From Event to Impact Reporting and Forecasting: The Future of GeoNet

Ken Gledhill and the GeoNet Team

GNS Science, Avalon, Lower Hutt, k.gledhill@gns.cri.nz

2015 NZSEE
Conference

ABSTRACT: GeoNet, New Zealand's integrated geological hazards monitoring system is about to enter its 15th year of operation. The series of significant geological hazards events during the last five years, particularly the Canterbury earthquake sequence of 2010-2011, provided an extreme test of all GeoNet systems, and has seen GeoNet become a household name in New Zealand and develop a "community of interest". Currently GeoNet is in a phase of urgent equipment and system renewal because of the deferred maintenance and technical debt caused by the necessity to divert resources during the long period of event responses within a fixed budget. Although GeoNet performed very well during the recent events, we believe it can contribute even more strongly to the wellbeing of New Zealanders. Examples include the continued development of the GeoNet Community with the involvement of all stakeholders, particularly in the context of the current paper - scientists, engineers and citizen scientists. Further, GeoNet can evolve to be a hazards information hub – a collector and distributor of data and information on New Zealand's hazards environment. A major change in what GeoNet provides is likely to be the move from event reporting to potential impact reporting and over time, the introduction of forecasting and early warning capability for some perils.

1 INTRODUCTION

Over the last five years New Zealanders have become very aware that we live on a tectonic plate boundary. Sitting astride the Pacific-Australian plate boundary, New Zealand is prone to earthquakes, volcanic eruptions, tsunami and landslides. Starting in 2009 (see Table 1), we have experienced damaging earthquakes, including the deadly and destructive Canterbury Earthquake Sequence of 2010-2011, tsunami from local, regional and distant sources, the Tongariro eruptions and landslides and rock falls caused by extreme weather and earthquakes. These events, particularly the Canterbury earthquakes, have provided an extreme test of all GeoNet systems, and have seen GeoNet become a household name in New Zealand. By 2009 GeoNet, New Zealand's integrated geological hazards monitoring system, which is funded by the Earthquake Commission (EQC), was approaching its designed sensor density and response capability, allowing fast data and information availability during the responses which followed.

GeoNet is a long way from its full potential to contribute to the wellbeing of New Zealanders. We are embarking on a process to assess how GeoNet's contribution can be sustained and enhanced over the next five to ten years. In this paper the current status of GeoNet will be discussed, before indicating how GeoNet is likely to make an even greater contribution in future.

2 GEONET IN 2015

GeoNet in 2015 is a stable and mature, integrated geological hazards monitoring system with deep and wide community engagement and support. Over 600 sensor sites (Figure 1) have been deployed throughout New Zealand and offshore islands, half of which record strong ground motion or the strong motion response of structures (Uma, et al., 2011). GeoNet performed very well during the long series of hazards events in the past five years, as confirmed by community feedback, international reviews (GeoNet review panel report, 2013) and detailed economic analysis (NZIER, 2014). GeoNet has remained innovative and has embraced technology changes to ensure continued high performance. And it has developed a "community of interest" and become a trusted provider of information about geological events, not only using traditional means such as the website, but also social media and smartphone apps. In the following sub-sections the performance of GeoNet will be highlighted through a series of examples and then the current status of the system will be outlined.

Table 1. Significant events in New Zealand since 2009.

Date	Event
2009 July	Dusky Sound Earthquake (M_W 7.6)
2009 September	Samoan Islands Tsunami
2010 February	Chile Tsunami
2010 September	Darfield Earthquake (M_W 7.1)
2011 February	Christchurch Earthquake (M_W 6.2)
2011 March	Japan Tsunami
2011 June	Canterbury Earthquake (M_W 6.0)
2011 December	Canterbury Earthquakes (M_W 5.8, 5.9)
2012 August	Tongariro Eruption
2012 November	Tongariro Eruption
2013 July	Cook Strait Earthquake (M_W 6.5)
2013 August	Lake Grassmere Earthquake (M_W 6.6)
2014 January	Eketahuna Earthquake (M_W 6.2)
2015 January	Wilberforce Earthquake (M_W 6.5)

