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# Pre-feasibility information relating to Mokihinui River hydro development

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**Study Validation Period**
**February 2011**

The findings contained within this report remain valid until the above date, after which time the study should be re-validated to reflect the current rapid advances in the science that underpins the study.

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# EXECUTIVE SUMMARY

This report addresses a request from DamWatch Services for GNS to provide an up-to-date summary of information held by GNS relating to seismic hazard and site conditions for hydro-electric development in the Mokihinui River area. GNS understands that the area of present primary interest for hydro development on the lower Mokihinui River is in the vicinity of the Lower Russell Crosses site. Preliminary seismic hazard estimates for this location at 41.533°S 172.040°E are also provided in terms of Modified Mercalli (MM) intensities and peak ground accelerations (pga).

A considerable amount of prior work was undertaken on the Mokihinui River hydro-electric scheme from 1960-1982, mainly through Ministry of Works investigations. Much of this work has been summarised or assembled in this report as a series of bibliographies of known geologic work. Relevant updated information is also presented.

New Zealand is a seismically highly-active region straddling the Pacific-Australia plate boundary, with varying amounts of tectonic strain from region to region. The Northwest Nelson region is on the flank of the main axis of deformation through New Zealand. There is a moderate to low seismic hazard posed by rupture of faults in the Buller – Northwest Nelson region to the proposed damsite along the Mokihinui River. Of most particular interest are a belt of active faults that include the Inangahua, Lyell and White Creek Faults. The Glasgow Fault, which has not been studied in detail, is also in the immediate vicinity. The White Creek fault has an estimated recurrence interval of c. 34,000 years. These faults probably have slip rates that are considerably less than 1 mm/yr (estimate for White Creek Fault is c. 0.2 mm/yr). Two of these four faults have ruptured during large historical earthquakes: the 1929 Buller earthquake (magnitude 7.6) and the 1968 Inangahua earthquake (magnitude 7.1). However, the occurrence of these two events is not consistent with the frequency of faulting events that is expected from the long term average slip rate. There is an added hazard posed by the generation of landslides and landslide-dammed lakes in the Mokihinui catchment as a consequence of large earthquakes. This process was particularly evident after the 1929 and 1968 earthquakes. Additional hazard associated with ground motions from large "national" seismic events outside of the Buller–Northwest Nelson region is low.

MM Intensities have been calculated for the Lower Russell Crosses site on the Mokihinui River, and compared to values for the four main urban centres (Table 2). Being close to the axial belt of faulting through New Zealand, the site has similar return periods to Wellington for MM6-7 levels of ground motions. For higher ground motions the return periods for MM8-9 begin to diverge from Wellington (they get longer) in accordance with the lack of high slip rate faults with short recurrence intervals in the region. However, the hazard from ground motions is always higher than that observed for Auckland, Christchurch and Dunedin. Calculated mean return periods for MM intensities 6, 7, 8 and 9 are 8, 35, 230 and 2400 years respectively.

Table 3 in the report (reproduced below) presents peak ground acceleration estimates for given mean return periods. These were computed for two different ground conditions. No magnitude weighting has been used. Note that MM8 shaking has a mean return period of 230 yr, similar to that for peak ground accelerations of c. 0.33g on weak rock and 0.44g on shallow soil.

| Mean Return Period (years) | Peak acceleration (g) | |
|---|---|---|
| | Weak Rock | Shallow Soil |
| 10 | 0.07 | 0.10 |
| 25 | 0.12 | 0.17 |
| 50 | 0.17 | 0.24 |
| 100 | 0.24 | 0.32 |
| 150 | 0.28 | 0.37 |
| 250 | 0.33 | 0.45 |
| 475 | 0.40 | 0.55 |
| 1000 | 0.49 | 0.67 |
| 2500 | 0.62 | 0.84 |
| 5000 | 0.71 | 0.96 |
| 10,000 | 0.81 | 1.08 |

**Table 3.** Peak ground acceleration estimates (g) for various mean return periods and two different ground conditions

Ground motion spectra (Figure 4 and Table 5) have also been computed using the attenuation of model of McVerry et al (2006).

The appropriateness of the estimated 10,000-year motions for design is questionable because the main contributions to the estimated hazard come not from large earthquakes on the major faults in the region, but from local earthquakes of about magnitude 5 to 6 modelled as part of the background seismicity. Even at a return period of 10,000 years, the background seismicity contributes more than 95% of the incidences of peak ground acceleration.

The New Zealand Dam Safety Guidelines allow the Maximum Design Earthquake (MDE) motions for High Importance Category Dams to be taken as either the motions for the "Maximum Credible Earthquake" (MCE) or the 10,000 year motions. Possible MCE motions are discussed in the body of the report, with their pgas found to range from about the 1000-year values of Table 3 to values in excess of the 10,000-year values. Event-specific MDE motions rather than 10,000-year motions merit consideration for the Mokihinui hydro development because the probabilistic hazard analysis for this project produces severe earthquake ground motions for return periods of about 1000 years and greater, exceeding about 0.5g on rock.

## 1.0 INTRODUCTION

This report summarises the results of a desktop study undertaken at GNS Science, compiling information relating to seismic hazard and site conditions for the development of a hydro-electric scheme on the Mokihinui River near Seddonville on the West Coast region of South Island. In particular, new work in this report focuses on estimations of earthquake ground motions at the preferred dam site at Russell Crosses (M12) and on regional seismic hazard.

The agreed scope of work is a desk study with the following components:

(i) An annotated bibliography of published and unpublished information at GNS pertaining to seismic hazard estimation of the Mokihinui River area;
(ii) An annotated bibliography of published and unpublished information at GNS pertaining to engineering and engineering geological information in the Mokihinui River area;
(iii) Earthquake ground motion estimates for the area, deduced from the National Seismic Hazard model; and
(iv) Comments regarding implications for seismic hazard evaluation and ground motion estimates of new information available since the completion of earlier seismic hazard and engineering geological investigations on the Mokihinui River.

Previous work on the Mokihinui River has been summarised in GNS reports to Royden Thomson. Some of that information is presented again here as a background to the ground motion and seismic hazard work.

## 2.0 SUMMARY OF PREVIOUS HYDRO INVESTIGATIONS ON THE MOKIHINUI RIVER

Located on the West Coast of the South Island, the North and South branches of the Mokihinui River converge before flowing westward through a very steep-sided valley to the west coast beyond Seddonville to the Tasman Sea. Previous investigations by the Ministry of Works (MWD) between 1960 and 1982 identified several sites, three of which were surveyed. Two sites that were surveyed by MWD have been adopted for recent studies, as subsequent regional geological mapping and topographic features both indicate that they are suitable for dam construction. The lower site takes advantage of the lower narrow valley to efficiently develop the head in the lower valley up to the head of the upper site. The upper site utilises the flatter upper valleys of the upstream North and South Branches of the Mokihinui River to provide storage and enable regulation of the river flows.

The following investigations by the Ministry of Works from 1960 through 1982 include work undertaken along the Mokihinui River:

1. A survey of the hydro-electric resources of the West Coast 1960.
2. A report in "Preliminary Considerations", 1973, summarised the potential of the Mokihinui River.
3. An office study of sites during 1974 was reported in "Karamea and Mokihinui Power development, Initial Site Studies" September 1974.
4. Site investigations continued to 1978 and were reported in "Mokihinui River Power Development Review of Investigations".

Three dam sites were identified by MWD, identified as M11 (Howarth Site), M12 (Russell Crosses) and M23 (Specimen Creek). Sites M11 and M12 are c. 1 kilometre apart. The M11 site is located where the valley opens out and was judged suitable for an embankment dam by MWD, however doubt was expressed over availability of embankment fill materials. This study focuses on the M12 site at Russell Crosses.

Cross-sections of three dam sites identified by MWD were surveyed during the above investigations and aerial mapping was partially completed in 1976. A geotechnical investigation was conducted by MWD at the lower Russell Crosses damsite in 1975 which included drilling and driving an adit into each abutment.

