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Peter Amos
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Dear Peter

Re: Update to Letter Report 2012/141R: Seismic hazard in the Oxford area

The following is our response to your request for an update to Letter Report 2012/141R on current knowledge of seismic hazard in the Oxford-Darfield region, Canterbury. This latest report contains some clarification in addition to the text of the original report.

We include comments on known tectonic structures, seismicity and the implications for seismic hazard in the region. Information is drawn from:

- New Zealand National Hazard Model (May 2010 update) developed by scientists from GNS Science, NIWA and Canterbury University
- Time-dependent hazard studies led by GNS Science
- Active seismic investigations conducted by ETH Zurich, University of Canterbury and GNS Science
- Earthquake relocations conducted at GNS Science

Active fault structures in the region

Major fault lines in the foothills and Southern Alps to the west of the Canterbury Plains e.g. Porters Pass – Amberley Fault Zone (Figure 1) and the Alpine Fault, are capable of generating large (magnitude ≥ 7.5) earthquakes that will impact on the region. In addition, lower-recurrence-rate tectonic structures beneath the plains have the potential to generate high local ground motions.

A number of such NE-SW or E-W trending active tectonic structures have been identified in the area surrounding the Oxford-Darfield region (e.g. Greendale Fault, Hororata Fault, Ashley Fault, Springbank Fault, Springfield Fault, Cust/Starvation Fault System; Figure 1). While active faults are traced in the foothills to the west, thick alluvium can mask evidence of these structures beneath the flat-lying plains. No known surface fault traces pass directly through the area between Oxford and Darfield, but detailed mapping would be required to confirm the absence of pre-existing traces. Furthermore, low-rate buried or partially buried structures will not necessarily have an identifiable surface expression.

Active source seismic lines to the south of the area reveal buried tectonic structures extending from the foothills beneath the plains (the interpreted extension of known fault systems is shown in Figure 2). The most significant known active feature identified close to the region of interest is the Hororata Fault (inferred to dip northwest) and its associated anticline (Racecourse Hill Anticline). The Hororata Fault is inferred to have a low probability of occurrence given the long (though poorly constrained) average recurrence interval of 17,000 years, but could produce earthquakes of magnitude ~7.2 (according to the National Seismic Hazard Model, Stirling et al. 2008, 2010). This feature and associated structures are inferred to extend into the Oxford-Darfield region to the north of seismic line S2, crossing the Waimakariri River southeast of Burnt Hill where the anticline has been identified on the northern river bank. The presence of Burnt Hill itself (a bedrock outcrop) suggests the presence of a nearby fault/fold that has elevated bedrock above the adjacent region, although no such fault has been mapped at the surface.

A lack of significant surface expression of tectonic structures in the region means any such features are considered to be low-rate structures that typically produce infrequent events.

