the wider floodplain of the river.

Lateral spread: The spread of sediments, often towards bodies of water such as a lake, as a result of seismically induced shaking.

Liquefaction: The process by which sediments and soils collapse from a sudden loss of cohesion. Deposits lose strength after being transformed to a fluid mass, often by seismic shaking.

Mass movement: The downhill movement of surface materials under the influence of gravity often induced or assisted by increased saturation of the slope.

Modified Mercalli Intensity: A measure of earthquake intensity by providing a descriptive list of effects based on the Richter scale of earthquake magnitude.

Morphology: The form or structure of the river.

Pleistocene: The interval of geological time spanning the period 1.8 million to 10,000 years before present.

Post-glacial terrace: A landform created by the deposit of debris and/or floodwater sediments in an area previously occupied by a valley glacier.

Scheelite: A mineral, which can have many colours, found in igneous rocks and used as an ore of tungsten.

Schist: Medium to coarse-grained metamorphic rock composed of laminated, often flaky parallel layers.

Sediment bars: A depositional feature composed of sediment on the margins or within the stream channel, formed as the channel shifts laterally. Such deposits are common in braided rivers.

Seiche: A wave that oscillates in lakes, bays, or gulfs from a few minutes to a few hours as a result of seismic or atmospheric disturbances.

Seismic hazard: Hazards derived from effects of an earthquake.

Spillway: A channel designed for the controlled and safe overflow of water.

Surface rupture: The displacement, upwards or across, of the earth's surface along a faultline, as a result of an earthquake.

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URS New Zealand Ltd. (2007b) *Glenorchy area geomorphology and geo-hazard assessment,* report reference: 42162267.00012.

Appendix 1 – Trends in historical rainfall characteristics (Mojzisek, 2005)

