EQC

GeoNet Strategic Review 2008

EQC called for an independent strategic review of GeoNet and its funding arrangements.

The report of the reviewing panel has now been received; its content and recommendations are still to be discussed and considered by the Board of EQC and by stakeholders.

Earthquake Commission
Level 20, Majestic Centre, 100 Willis Street, Wellington, New Zealand
Corporate Mail: PO Box 790, Wellington Claims Mail: PO Box 311, Wellington
Telephone: (04) 978-6400 Fax: (04) 978-6431
www.eqc.govt.nz

GeoNet Panel Review

From Capability to Continuity

1 December 2008

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Acknowledgements

The Panel greatly benefited from the insights from all those interviewed. Many thanks are extended to those listed in Annex Three.

Summary

This review was charged with assessing GeoNet's developments to date and current fitness for purpose. GeoNet has delivered on the original proposal in March 2000, and in some cases exceeded requirements. Its cautious, staged roll-out of equipment has been a wise approach to ensuring the long term stability of the networks and the data collected.

EQC has shown unique leadership for GeoNet in providing the backbone for other agencies to extend so that New Zealand has a leading edge integrated hazard monitoring network.

The Panel encourages the parties to begin discussions on the possible renewal of the current contract as soon as possible. The new contract should seek to obtain a similar or better stability of future cash flows, with an appropriate pressure on GNS to spend the money wisely on the appropriate balance of investment, replacement capital, maintenance and operations.

Looking to the future the Panel recommends the following critical capabilities in order to strengthen GeoNet's ability to respond to major events:

1. **Increase investment in the area of urban strong motion instrumentation, including representative structures.**
2. **Improve strong motion coverage along selected, major fault lines in the South Island.**
3. **Extend regular surveying of volcanic centers using InSAR and diffuse CO_2 Monitoring.**
4. **Install a small network of tiltmeters high on Ruapehu.**
5. **Priority test the information delivery systems for emergency managers at all levels of government.**
6. **Increase the skill level of tsunami interpretation for GeoNet on-duty officers**.
7. **Improve the capacity of the website to serve information.**

The Panel also recommends a broader set of enhancements to improve the wider operation of GeoNet. The first order priorities are listed below grouped into technical and relationship enhancements:

First Order Technical Enhancements	First Order Relationship Enhancements
Increase instrumentation and upgrade networks and monitoring, especially at Mt Taranaki.	**Connect with the 'Science Learning Hub.**
Faster serving of earthquake event information.	**Extend the relationship with DOC in Taupo/Tongariro to other conservancies and the national DOC office.**
Additional support for routine provision of requested/required higher-level data products.	**Develop scenarios that involve media and public in active participation and learning about emergency management.**
Improved data access tools for research scientists and engineers.	

Finally the Panel lists a set of further valuable extensions to GeoNet which expand the dialogue and investment in GeoNet. In some cases they go beyond the current mandate of EQC or the other GeoNet funder LINZ. Nevertheless, these recommendations demonstrate the thinking that will be needed to keep this project at the leading edge.

Introduction

Since the last review GeoNet has become an integral part of the New Zealand emergency management landscape. By integrating real time monitoring across a wide range of hazards GeoNet is putting New Zealand in the forefront of international developments.

Overall the network has delivered what was proposed in March 2000. In some cases it has exceeded requirements. The tsunami gauge network, for example, has moved faster than anticipated as a result of the Boxing Day tsunami. This work has built a strong platform of engagement with LINZ and emergency management agencies and has cemented the multi hazards approach envisaged in the original concept.

In undertaking this review the Panel heard from the GeoNet team and connected with a wide range of stakeholders to hear their views. It is clear to the Panel that all these parties regard the GeoNet system as having met or exceeded the original design specifications, and in addition, and more importantly, exceeded the individual user's expectations.

The only specific area of short fall as shown in the June 2008 work plan is the minor short fall in the Strong Motion programme caused by problems in gaining suitable access to appropriate buildings.

The Panel were impressed with the professionalism and the openness of the GeoNet team to discuss the strengths and the (few) weakness of the current system and in particular the innovative ideas for the future development of the network and management of the data to provide real value to all New Zealanders.

The terms of reference (Annex One) asked the Panel to assess GeoNet's current fitness for purpose in relation to international best practice and the New Zealand context. As a Panel we benefited from a wide range of New Zealand and international perspectives. Annex Two outlines the Panel members.

This report provides our assessment of GeoNet under the following headings:

1. **Highlights of project delivery** – this section outlines the Panel's assessment of what has been achieved to date and the type of likely future requirements.

