AGRICULTURAL LAND REHABILITATION FOLLOWING 2010 DARFIELD (CANTERBURY) EARTHQUAKE: A PRELIMINARY REPORT

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SUMMARY

This paper describes the nature of earthquake damage and rehabilitation of rural land affected by fault rupture and liquefaction following the 4 September 2010 Darfield (Canterbury) Earthquake. Remediation of land damaged by fault rupture and liquefaction was a significant concern for affected farmers and land-owners. A multidisciplinary team of researchers linked to the Rural Recovery Group (responsible for recovery of rural areas following the Canterbury earthquake) used a variety of techniques to assess land damage and evaluate the effectiveness of various rehabilitation techniques.

It was found that land damage caused by strike slip fault rupture could generally be repaired by heavy roller. In areas of severe surface deformation and fracturing, deep cultivation followed by rolling was necessary to close surface fractures and flatten fault micro-topography to restore the land to a useable condition for agricultural use. Liquefaction damage to land consisted of blistered topography (by liquefied sediment injecting between topsoil and sub-soil) and liquefied sediment ejection at the surface. Both surfaces were often unsuitable for continuing agricultural operations. Several passes by a rotary-hoe and power-harrow effectively smoothed blisters and returned paddocks to a suitable state. Land severely affected by sediment ejection required scraping or grading of the sediment to < 50 mm and cultivation of the material into the topsoil. Both treatments resulted in destruction of current pasture or crop. Land less severely affected could be treated by spreading only, which conserved the existing pasture. Future work will track the on-going recovery of remediated and un-remediated land.

INTRODUCTION

This paper describes the nature of earthquake damage and rehabilitation of rural land affected by fault rupture and liquefaction following the 4 September 2010 Darfield (Canterbury) Earthquake.

Within several days of the earthquake a Rural Recovery Group convened with Allan Baird as facilitator (Mid Canterbury Rural Support Trust), which consisted of Ministry of Agriculture and Forestry (MAF), local territorial authorities (led by Selwyn District Council), Federated Farmers, agri-business representatives, North Canterbury Rural Support Trust, Rural Women, Inland Revenue, Ministry for Social Development and others. This group organised as rapidly as it did on the strength of the relationships and structures established in response to other natural disasters that had affected rural Canterbury over the past decade.

A public meeting in Darfield on the 9th of September was organised by Federated Farmers with the aim of informing the rural community about technical matters relating to the earthquake and the support measures in place. It was also a forum for the rural community to raise concerns about rural businesses and homes. Key concerns raised related to confusion about insurance cover for dwellings and businesses which often centred on the scope of EQC cover; changes to the groundwater table and best-practise for irrigation pump start-up; stress and anxiety from the experience of the earthquake and aftershocks and significantly increased workloads; and rehabilitation of land damaged by fault rupture. This last issue remained unaddressed at the meeting as knowledge and expertise was unavailable. The following day researchers from Canterbury and Lincoln Universities assembled a team with geological, geotechnical, soil science and agricultural expertise with the approval of the Rural Recovery Group to assess land damage and rehabilitation strategies along the fault rupture zone.

Later it became clear that liquefaction affecting urban areas such as Halswell had extended into rural areas and caused damage to dwellings and farm and lifestyle block land. Allan Baird again engaged the research team to survey the extent of liquefaction damage and consider rehabilitation options for land.

4 September Darfield earthquake

At 4:35 am on September 4th NZ Standard Time the rupture of the previously unrecognized Greendale strike-slip fault beneath the Canterbury Plains of New Zealand's South Island produced a Mw 7.1 earthquake that caused widespread damage throughout the region. No deaths occurred and only two injuries were reported despite the epicentre lying only ~30 km west of the city of Christchurch (pop. ~386,000). The event produced a ≥ 28 km long, dextral strikeslip surface rupture trace, aligned approximately west-east, with a component of reverse faulting at depth (Figure 1; Quigley *et al. this issue*). A maximum horizontal displacement of ~5 m

