



**Amplified ground shaking and liquefaction
susceptibility, Invercargill City**

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EXECUTIVE SUMMARY

The most recent geological map of the Invercargill City area has been used to update earthquake hazard maps for ground shaking amplification and liquefaction susceptibility and supersedes classifications made in 1993 and 2006. Much of Invercargill City is constructed on “Deep or Soft Soil” or “Very Soft Soil” that is likely to amplify ground shaking depending on whether the earthquake source is distant or nearby.

For much of the current built up area of the city, the liquefaction susceptibility is “Negligible” or “Low”. However it should be noted that key infrastructure, such as the wharf at Bluff and the Airport, are located in areas classified as having a “Very High” susceptibility to liquefaction.

The classifications are indicative only and are to be used by the council for planning and consent purposes. Actual ground conditions can only be ascertained by a site investigation that includes subsurface investigations.

The probability of earthquake shaking strong enough to cause the onset of liquefaction and/or produce amplified ground shaking sufficient to cause damage in Invercargill City is low when compared to Te Anau and Wellington.

It is recommended that the seismic hazard for Invercargill city be revised to take into account new source information and improvements in the modelling process.

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1.0 INTRODUCTION

Invercargill City Council is revising its District Plan. As part of this revision, the Council would like to update the 1993 earthquake ground shaking amplification and liquefaction susceptibility zonation (Van Dissen *et al.*, 1993). Since 1993, GNS Science has updated the geology of the Invercargill City area (Thomas and Turnbull, 2001). GNS Science has also developed simple correlations between mapped surface geology and the response of the ground to earthquake shaking in terms of amplification of the ground motions and liquefaction susceptibility.

2.0 GEOLOGY

2.1 Geological Units

The ground shaking and liquefaction susceptibility of the Invercargill City area reported by Van Dissen *et al.* (1993) was based on geological mapping published by Wood (1966) and on unpublished material (Wood and Hitt, 1967). Since then the regional geology has been updated (Turnbull and Allibone, 2003) as part of the Quarter Million Geology Map (QMAP) of New Zealand, which enabled a geological map of Invercargill City at 1:50 000 (Thomas and Turnbull, 2001 – see Figure 1) to be produced. This map incorporated new field mapping and available subsurface geology information, mainly from the coal drillhole database.

Invercargill City is located adjacent to the New River Estuary, formed where a number of rivers meet Foveaux Strait, and is for the most part built on Holocene (0-14,000 years) estuarine silts and river alluvium, and older Quaternary gravels. Gore Lignite measures outcrop near the margins of the city limits to the east, and underlie the Quaternary sediments. Older intrusive igneous rocks and meta-sediments form the Green Hills and Bluff Hill, to the south.

2.2 Earthquake hazard

The return periods for different levels of earthquake shaking for Invercargill were reported by Van Dissen *et al.* (1993) and updated by Glassey (2004 and 2006) based on the national Probabilistic Seismic Hazard Model current at the time. Ground shaking intensities of greater than MMVII (Modified Mercalli 7) in Invercargill were reported by Glassey (2006) as having a probability of less than 2% in 50 years, approximately a 2500 year or greater return period.

The seismic hazard model is currently being revised incorporating new fault and other earthquake source information (Stirling; McVerry *et al.*, in press). Return periods for earthquakes that can cause significant ground shaking amplification and the onset of liquefaction at Invercargill may have changed slightly when compared with those reported by Glassey (2006). Irrespective of this, the model shows that the probability of earthquake shaking strong enough to cause liquefaction in Invercargill is low when compared to Te Anau and Wellington, for example (Stirling *et al.*, 2002), and this is unlikely to change.

Determining the current seismic hazard for Invercargill City is not part of the scope of this work