2. **Appropriateness of the form of contract between EQC and GeoNet** –this section tests the funding model for GeoNet and in particular the form of contract between EQC and GeoNet.

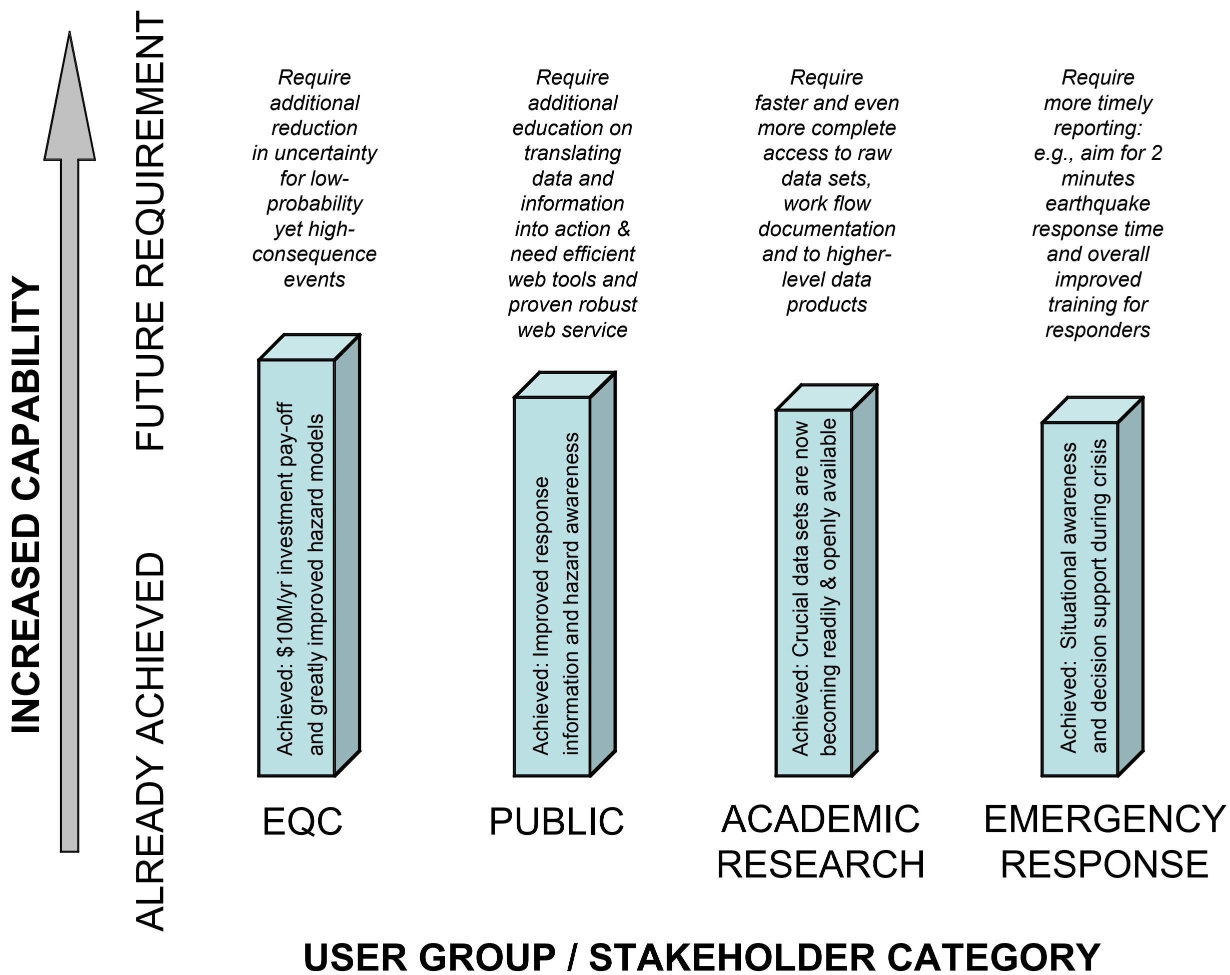
3. **Critical capabilities needed to strengthen GeoNet's ability to respond to major events –** the Panel were asked to assess GeoNet's current ability to respond to major events and recommend any strengthening of the system. Mindful of the danger of providing a wish list to cover all eventualities the Panel focused on high probability events and capabilities that they judged critical in preparing for these events.

4. **Enhancements that would improve the wider operation of GeoNet** – this section describes the key areas in which additional investment would ensure more complete use of GeoNet data, information, and resulting interpretation. Given the large list of possible enhancements the Panel has signaled first and second order enhancements.