2.1 The GeoNet Community

What do I mean by the GeoNet Community? Before the start of the Canterbury earthquakes GeoNet had a small following via our website and social media. We were essentially a data collection system providing the raw material for researchers and information on events for the emergency management sector and the small number of interested people in the wider community. That changed on 4 September 2010 when suddenly GeoNet became a critical source of information about what Cantabrians were experiencing. Other websites sprung up taking feeds from the freely available GeoNet data but presenting it in different ways. The open data policy, required by GeoNet's funder, EQC, was crucial to this process - data and information was available when people needed it. The people of Canterbury took to submitting GeoNet 'felt reports' in great numbers during the extended earthquake sequence. The GeoNet Facebook site became very popular - people wanted to report and discuss what they were experiencing. And a large number of people became avid followers of our work and the information we provide. In short, the GeoNet Community was born!

2.2 The Canterbury Earthquake Sequence

The Canterbury earthquake sequence began with the M 7.1 Darfield earthquake, 40 km west of New Zealand's second-largest city, Christchurch, in the early hours of 4 September 2010 (Gledhill et al., 2010, 2011). Its shallow depth and proximity to the city made it the most damaging New Zealand earthquake since the 1931 Hawke's Bay event. The sequence continued in a series of aftershocks through the remainder of 2010 and early 2011, then a M 6.2 earthquake beneath metropolitan Christchurch on 22 February 2011 resulted in 185 deaths, tens of billions of dollars of damage and extensive liquefaction (Bannister, et al., 2011). Further significant events occurred on 13 June and 23 December 2011, causing more liquefaction and damage.

Figure 1. The New Zealand strong ground motion sites. Green symbols are National Strong Ground Motion Network sites and red symbols are National Seismograph Network sites.

The entire Canterbury earthquake sequence was well recorded by the permanent GeoNet network and additional temporary instruments in the region (Figure 2), providing a rare set of near-source recordings of high ground accelerations and broadband waveforms that will inform earthquake studies in New Zealand and overseas for decades to come (Bannister & Gledhill, 2012). A feature of the earthquake sequence was the high impact and high levels of recorded shaking of the events compared to the measured magnitudes. The maximum recorded vertical shaking during the Darfield earthquake of September 2010 was greater than the force of gravity (at 1.26 g), while the Christchurch earthquake of 22 February 2011 recorded peak vertical shaking levels of more than two times the force of gravity (at 2.2 g) in the Heathcote Valley, near the epicentre. The June 2011 earthquake in the sequence also resulted in measured horizontal shaking levels of over two times the force of gravity. The proximity of the sequence to Christchurch city resulted in very high levels of damage in the central business district and the eastern suburbs.