Geological Map of Invercargill City

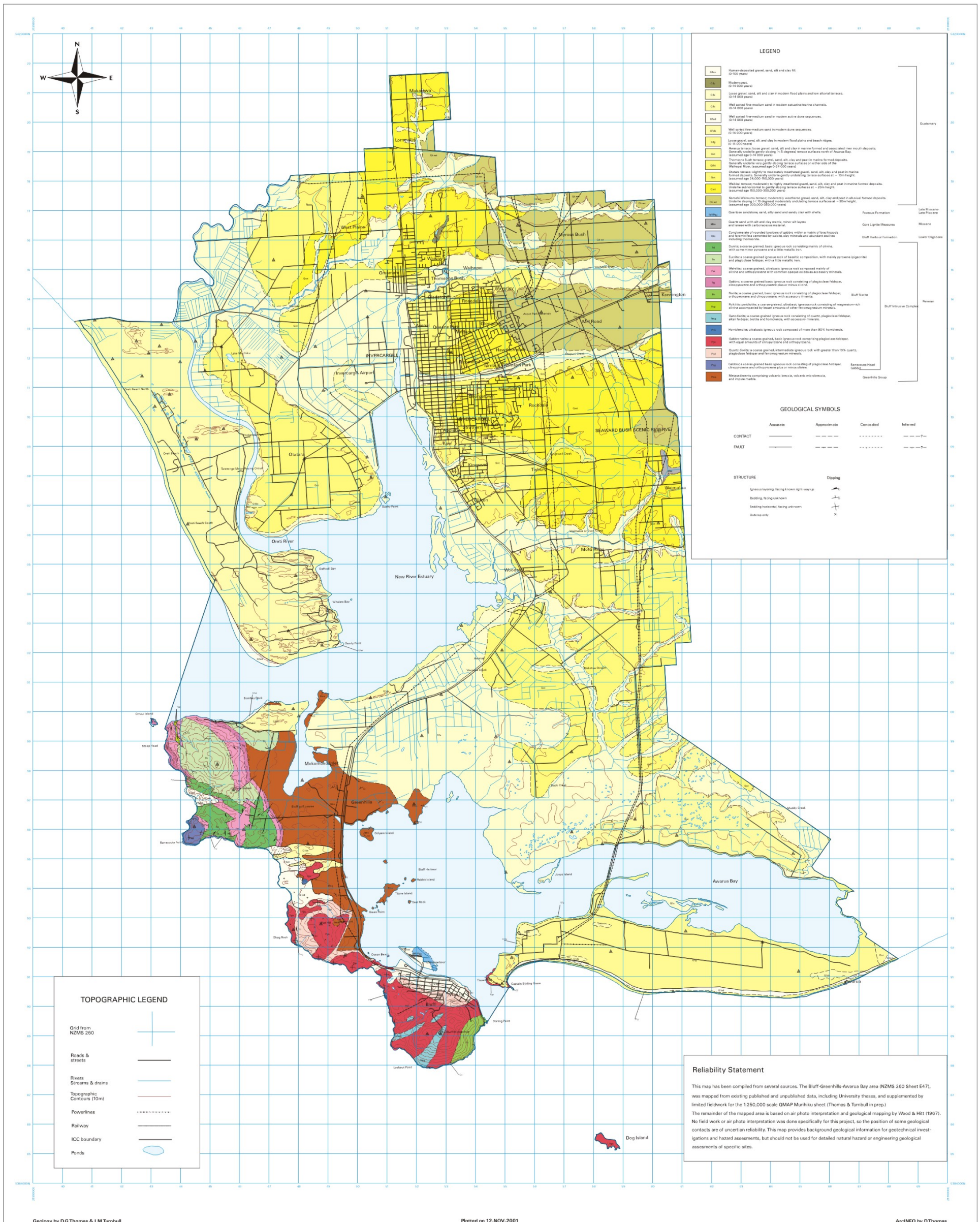


Figure 1: Geology of the Invercargill City Area – Thomas and Turnbull 2001

3.0 EARTHQUAKE GROUND SHAKING AMPLIFICATION

In general, earthquake shaking decreases with distance away from the earthquake source. However, local geological conditions significantly influence the character of earthquake shaking at a site. In general, soft soil can increase the level and duration of shaking depending on the proximity of the earthquake source to the site, and can affect how a structure may react.

Using the updated geology of Thomas and Turnbull (2001), we have classified the geological units in terms of engineering soil classification based on the Australia/New Zealand Standard 1170; 2002. A map of the soil classification is shown in Figure 2. Such a classification is coarse and simplistic and does not incorporate engineering testing of the subsurface materials. Buffer zones have been created at the margins of the zones to indicate areal uncertainty. This classification is a guide only and is no substitute for detailed site investigations, including subsurface investigations, to determine ground conditions.

The likely response of these “soils” during a strong distant earthquake and a strong, nearby earthquake are described in Table 1 and Table 2 respectively.