5. **Further stretch opportunities that would give GeoNet a world leading position** – in this section we recommend valuable extensions to GeoNet well beyond current capabilities and possibly the mandate of EQC and LINZ. Nevertheless, they offer the opportunity to continue the leadership EQC showed in establishing GeoNet.

1. Highlights of project delivery

The GeoNet Project team has developed strong relationships with all parties involved with the GeoNet system. The table below outlines the Panel's assessment of what has been achieved to date and where future opportunities lie.



It is the Panels view that GeoNet data is supporting world class research in New Zealand. From the information provided to us we judge that this research has contributed directly to improved earthquake hazard assessment and a revised RMS model for New Zealand earthquake hazard. As shown in the above chart, the revised model has yielded benefits to EQC of an identified $10 million per year reduction in the EQC reinsurance premiums. The lower reinsurance rates are setting an international standard and also providing a wider benefit to the international insurance industry.

The reinsurance pay-off is the product of total investment in geological hazards research during the previous decade, to which GeoNet has made a major contribution. This outcome, for a capital outlay of an initial $5 million, rising to $8 million per year, has been an extremely good investment for New Zealand in applied science. This does not count the probably far greater benefits to the wider New Zealand society from a world class, comprehensive and integrated Hazards Warning System. There would be benefit in providing a comprehensive economic and social benefit study to better quantify the contribution the Hazards Warning System is, and will make to New Zealand society and the "world hazards community". This is a real science success story and could be told to a wider audience.

The gains outlined in the table have been driven by a cautious, pragmatic approach to investment and strong implementation of policies on equipment types and quality of delivery. The focus has been on the long-term utility (operability and maintainability) of the network. Although this careful evolution of the system has caused short delays to the project in the past, the Panel was clear that cautious, staged rollout of equipment is a wise approach to ensure long-term stability of the networks and data.

There are further research opportunities to come. Many of them arise from growing expectations of how raw data are captured and presented as a result of new technologies. Already open source software has allowed the project to develop innovative service delivery. In particular, the "ShakeNZ" map for the internet and mobile phones is an innovative means of getting critical information rapidly into the hands of those who need it quickly to identify or respond to hazards.

The open data policy for all researchers (not just GNS) is an important part of building robust and reliable information on which new models can be built. Encouraging the international community to become users of the data is also a powerful route to ensuring a robust and credible research base. The Panel noted that there are opportunities to engage with additional networks, particularly those with comparable geographic coverage (eg Italy, California and Pacific). GNS currently looks to the USGS global network (NEIC) as a primary point of reference. This may not be the best analog for GeoNet and they could look to the regional networks along the Pacific coast of North America[1] for a more relevant comparison

The relationship between the GeoNet Team and the other scientific staff at GNS has provided the link that has turned data from the monitoring network, with the application of science, into information and knowledge. This process has been the key to the success of the GeoNet Project. The Panel would be concerned if this valuable link was to be disrupted by any organisational or asset ownership change.

[1] These would include the Southern California Seismic Network (cooperated by Caltech and USGS Pasadena); Northern California Seismic Network (cooperated by USGS Menlo Park and UC Berkeley), the Pacific Northwest Seismic Network (covering Oregon and Washington and operated by the University of Washington and USGS Seattle), and the western Canadian seismic network (operated by the Geological Survey of Canada, Sidney). The operations and issues in the Italian national network (operated by Istituto Nazionale de Geofisica e Volcanologia, Rome) are also very comparable in terms of numbers of stations and territory covered and includes both tectonic faults and active volcanoes in the monitoring responsibilities.

2. Is the form of the contract appropriate?

Currently GeoNet receives the bulk of its funding from EQC and LINZ. The EQC contract is for 10 years (due for renewal in 2011) and LINZ has previously renewed its commitment on a three-yearly cycle. EQC provided funding of $5 million per year from 2001, increasing to $8 million per year since 2005, whereas the LINZ investment since 2001 has averaged about $750,000 per year overall.

While important contributions to the core program are being provided by a limited number of interested parties, such as LINZ, MetService, FRST and others, the Panel concluded that the EQC has provided the platform that has leveraged funding from others for their specific needs. In an ideal world, the costs of maintaining and operating the GeoNet would be shared across government and the private sector. Today's reality, however, indicates that if GeoNet is to continue it is likely to require the full support and commitment of EQC. We think that this continued commitment is justified. Firstly, GeoNet has clearly been a good investment for EQC in terms of the significant contribution it has made to a reduction in reinsurance costs. But even were this not so, the Panel agrees that EQC's investment in GeoNet is consistent with the Commission's mandate to support public education and research relating to natural hazards. GeoNet is clearly serving this purpose in critical areas of research and its application. This is justification enough for EQC's continued support.