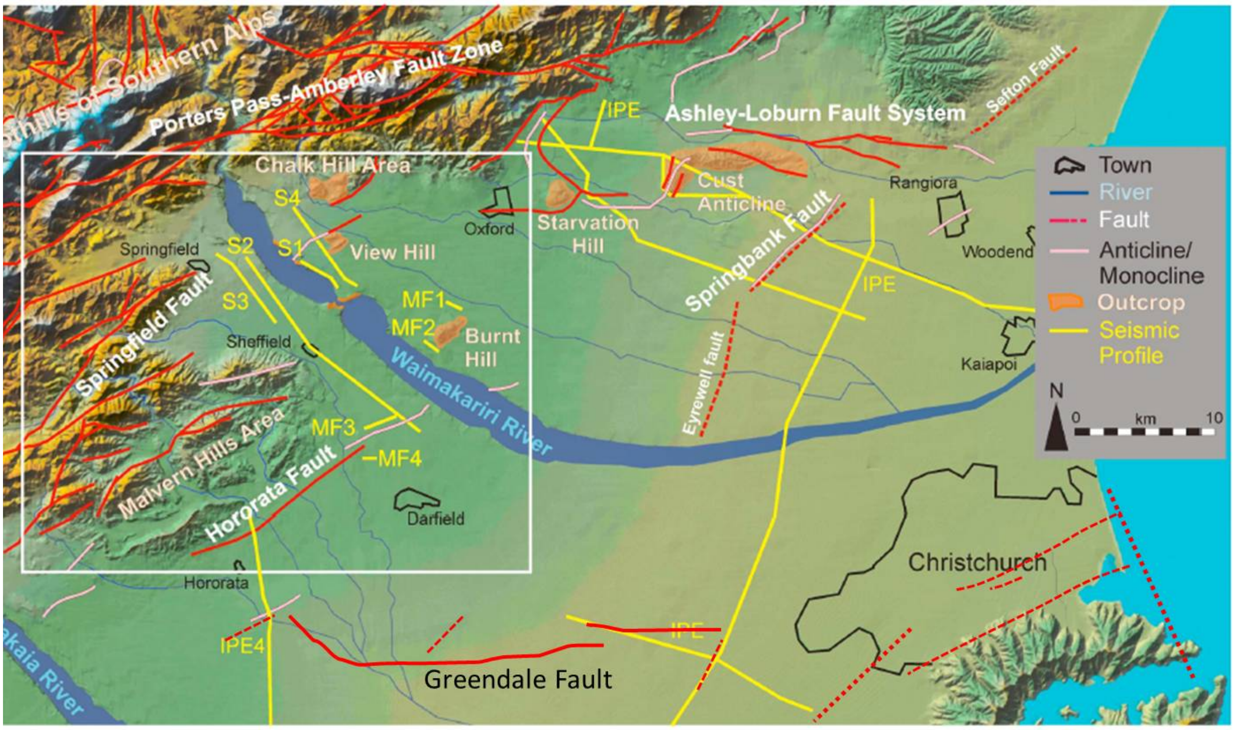

Figure 1 Map of the northwest Canterbury Plains (modified from Dorn et al. 2010) showing the location of seismic lines (yellow lines) and mapped faults and folds (red and pink lines, GNS active faults database; dashed lines indicate locations of known significant buried structures inferred from seismic lines, geomorphology and/or recent seismicity). White box denotes extent of zoomed area in Figure 2.

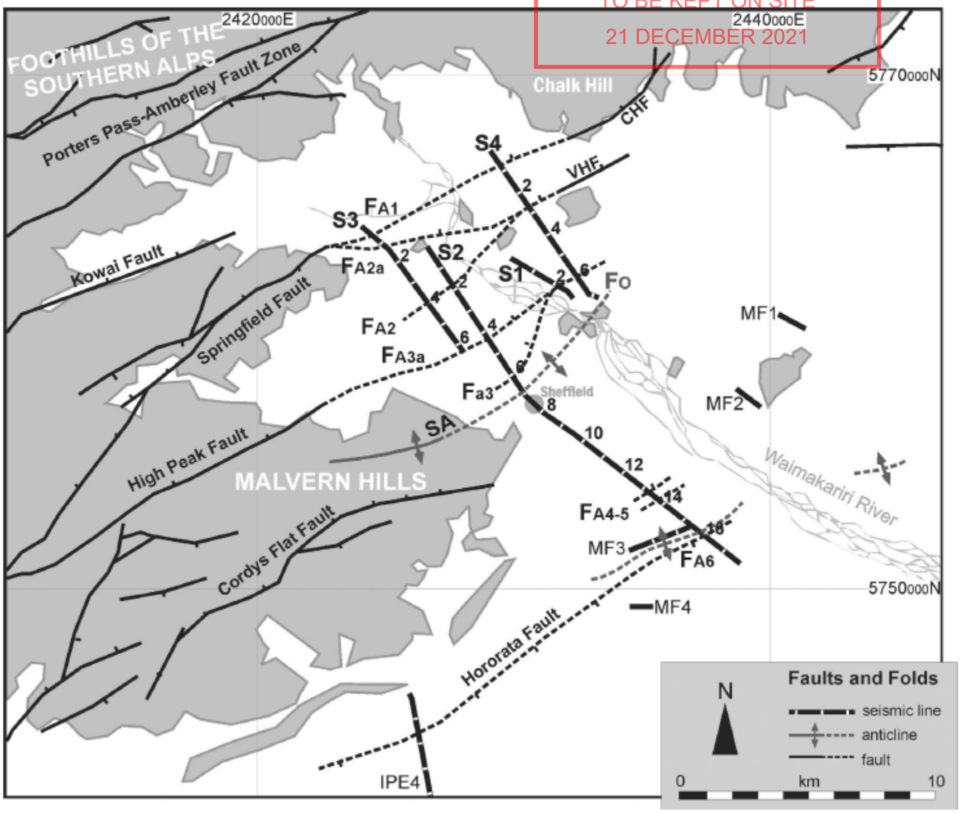

Figure 2 Map showing mapped faults and folds (solid black and grey lines respectively) from the GNS active faults database. An interpretation of the extension of these features beneath the plains is shown by the dashed lines (reproduced from Dorn et al. 2010).