Likely response during a strong distant earthquake	
Type of rock or soil	Likely response in a strong distant earthquake compared to a 'Shallow Soil' site:
Strong rock	LITTLE or NO increase in shaking
Weak Rock	LITTLE or NO increase in shaking
Shallow Soil	NO increase in shaking
Deep or Soft Soil	MODERATE increase in shaking
Very Soft Soil	LARGE increase in shaking

Table 1: Likely response of ground classes during a strong distant earthquake

Likely response during a strong nearby earthquake	
Type of rock or soil	Likely response in a strong nearby earthquake compared to a 'Shallow Soil' site:
Strong rock	SLIGHT increase in shaking
Weak Rock	SLIGHT increase in shaking
Shallow Soil	NO increase in shaking
Deep or Soft Soil	MODERATE increase in shaking
Very Soft Soil	MODERATE decrease in shaking (houses) MODERATE increase in shaking (high-rise buildings)

Table 2: Likely response of ground classes during a strong nearby earthquake

When an earthquake is large and located nearby, shaking intensities can be very strong (MM8 or greater) over most rock or soil types, but with one exception. Past earthquakes have shown that very soft soils may reduce the high levels of shaking associated with strong nearby earthquakes because the very soft materials can absorb some of the shock rather than transmitting it. In general this tends to protect houses from much of the earthquake shaking and resulting damage, but may not protect high-rise buildings. The intensity of shaking can also be amplified in some places by the shape of valleys and ridges (topographic amplification). The construction style and height of a building can also influence the amount of shaking damage that occurs.