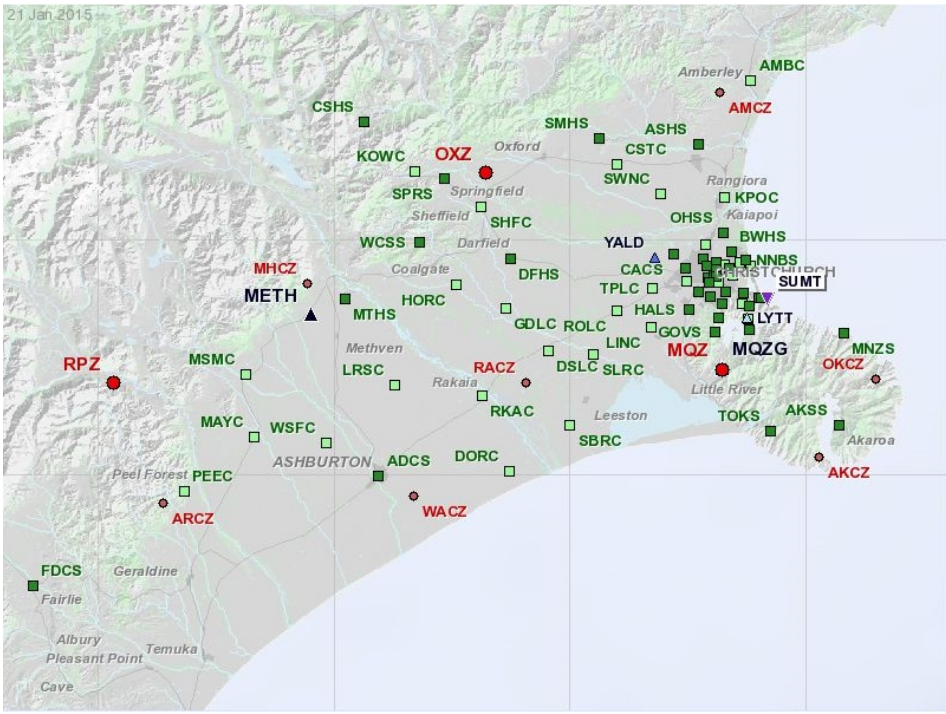

Figure 2. Strong Ground Motion and seismograph sites in the Canterbury region. Light green squares are Canterbury Strong Motion Network sites, dark green squares are National Strong Motion Network sites, small red circles are regional seismograph sites and the larger red circles are National Seismograph Network sites.

GeoNet assisted with the evaluation and rapid publication of scientific and engineering information to aid in the response and recovery, and develop understanding of the earthquakes. GeoNet data have been widely used by engineers and other researchers, and investigators assessing both land and building damage. The data recorded by GeoNet in Canterbury now underpins virtually all engineering assessment and modelling of land and building performance for the recovery, and was critical to the deliberations of the Canterbury Earthquakes Royal Commission. This includes the vital work being undertaken to assess which land will be fit for rebuilding or repair following the extensive liquefaction and rockfall caused by the earthquakes. This work is carried out by many researchers and organisations but GeoNet data forms the foundation for all of the studies by providing the input "ground-truth" shaking levels.

2.3 **The Tongariro Eruptions**

The eruption of Te Maari craters on 6 August 2012 signalled the end of nearly 120 years of quiescence in the northern vents of Tongariro volcano. It followed three weeks of unrest evidenced by an increase in hybrid earthquake activity and changes in fluid chemistry at nearby fumaroles, leading GeoNet to raise the alert level for the volcano. Fortunately the eruption happened just before midnight and there were no hikers on the Tongariro Alpine Crossing, nor staying at the nearby Ketetahi Hut, as substantial damage was incurred on the track and to the building.

This eruption was small on a global scale: it was short-lived, with the main ejection of material only lasting 2 minutes, and the eruption cloud only reaching a height of 9 km. Nevertheless, it triggered a multi-agency response with GeoNet at the core, which continued for several weeks. A further smaller eruption occurred in November 2012, and during that same period White Island was also active with several small eruptions recorded.

2.4 Tsunami responses

GeoNet capabilities allowed GNS Science to play an important role during New Zealand's response to two recent Pacific basin-wide tsunami events and a number of regional tsunami during the last five years. For example, working with the Ministry of Civil Defence and Emergency Management (MCDEM), GNS Science mounted a comprehensive response to the Japanese tsunami threat of 11 March 2011. The GeoNet-led Tsunami Experts Panel was convened during the evening of 11 March in response to the magnitude 9.0 Japan earthquake. Science Liaison Officers were deployed to the National Crisis Management Centre (NCMC) to ensure effective communications with MCDEM and regional CDEM groups. The Tsunami Experts Panel and the Science Liaison Officers were stood down late in the afternoon of 12 March after the tsunami warning was cancelled. For the first time in an actual event (as distinct from an exercise), forecast models were used to place parts of the New Zealand coast under different levels of warning, allowing normal activities to continue on unaffected coasts.

2.5 GeoNet Rapid

Throughout 2011 - 2012 the GeoNet earthquake location system was completely replaced. This was a huge undertaking during a period when the Canterbury earthquakes were continuing. The goal of the redevelopment was to make earthquake information available on the web within five minutes of an earthquake occurring (hence the name "GeoNet Rapid") and to locate all earthquakes that might have been felt in New Zealand. At the heart of the new earthquake location system is SeisComP3, a modern, scalable, distributed system of computer programmes. SeisComP3 was developed as part of the German Indonesian Tsunami Early Warning System project (Hanka et al., 2010). We tuned and tested the system for New Zealand and also worked with German and Swiss colleagues to further develop the system.