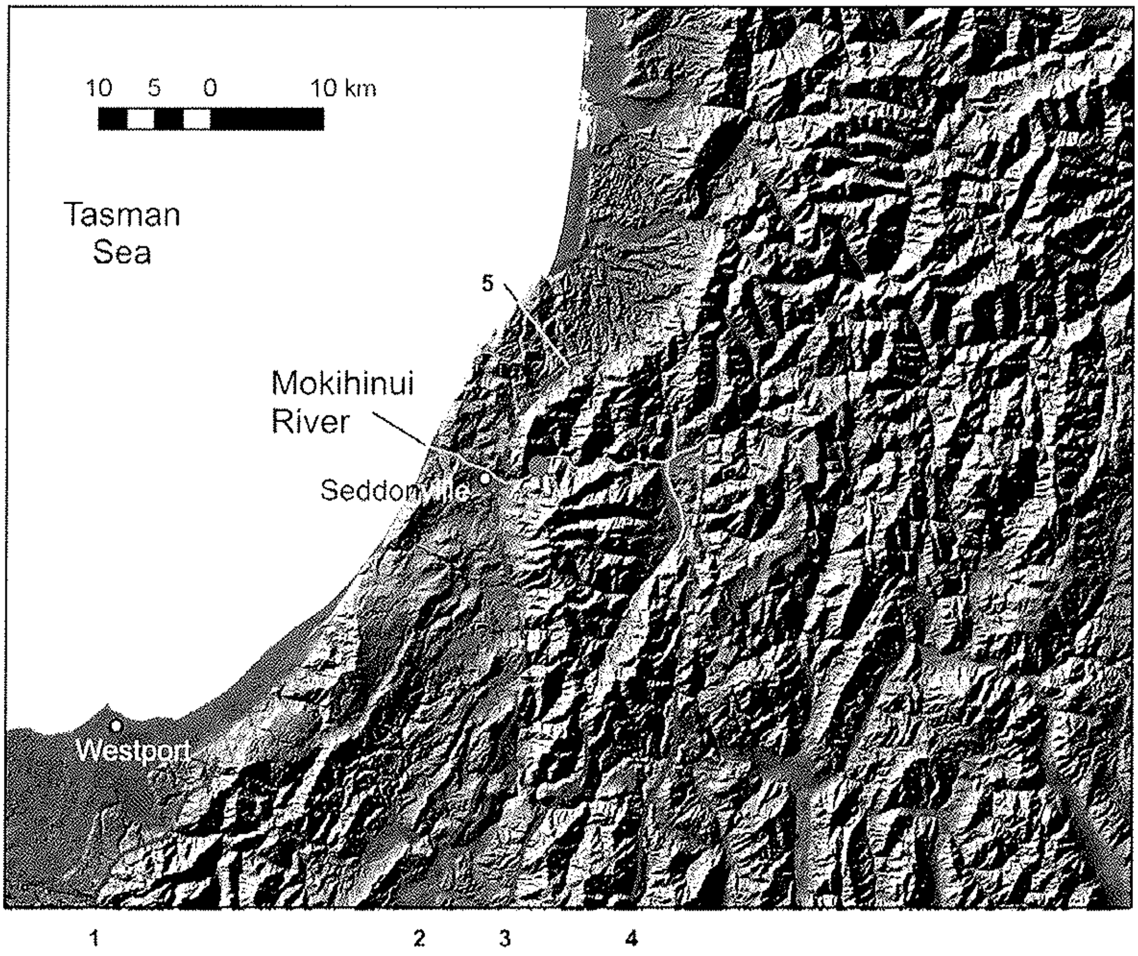


**Figure 1.** Digital elevation model of the NW Nelson region and Mokihinui River catchment area. Map includes Active Faults from the GNS Active faults database: 1, Paparoa Range Fault; 2, Inangahua Fault; 3, Lyell Fault; 4, White Creek Fault; 5, Glasgow Fault. The Russell Crosses site is shown in blue.

# 3.0 REVIEW OF PLATE TECTONICS AND SEISMIC HAZARD

## 3.1 Tectonic setting of New Zealand

New Zealand straddles the boundary of the Australian and Pacific plates, where relative plate motion is obliquely convergent across the plate boundary. The relative plate motion is expressed in New Zealand by the presence of many active faults, a high rate of "small-to-moderate" earthquakes (M<6.5), the occurrence of many "large" earthquakes (M6.5-7.9) and one "great" earthquake (M>8) in historical time. A northwest-dipping subduction zone lies at the northeastern end of the country ("Hikurangi subduction zone" in Figure 2). It is linked to a major southeast-dipping subduction zone in the southern South Island ("Fiordland subduction zone") by a 1000 km long zone of right-lateral oblique slip faults ("Axial tectonic belt").

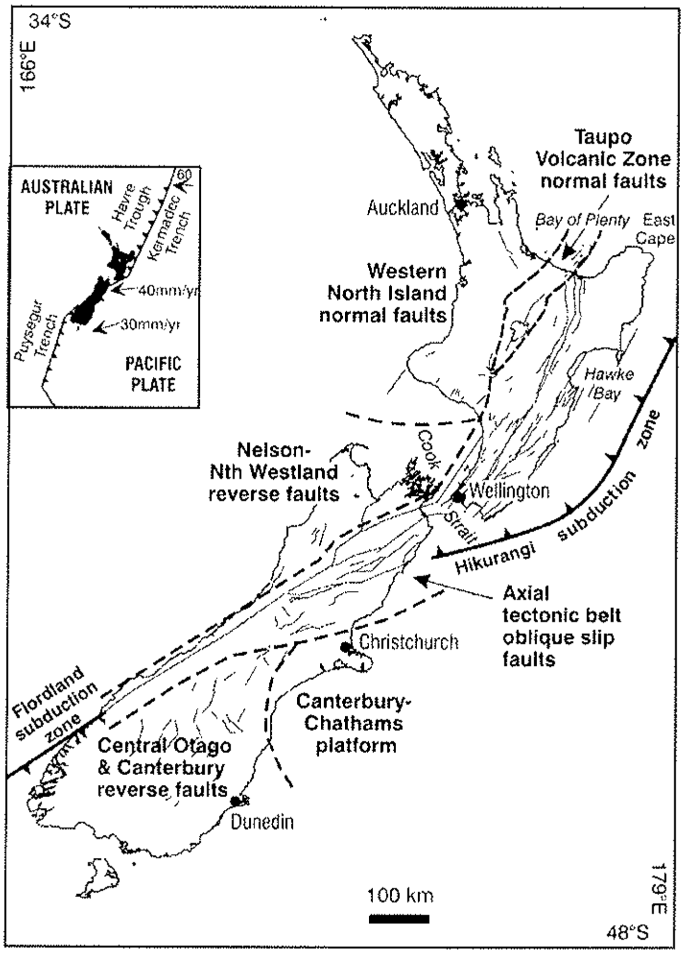


**Figure 2.** Zones of active faulting in New Zealand (modified from Stirling et al. 2002).

Essentially all of the relative, upper plate motion is accommodated by the faults of the axial tectonic belt in the area between the Fiordland and Hikurangi subduction zones. Some of the highest rates of seismicity in the country occur within the dipping slabs of the subduction zones. Frequent moderate earthquakes also occur above the Fiordland subduction zone, and to a lesser extent above the Hikurangi subduction zone.

The axial tectonic belt is a zone that is composed of right-lateral strike-slip motion and compression. Many moderate or larger earthquakes have occurred within the axial tectonic belt in historic time, including New Zealand's two largest historical earthquakes (the $M_w$ 8.1-8.2, 1855 Wairarapa earthquake, and $M_w$ 7.8 Hawke's Bay earthquake). The axial tectonic belt includes the Alpine Fault. This fault accommodates virtually all of the relative plate motion in the central South Island, but has not produced any large or great earthquakes in historic time. Geologic data provide evidence for the occurrence of great earthquakes on the Alpine Fault with return times of about 300 years. The last event on the Alpine Fault is believed to have occurred in or about AD 1717.

The Mokihinui River catchment occurs within the Nelson – North Westland region of the northern South Island. This is a region of generally north-striking geologic structure with faults cross-cutting pre-Tertiary crystalline rocks of the Australian plate. The damsites occur c. 65 km or more from the edge of the Axial Tectonic Belt marked by the Alpine Fault and Marlborough Fault System.

## 3.2 Regional seismicity

Seismicity in New Zealand varies regionally from moderate to very high on a world scale. Wellington lies in one of the most active of New Zealand's seismic regions and Auckland in one of the least active. Dunedin lies in a region that is a little more active than the Auckland region. Activity in the Christchurch area is intermediate between that of Wellington and Dunedin. These differences are illustrated by Figure 3, which shows the locations of the major earthquakes that have occurred in the New Zealand area since AD 1840.

The Buller-Northwest Nelson region has been one of high seismicity rates and large earthquakes in New Zealand (Fig. 3) in the historic period since 1840. North-striking, reverse-slip faults dominate the structural grain in the bedrock terranes of NW Nelson (Figs. 1 and 2). Although these structures are considered to be outside of the main plate boundary zone, they have been seismically active in a belt that continues north beyond Cape Foulwind to Cape Egmont, Taranaki in the North Island (Berryman & Beanland 1988). Two of the largest events during the historic period, the 1929 M 7.6 Murchison and 1968 M 7.4 Inangahua earthquakes, have occurred in the Buller region (Anderson et al. 1994; Berryman 1980) (Fig. 3). Both earthquakes have produced surface displacements and deformation associated with a compressive style of tectonic deformation (http://data.gns.cri.nz/af/). The release of seismic energy as a consequence of these two events far outweighs the regional rate of release that would be expected on average over a longer time period, i.e. slip over the last century is far greater than would be expected from fault slip rates and regional strain (Berryman 1980; Wallace et al. 2005).