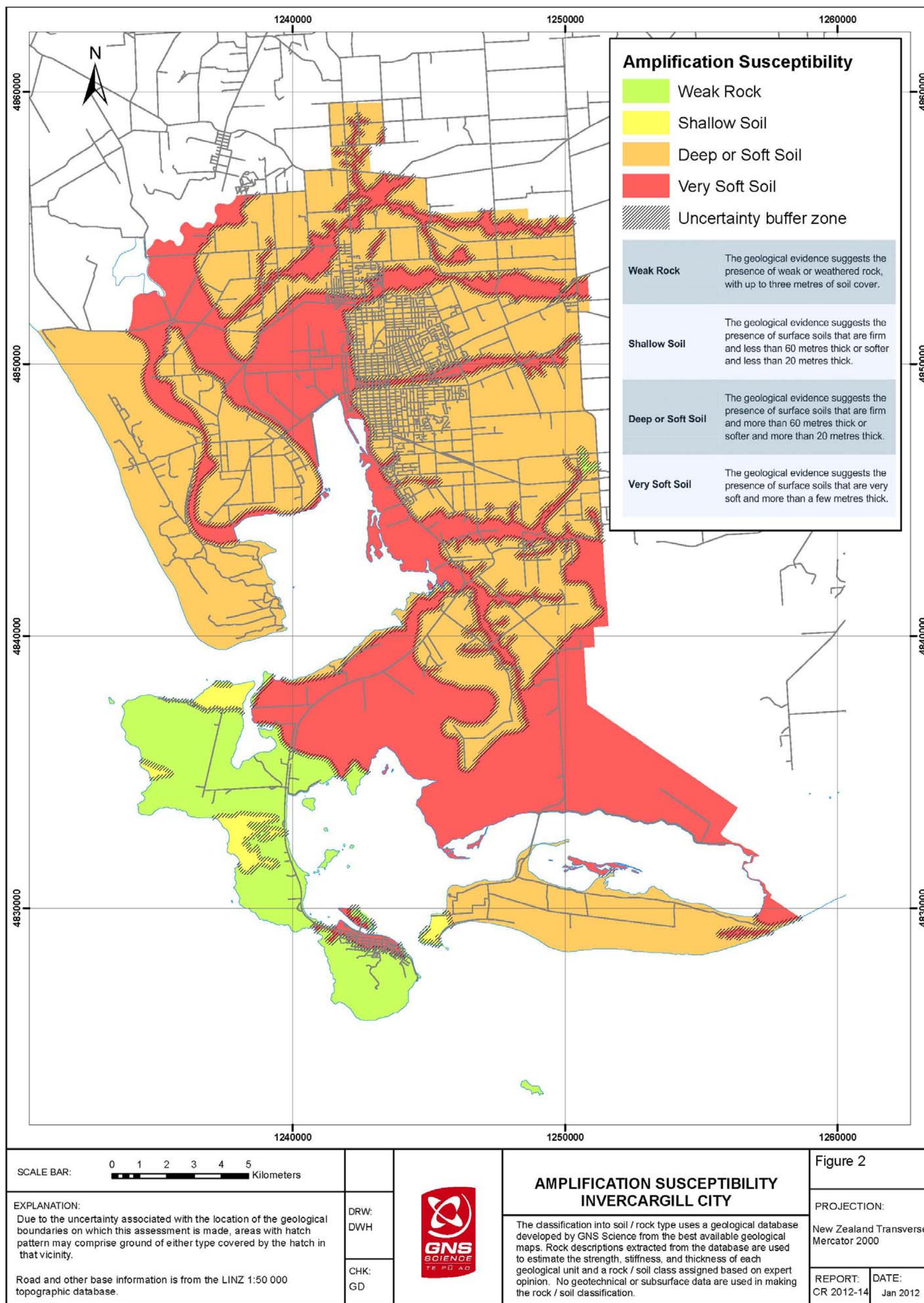


Figure 2: Soil Classification for Earthquake Ground Shaking Amplification, Invercargill City

4.0 LIQUEFACTION SUSCEPTIBILITY

Strong shaking during earthquakes can result in liquefaction, as has been dramatically re-emphasised and illustrated in both the 2010 M7.1 Darfield and 2011 M6.3 Christchurch earthquakes. Liquefaction is the process where strong shaking may cause certain soils to consolidate, increasing pore water pressure and decreasing shear strength to a point where the soil is transformed to a liquid state and water is expelled. Liquefaction is most likely to occur in saturated, relatively uniform, cohesionless, fine sands, silty sands, or coarse silts of low relative density (loose), generally at depths of up to 15 to 20 m below ground level, and in areas where the water table is within 5 m of the ground surface. Coastal areas and river flood plains are susceptible to liquefaction. Liquefaction often results in significant ground deformation and is responsible for lateral spreading along river banks. Liquefaction also reduces the bearing capacity of soil and the ground's ability to support a building or structure is reduced.

The liquefaction susceptibility classification presented here is loosely based on a similar methodology that was applied to the Heretaunga Plains, Hawke's Bay (Dellow *et al.*, 2003) which was calibrated by recorded historic occurrences of liquefaction. For this project the historic record or prehistoric evidence of liquefaction within the Invercargill City area has not been researched. There is however evidence of liquefaction in western Southland, closer to Fiordland (Glasse 2006).

For this project, liquefaction susceptibility has been based on the ages and description attributes of the geological units, using the updated geology of Thomas and Turnbull 2001. Holocene sediments (0-14 k years) are commonly unconsolidated, close to the surface and saturated. Sediments older than Holocene (i.e. >14 k years) are more consolidated and occur in elevated terraces; therefore they are commonly well drained, unsaturated, and less susceptible to liquefaction. There are one or two examples from Christchurch where liquefaction may have occurred in these older sediments where shaking was in the order of MM10. Proximity to water bodies is also taken into consideration.

The liquefaction susceptibility map for Invercargill City is given as Figure 3. For much of the current built up area of the city, the liquefaction susceptibility is "Negligible" or "Low". However it should be noted that key infrastructure, such as the wharf at Bluff and the airport, are located in areas classified as having a "Very High" susceptibility to liquefaction.

Liquefaction susceptibility describes the nature of the soils and indicates whether they may liquefy given significant ground shaking. Liquefaction damage may begin in "Very High" susceptibility soils with ground shaking intensity in the order of Modified Mercalli 7 (MM7), but the damage is probably going to be minor. Those soils classified as having "Low" susceptibility may liquefy given strong shaking of MM10, where damage is likely to be minor, whereas with this order of shaking, the damage on "Very High" soils will be extensive and significant.

A liquefaction damage rating for each of these zones is given in Table 3 and the earthquake shaking intensity required to initiate liquefaction of each zone is given in Table 4. As indicated in section 2, we have not revised the likelihood of this ground shaking occurring in Invercargill City.