Switching to SeisComP3 introduced a number of significant changes to the website content and information delivery. These were introduced to the public and other end users during a public beta test period from March to September 2012. The public beta gave us a chance to continue fine tuning the system and introduce the changes in parallel with the previous approaches to earthquake location. This was an example of the GeoNet Community in action.

2.6 GeoNet Status

Although GeoNet is now a stable and mature hazards monitoring system, sustaining current levels of performance is becoming a challenge. Currently GeoNet is in a phase of urgent equipment and system renewal. The events of recent years required a redirection of effort and resources to event response and enhanced community engagement. This was largely achieved by slowing, or in some cases halting, the equipment replacement programme and the modest planned sensor network expansion. Most of the resources planned for the upper South Island and the planned additional strong motion installations were diverted to Canterbury or deferred following the start of the earthquake sequence in the region. Similarly, following the eruption of Tongariro in 2012, resources were again diverted to monitor the volcano more closely and enhance the sensor sites in the region. The most recent earthquakes in central New Zealand required less redirection because the sensor networks in the region were adequate for locating and monitoring the activity, but the responses required resources which again largely came from halting equipment replacement.

The net result of five years of almost continuous event responses (Table 1) is the build-up of a "bow-wave" of deferred sensor network expansion work, site and system maintenance, software development and equipment replacement.

Added to this are the huge technological changes which have been required to maintain the very high levels of GeoNet performance, as demand for GeoNet data and information grew following the Canterbury earthquakes and the volcano, tsunami and other earthquake events. The improvements included more robust data communications, the move from a dual to a distributed data centre model, mobile technology and cloud computing. Much more effort was also required dealing with the media, researchers and the wider community. The pace of change required the core GeoNet team to take on a much greater role in the management and operation of GeoNet computer systems. The overall effect of this has been a reduction in our capacity in related system development and other technical areas, slowing progress on some projects.

At current levels of resourcing, GeoNet cannot maintain the current high levels of performance in all areas of activity. Many GeoNet systems and sensor network sites are in need of upgrading and in some cases capability improvement to meet growing demands. Further, the value of the investment in GeoNet can be greatly enhanced by taking advantage of the developed capability to support an even greater contribution to New Zealand's wellbeing. This is the focus of the next section of this paper.

3 FUTURE DIRECTIONS

3.1 The Future of the GeoNet Community

In future GeoNet will develop apps to let people talk back. The intention is to extend the very successful felt reporting system already operated by GeoNet (on the website) to other platforms and other perils. For example, during the Eketahuna earthquake of January 2014 people were successfully encouraged to "dob in a landslide". This demonstrated what is possible with the widespread availability of smartphones. People now expect to be able to help us wherever they are by reporting geological phenomena from their mobile devices, together with pictures. Given the resources, extending citizen science initiatives such as having local schools and communities "adopting an instrument" would allow them to participate in our work. The effective two-way communication between GeoNet and the community will be critical to raising awareness of our geological hazards and how we can prepare and respond to them. The major aim is for GeoNet data and information to play a significant role in education, policy, planning and decision making. However, the important change in the future will be improvements in two-way communications, enabled through technology and personal interaction.

The widening of the GeoNet Community will see more scientists and engineers invited into technical conversations more regularly. We propose to develop mechanisms for consultation with the GeoNet Community between the major four-yearly reviews. While the current GeoNet technical committees are largely operational in nature we envisage conversations on the longer term direction of GeoNet, while acknowledging that the governance of GeoNet is the joint responsibility of EQC and GNS Science.

GeoNet will continue and extend our efforts to help researchers make effective use of the large quantities of data - improving New Zealanders' understanding of geological hazards and helping the targeting of future GeoNet initiatives. Given the resources this will include providing cloud-based computing and data archives and training to facilitate the easy use of GeoNet data for research.