The background seismicity rates for this part of the country in the National Seismic Hazard model are higher than anywhere else in the country, based on the recorded seismicity of the past 40 years. This is an anomaly in the light of low strain rates observed in the area (Wallace, pers. comm.). One suggestion for this (Reyners, pers. comm.) is that the present seismicity may in fact be largely composed of still-persisting aftershocks of the 1929 earthquake on the White Creek Fault. In this region, such an aftershock sequence is likely to persist for another century or more. The consequences of this are (a) in terms of large earthquakes occurring within the design life of the structure with an annual probability of 1 in 10,000, the present seismicity is a reliable guide, but (b) in terms of earthquakes likely to occur within the next 10,000 years, the present seismicity may significantly overestimate the hazard. In the light of (a) we recommend the seismicity rates from the National model as the best guide for the next few decades to century. Implications of these high seismicity rates for the estimated hazard are discussed in Section 4.

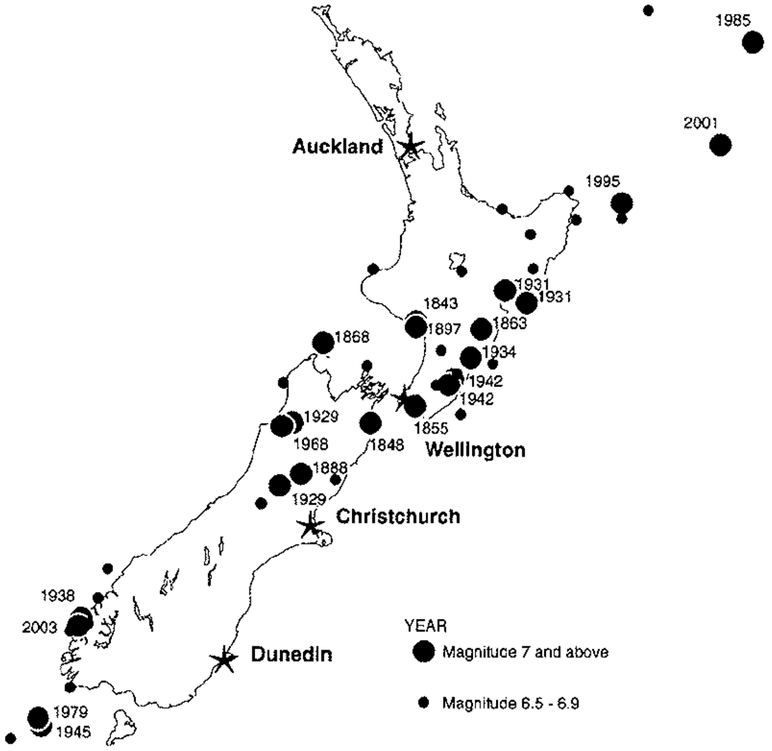


**Figure 3.** Occurrence of large earthquakes in New Zealand since 1840.

The Inangahua Fault links to the north with the Glasgow Fault, a large-bounding fault that occurs along the rangefront downstream of the Russell Crosses damsite (faults 2 and 5 in Fig. 1). In the upper reaches of the Mokihinui River catchment the Lyell and White Creek Faults form a structural basin, where the North and South river branches also join (Rattenbury et al. 1998). The region remains seismically active since the 1929 and 1969 earthquakes and can be expected suffer future large earthquakes. The White Creek Fault (average recurrence interval c. 34,000 yr) and other faults in this belt probably have long recurrence times for surface faulting events, corresponding with their low perceived geologic slip rates and low regional strain in this area (Anderson et al. 1994; Berryman 1980).

Therefore, while it is reasonable to assume that the White Creek Fault will not rupture again in a very long time. However other structures such as the Lyell Fault and Glasgow Fault may have been loaded by the nearby large earthquakes and may rupture in the future.

The Glasgow Fault has not been studied in detail, and is not currently listed as a source in the National Hazard Model. However other faults in the region have long recurrence intervals so that without specific detailed study, faults such as the Glasgow Fault might be interpreted as inactive. They would be better classified as "unknown activity", rather than inactive. In this study we include the Glasgow Fault as a deterministic case study as part of the sensitivity analysis.

In summary, there is a moderate seismic hazard posed by the faults of the Buller – Northwest Nelson region to the proposed damsite along the Mokihinui River. Of most particular interest are a belt of active faults that included the Inangahua, Glasgow, Lyell and White Creek Faults. Two of the four structures have ruptured during historical earthquakes, though the frequency of these two events is much greater than is expected from the long term average. The White Creek Fault has an estimated recurrence interval of c. 34,000 yr, based on the fact that the widespread, glacial aggradation surface of the Buller River has been faulted only once (Berryman 1980). A single event displacement of 4.6 m (vertical + left-lateral) as observed in 1929, with this recurrence interval produces a slip rate of c. 0.2 mm/yr.

## 3.3 Bibliography

Listed below are a number of the key published articles relating to the style and rates of tectonic deformation in the Buller-Northwest Nelson region. An up-to-date list of all GNS material on the Mokihinui River area and the geology of the surrounding region can be found in Appendix B.

Anderson H, Beanland S, Blick G, Darby D, Downes G, Haines J, Jackson J, Robinson, R Webb T 1994. The 1968 May 23 Inangahua, New Zealand, earthquake: an integrated geological, geodetic, and seismological source model. *New Zealand Journal of Geology and Geophysics* 37: 59-86.

- *comprehensive summary paper concerning the geology, geodesy and seismology of the 1968 Inangahua earthquake, related to deformation on the Inangahua Fault and surrounding structures.*

Berryman K 1980. Late Quaternary movement on White Creek Fault, South Island, New Zealand. New Zealand, *New Zealand Journal of Geology and Geophysics* 23:93-101.

- *describes active faulting related to the White Creek Fault, which was responsible for the 17 June, 1929 Murchison earthquake. Discusses evidence for a long repeat time.*

Berryman K, Beanland S 1988. Ongoing deformation of New Zealand: Rates of tectonic movement from geological evidence. *IPENZ Annual Conference, Transactions* 15: 25-35.

- *describes the styles and amounts of deformation from province to province through out New Zealand. There are mentions of the style and activity of the Northwest Nelson area.*

Bishop DJ 1992. Neogene deformation in part of the Buller Coalfield, Westland, South Island, New Zealand. *New Zealand Journal of Geology and Geophysics*, 35: 249-258.

Coleman AC, Johnston MR 1975. Northern Buller power scheme: proposed damsites (M11, M12), Mokihinui River (S25). *New Zealand Geological Survey report* EG 214 http://data.gns.cri.nz/af/

- *the URL for the GNS Active Faults data base which shows faults throughout New Zealand and documents neotectonic data for these structures.*

Morgan PG, Bartrum JA 1915. The geology and mineral resources of the Buller-Mokihinui subdivision, Westport division. *New Zealand Geological Survey Bulletin* 17, Wellington : Government Printer. Many refs; 18 figs; 14 tables; 19 plates; 9 maps; 6 charts ; 2 appendices : 210 p.

- *forms a comprehensive report on the geology and mineral resources of the Buller-Mokihinui subdivision, which includes the whole of the Buller coalfield, as well as less important mining areas.*

Johnston MR 1973. Northern Buller power scheme, proposed dam sites, Mokihinui River (S25), preliminary geological inspection. November 1973. *New Zealand Geological Survey report* EG ; 179.

Nicol A, Nathan S 2001. Folding and the formation of bedding-parallel faults on the western limb of Grey Valley Syncline near Blackball, New Zealand. *New Zealand Journal of Geology and Geophysics* 44: 127-135.

- *describes the style of faulting and folding observed along the Montgomerie Fault/ Grey Valley Syncline, in particular the evidence for flexural-slip faulting. This style of deformation may be common in the NW Nelson region.*

Rattenbury MS, Cooper RA, Johnston MR (compilers) 1998. Geology of the Nelson area. *Institute of Geological and Nuclear Sciences 1:250 000 geological map* 9. 1 sheet + 67p. Lower Hutt, New Zealand.

- *constitutes the most up-to-date geological mapping from the GNS QMAP (1:250,000) series, covering the Nelson sheet. The map shows all bedrock geology, faults and active faults, including the Lyell, White Creek, Inangahua and Glasgow Faults.*

Robinson R. 2004. Potential earthquake triggering in a complex fault network: the northern South Island, New Zealand. *Geophysical Journal International* 159 (2): 734-748.