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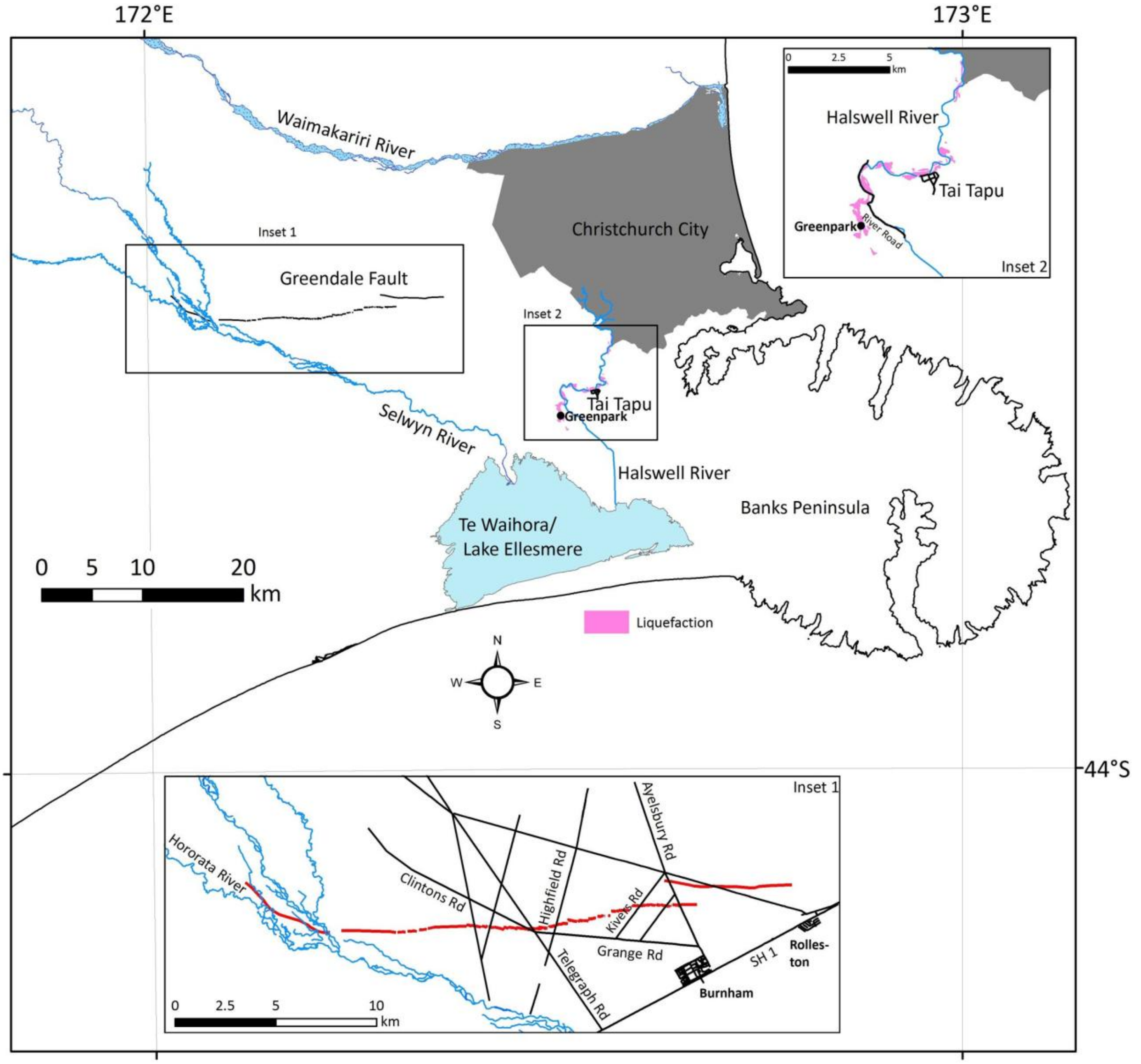

Figure 1: ***Location of the Greendale Fault and liquefaction in the Greenpark-Tai Tapu area.***

and up to 1.5 m of vertical displacements occurred at the surface rupture. The surface rupture trace occurred in an area of high intensity arable and pastoral farming (mainly dairy) leading to significant damage to farm businesses. Close to the fault the strong ground shaking resulted in felt intensities as much as MM9 and peak ground accelerations over 1.2 g close to the fault.