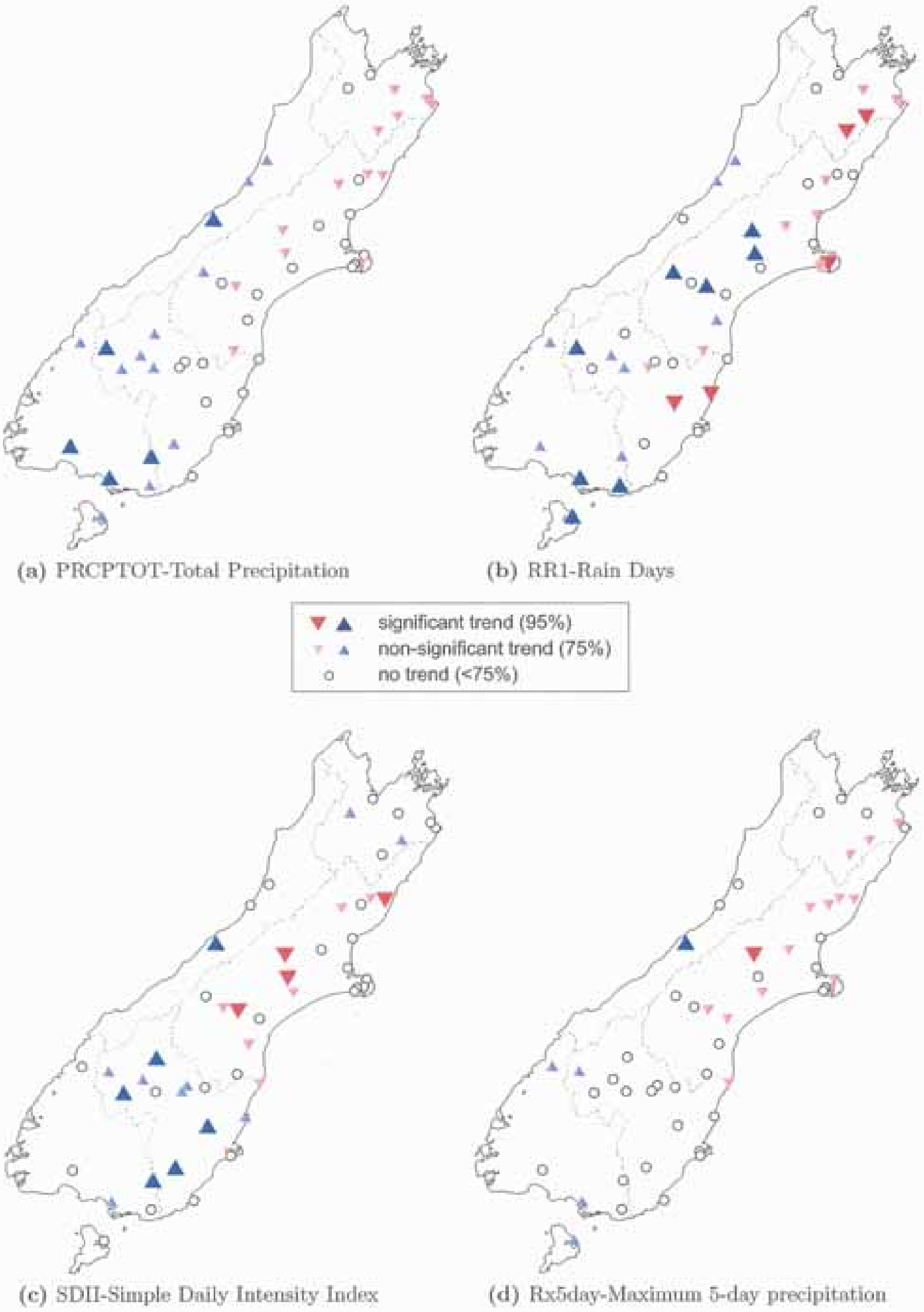
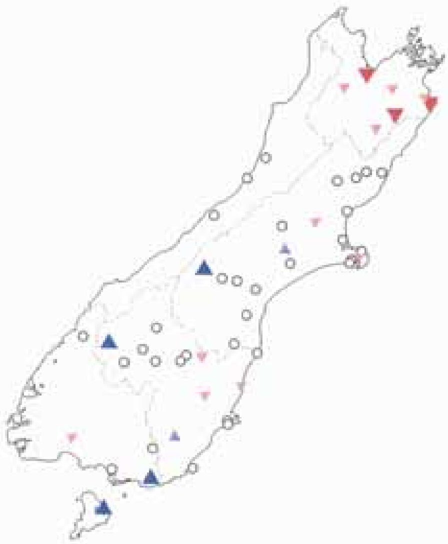
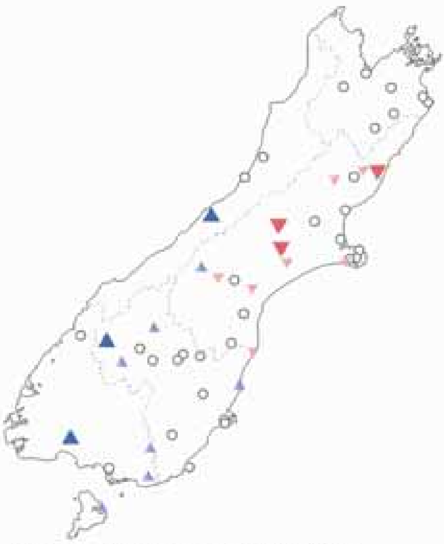


Figure 5.3: Spatial variability of trends of extreme precipitation trends in the South Island of New Zealand over the 1951-2003 period for (a) Total Precipitation, (b) number of Wet Days, (c) Simple Daily Intensity Index, (d) Maximum annual 5-day precipitation total.



(e) CWD-Consecutive Wet Days



(f) R95p-Number of Very Wet Days

(g) R95pTOT-Percentage due to Very Wet Days

Figure 5.3: Spatial variability of trends of extreme precipitation trends in the South Island of New Zealand over the 1951-2003 period for (e) Consecutive Wet Days, (f) number of Very Wet Days, (g) percentage of precipitation from very wet days.

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Appendix 2 – MODIFIED MERCALLI INTENSITY SCALE (Opus, 2004b)

MM1

People
Not felt except by a very few people under exceptionally favourable circumstances.

MM2

People
Felt by persons at rest, on upper floors or favourably placed.

MM3

People
Felt indoors; hanging objects may swing, vibration similar to passing of light trucks, duration may be estimated, may not be recognised as an earthquake

MM4

People
Generally noticed indoors but not outside. Light sleepers may be awakened. Vibration may be likened to the passing of a heavy traffic, or to the jolt of a heavy object falling or striking the building.

Fittings
Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock.

Structures
Walls and frame of buildings, and partitions and suspended ceilings in commercial buildings, may be heard to creak.

MM5

People
Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people alarmed.

Fittings
Small unstable objects are displaced or upset. Some glassware and crockery may be broken.
Hanging pictures knock against the wall.
Open doors may swing.
Cupboard doors secured by magnetic catches may open.
Pendulum clocks stop, start, or change rate.