- *concerns the likelihood of earthquake triggering for faults in the Marlborough and Northwest Nelson regions as a consequence of Alpine Fault ruptures*

Saul G 1994. The basin development and deformation associated with the Kongahu (Lower Buller) fault zone over the last 12 Ma, Mokihinui River, West Coast, South Island, New Zealand, Journal of the Royal Society of New Zealand, 24 (3): 277-288.

Saul G. 1991. The mid Miocene to recent stratigraphy, basin development and deformation of the Nikau area, West Coast, South Island. In: Stewart, R.B. (ed.); Palmer, A.S. (ed.); Todd, A. (ed.) *Geological Society of New Zealand and New Zealand Society of Soil Science Joint Annual Conference, Palmerston North 1991, November 25-29 : programme and abstracts.* Geological Society of New Zealand. Geological Society of New Zealand miscellaneous publication 59A: 122.

Stirling MW, McVerry GH, Berryman KR 2002. A new seismic hazard model for New Zealand. *Bulletin of the Seismological Society of America,* 92(5): 1878-1903.

- *the most recent version of the National Seismic Hazard Model, which incorporates active faults, historical seismicity patterns, and attenuation models for New Zealand.*

Wallace, L. M.; Beavan, J.; McCaffrey, R.; Darby, D. 2005: Subduction zone coupling and tectonic block rotations in the North Island, New Zealand. *Journal of Geophysical Research*, 109, B12406, doi:10.1029/2004JB003241.

## 4.0 NEW ZEALAND DAM SAFETY GUIDELINES

The New Zealand Dam Safety Guidelines (NZSOLD, 2000), in common with international practice in other developed countries with moderate to high seismicity similar to New Zealand, define performance criteria for two levels of earthquake motions, the Maximum Design Earthquake (MDE) motions and the Operating Basis Earthquake (OBE) motions. The OBE motions usually correspond to those with an annual exceedance probability of 1/150 i.e. 150-year return period motions. Only minor damage is acceptable in OBE motions.

The MDE motions are used for seismic safety evaluation, with the requirement that the dam maintains its impounding capacity when subjected to that level of seismic load. Selection of the MDE motions depends on the Potential Impact Classification (PIC) of the dam. For high PIC dams, the MDE is usually taken as the Maximum Credible Earthquake (MCE) motions or 1/10,000 Annual Exceedance Probability (APE) motions. Lower MDE motions are acceptable for medium or low PIC dams.

The Maximum Credible Earthquake is defined as "the largest reasonably conceivable earthquake that appears possible along a recognised fault or within a geographically defined tectonic province, under the presently known or interpreted tectonic framework". The Guidelines do not define the probability level of motions that should be associated with this event, and also fail to recognise that an earthquake of somewhat lower magnitude than the MCE but closer to the dam may produce stronger motions.

Mejia et al (2004) discuss the interpretation of the guidelines as adopted by two New Zealand owners of large dams, Meridian Energy Limited and Mighty River Power Limited. In place of MCE they use the term Controlling Maximum earthquake (CME). They define the CME as "the maximum earthquake on the seismic source that is capable of inducing the largest seismic demand on a dam". This recognises that the largest magnitude earthquake in a region may not necessarily be the one that places the most severe seismic demand on a dam. They also specify the percentile levels to be used in conjunction with the CME, and the relationship between the CME motions and those derived probabilistically for various return periods. These are summarised in Table 1, adapted from Mejia et al. (2004).

| | Potential Impact Category | | |
|---|---|---|---|
| | High | Medium | Low |
| MDE motions | CME at 84-percentile level. Need not exceed 10,000-year motions. | CME at 50- to 84-percentile level. Need not exceed 2,500-year motions. | CME at 50-percentile level. Need not exceed 500-year motions. |

**Table 1.** Ground motion criteria for Maximum Design Earthquake motions

The discussions leading to the current study indicated that 10,000-year motions were required. Accordingly, it is assumed that a high PIC dam is under consideration. The hazard results will also consider scenario earthquakes to obtain candidates for CME motions, as well as listing results for various return periods.

## 5.0 EARTHQUAKE GROUND MOTION ESTIMATES FOR MOKIHINUI RIVER SITE

The National Seismic Hazard Model (Stirling et al, 2002) identifies more than 300 active faults throughout New Zealand, and for each one estimates the characteristic magnitude and mechanism of earthquakes, and the average recurrence interval. In addition to the faults, the Model takes account of the extensive background seismicity by determining earthquake rate parameters at a grid of sites which covers the country. Using these two parts of the model, it has been possible to construct a synthetic catalogue of earthquakes that represent those likely to occur over a period of 1,000,000 years.

### 5.1 MM intensity and Peak Ground Acceleration

The likely ground motion at the Lower Russell Crosses site (41.553°S 172.040°) has been calculated using the attenuation function for Modified Mercalli (MM) intensity prepared by Dowrick & Rhoades (1999). This function estimates the likely intensity in terms of the magnitude and mechanism of the earthquake, together with its location with respect to the site. Using this function, the MM intensity has been computed at the site for all the earthquakes in the 1,000,000-year synthetic catalogue. From these instances of MM intensity we have determined the following table of mean return period for the various intensity levels. We also present, for comparison purposes, the mean return periods for Auckland, Wellington, Christchurch, and Dunedin. The various descriptions of earthquake effects that constitute the MM scale are given in Appendix A.

| | Mokihinui | Auckland | Wellington | Christchurch | Dunedin |
|---|---|---|---|---|---|
| MM 6 | 8 | 130 | 10 | 25 | 97 |
| MM 7 | 35 | 860 | 44 | 160 | 530 |
| MM 8 | 230 | 7400 | 170 | 1900 | 2800 |
| MM 9 | 2400 | - | 450 | - | - |
| MM 10 | - | - | 1500 | - | - |

**Table 2.** Mean return periods (years) for MM intensity 6 to 10 at the Mokihinui site and four other locations, for comparison.

The term *return period* may need clarification. We have essentially calculated the annual probability that this level of ground motion will occur. It is a cumulative measure, e.g. we have calculated the probability that a given intensity *or greater* will occur within any given year. The return period has a precise definition, but for the range of annual probabilities considered here it is approximately equal to the average interval between occurrences of the event, and to the reciprocal of the probability. So a return period of 200 years is equivalent to a probability of 1 in 200 that the event will occur in any one year.

There are two common misconceptions about the concept of return period. One is that it is the time period within which the intensity can be expected to occur. The other is that it is the largest that can be expected within that period. *Neither of these is true.* If an intensity of MM 7 has a return period of 100 years, for instance, higher intensities could occur within that period, or such an intensity might not occur at all within that period. The return period is simply a measure of annual probability, used because the numerical results are easier to interpret in this form.

Table 3 presents the hazard estimates in terms of peak ground acceleration, which we can estimate using the attenuation function of McVerry et al (2006). We use the National Seismic Hazard Model (Stirling et al, 2002) for earthquake sources, and compute the peak acceleration for two different ground conditions: weak rock and shallow soil. The weak rock ground class is for material with a comparative strength between 1 and 50 MPa, underlain by no more than 3m of soil (material with compressive strength less than 1 MPa). Shallow soil sites have a low amplitude natural period less than 0.60, or depth of soil not exceeding those listed in Table 3.2 of NZS1170.5:2004. No magnitude weighting has been applied in the estimates.

| Mean Return Period (years) | Peak acceleration (g) | |
|---|---|---|
| | Weak Rock | Shallow Soil |
| 10 | 0.07 | 0.10 |
| 25 | 0.12 | 0.17 |
| 50 | 0.17 | 0.24 |
| 100 | 0.24 | 0.32 |
| 150 | 0.28 | 0.37 |
| 250 | 0.33 | 0.45 |
| 475 | 0.40 | 0.55 |
| 1000 | 0.49 | 0.67 |
| 2500 | 0.62 | 0.84 |
| 5000 | 0.71 | 0.96 |
| 10,000 | 0.81 | 1.08 |

**Table 3.** Peak ground acceleration estimates (g) for various mean return periods and two different ground conditions.

## 5.2 Deaggregation

The following table gives the percentage contributions of the three main faults to the above pga figures, at three selected return periods, together with the contribution of background seismicity.

| Source | 150 yrs | 1000 yrs | 10000 yrs |
|---|---|---|---|
| Inangahua fault | 1.1% | 2.2% | 2.5% |
| Lyell fault | 0.5% | 0.4% | 0.7% |
| White Creek fault | 0.2% | 0.4% | 0.5% |
| Background | 96.3% | 96.0% | 95.8% |

**Table 4.** Deaggregation of peak ground acceleration hazard at three selected return periods

The important conclusion to be drawn here is that the overwhelming contribution, even at return periods as long as 10,000 years, is from the background seismicity. The three nearby faults have minimal effect on the hazard. The background seismicity rates for this part of the country in the National Seismic Hazard model are higher than anywhere else in the country, based on the recorded seismicity of the past 40 years. This is an anomaly in the light of low strain rates observed in the area (Wallace, pers. comm.). One suggestion for this (Reyners, pers. comm.) is that the present seismicity may in fact be largely composed of still-persisting aftershocks of the 1929 earthquake on the White Creek fault. The consequences of this are (a) in terms of large earthquakes occurring within the design life of the structure with an annual probability of 1 in 10,000, the present seismicity is a reliable guide, but (b) in terms of earthquakes likely to occur within the next 10,000 years, the present seismicity may significantly overestimate the hazard. In the light of (a) we recommend the hazard estimates based on the National model.