The earthquake struck in the very early morning when most people were still asleep, minimizing human population exposure to co-seismic hazards. However, many dairy farms were about to begin milking and some dairy cows on concrete pads situated close to the fault suffered broken legs and pelvises.

Extensive liquefaction, differential subsidence, and ground cracking associated with lateral spreading occurred in areas close to major streams and rivers throughout Christchurch, Kaiapoi, and Taitapu. This was devastating for many urban areas, but also created significant impacts for affected farms.

In the months following the main shock, the region has incurred thousands of aftershocks of ML>2 including a number of ML≥5.0 leading to significant stress and anxiety for communities close to the fault and at the tips of the fault, where aftershocks have been concentrated. The frequency of ML>2 aftershocks has decreased by an order of magnitude since the days immediately following the main shock.

METHODS

Fault Rupture

Ten farms spaced along the length of the fault trace were visited on 11 and 12 September to assess the level of damage, what rehabilitation methods had proved successful and what methods might be beneficial in the future. In all cases farmers were contacted by telephone to arrange a suitable time to go onto their land to observe damage and interview them about their experience of the earthquake, focusing on rehabilitation of land. The research was reviewed and approved by Prof. Ian Town acting on behalf of the University of Canterbury ethics committee. A retrospective review and approval of the research was made by the full Canterbury University Ethics Committee once the university reopened.

A brief report was made of the assessment to the Rural Recovery Group on 13 September. It was decided at the meeting that more detailed assessment of the stability of the fault rupture zone would be desirable, following concerns about the potential for localised subsidence of the fault rupture zone following collapse of voids at depth.

The research team therefore undertook Ground Penetrating Radar (GPR) and Dynamic Cone Penetrometer (DCP) transects of cultivated, heavy rolled and unaltered fault scarp to analyse the performance of different rehabilitation techniques stabilising the fault rupture zone. Ground Penetrating Radar is a standard technique used to constrain the location of faults and to analyse their subsurface structure. The DCP transects were used to assess soil strength and investigate whether void spaces were present in the fault rupture zone. Sampling occurred every 2 m along 50 m N-S transects approximately perpendicular to the fault trace. The survey was carried out near Highfield Road close to the worst land damage on 15 September. Results were presented to the Rural Recovery Group on 20 September. By this stage a 'heavy land rehabilitation' implement was being trialled in the region and an additional GPR survey was made of land near Courtney Road immediately before and after cultivation on 21 September.

Ground Penetrating Radar profiles were acquired using a Sensors & Software pulseEKKO Pro with 100 MHz antennas, and using both 500 and 1000 V transmitting power. The DCP was a 10 mm diameter steel shaft with 5 x 1 m extensions driven by a 15 kg hammer (weight) falling 300 mm. Both GPR and DCP transects lines were recorded with GPS to allow repeat of the surveys in the future.

Liquefaction

At the time of our initial investigations, the available post-earthquake imagery (September 4, Multispectral GeoEYE satellite image) did not cover the Tai Tapu to lower Greenpark areas where liquefaction damage was significant. Consequently, in order to facilitate mapping in this area, we commissioned our own aerial survey, flying lines following the Halswell River mostly outside the extent of the GeoEYE image but with some overlap. Photographs were taken at about 1500 m altitude with a film camera fitted with a 55 mm focal length lens. After scanning of negatives and georeferencing the images had a resolution of ca 0.5 m per pixel. In a GIS we mapped the extent of liquefaction damage on the basis of sand ejecta visible in the images. Remote sensing was complemented by ground truthing in which we mapped surface extent of ejecta and other forms of liquefaction damage, and estimated volumes of ejected sand. We also dug pits and augered cores to examine subsurface stratigraphy and determine the origin of the sand. At the time of our surveys, a local agricultural contractor was already involved in land rehabilitation on Greenpark properties. We discussed his experiences with him and then engaged him to carry out some controlled trials to assess the performance of different rehabilitation practices.