Structures
Some windows Type I cracked.
A few earthenware toilet fixtures cracked.

MM6

People
Felt by all.
People and animals alarmed.
Many run outside.
Difficulty experienced in walking steadily.

Fittings
Objects fall from shelves.
Pictures fall from walls.
Some furniture moved on smooth floors, some free-standing unsecured fireplaces moved.
Glassware and crockery broken.
Very unstable furniture overturned.
Small church and school bells ring.
Appliances move on bench and table tops.
Filing cabinets or ‘easy glide’ drawers may open (or shut).

Structures
Slight damage to Buildings Type I.
Some stucco or cement plaster falls.
Windows Type I broken.
Damage to a few weak domestic chimneys, some may fall.

Environment
Trees and bushes shake, or are heard to rustle.
Loose material may be dislodged from sloping ground, e.g. existing slides, talus slopes, shingle slides.

MM7

People
General alarm.
Difficulty experienced in standing.
Noticed by motorcar drivers who may stop.

Fittings
Large bells ring.
Furniture moves on smooth floors, may move on carpeted floors.
Substantial damage to fragile contents of buildings.

Structures
Unreinforced stone and brick walls cracked.
Buildings Type I cracked with some minor masonry falls.
A few instances of damage to Buildings Type II.
Unbraced parapets, unbraced brick gables, and architectural ornaments fall.
Roofing tiles, especially ridge tiles may be dislodged.
Many unreinforced domestic chimneys damaged, often falling from the roof-line.
Water tanks Type I burst.
A few instances of damage to brick veneers and plaster or cement-based linings.
Unrestrained water cylinders (water Tanks Type II) may move and leak.
Some windows Type II cracked.
Suspended ceilings damaged.

Environment
Water made turbid by stirred up mud.
Small slides such as falls of sand and gravel banks, and small rock-falls from steep slopes and cuttings.
Instances of settlement of unconsolidated or wet, or weak soils.
Some fine cracks appear in sloping ground. A few instances of liquefaction (i.e. small water and sand ejections).

MM8

People
Alarm may approach panic.
Steering of motor cars greatly affected.

Structures
Building Type 1, heavily damaged, some collapse.
Buildings Type II damaged, some with partial collapse.
Buildings Type III damaged in some cases.
A few instances of damage to Structures Type IV.
Monuments and pre-1976 elevated tanks and factory stacks twisted or brought down.
Some pre-1965 infill masonry panels damaged.
A few post-1980 brick veneers damaged.
Decayed timber piles of houses damaged.
Houses not secured to foundations may move.
Most unreinforced domestic chimneys damaged, some below roof-line, many brought down.

Environment
Cracks appear on steep slopes and in wet ground.
Small to moderate slides in roadside cuttings and unsupported excavations.
Small water and sand ejections and localised lateral spreading adjacent to streams, canals, lakes etc.

MM9

Structures
Many Buildings Type I destroyed.
Buildings Type II heavily damaged, some collapse.
Buildings Type III damaged, some with partial collapse.
Structures Type IV damaged in some cases. Some with flexible frames seriously damaged.
Damage or permanent distortion to some Structures Type V.
Houses not secured to foundations shifted off.
Brick veneers fall and expose frames.

Environment
Cracking of ground conspicuous.
Landsliding general on steep slopes.
Liquefaction effects intensified and more widespread, with large lateral spreading and flow sliding adjacent to streams, canals, lakes etc.

MM10

Structures
Most Buildings Type I destroyed.
Many Buildings Type II destroyed.
Buildings Type III heavily damaged, some collapse.
Structures Type IV damaged, some with partial collapse.
Structures Type V moderately damaged, but with few partial collapses.
A few instances of damage to Structures Type VI.
Some well-built timber buildings moderately damaged (excluding damage from falling chimneys).

Environment
Landsliding very widespread in susceptible terrain, with very large rock masses displaced on steep slopes.
Landslide dams may be formed.
Liquefaction effects widespread and severe.

MM11

Structures
Most Buildings Type II destroyed.
Many Buildings Type III destroyed.
Structures Type IV heavily damaged, some collapse.
Structures Type V damaged, some with partial collapse.
Structures Type VI suffer minor damage, a few moderately damaged.

MM12

Structures
Most Buildings Type III destroyed.
Many Structures Type IV destroyed.
Structure Type V heavily damaged, some with partial collapse.
Structures Type VI moderately damaged.