## 5.3 Pgas for fault rupture scenarios

As an alternative to the probabilistic calculations for a range of return periods, a number of earthquake scenarios have been considered for the MDE motions. Table 5 lists the fault parameters, and the 50- and 84-percentile peak ground accelerations at the Russell Crosses site estimated using the McVerry et al. (2006) model for rock and shallow soil site conditions. As in the probabilistic estimates with the NSHM, hanging wall effects have not been accounted for in the estimates.

| Fault | Magn. | Mech. | Recurrence Interval | Distance From site | Predicted pga (g) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Weak rock | | Shallow soil | |
| | $(M_w)$ | | (years) | (km) | 50% | 84% | 50% | 84% |
| Inangahua | 7.4 | rv | 4400 | 22 | 0.27 | 0.42 | 0.36 | 0.56 |
| Lyell | 6.7 | ro | 4700 | 24 | 0.17 | 0.27 | 0.23 | 0.36 |
| White Creek | 7.6 | rv | 34,000 | 14.5 | 0.36 | 0.57 | 0.49 | 0.77 |
| Glasgow | 7.4? | rv | Unknown | 3 | 0.58 | 0.91 | 0.78 | 1.23 |

**Table 5.** Parameters for rupture scenarios of four faults that are close to the site, and their 50- and 84-percentile pgas at the dam site estimated from the McVerry et al. (2006) attenuation model.

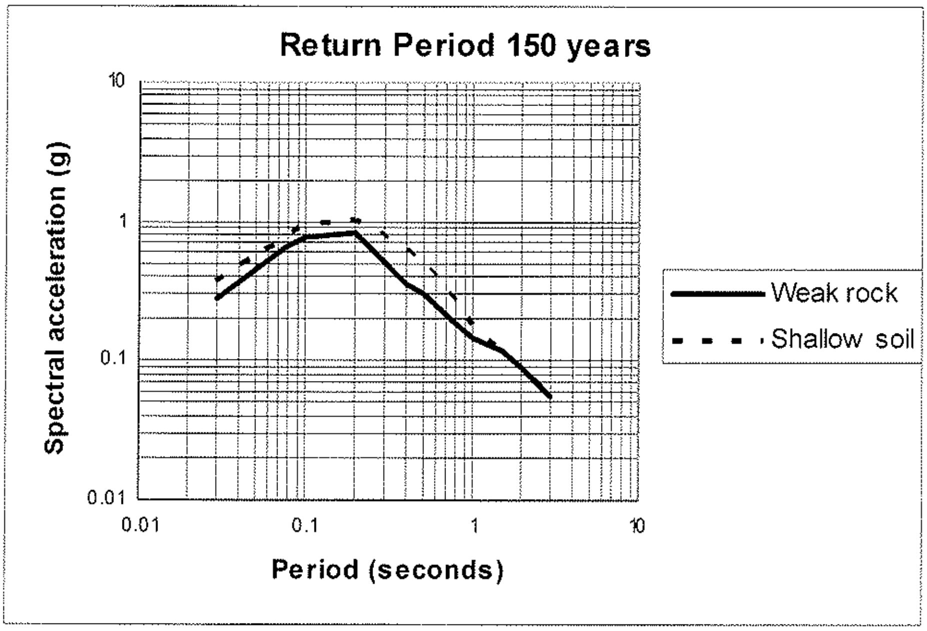
Fault parameters listed are moment magnitude $M_w$, shortest distance from the site to the rupture, average recurrence interval and mechanism (rv=reverse, ro=reverse-oblique). The Inangahua, Lyell and White Creek faults are included in the NSHM. The White Creek scenario uses a reduced distance of 14.5 km rather than 19 km as in the NSHM, increasing the scenario pga estimates by about 16 per cent. The reduced distance corresponds to that from the site to the northern extension of the fault indicated by the dashed line in Figure 1. Little is known about the activity of the Glasgow Fault, and it is not included in the probabilistic estimates from the NSHM. As it is considerably closer to the dam site than the three modelled faults, it has been considered as an alternative scenario source, using the magnitude of the 1968 Inangahua earthquake.

## 5.4 Acceleration spectra

Using the attenuation function of McVerry et al (2006) we have also computed ground motion spectra. We understand that the Operating Basis Earthquake for the proposed dam corresponds to 150 years return period, and the Maximum Design Earthquake to 10,000 years. Accordingly we present ground motion spectra for these two return periods in Table 6 and Figure 4, for both the ground conditions used above.

| **Period** | **150 yrs** | | **10,000 yrs** | |
|---|---|---|---|---|
| Sec | Weak Rock | Sh. Soil | Weak Rock | Sh. soil |
| 0.03 | 0.28 | 0.37 | 0.81 | 1.08 |
| 0.075 | 0.65 | 0.77 | 2.26 | 2.77 |
| 0.1 | 0.78 | 0.94 | 2.73 | 3.44 |
| 0.15 | 0.80 | 1.00 | 2.57 | 3.40 |
| 0.2 | 0.84 | 1.05 | 2.75 | 3.38 |
| 0.25 | 0.63 | 0.89 | 1.88 | 2.69 |
| 0.3 | 0.51 | 0.78 | 1.42 | 2.20 |
| 0.35 | 0.42 | 0.69 | 1.13 | 1.90 |
| 0.4 | 0.36 | 0.62 | 0.94 | 1.71 |
| 0.5 | 0.30 | 0.50 | 0.84 | 1.35 |
| 0.75 | 0.19 | 0.28 | 0.57 | 0.80 |
| 1 | 0.14 | 0.18 | 0.46 | 0.55 |
| 1.5 | 0.12 | 0.12 | 0.41 | 0.40 |
| 2 | 0.09 | 0.09 | 0.30 | 0.29 |
| 3 | 0.06 | 0.06 | 0.24 | 0.25 |

**Table 6.** Spectra for 150 yrs and 10,000 yrs return period, on weak rock and shallow soil



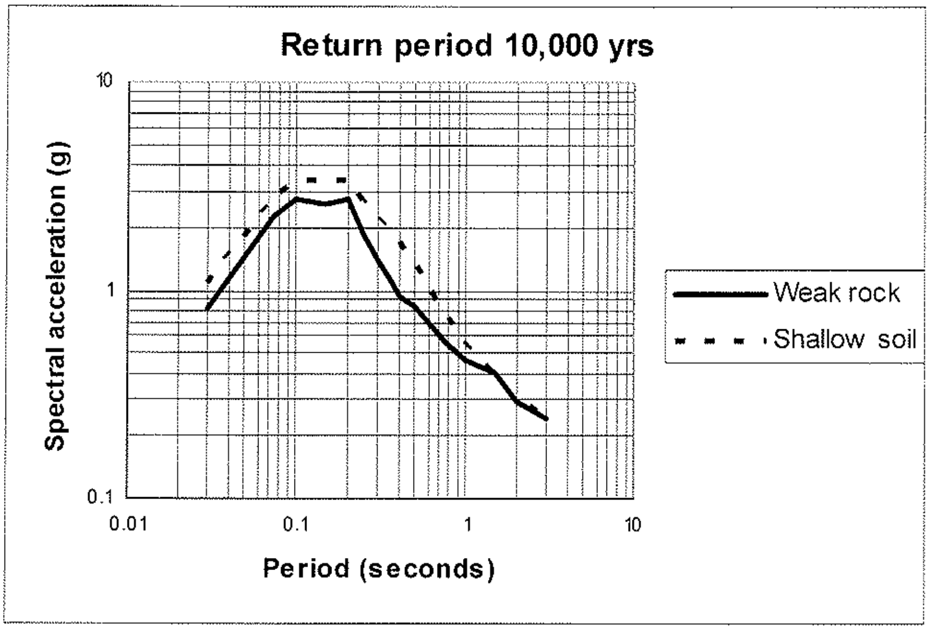


**Figure 4.** Spectra at 150 years return period (upper) and 10,000 years (lower), for the two ground conditions: weak rock and stiff soil.