GeoNet hazards monitoring in New Zealand would take a major step backwards if EQC withdrew its funding. We heard that:

- National science funding is unlikely to pick up a major monitoring role;
- Local Government would struggle to find the collective funding necessary;
- MCDEM would require a new budget appropriation.

The presentations made by the GeoNet Team to the Panel referred several times to the value of the long term funding from EQC. This funding has allowed the Project to plan and, more importantly, innovate in the delivery of the original objectives.

The long term funding has also been vital in encouraging funding from other parties. Other partners have come on board confident that GeoNet will be around for the long term. Coming on board has expanded the reach and value of GeoNet’s activities. For example, the additional funding for the GPS tracking network from LINZ has meant resources were able to be redeployed to take advantage of the scientific opportunity presented by insights into “slow slip” earthquake discoveries.

The Panel encourages both parties to begin discussions on the renewal of the current contract as soon as possible. Any new contract should seek to obtain a similar, or better, stability of future cash flows. This stability will continue to attract other funders and should be balanced with an appropriate pressure on GNS to spend the money wisely on the appropriate balance of investment, replacement capital, maintenance and operations.

The relationship between the parties has the potential to become a true text book "Alliance Contract Partnership". The Panel observed that the relationship between the "Asset Owner" – EQC, and the "Service Provider" is increasingly built around a shared common vision and objectives as well as effective senior managers. There is evidence that this has been a major contribution to the current outstanding success of the present Hazards Warning System. The Panel suggests that the renewal of the contractual arrangement continues to ensure these success factors continue regardless of key individuals who may, or may not be involved, over the next contractual cycle.

Given that the GNS and EQC are working for the benefit of New Zealand, the two organisations form a highly mutually dependent relationship in the funding and production of hazard information and research. The contract for GeoNet therefore, needs to be tailored to their joint interests in ensuring New Zealanders are protected from hazards.

One possible route to consider for the new contract is the "evergreen" contract, with a relatively long (one to two years) termination clause available to either party, that two other Government bodies have recently signed. In 2003 the Electricity Commission (the Regulator) signed an evergreen contract with Transpower NZ for the provision of System Operator services to the electricity industry. The contract is evergreen until either party issues a two year termination notice. In such a contract the annual budgeting and planning becomes the management tool for both parties.

Within such a contract EQC would still be looking to maintain the efficiency pressures on both the operating and maintenance costs and the replacement capital. Techniques such as CPI-X (funding indexed to inflation less a specific allowance for productivity improvement) are common to achieve suitable pressure to achieve the desired efficiency gains. The productivity improvements are most likely to come from technological improvements. Capital for new initiatives would require negotiation on a regular basis with perhaps three year wash ups to ensure the money has been appropriately invested.

We did not get a clear picture from our discussions with GNS and EQC of how they might be protected against suit for damages in the case of third parties who rely on advice from the Hazards Warning System. We think it would be prudent for each of GNS, EQC, and LINZ to take legal advice to ensure that the disclaimers they publish with the advice are sufficient protection, and to cover this risk in their contracts with each other.

It may also be worth considering adjusting the contract for the LINZ tsunami Warning System to a similar contractual structure and time period as the renewed EQC contract.

Finally, a process that formally allowed GNS as service provider to propose new directions for the system and new investments, supported by appropriate investment analyses, could add real value to the future system, and could usefully be provided for formally in the new Contract.

3. Critical capabilities needed to strengthen GeoNet's ability to respond

The future ability of the GeoNet to carry out its mission depends critically on the uninterrupted operation of its core reporting activities while it continues to provide high-quality information to end-users for emergency management, risk reduction and research purposes.

The staged rollout approach has served all of the stakeholder communities well over the past eight years and should continue to be the underlying design philosophy for future growth and evolution of the GeoNet. The task of building the GeoNet is not done, however. In this section, a number of critical, new capabilities and tasks are discussed that emerged through the Panel's discussions with a broad cross section of stakeholders.