Grab samples of ejecta were taken for particle size analyses by dry sieving. Grab samples were also taken of the top 10 cm of rehabilitated paddocks for soil fertility tests (MAF Quick Tests conducted at Hill Laboratories). Core samples (78 mm diameter by 74 mm deep) were taken in the same locations as the soil fertility samples for characterisation of moisture release properties which can be used to estimate soil moisture storage. The latter was carried out on tension tables at Lincoln University. Interpretations rather than the raw data are presented here.

STYLES OF EARTHQUAKE DAMAGE TO RURAL LAND

Fault Rupture

The gross morphology of the fault is that of a series of E-W striking, NE-stepping surface traces that in detail consist of ESE trending Riedel fractures with right-lateral displacements, SE-trending extensional fractures, SSE- to S-trending Riedel fractures with left-lateral displacements, and NE-striking thrusts and folds (Quigley et al. *this issue*). The extent of land damage was typically worst in the middle of the rupture trace and reduced towards each tip.

We have defined three damage zones along the fault rupture characterised by different styles of damage to farms, soils and groundwater/surface drainage conditions. They are:

- Central zone from Courtenay Road to Kivers Road. This was the zone of greatest vertical and horizontal (typically > 3 m) displacement on the fault. Soils are Lismore series (Brown Soils) formed on Burnham formation (c. 18,000 a). Land-use is high intensity cropping and pastoral farming (typically dairy) reliant on groundwater fed irrigation. Land damage was characterised by a distinct fault scarp with Riedel fractures and significant micro-topography (folds and thrusts). Buried services were sheared and broken, with surface farm infrastructure, such as fences, water-races and tracks, significantly displaced.

- West zone from Courtenay Road to the Hororata River. This was a broader zone of deformation through the flood plains and low terraces of the Hororata and Selwyn rivers. Soils are typically younger forming on the Templeton age surface on Springston formation (c. 3000-6000 a). Land use is lower intensity cropping and pastoral farming (dairy and sheep-and-beef). In areas close to channels with a high groundwater table and strong ground shaking, course textured sediment (gravels and cobbles) was ejected in localised liquefaction adjacent to the fault rupture. Due to the high ground acceleration (> 0.7 g) significant damage occurred to farm and residential structures. Fault displacement of a meander bend of the Hororata River forced an avulsion leading to localised flooding that affected three farms.

- East zone from Kivers Road to Rolleston. The eastern zone has similar soil and land use characteristics to the central zone, but horizontal fault displacement was much less (< 3 m) and vertical displacement was generally less and took the form of surface flexure with much less fracturing. This led to less damage to the land surface, but buried services and surface infrastructure (e.g. fences) where still affected.

Liquefaction

Liquefaction damage included lateral spreading, surface ejection of sand, and injection of sand into the upper layers of soils, which inflated the soil surface to form 'blisters'. The land affected was within lifestyle blocks and small farm holdings. The soils associated with liquefaction damage were usually Kaiapoi or Tai Tapu soil series (Recent and Recent Gley Soils respectively), especially where sand occurred at depth. Productive land use was commonly pastoral production for livestock and supplementary feed. Remaining areas were in amenity plantings, residential lawns or supported dwellings.

Lateral spreading was limited to areas immediately adjacent to the Halswell River and some drains, but resulted in damage to a few roads and bridges, which forced their closure for several weeks. Sand ejecta occurred along a zone ranging from 100 to 350 m-wide that broadly followed the Halswell River but swapped from the left bank to the right bank to remain within the inside of bends. Ejecta was fine sand with a small silt component (typically 80% fine sand, 5 % silt) which formed long arcuate ridges with a radius of curvature similar to that of the adjacent bend of the Halswell River. In places ejecta was in the form of isolated, irregularly shaped sand volcanoes up to 16 m in dimension. Importantly, the zone of sand ejecta departed from the Halswell River in its lower reaches, indicating that lateral spreading into the Halswell River channel and resultant surface fracturing were not the primary causes of sand ejection.