## 5.5 Probabilistic versus scenario estimates

The ground motions given in this report are all very strong for return periods of about 1000 years and greater, with the 10,000-year values at levels approaching the bounds of physical reasonableness. These ground motions are caused almost entirely by earthquakes in the background seismicity, and not by the three main faults in the vicinity. The three nearby faults have minimal effect on the hazard.

Even at a return period of 10,000 years, the background seismicity contributes more than 95% of the incidences of peak ground acceleration. However, the probability levels for the motions associated with these events are very low, between 2% and 0.2% exceedance probabilities should the events occur. Although probabilistic hazard calculations typically retain values up to three standard deviations above the median (0.13% exceedance probabilities), "deterministic" scenario analyses typically consider motions only to the one standard deviation level, corresponding to a 16% exceedance probability. The very low exceedance probabilities arise in the probabilistic analyses for this site because of the very high current seismicity of the region, attributable to continuing aftershocks from the 1929 earthquake which may well continue for another century. The overall exceedance rate is the product of the earthquake rate and the exceedance probability, with high earthquake rates allowing lower than usual probability exceedance levels for a given return period. As estimated ground motion exceedance rates involve the products of earthquake rates and the probability of exceedance of a particular ground motion when an earthquake occurs, the very high current seismicity rates in the region allow the associated probability levels to be unusually low for a given return period.

The alternative scenario analyses for the three faults known to be active produce maximum 84-percentile peak ground accelerations of about 0.6g on rock and about 0.8g on soil, for a magnitude 7.6 earthquake on the White Creek Fault at a distance of 14.5 km. These are severe but more plausible motions than the 10,000-year estimates. The Glasgow Fault at the short distance of 3 km from the dam site produces 84-percentile pga estimates in excess of the 10,000-year values. Given the uncertainty about the activity of this fault, a 50-percentile scenario is perhaps more reasonable if this fault is to be considered. The 50-percentile pga estimates for this fault are almost identical to the 84-percentile estimates for the White Creek Fault. The values correspond to about 2000-year probabilistic estimates.

The 84-percentile White Creek scenario is recommended as a more realistic alternative to the estimated 10,000-year motions as the Maximum Design Motions for the dam.

## 6.0 CONCLUSIONS

A considerable amount of prior work has been undertaken on the Mokihinui River hydro-electric scheme from 1960-1982, mainly during the Ministry of Works governmental era. Much of this work has been summarised or assembled in this report as a series of bibliographies of known geologic work.

New Zealand is a seismically highly-active nation straddling the Pacific-Australia plate boundary, with varying amounts of tectonic strain from region to region. There is a moderate seismic hazard posed by rupture of faults in the Buller – Northwest Nelson region to the proposed damsite along the Mokihinui River. Of most particular interest are a belt of active faults that include the Inangahua, Glasgow, Lyell and White Creek Faults. Some of the parameters of these faults, particularly their average recurrence intervals, are poorly known. The White Creek fault has an estimated recurrence interval of c. 34,000 years. These faults probably have slip rates that are considerably < 1 mm/yr (est. for White Creek Fault is c. 0.2 mm/yr). Two of the four structures have ruptured during historical earthquakes, though the occurrence of these two events is not consistent with the frequency of faulting events that is expected from the long term average slip rate.

MM Intensities have been calculated for the Lower Russell Crosses site on the Mokihinui River, and compared to values for the four main urban centres. Being close to the axial belt of faulting through New Zealand, the site has similar return periods to Wellington for MM6-7 levels of ground motions. For higher ground motions the return periods for MM8-9 begin to diverge from Wellington (they get longer) in accordance with the lack of high slip rate faults with short recurrence intervals in the region c.f. Wellington. However, the hazard from ground motions is always higher than that observed for Auckland, Christchurch and Dunedin. Table 3 in the report presents peak ground acceleration estimates for given mean return periods. For example, MM8 shaking has a mean return period of 230 yr, which approximates to peak accelerations of c. 0.33 and 0.44 on weak rock and stiff soil, respectively. MM9 has an estimated return period of 2400 years, similar to that estimated for peak ground accelerations of about 0.6g on rock and 0.8g on shallow soil. Ground motion spectra have also been computed using the attenuation of model of McVerry et al (2006).

Selection of Maximum Design Earthquake motions for the site is problematical. The probabilistic 10,000-year motions are very extreme, and rather unrealistically governed by very low exceedance probability motions from local background seismicity rather than by the major fault sources in the region. Consideration of fault-rupture scenarios produces maximum 84-percentile pgas for the three known active faults close to the dam of about 0.6g on rock and 0.8g on shallow soil, for a magnitude 7.6 White Creek Fault event at a distance of 14.5 km from the site. Similar pgas are obtained as the 50-percentile estimates for the Glasgow Fault scenario. Given that the activity of this fault is unknown, a 50-percentile scenario can be argued to be reasonable for this fault. These pgas have a return period of about 2000 years from the probabilistic scenario, and are offered as a reasonable candidate for the MDE motions.

## 7.0 ACKNOWLEDGEMENTS

This report has been reviewed by Nick Perrin. We are also grateful to Kelvin Berryman and Martin Reyners for helpful comments.

## 8.0 REFERENCES

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Mejia L, Gillon M, Walker J and Newson T. Criteria for developing seismic loads for the safety evaluation of dams of two New Zealand owners. *Proceedings of New Zealand Society on Large Dams and Australian National Committee on Large Dams (NZSOLD-ANCOLD). 2001 Conference on Dams, Auckland, New Zealand.*(Reprinted in *NZSOLD Newsletter* No.37)

NZSOLD 2000. *New Zealand Dam Safety Guidelines.* New Zealand Society on Large Dams, PO Box, Wellington, New Zealand. www.ipenz.org.nz\nzsold\

Stirling MW, McVerry GH, Berryman KR 2002. A new seismic hazard model for New Zealand. Bulletin of the Seismological Society of America 92 (5): 1878-1903.

## APPENDIX A — MODIFIED MERCALLI SEISMIC INTENSITY SCALE FOR NZ - 2002

**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 favourable 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 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 frames 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 start, stop, or change rate (H).

***Structures***

Some Windows Type I cracked.
A few earthenware toilet fixtures cracked (H).

**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 (H).
Some furniture moved on smooth floors, some unsecured free-standing fireplaces moved.
Glassware and crockery broken.
Very unstable furniture overturned.
Small church and school bells ring (H).
Appliances move on bench or 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.
A few cases of Chimney damage.
Damage to a few weak domestic chimneys, some may fall.

*Environment*

Trees and bushes shake, or are heard to rustle.
Loose material dislodged on some slopes, e.g. existing slides, talus and scree slopes.
A few very small ($\leq 10^3 m^3$) soil and regolith slides and rock falls from steep banks and cuts.
A few minor cases of liquefaction (sand boil) in highly susceptible alluvial and estuarine deposits.

**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, some with 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 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*

Very small ($\leq 10^3 m^3$) disrupted soil slides and falls of sand and gravel banks, and small rock-falls from steep slopes and cuttings are common.
Fine cracking on some slopes and ridge crests.
A few small to moderate landslides ($10^3$-$10^5$ $m^3$), mainly rock falls on steeper slopes (> 30°) such as gorges, coastal cliffs, road cuts and excavations.
Small discontinuous areas of minor shallow sliding and mobilisation of scree slopes in places.
A few instances of non-damaging liquefaction (small water and sand ejections) in alluvium.

**MM8** *People*

Alarm may approach panic.
Steering of motorcars greatly affected.

*Structures*

Buildings Type I 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.
Significant landsliding likely in susceptible areas.
Small to moderate slides ($10^3$-$10^5$ $m^3$) widespread; mainly rock and disrupted soil falls on steeper slopes (steep banks, terrace edges, gorges, cliffs, cuts etc).
Significant areas of shallow regolith landsliding, and some reactivation of scree slopes.
A few large ($10^5$-$10^6$ $m^3$) landslides from coastal cliffs, and possibly large to very large ($\geq 10^6 m^3$) rock slides and avalanches from steep mountain slopes.
Larger landslides in narrow valleys may form small temporary landslide-dammed lakes.
Roads damaged and blocked by small to moderate failures of cuts and slumping of road-edge fills.
Evidence of soil liquefaction common, with small sand boils and water ejections in alluvium, and localised lateral spreading (fissuring, sand and water ejections) and settlements along banks of rivers, lakes and canals 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 damage to some Structures Type V.
Houses not secured to foundations shifted off.
Brick veneers fall and expose frames.