3.2 GeoNet as an Information Hub

GeoNet has the potential to be the "one-stop shop" for both the collection and distribution of data and information on New Zealand's hazards environment. This would be an extension of the current GeoNet Community and a part of the citizen science initiative and planned science experiments, allowing the community to contribute and share data, information and observations on events and the planning for events. It would be planned and undertaken in consultation with EQC, Civil Defence, science organisations and other key players. Emergency managers, planners, insurers, researchers and decision makers will then have quick access to all the data and information needed to improve the preparation, response and recovery from natural events.

3.3 **Potential Impact Reporting**

Our vision is that GeoNet will be able to provide near-real-time potential impact reporting not just for earthquakes, which is feasible now (see Figure 3), but also for volcanic eruptions, tsunami impacts and landslide potential. The impact reports can then feed directly into systems designed to estimate the likely levels of damage given the people and infrastructure at risk. This is a major move from event reporting (where, when, how big) to impact reporting (what will be the likely effects where people or infrastructure reside). This reporting will use instrumental data, community reporting (citizen science) and effective modelling.

If we consider earthquakes, then felt intensity is a form of impact reporting. The magnitude of an earthquake estimates the physical size of the event where it ruptured, whereas the intensity relates to its impact on people, landforms, buildings and infrastructure. Reporting an earthquake’s location, depth and size is therefore event reporting, but providing intensity estimates at multiple locations (ShakeMap, see Figure 3) where people live and work is impact reporting.

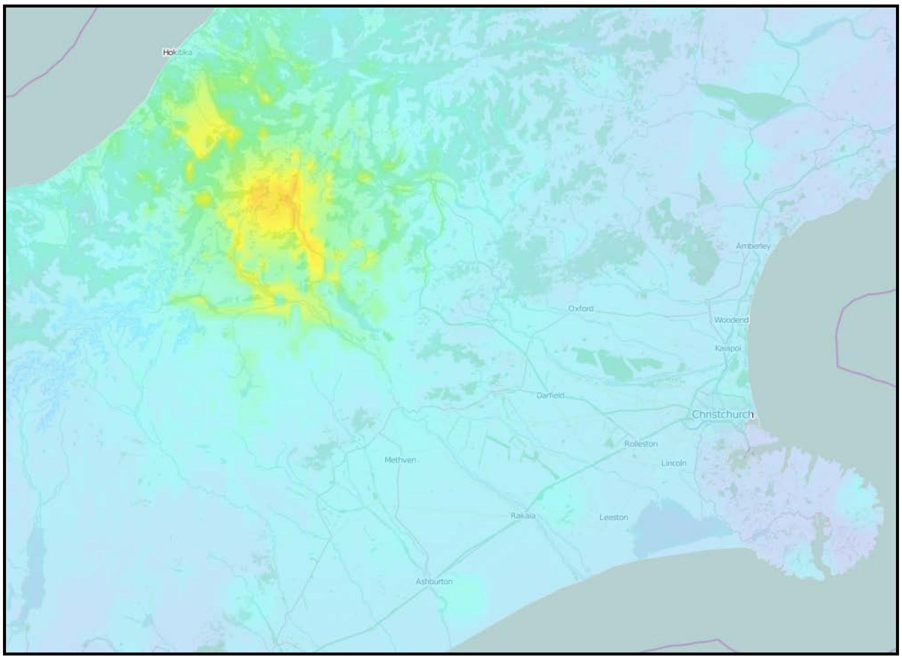

Figure 3. ShakeMap of the Wilberforce earthquake of 6 January 2015 showing shaking intensity at the surface. The maximum accelerations indicated in the yellow and orange zones (around 0.2 g) could potentially have caused minor damage if the location was not so remote.

3.4 **Forecasting and Early Warning**

GeoNet has much of the infrastructure and technology necessary to provide a forecasting and early warning capability for New Zealand for some perils. The lack of a fully staffed 24/7/365 warning centre is the major component not currently available. Forecasting is a form of time-dependent hazard assessment, whereas early warning requires that the hazard is identified and the likely time of impact estimated. Sensor network expansion and increased robustness is required, and research and development is needed to take the outcomes of scientific research and transform these into operational tools.