Blisters were impossible to map from aerial photographs and we found them strongly expressed in only two areas, though the agricultural contractor reported other occurrences. We have no reliable quantification of their extent at this stage. Blisters always occurred amongst sand ejecta but could be the major form of damage depending on the nature of the ground cover. Blisters tended to dominate where there was a tight thatch or long-established pasture in which roots strongly reinforced the topsoil. Regularly cultivated paddocks were more prone to surface fracturing and sand ejection.

FAULT RUPTURE DAMAGE AND REHABILITATION

Central Zone

The fault rupture zone typically occurred over a 20-50 m-wide area with fractures up to 1 m deep and 0.5 m wide.

The main impact to agricultural operations was the ~1 m high fault scarp, and fracturing associated with the vertical and horizontal displacement of the ground. Fractures were sub-parallel and oblique to the fault trace. In areas of unmodified fault scarp, subsoil fractures had partially in-filled from collapsed gravel subsoil and topsoil two weeks after the earthquake. This process is continuing at the time of writing in mid November.

These features resulted in a microtopography in the fault rupture zone which presented problems for livestock, machinery and productivity. Farmers feared high value livestock, such as dairy cows, could injure themselves if they stumbled into a fracture. High value irrigation machinery, designed for flat, even Canterbury paddocks, could not traverse the fault scarp or fractures safely. Nor could spraying, fertilising, mowing, harvesting and baling machinery safely or effectively operate across the fault rupture zone. Adjacent to the fractures soils exposed to the atmosphere would dry and cause moisture stress which would reduce plant growth even if irrigation were applied. Farmers were also concerned for their safety, being worried that the affected ground may have void spaces at depth which would collapse when driven over with heavy machinery.

Interviews on 11-12 September with farmers in the central zone indicated deep cultivation across the scarp (ploughing and/or rotocrumbling to 400 mm), followed by rolling was sufficient to close fractures and reduce the contour to allow normal farming practice. Where fractures were deep and persistent, subsoiling to disturb the gravels (300-800 mm depth) followed by rolling were sufficient to mitigate this.

Despite the apparent success of cultivation closing surface fractures, concerns remained about the potential for subsidence of the fault rupture zone following collapse of voids at depth. Ground Penetrating Radar survey of unmodified fault scarp close to Highfield Road showed void spaces in the gravels down to about 8 m depth. Diffractions were consistent with voids 50-500 mm across, which did not continue for significant vertical distances (>500 mm) (Figure 3). Where the fault scarp had been heavy rolled, the surface fractures were closed and GPR survey showed fractures and voids in the top 2 m were smaller by 50-95% than fractures in the area of unmodified fault scarp. However, there was little, if any, modification of the gravels below 2 m depth. We then surveyed an adjacent paddock that had been heavily cultivated

Figure 2 : Early cultivation of the Greendale fault. Several passes with roto-crumbler cultivation has been used in the left paddock; whilst the paddock on the right shows the unaltered surface rupture.

by roto-crumbling (x2), followed by ploughing and then another roto-crumble pass. No fractures were apparent at the surface and the GPR survey showed voids at depth of 1-6 m were slightly smaller in size compared to those of the unmodified fault scarp sub-strata. However, the lack of a pre-treatment GPR profile was a significant limitation of this analysis. The GPR transect was followed by a DCP transect across the unaltered fault rupture zone indicated that soil and gravel had been weakened in a zone of 35 m across the fault rupture zone. It was difficult to penetrate beyond 1 m outside of the rupture zone. However, in the rupture zone we commonly reached 3 m depth, with clear void spaces of 5-30 cm evident. A DCP transect across the cultivated and rolled fault rupture zone indicated the upper 0.5 m of soil was weaker, as would be expected after cultivation. However, the upper 2 m of soil and gravel was much stronger, suggesting that vibrations and compaction from cultivation and rolling may have caused some consolidation of the upper level gravels. The zone of weakness across the fault had also reduced to 10 m and it was generally difficult to penetrate beyond 1.5 m. It appeared the cultivation and rolling had increased soil strength and filled voids in the upper 2 m, which is consistent with the GPR results. However, these results are only a crude guide to soil strength given only two reconnaissance transects were undertaken.