***Environment***
Cracking on flat and sloping ground conspicuous.
Landsliding widespread and damaging in susceptible terrain, particularly on slopes steeper than 20°.
Extensive areas of shallow regolith failures and many rock falls and disrupted rock and soil slides on moderate to steep slopes (20°-35° or greater), cliffs, escarpments, gorges and man-made cuts.
Many small to large ($10^3$-$10^6$ $m^3$) failures of regolith and bedrock, and some very large landslides ($10^6 m^3$ or greater) on steep susceptible slopes.
Very large failures on coastal cliffs and low-angle bedding planes in Tertiary rocks. Large rock/debris avalanches on steep mountain slopes in well-jointed greywacke and granitic rocks.
Landslide-dammed lakes formed by large landslides in narrow valleys
Damage to road and rail infrastructure widespread with moderate to large failures of road cuts and slumping of road-edge fills. Small to large cut slope failures and rock falls in open mines and quarries

Liquefaction effects widespread with numerous sand boils and water ejections on alluvial plains, and extensive, potentially damaging lateral spreading (fissuring and sand ejections) along banks of rivers, lakes, canals etc. Spreading and settlement of river stopbanks likely.

**MM10** ***Structures***
Most Buildings Type I destroyed.
Many Buildings Type II destroyed.
Many Buildings Type III heavily damaged, some collapse.
Structures Type IV damaged, some with partial collapse.
Structures Type V moderately damaged, but 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.
Similar effects to MM9, but more intensive and severe, with very large rock masses displaced on steep mountain slopes and coastal cliffs. Landslide-dammed lakes formed. Many moderate to large failures of road and rail cuts and slumping of road-edge fills and embankments may cause great damage and closure of roads and railway lines.
Liquefaction effects (as for MM9) widespread and severe. Lateral spreading and slumping may cause rents over large areas, causing extensive damage, particularly along river banks, and affecting bridges, wharves, port facilities, and road and rail embankments on swampy, alluvial or estuarine areas.

**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.
Many Buildings Type V heavily damaged, some with partial collapse.
Structures Type VI moderately damaged.

## Categories of Construction

**Buildings Type I:**
Buildings with low standard of workmanship, poor mortar, or constructed of weak materials like mud brick or rammed earth. Soft storey structures (e.g. shops) made of masonry, weak reinforced concrete, or composite materials (e.g. some walls timber, some brick) not well tied together. Masonry buildings otherwise conforming to Buildings Types I-III, but also having heavy unreinforced masonry towers. (Buildings constructed entirely of timber must be of extremely low quality to be Type I).

**Buildings Type II:**
Buildings of ordinary workmanship, with mortar of average quality. No extreme weaknesses, such as inadequate bonding of the corners, but neither designed nor reinforced to resist lateral forces. Such buildings not having heavy unreinforced masonry towers.

**Buildings Type III:**
Reinforced masonry or concrete buildings of good workmanship and with sound mortar, but not formally designed to resist earthquake forces.

**Structures Type IV:**
Buildings and bridges designed and built to resist earthquakes to normal use standards, i.e. no special collapse or damage limiting measures taken (mid-1930's to c. 1970 for concrete and to c.1980 other materials).

**Structures Type V:**
Buildings and bridges designed and built to normal use standards, i.e. no special damage limiting measures taken, other than code requirements, dating from since c. 1970 for concrete and c.1980 other materials.

**Structures Type VI:**
Structures, dating from c. 1980, with well-defined foundation behaviour, which have been specially designed for minimal damage, e.g. seismically isolated emergency facilities, some structures with dangerous or high contents, or new generation low-damage structures.

**Windows Type I:**
Large display windows, especially shop windows.

**Windows Type II:**
Ordinary sash or casement windows.

**Water Tanks Type I:**
External, stand mounted, corrugated iron water tanks

**Water Tanks Type II:**
Domestic hot-water cylinders unrestrained except by supply and delivery pipes.

**H (Historical):**
Important for historical events. Current application only to older houses, etc.

**General Comment:**

- "Some" or "a few" indicates that the threshold of a particular effect has just been reached at that intensity.
- "Many run outside" (MM6) variable depending on mass behaviour, or conditioning by occurrence or absence of previous quakes, i.e. may occur at MM5 or not until MM7.
- "Fragile contents of buildings". Fragile contents include weak, brittle, unstable, unrestrained objects in any kind of building.
- "Well-built timber buildings" have: wall openings not too large; robust piles or reinforced concrete strip foundations; superstructure tied to foundations.
- Buildings Type III-V at MM10 and greater intensities are more likely to exhibit the damage levels indicated for low-rise buildings on firm or stiff ground and for high-rise buildings on soft ground. By inference lesser damage to low-rise buildings on soft ground and high-rise buildings on firm or stiff ground may indicate the same intensity. These effects are due to attenuation of short period vibrations and amplification of longer period vibrations in soft soils.

## References

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Dowrick, D.J. "The Modified Mercalli Earthquake Intensity scale – Revisions arising from recent studies of New Zealand earthquakes". *Bulletin of the New Zealand National Society for Earthquake Engineering*, 29(2):92-106 (1996).

Hancox, G.T., Perrin, N.D. and Dellow, G.D. "Recent studies of historical earthquake-induced landsliding, ground damage, and MM intensity in New Zealand. *Bulletin of the New Zealand Society for Earthquake Engineering* 35(2): 59-95 (2002).

## APPENDIX B — DETAILED GNS LIBRARY SEARCH

1.

**ID** 14306
**LINK** 4457; 4458
**DOC TYPE** Report
**RECORD NO** L28/71; L28/710
**TITLE** Buller region granitoids, 27 Sept-1 Oct 1993
**DATE** 1993
**AUTHOR** Forsyth, P.J.
**KEYWORDS** Buller Region; Granitic Composition; Oparara; Karamea Gorge; Karamea Granite; Karamea Bluffs; Mokihinui; Glasgow Range; Greenland Group; Welcome Creek; Granites; Intrusive Rocks; Faulting
**NZMS260** L27; L28; L29
[SCIENCE DOCUMENTS]

2.

**DOC_TYPE** TECHFILE
**RECORD NUMBER** *L28/71*
**TITLE** Field report along Mokihinui Gorge
**AUTHOR** Muir, R.
**DATE** 1993
**KEYWORDS** Granite; Glasgow Range; Dunphy Granite; Mokihinui Gorge; Welcome Creek; O'sullivans Granite; Johnny Cake Creek; Karamea Granite; Pensini Granodiorite; Duncan Mine; Manlys Mine
**LOCATION** *LOWER HUTT, REGIONAL GEOLOGY*
**NZMS260** L28

3.

**DOC_TYPE** TECHFILE
**RECORD NUMBER** *L28/71*
**TITLE** Geology of Mokihinui River Area
**AUTHOR** Wellman, H.W.
**DATE** 1946
**KEYWORDS** North Westland; Ngakawau River; Whareatea Creek; Tertiary Sediments; Kaiatia Mudstone
**LOCATION** *DUNEDIN*
**NZMS260** L28

4.

**DOC_TYPE** TECHFILE
**RECORD NUMBER** *L28/71*
**TITLE** Geology of the Upper Karamea - Mokihinui Districts
**AUTHOR** Wellman, H.W.
**DATE** 19--?
**KEYWORDS** North Westland; Matiri Tops; Limestone; Tertiary Sediments; Kaiatan;

Runangan; Whangaroan; Waitakian; Brunner Beds; Coal Seams; Hawkes Crag Breccia
**LOCATION** *DUNEDIN*
**NZMS260** L28

5. **ID** 1045
**DOC TYPE** FILE
**SERIES TYPE** Science
**SERIES NAME** Engineering Geology Techfile
**SUB SERIES** NHRA Projects Including Large Scale Hydro
**RECORD** 977/10
**TITLE** Mokihinui M1-M2
**DATE** 1972-1979
[SCIENCE RECORDS]

6.
**ID** 784
**RECORD NO** 346A
**TITLE** Mokihinui
**DATE** 1998
**AUTHOR** Rattenbury, M.S.; Cooper, R.A.; Johnston, M.R.
**KEYWORDS**
**NZMS260** L28
[SCIENCE DOCUMENTS]

7.
**ID** 785
**RECORD NO** 347A
**TITLE** Mokihinui
**DATE** 1998
**AUTHOR** Rattenbury, M.S.; Cooper, R.A.; Johnston, M.R.
**NZMS260** L28
[SCIENCE DOCUMENTS]

8.
**ID** 786
**RECORD NO** 348A
**TITLE** Mokihinui
**DATE** 1998
**AUTHOR** Rattenbury, M.S.; Cooper, R.A.; Johnston, M.R.
**NZMS260** L28
[SCIENCE DOCUMENTS]