Liquefaction Damage Rating	Description of expected liquefaction induced ground damage
0	No liquefaction damage is seen
1	A few sand boils and minor fissures. Estimate up to 10% of total area affected.
2	Sand Boils and moderate fissuring – more extensive near basin edges and in waterlogged areas: banks of rivers broken up, and embankments slumped. Settlements of up to 0.2 m. Estimate 10-20% total area affected.
3	Lateral Spreading common, with many fissures in alluvium (some large), slumping and fissuring of stopbanks, common sand boils. Settlements of up to 0.5 m. Estimate 20 – 50 % of total area affected.
4	Lateral spreading widespread, with extensive fissures and horizontal (and some vertical) displacements of up to 10 m common especially near channel edges. Settlement of uncontrolled fills by up to 1.0 m. Estimate > 50% of total area affected.

Table 3: Descriptions of expected liquefaction induced ground damage for liquefaction damage ratings.

Liquefaction Susceptibility Class	MM Intensity				
	MM6	MM7	MM8	MM9	MM10
Very High	0	1	2	3	4
High	0	0	1	2	3
Moderate	0	0	0	1	2
Low	0	0	0	0	1
Negligible	0	0		0	0

Table 4: Liquefaction damage ratings assigned to liquefaction susceptibility classes at different MM shaking intensities.