Seismicity in the region

The Oxford-Darfield region lies on the northern fringe of the aftershock zone associated with the 2010 M_w7.1 Darfield earthquake. Figure 3 shows seismicity in the region for the time period between September 3rd 2010 and January 2012, (i.e. since the Darfield earthquake). The earthquake locations shown here were derived using double-difference relocation analysis (Bannister & Gledhill, 2012), using a 3-D velocity structure model specifically developed by GNS Science for the Canterbury region.

Seismicity levels in the Oxford region were relatively low in the region prior to the Darfield earthquake. The intense seismicity near Darfield, seen at latitude -43.5 in Figure 3, represents the immediate aftershock activity following the Darfield earthquake, mostly occurring in September-November 2010. That activity extended up to the Waimakariri River, although there was also some activity 7 km south of Oxford township (e.g. a M_L4.3 event on 13th June 2011, at 6 km depth). Other activity, at latitude -43.2, is occurring near and possibly on the Porters Pass-Amberley fault zone. The event labelled 'ev1' in Figure 3 (with magnitude M_w 3.7, occurring on Jan 28th 2011) is close to the surface expression of the Springfield fault (Figure 2). Moment tensor solutions (which illustrate the style of deformation of the earthquake source) are shown in Figure 3 for three events in the region, including event "ev1"; the solutions indicate right-lateral strike-slip faulting.

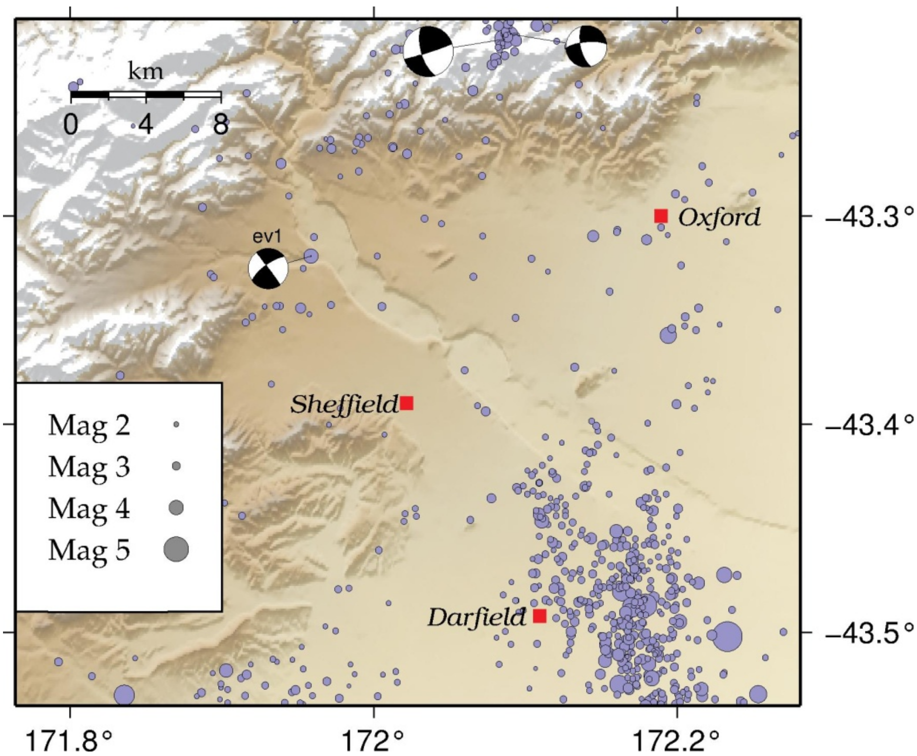

Figure 3 The location of earthquakes in the Oxford area detected by GeoNet between September 2010 and January 2012, and subsequently relocated using a 3D velocity model developed for the Canterbury region. Note, that only well-constrained earthquake relocations are shown here; events in the GeoNet catalogue with insufficient phase information or that were poorly constrained after relocation have not been included. Moment tensor solutions, shown for three events, indicate right-lateral strike-slip faulting. The event labelled 'ev1', (M_w 3.7, on 2011-01-28) is close to the surface expression of the Springfield fault (Figure 2), suggesting some activity on that fault. There is also some focused activity near and on the Porters Pass-Amberley fault zone.