9.
**ID** 17825
**RECORD NO** North Buller Power Scheme Mokihinui
**TITLE** Mokihinui River

**NZMS260** L28
[SCIENCE DOCUMENTS]

10.
**ID** 17826
**RECORD NO** North Buller Power Scheme Mokihinui
**TITLE** Mokihinui River engineering geology
**DATE** 1975
**AUTHOR** [Wood, P.?]
**KEYWORDS** Mokihinui River; Buller Region; Hydroelectric Power Development; Engineering Geology
**NZMS260** L28
[SCIENCE DOCUMENTS]

11.
**ID** 17828
**RECORD NO** North Buller Power Scheme Mokihinui - L28
**TITLE** Mokihinui fieldsheets
**AUTHOR** Nathan, S.; Oliver, P.
**NZMS260** L28
[SCIENCE DOCUMENTS]

12.
**ID** 17829
**RECORD NO** North Buller Power Scheme Mokihinui - L28D - 7&8
**TITLE** Mokihinui River
**AUTHOR** Nathan, S.; Oliver, P.
**NZMS260** L28
[SCIENCE DOCUMENTS]

13.
**ID** 18332
**RECORD NO** Buller Coalfield
**TITLE** Mokihinui dam site
**DATE** 1975
**AUTHOR** Johnston, M.R.
**KEYWORDS** Mokihinui; Dams; Buller Coalfield; Geologic Maps
**NZMS260** L29
[SCIENCE DOCUMENTS]

14.
**DOC_TYPE** TECHFILE
**RECORD NUMBER** *L28/911*
**TITLE** Mokihinui Power Development - Geological Investigation
**AUTHOR** Paterson, B.R.
**DATE** 1978
**KEYWORDS** North Westland; M2 Site

**LOCATION** *DUNEDIN*
**NZMS260** L28

15.
**DOC_TYPE** TECHFILE
**RECORD NUMBER** *M28/71*
**TITLE** Immediate report, QMAP Nelson fieldwork
**AUTHOR** Rattenbury, M.S.
**DATE** 1996-1997
**KEYWORDS** Wangapeka Track; Kakapo River; Glasseye Creek; Little Wanganui River; Tarn Basin; Herbert Range; Taipo Hut; Luna Slips; Helicopter Flat; Karamea River; Waters Creek; Right Branch Allen River; North Branch Mokihinui River; Pike Peak; Pannikin Creek; Stag Flat Hut; Zetland Basin; Granitoids; Tidal Creek; Kiwi Creek; White Creek Fault
**LOCATION** *LOWER HUTT, REGIONAL GEOLOGY*
**NZMS260** M28; L27; L28; M27

16.
**DOC_TYPE** TECHFILE
**RECORD NUMBER** *831/7*
**TITLE** Lyell-Mokihinui Saddle and South Branch Mokihinui River down to Larrakins Creek
**AUTHOR** Suggate, R. P.
**DATE** 1951
**KEYWORDS** Lyell Saddle; Granite Creek; Silver Creek; Stern Creek; Fault; Larrakins Creek; Lake Perrine; Specimen Creek
**LOCATION** *EDS, Lower Hutt*

17.
**DOC_TYPE** TECHMAP
**RECORD NUMBER** *North Buller Power Scheme Mokihinui*
**TITLE** Mokihinui River
**AUTHOR** unknown
**DATE** 19--?
**LOCATION** *MAPPING SECTION, LOWER HUTT (METRIC)*
**NZMS260** L28

18.
**DOC_TYPE** TECHMAP
**RECORD NUMBER** *North Buller Power Scheme Mokihinui*
**TITLE** Mokihinui River Engineering Geology
**AUTHOR** [Wood, P.]
**DATE** 1975
**LOCATION** *MAPPING SECTION, LOWER HUTT (METRIC)*
**NZMS260** L28

19.

ID 9152
DOC TYPE Field Notebook
TITLE Site notebooks - Strong Motion Network
DATE [1960?]-1986
KEYWORDS Strong Motion; Sites; Gisborne; Haast; Hamilton; Haywards; Hutt Valley; Microzonation; Kikiwa; Karioi; Kaipara Harbour; Iwitahi; Inangahua; Manapouri; Mangaweka; Maraenui; Marsden Point; Martinborough; Massey University; Palmerston North; Matahina Dam; Maui; Milford; Moawhango; Mohaka; Mokihinui; Mount Cook; New Plymouth; Oaonui; Ohakea
NZMS260
[SCIENCE DOCUMENTS]

20.

ID 11164
TITLE Plan of Mokihinui
DATE 1864
AUTHOR Burnett, J.
KEYWORDS Mokihinui; Buller Coalfield; Coal Fields; Coal; Mokihinui River; West Coast
NZMS260 L28
[SCIENCE DOCUMENTS]

21.

DOC_TYPE TECHFILE
RECORD NUMBER L28/90
TITLE Report on visit to Buller area possible Hydroelectric and Thermal Power Station with Ministry of Works and Development Party
AUTHOR Coleman, A.C.
DATE 1974
KEYWORDS Creek Dam Site; Mokihinui Gorge; Granite; West Coast; Specimen Creek Site; Lower Gorge Dam Site; Te Kuha Site; Granity Site; Waimaire Site; Mokihinui Site; Fairdown Site; Ngakawau Gorge; Upper Waimangaroa Sites
LOCATION LOWER HUTT, REGIONAL GEOLOGY
NZMS260 L28

22.

DOC_TYPE TECHFILE
RECORD NUMBER L28/71
TITLE Special Report on Examination of South Branch of Mokihinui River
AUTHOR Evans, H.J.
DATE 19--?
KEYWORDS North Westland; Tertiary Sediments; Greywackes; Mudstone; Sandstone; Limestone; Gravels; Reefs; Ore Bodies; Amber; Fossils
LOCATION DUNEDIN
NZMS260 L28; L29

23.
DOC_TYPE TECHFILE
RECORD NUMBER L28/91
TITLE Report on Visit to Buller Area Possible Hydroelectric and Thermal Power Station Sites with Ministry of Works and Development Party
AUTHOR Coleman, A.C.
DATE 1974
KEYWORDS North Westland; Mokihinui River; Specimen Creek; Te Kuha; Granity; Fairdown; Ngakawau River; Upper Waimangaroa
LOCATION DUNEDIN
NZMS260 L28

24.
DOC_TYPE TECHFILE
RECORD NUMBER L28/91
TITLE Northern Buller Hydro-electric Power Development
AUTHOR Oborn, L.E.; Johnston, M.R.
DATE 1974
KEYWORDS North Westland; Mokihinui River; Karamea River; Proposed Dam Sites
LOCATION DUNEDIN
NZMS260 L28

25.
DOC_TYPE TECHFILE
RECORD NUMBER L28/91
TITLE Preliminary Reports on Proposed Dam Sites, Northern Buller Power Scheme
AUTHOR Johnston, M.R.
DATE 1974
KEYWORDS North Westland; Mokihinui River
LOCATION DUNEDIN
NZMS260 L28

26.
DOC_TYPE TECHFILE
RECORD NUMBER L28/911
TITLE Report on Visit to Westport Area
AUTHOR Coleman, A.C.
DATE 1974
KEYWORDS Mokihinui River; North Westland; Dam Site
LOCATION DUNEDIN
NZMS260 L28

27.
DOC_TYPE TECHFILE
RECORD NUMBER L28/911
TITLE Northern Buller Power Scheme: Site Investigations

AUTHOR Various
DATE 1975
KEYWORDS North Westland; Mokihinui River; Drill Core; Stratigraphy; Hazards; Subsurface; Howarth Site
LOCATION DUNEDIN
NZMS260 L28

28.
DOC_TYPE TECHFILE
RECORD NUMBER L27/911
TITLE Northern Buller Power Scheme Proposed Dam Site, Karamea River- Preliminary Geological Inspection
AUTHOR Coleman, A.C.
DATE 1973
KEYWORDS Mokihinui; Kohaihai Fault; Granite; Alluvium; Lithologies; Foliation; Weathering; Jointing; Shearing; Sub-Scree; Alluvium; Silt; Fault; Potentially Active; North Westland
LOCATION DUNEDIN
NZMS260 L27

29.
DOC_TYPE TECHFILE
RECORD NUMBER LD7/914
TITLE Report on Visit to Buller area possible Hydroelectric and Thermal Power Station sites with Ministry of Works and Development party, July 1974
AUTHOR Coleman, A.C.
DATE 1974
KEYWORDS Dam Sites; Mokihinui Gorge; Thermal Power Station; Granity Site; Waimaire Site; Fairdown Site; Mokihinui Site; Ngakawau River
LOCATION ENGINEERING GEOLOGY, LOWER HUTT
NZMS260 L28; M28; L29; M29