A further GPR survey was made of a section of fault scarp close to Courtenay road prior to heavy cultivation with an implement used commonly for conversion of forestry land to dairy pasture. This was to assess the implement's effectiveness and to directly compare GPR profiles of the same transect immediately before and after cultivation; which was a limitation of the previous profiles. Comparison of the before and after GPR profiles showed fractures and voids in the top 2 metres were mostly filled or closed, but voids beyond 2 m depth were not substantially modified (Figure 3). The cultivation significantly reduced the micro-topography of the fault scarp (by up to 0.5 m) and infilled fractures resulting in an acceptable surface for normal farm practices, especially when followed by Cambridge or heavy rolling. For the voids which remain at depth, we anticipate the gravels will eventually fill them in over time, without significant subsidence at the surface. Observations of the rehabilitated land in late October 2010 indicated no noticeable subsidence in the fault rupture zone. GPR surveys are planned for March 2011 to track the behaviour of the voids.

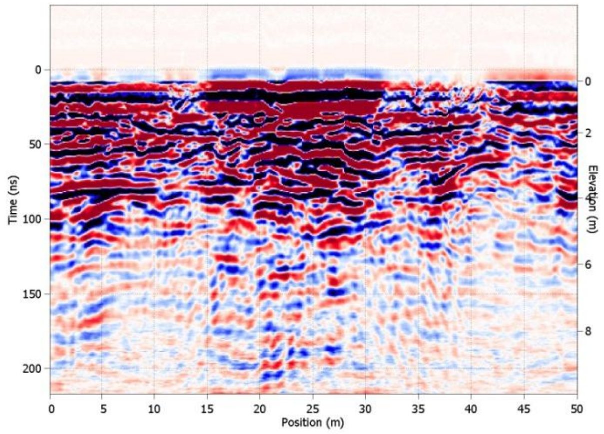

***Figure 3:** Migrated difference between pre- and post-cultivation of fault scarp GPR profiles (0.10 m/ns) at Courtney Road site. GPR profiles were 500 V and use spreading and exponential compensation (SEC) gains, with a maximum gain of 150 and attenuation of 1 dB/m.*

The fault rupture produced a multitude of fault deformation features, such as fracture arrays and offsets across roads, fence lines, shelter belts and water channels and pipes for irrigation and livestock water supply. These features were a geologist's dream; however they represented significant damage to affected farms. Many farmers immediately moved livestock out of affected paddocks due to fears for livestock welfare in the fractured, unstable ground and damaged fences. Fence wires became slack or over-tensioned and broke depending on their orientation relative to the fault. Fence lines were put out of alignment, especially those with a north – south orientation, to such an extent that straightening would be necessary before re-tensioning wires. Horizontal and vertical dislocation of water channels caused damming upstream of the fault trace (typically on down-thrown northern side of the fault) and reduced flow downstream. This required straightening and deepening of the channel on the up-thrown hanging wall side. Buried water pipes were sheared and stretched in the fault rupture zone, however repairs were typically rapid in most instances following a large and dedicated mobilisation of contractors. Old, brittle asbestos concrete pipes tended to perform poorly compared to newer, flexible PVC pipes.

Western Zone and Eastern Zone

In these zones the fault was a zone of deformation with less horizontal and vertical offsets. Except for anomalously high vertical offsets at the western limit of the fault trace. Fractures were shorter (1-5 m), narrower (< 0.1 m) and didn't extend to as great a depth (< 0.2 m) in the soil.

Heavy rolling alone was generally successful in closing the fractures to less than 10-20 mm width.

An important note was the time of the year during which remediation occurred. The earthquake occurred in early Spring when soils are moist and in an ideal condition for maximum benefit from rolling, or cultivation and rolling strategies. Soils that were too wet to roll, rapidly dried following generally dry and warm conditions throughout September and were suitable within a month.