The compelling case for early warning capability in New Zealand is the potential for local or near-regional source tsunami. The 2013 update of the 2005 tsunami hazard assessment for New Zealand (Power 2013) demonstrated that a regionally generated tsunami from a Kermadec earthquake could impact highly populated parts of the North Island from Bay of Plenty through the Auckland and Northland regions with travel times of between one and two hours. Further, it is likely the causal earthquake would not be strongly felt because of the attenuating effects of the volcanic region, negating the effectiveness of using natural warning signs. Local-source tsunami from the Hikurangi subduction zone also pose a threat, making tsunami the most crucial of the perils regarding early warning capability.

The GeoNet volcano monitoring programme already provides a level of volcano forecasting which would be enhanced by a 24/7/365 warning centre, improved remote data collection systems and additional research and development. Earthquake early warning, on the other hand, although already operational in places like Japan, is probably the lower priority because of the very short warning times, marginal outcome improvements and the much higher requirements for robustness and sensor densities for its effectiveness. Landslide potential is site specific, but forecasting can be based on rainfall rates, earthquake shaking and volcanic activity (lahars and other forms of debris flows) and the severity of likely landslides reported.

4 CONCLUSIONS

GeoNet performed extremely well during the geological hazards events of the last five years, but must now go through a period of urgent equipment and system renewal. This is necessary because the event responses were resourced by diverting funding from maintenance and equipment and software replacement. Over the 14 years of GeoNet's operation it has developed into a stable and mature hazards monitoring system trusted by a large community, providing critical data and information for professionals in many disciplines and the wider community. However, GeoNet has huge potential to contribute even more strongly to New Zealand's wellbeing by becoming the hub of information to inform New Zealanders about our geological hazards, including how to prepare and respond to them. Additionally, GeoNet's information in future will move from event to potential impact reporting, and over time to event forecasting and early warning, at least for some perils.

ACKNOWLEDGEMENTS

We acknowledge New Zealand GeoNet and its sponsors EQC, GNS Science and LINZ, for providing the ideas, data and images used in this study.

REFERENCE

Bannister, S.C., Fry, B., Reyners, M.E., Ristau, J., Zhang, H. 2011. Fine-scale relocation of aftershocks of the 22 February Mw 6.2 Christchurch Earthquake using double-difference tomography. Seismological research letters, 82(6): 839-845; doi: 10.1785/gssrl.82.6.839

Bannister, S.C., & Gledhill, K. 2012. Evolution of the 2010-2012 Canterbury earthquake sequence. New Zealand journal of geology and geophysics, 55(3): 295-304; doi: 10.1080/00288306.2012.680475

GeoNet review panel report, 2013. Available at: http://info.geonet.org.nz/download/attachments/6062517/GeoNet_Strategic_Review_2012.pdf?api=v2

Gledhill, K.R., Ristau, J., Reyners, M.E., Fry, B., Holden, C. 2010. The Darfield (Canterbury) earthquake of September 2010: preliminary seismological report. Bulletin of the New Zealand Society for Earthquake Engineering, 43(4): 215-221

Gledhill, K.R., Ristau, J., Reyners, M.E., Fry, B., Holden, C. 2011. The Darfield (Canterbury, New Zealand) Mw7.1 earthquake of September 2010: a preliminary seismological report. Seismological research letters, 82(3): 378-386; doi: 10.1785/gssrl.82.3.378

Hanka, W., J. Saul, B. Weber, J. Becker, P. Harjadi, Fauzi, and GITEWS Seismology Group 2010. Real-time earthquake monitoring for tsunami warning in the Indian Ocean and beyond, Nat. Hazards Earth Syst. Sci. 10, 2611–2622.

NZIER, 2014. The value of information on natural hazards: Unpacking the value of GeoNet. Available at:

http://info.geonet.org.nz/download/attachments/6062517/NZIER_GeoNet_Report_19May14.pdf?api=v2

Power, W. (compiler), 2013. Review of tsunami hazard in New Zealand. Available at:

http://civildefence.govt.nz/assets/Uploads/publications/GNS-CR2013-131-Tsunami-Report-Full.pdf

Uma, S. R., King, A., Cousins, J., Gledhill, K. 2011. The GeoNet building instrumentation programme. Bulletin of the New Zealand Society for Earthquake Engineering 44(1): 53-63.