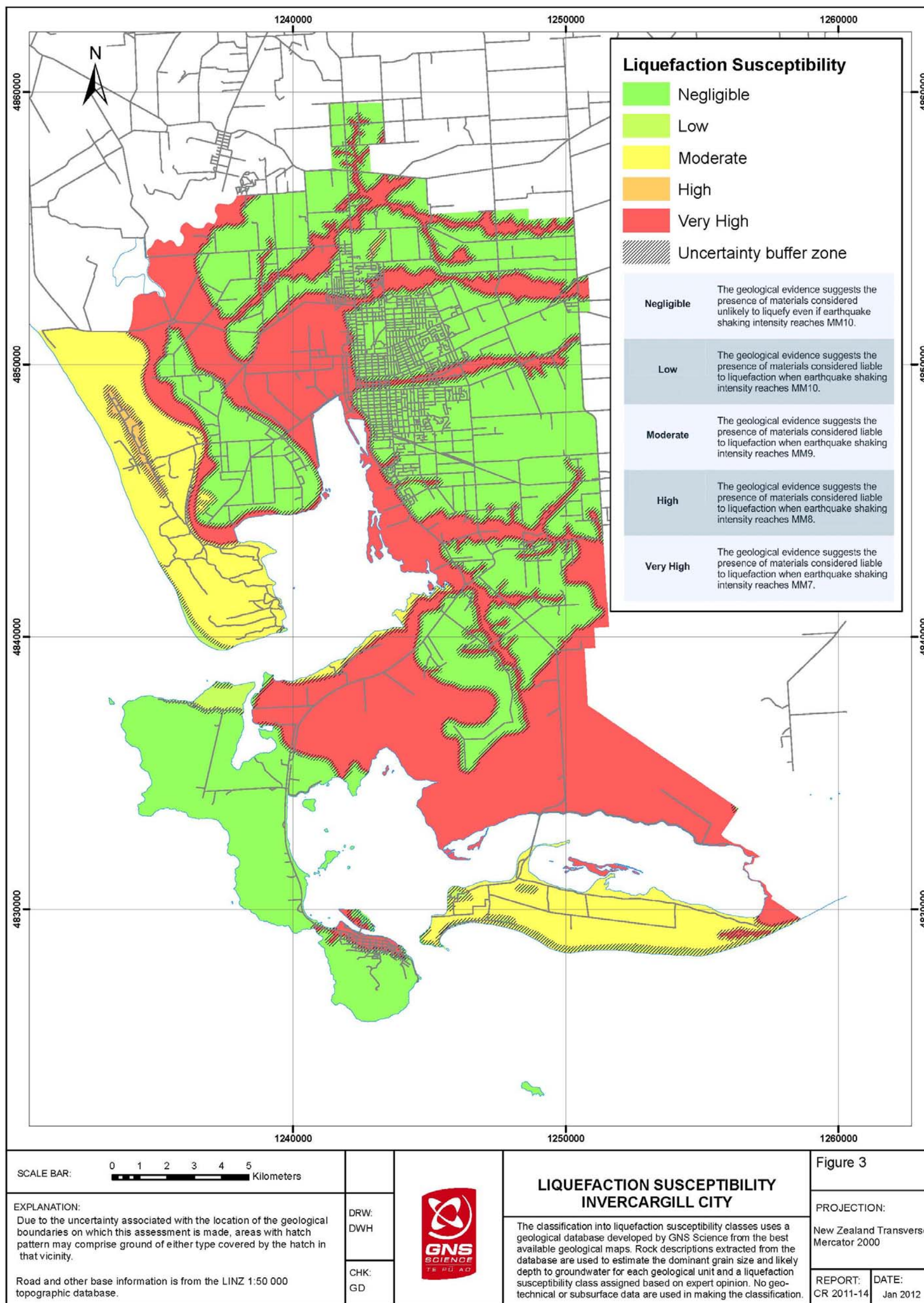


Figure 3: Liquefaction Susceptibility, Invercargill City

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Much of Invercargill City is constructed on “Deep or Soft Soil” or “Very Soft Soil” that is likely to amplify ground shaking, depending on whether the earthquake source is distant or nearby.

For much of the current built up area of the city, the liquefaction susceptibility is “Negligible” or “Low”. However it should be noted that key infrastructure, such as the wharf at Bluff and the airport, are located in areas classified as having a “Very High” susceptibility to liquefaction.

The classifications are indicative only and are to be used by the council for planning and consent purposes. Actual ground conditions can only be ascertained by a site investigation that includes subsurface investigations.

The probability of earthquake shaking strong enough to cause the onset of liquefaction and/or produce amplified ground shaking sufficient to cause damage in Invercargill City is low when compared to Te Anau and Wellington, for example.

5.2 Recommendations

It is recommended that the seismic hazard for Invercargill City be revised to take into new source information and improvements in the modelling process, to update the likelihood of strong earthquake motion causing ground damage and the onset of liquefaction.

6 ACKNOWLEDGMENTS

This report has been reviewed by Jane Forsyth (GNS Science, Dunedin), and Grant Dellow (GNS Science, Lower Hutt).

7 REFERENCES

- Dellow, GD; Barker, PR; Beetham RD; Heron D, 2003 : A deterministic method for assessing the liquefaction susceptibility of the Heretaunga Plains, Hawke's Bay, NZ. p. 111-120 *IN: Crawford, S.; Baunton, P.; Hargraves, S. Geotechnics on the volcanic edge, Tauranga, March 2003. Wellington: Institution of Professional Engineers New Zealand. Proceedings of technical groups / Institution of Professional Engineers New Zealand 30(1 GM).*
- Glasse, PJ, 2004: Geological Hazards. *In* "Working Together to Reduce Risk – Engineering Lifelines Project Report – Invercargill". *Invercargill Lifelines Project, Invercargill City Council 2004.*
- Glasse, PJ, 2006: Geological hazards: Southland District Council Lifelines study. *GNS Science Consultancy report 2006/100. June 2006.*
- Stirling, MW; McVerry GH; Berryman, KR, 2002. A new seismic hazard model of New Zealand. *Bull. Seis. Soc. Am.* **92**, 1878-1903.
- Stirling, MW; McVerry, GH, *et al.* (in press): National Seismic Hazard Model for New Zealand: 2010 Update. *Submitted to: Bulletin of the Seismological Society of America, June 2011.*
- Thomas, DG; Turnbull, IM, 2001: Geological map of Invercargill City, 1:50 000. *Institute of Geological & Nuclear Sciences Ltd client report 2001/117.*
- Turnbull, I M; Allibone, AH (compilers), 2003: Geology of the Murihiku area. Institute of Geological and Nuclear Sciences 1:250 000 geological map 20. *1 sheet and 74 p. Lower Hutt, New Zealand. Institute of Geological and Nuclear Sciences Ltd.*
- Van Dissen, RJ; Lindqvist, JK; Turnbull, IM; 1993: Earthquake hazard in the Southland Region. *Institute of Geological & Nuclear Sciences Ltd client report 1993/66.*
- Wood, BL. 1966: Sheet 24, Invercargill. Geological map of New Zealand 1:250000. Wellington DSIR.
- Wood BL.; Hitt G, 1967: Invercargill City Geological map and cross sections. Unpublished map 1 sheet + 1 cross-section. *Dunedin, New Zealand. Institute of Geological and Nuclear Sciences Ltd.*



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