LIQUEFACTION DAMAGE AND REHABILITATION

On the basis of aerial photograph interpretation we allocated damage by surface ejection of sand into one of three classes, slight, moderate, and severe. Severe damage included areas of dense sand bodies covering more than 50% of the local area. Sand boils formed ridges up to 50 m long, 4 m-wide and sand was up to 300 mm thick at the axial ridge. We estimated the sand volume at ca 500 m^3/ha. The blistered land we investigated was closely associated with severe sand ejection damage (Figure 4). Moderately affected areas had semi-continuous ridges up to 500 m long, more widely spaced than the severely affected land, but similar in other respects. Slightly affected land was characterised by discrete boils or short ridges of thin (ca 100 mm) sand. Estimated volume of sand was 25 m^3/ha.

Severe sand ejection

This level of sand ejection produced so much sand that pasture production was severely compromised and the microtopography created by the sand boils presented problems for access by harvesting equipment. Prior to our trials the contractor had attempted to rehabilitate severely affected permanent pasture using power harrows to loosen and distribute sand, followed by Dutch harrows to further spread it. However, he was not convinced of the efficacy of this treatment, being concerned that the sand remained thick enough in places that drilling to re-establish a good pasture would place the seed in the sand and germinated seed could be killed by desiccation. The main problem was that the sand boils were so dense and thick that the area available for spreading sand was limited.

After this initial experience and further trials with modified power harrows we concluded that scraping would be much more efficient at spreading sand. By this stage (four weeks after the earthquake) grass beneath the sand was in an advanced state of decomposition, and resowing appeared to be the preferred option for re-establishing pasture over waiting for grass to regrow through the sand. Our trials suggested it would be difficult to evenly thin sand to less than 4 cm thick, which may not be thin enough to create a good medium to drill into. We therefore carried out a cultivation trial to test what thickness of sand could be cultivated to produce a good seed bed. We found that sand thinned to 5 cm or less was well incorporated with two passes of a rotary hoe followed up by two passes with power harrows.

Slight and Moderate sand ejection

For moderately and slightly affected land the loss of production due to death of grass beneath sand is much less severe and the volume of sand is sufficiently low that spreading alone is effective. We used power harrows to treat areas affected to these levels but other forms of spreading are likely to be equally effective.

Blistered land

Blisters, while not immediately reducing pasture production, needed to be removed in order to produce a suitable microtopography for harvesting machinery. The blisters were sufficiently steep and high that tines and plates on bailing equipment would catch on them and get bent. Our pits showed that the sand inflating the blisters was generally injected into the boundary between the topsoil and the subsoil where the density of roots decreased (Figure 5). We found that two passes of a rotary hoe followed by two passes with power harrows completely removed even the largest blisters (Figure 6). Across the crest of the blisters much more topsoil was removed and cultivated layer had a much larger component of ejected sand mixed in with it; so much so that in places the topsoil re-liquefied with the vibration caused by cultivation. However, we found that within two days the materials had dried out sufficiently to have solidified.

Figure 4: *A liquefaction blister, ~300 mm high. The ejected liquefaction sediment to the right of the blister was caused by excessive extension of the topsoil, causing the blister to 'burst'.*

Figure 5: *Soil pit exposure of a liquefaction blister. Blue-grey sand has been injected beneath the topsoil, inflating the ground surface. Note the feeder dyke from the liquefied sand beneath the water table.*

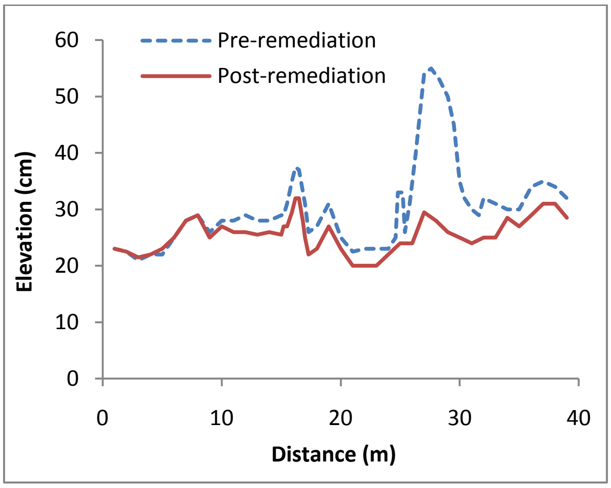

Figure 6: *Topographic surveys of 'blistered' land before and after treatment by rotary hoeing and power harrowing.*

Physical and chemical characteristics of ejecta and rehabilitated soils

The electrical conductivities (EC) of nine samples of ejecta taken from three locations in Greenpark in areas mapped as Kaiapoi and Taitapu soils were very low indicating that the materials were essentially non-saline. All samples fell within the lower 50th percentile of NZ soils based on data from the New Zealand National Soil Database. Even a sample of ejecta from lower Greenpark adjacent to a soil map unit showing Motukarara Soils (Saline Gley Soils) had a very low EC of 0.04 mMho/cm.