Implications for seismic hazard

The long-term seismic hazard in the region predicted by the National Seismic Hazard Model (Stirling et al. 2008, 2010) for return periods of less than 2500 yrs is dominated by earthquakes on major faults in the foothills and Southern Alps to the west (e.g. Porters Pass Fault, Alpine Fault). These faults typically have shorter recurrence intervals than local faults in the region, although local faults have the potential to generate higher ground accelerations.

Since the Darfield earthquake revisions to hazard models in the Canterbury region have been necessary to reflect the increased short-term seismicity associated with the Canterbury earthquake sequence. Revised hazard results are currently nearing completion for central Christchurch, but the corresponding hazard maps are not yet available. A preliminary reassessment of the hazard factor Z and the associated return period factors of the New Zealand structural design standard NZS1170.5:2004 (Standards New Zealand, 2004) was undertaken, by Gerstenberger et al. (2011) using time-varying seismic source models to represent the ongoing earthquake sequence. These models were updated in July 2011 to include seismicity up until 16 June 2011. Figures 4 and 5 show hazard factor (Z) and 500-yr deep soil return ground motions for the Canterbury region derived using these time-dependent models. Note, that the standard relationship (according to the New Zealand Design Standard NZS1170.5:2004) between hazard factor (Z) and peak ground acceleration is not appropriate for these models, because of the dominance of the estimated hazard in the Christchurch region by earthquakes of about magnitude 6 or less. For return periods shorter than 500 years, the ratios of the spectra to their 500-year values are higher than indicated by the NZS1170.5 return period factors R. For example, when the Department of Building and Housing (2011) promulgated the earlier interim Z-factor of 0.3 for Christchurch in May 2011, the 25-year R-factor for the serviceability limit state was increased to 0.33 from the standard value of 0.25 in NZS1170. Using a log-log interpolation of R-factor with return period between return periods of 25 years and 500 years, Table 1 compares the factors for other return periods with the NZS1170 values. The ratios for return periods longer than beyond 500 years are not listed because they appear to be reasonably consistent with the NZS1170 values.

Table 1: Approximate return period factors consistent with R=0.33 at 25 years

Return Period	NZS1170 R-factor	R-factor from the earlier Christchurch Z=0.3 model
25 years	0.25	0.33
50 years	0.35	0.43
100 years	0.5	0.55
150 years	0.6	0.64
250 years	0.75	0.77
500 years	1	1