MAF Quick Tests on ejected material (data supplied by Foundation for Arable Research) are typical of fresh, unweathered sand. The material has moderate to high pH, but is low in available phosphorus, as measured by Olsen P, and has low exchangeable bases (Ca, Mg, K). Being dominantly sand, the cation exchange capacity is very low (≤ 7 meq%).

In order to characterise the effectiveness options for rehabilitation we took samples for soil fertility and soil moisture holding capacity from paddocks that had been rehabilitated by spreading and cultivation, and from a paddock with spreading only. Samples from the ‘Spread only’ paddock were thoroughly homogenised before being submitted to Hill Laboratories in order to provide a representative characterisation of the top 100 mm of the root environment.

No systematic pattern in soil fertility occurred with changes in original sand thickness on the cultivated paddock even though samples with no or very little sand ejecta were included. We conclude that the incorporation of the sand has been thorough enough that the effect of the sand does not overwhelm natural variability of soil fertility within the paddock we studied.

Surprisingly, we found a similar result for the ‘Spread only’ treatment. One sample with no sand cover had lower Olsen P than a sample with 70 mm of sand cover. However, CEC and exchangeable bases were lower in the latter. Again we must conclude that the effect of sand, once incorporated into the sand by natural mixing processes, will not be the major variable affecting soil fertility.

Moisture release data are also surprising. Sand, either on the surface or incorporated into the soil by cultivation increased moisture holding capacity. Soil cores with surface sand in the ‘Spread only’ treatment held more readily available water- . water released between -1 kPa (field capacity) and -1.5 Pa - than cores with no sand cover. Similarly, cores with more incorporated sand in the cultivation treatment also had more readily available water. Clearly, the sand is so fine that it can create pores of a size that hold on to moisture in this tension range. Together the soil chemical and physical characterisation suggests the greatest limitation of the ejected material relates to its chemistry, which is readily overcome by spreading and incorporation.

We will continue to monitor pasture performance in the rehabilitated paddocks to determine the medium and long term effects of no-, ‘Spread only’ and full incorporation treatments.

SUMMARY

This study was a preliminary description of the nature of earthquake damage and rehabilitation of rural land affected by fault rupture and liquefaction following the 4 September 2010 Darfield (Canterbury) Earthquake. The extent of damage and what remediation options would be appropriate were a significant concern for affected farmers and land owners.

It was found that land damage caused by strike slip fault rupture could generally be repaired by a heavy roller. In extreme cases deep cultivation followed by rolling was necessary to close surface fractures and flatten fault micro-topography to restore the land to a useable condition for agricultural use. Liquefaction damage to land consisted of blistered topography (by liquefied sediment injecting between topsoil and sub-soil) and liquefied sediment ejection at the surface. Both surfaces were unsuitable for continuing agricultural operations. Several passes by a rotary-hoe and power-harrow effectively smoothed blisters and returned paddocks to a suitable state. Land severely affected by sediment ejection required scraping or grading of the sediment to < 50 mm and cultivation of the material into the topsoil. Both treatments resulted in destruction of current pasture or crop. Future work will track the on-going recovery of remediated land.

By documenting this event we anticipate that lessons learned from this experience can be transferred to future earthquakes where land damage due to fault rupture and liquefaction has occurred. It also highlights the value of rapid deployment of multidisciplinary teams which can answer questions in clear, concise language appropriate for the end-user audience. during a disaster response and recovery. We also highlight the value of researchers being closely linked to emergency management organisations (such as the Rural Recovery Group in this case) which allowed dynamic and on-going interaction.

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