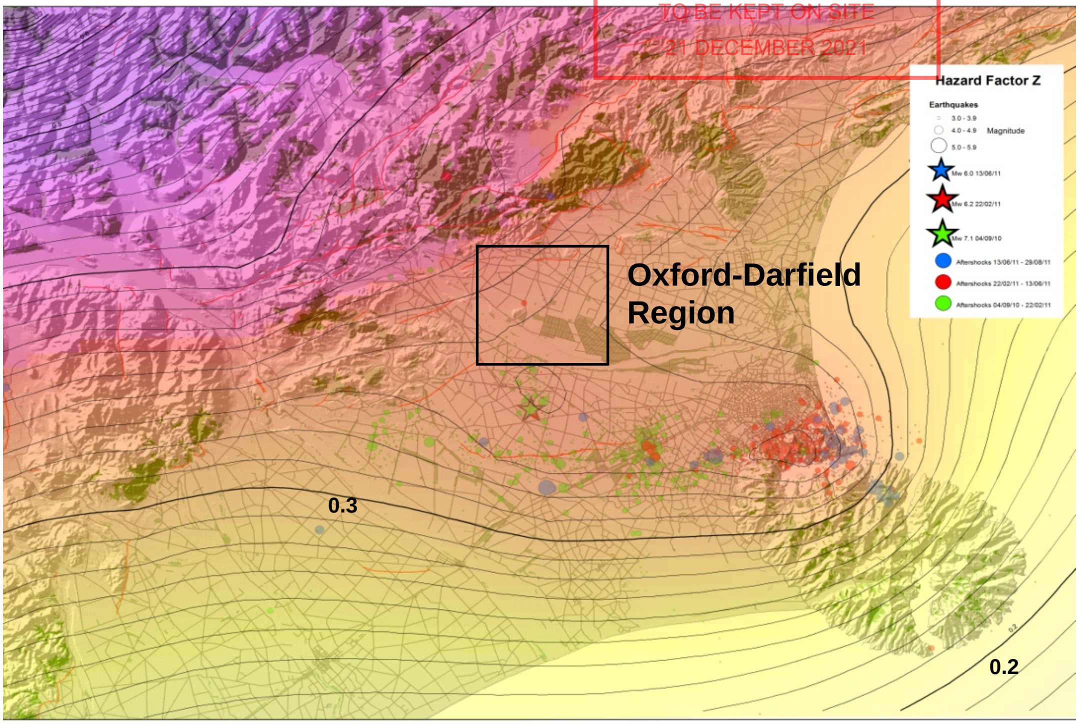

Figure 4 The hazard factor Z calculated from matching the 500-year deep soil spectrum at 1.5s period, shown over the Canterbury region. Contours are at intervals of 0.01, with bold contours at 0.1 intervals. The Z-factor is a parameter that describes the relative level of seismic hazard around New Zealand in terms of the strength of shaking expected with a particular annual probability of exceedance, and is used to scale the NZS1170 design spectra for the location of interest. Values in the Oxford-Darfield region range from 0.33 - 0.35.

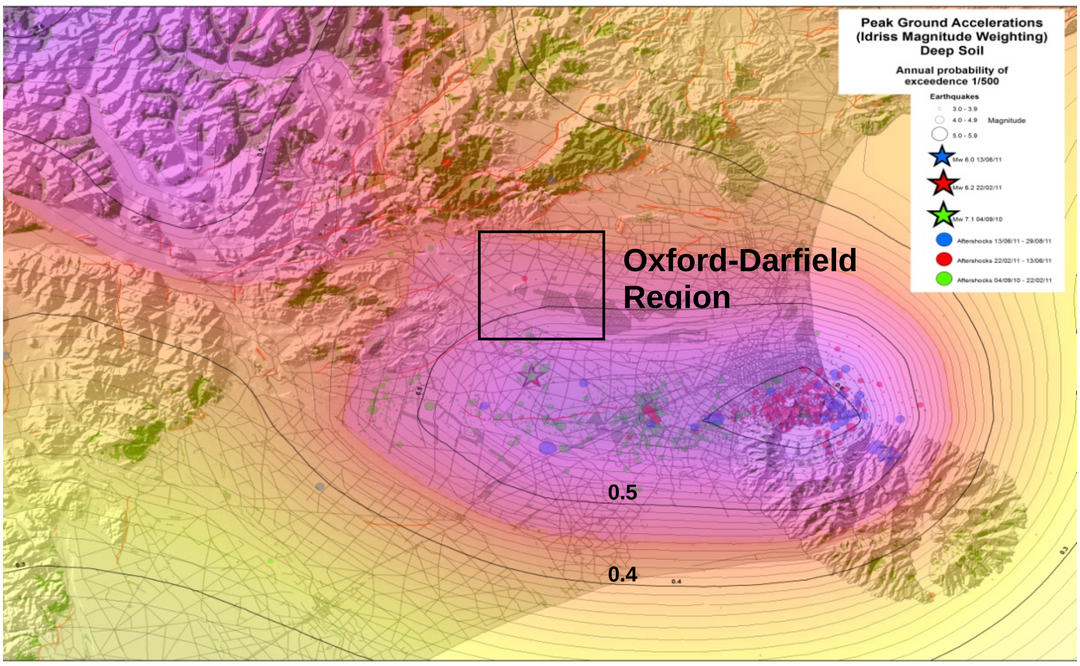

Figure 5 500-year deep soil peak ground accelerations for structural applications. Contours are at intervals of 0.01g, with bold contours at 0.1g intervals. Values in the Oxford-Darfield region range from 0.45 - 0.53 g.

Yours sincerely

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