We have grouped our recommendations in this section under:

a. <u>Technical improvements</u> to the timely and accurate information on geologic events that pose a threat to life and property. In particular we recommend:

   - **Additional investments in the area of strong motion instrumentation for both engineering and hazard modeling purposes**. Both areas contribute directly to the loss models used by EQC in establishing reinsurance premiums and more widely to the FRST-funded "Riskscape" programme, through which losses due to natural hazard events may be modeled and the potential efficacy of various mitigation measures tested. Better information will contribute directly to the reduction of uncertainty in the loss forecasts. Earthquake risk and potential losses are highly concentrated in the greater Wellington area, yet it remains under instrumented by international standards. A dense network of strong motion recorders in the urban area would provide data needed to test and improve fragility curves for buildings (a critical parameter in all loss models), and quantify the hazard posed by soft ground conditions in the central business district and industrial districts. The instrumentation of representative structures also needs to be accelerated. Although there are challenges to be overcome in securing access to privately owned buildings, there is no substitute for the information gained from earthquake recordings in New Zealand buildings for the purpose of evaluating and improving the seismic safety provisions of the national building codes. The government should also consider enlisting the cooperation of its own departments and agencies in permitting access to their buildings for instrumentation.

   - **Improved strong motion coverage along selected major fault lines in the South Island.** The Marlborough, Hope and Alpine fault systems are poorly covered by the backbone network. If adequately instrumented, the rupture of any one of these faults in a major earthquake would fill a critical gap in the global knowledge of how strong the ground shakes very near the fault. The lack of data from within 10-15 km of the fault in large magnitude earthquakes is one of the major sources of uncertainty in both hazard and loss models. Filling this gap would significantly improve the accuracy of the EQC's loss model for New Zealand.

- **Regular survey of volcanic centers using InSAR and diffuse CO_2 measurements**. The active and dormant volcanoes and volcanic fields of the North Island pose a significant threat to life and limb, property, vital communications and aircraft safety. The existing capabilities of the GeoNet are being effectively used to monitor their activity. There are critical gaps in the monitoring systems, however, that should be filled to provide earlier detection of emerging volcanic activity. Early signs of subterranean movement of magma can be reliably detected using a combination of space-based and chemical monitoring systems, neither of which is currently fully developed in New Zealand. The recently launched Japanese radar satellite "ALOS" provides the capability to detect subtle uplift of the land around a volcano long before magma rises to the surface using well-established methods of Interferometric Synthetic Aperture Radar (InSAR). New Zealand would benefit from the extension of regular surveying of its volcanic centers using this satellite-based technology, for which the data is available at low or nominal cost. As magmas ascend from depth, they release carbon dioxide gas which it can be detected in the atmosphere. The volcano surveillance component of the GeoNet should extend the regular surveys of outgassing rates at White Island and Mt Ruapehu to the other active and potentially active volcanic centers to develop baseline outgassing rates and monitor for significant changes. Together, these complementary technologies would significantly enhance the potential for early identification of volcanic activity.

- **Installing a small network of tiltmeters high on Ruapehu.** Ruapehu volcano presents particularly serious monitoring challenges. Skiers on the slopes may have as little as 90 seconds to evacuate from the flowpaths for summit eruptions (lahars). Although there is a capable warning system in place, the 2007 eruptive activity occurred without early warning. The review identified a well-established technology that might detect warning signs of even small summit eruptions. A small network of tiltmeters emplaced high on the mountain would stand the best chance of catching the build-up of near-surface pressure that leads to small but dangerous phreatic (steam) explosions. Tiltmeters, whether of the platform or shallow borehole type, are significantly less expensive and easier to install than borehole strainmeters, and thus more suitable than the latter for installation high on the cone where pressurization of the shallow hydrothermal system is expected.

b. Activities that strengthen the <u>relationships</u> between the scientific and technical staff of GeoNet and the users of GeoNet information. Existing relationships with MCDEM, MetService, affected local governments and DOC, etc. benefit from regular engagement. More frequent training exercises and introduction to new GeoNet products and services would be of particular value. In particular we recommend:

- **Priority be given to testing of the information delivery systems for emergency managers at all levels of government**. The GeoNet has dramatically improved the speed of delivery and information content of hazard information to emergency responders and the public alike through the linkage of its volcano and earthquake surveillance networks to modern information delivery systems. Since their development, the GeoNet webpages, mobile phone services, etc have been gaining wide acceptance and utilization. The 2007 Gisborne earthquake provide the best test, to date, of these information delivery systems. It was not a major event, however, and serves as a reminder that ongoing testing and monitoring of the information delivery systems are required to ensure that warnings and critical hazard advisories promptly reach their target audiences when a major geological event occurs.

- **Increase skill level of tsunami interpretation for GeoNet on-duty officers**. The MCDEM Director noted that additional training is required so that all available data types will be properly interpreted in real-time situations by officers who may not already have tsunami expertise. By familiarizing themselves to a greater extent with the full range of data types, more accurate interpretation of the data will lead to better decisions.

- **Special attention should be given to the capacity of the website to serve information.** The New Zealand public has already established a healthy interest in the GeoNet website, evidenced by growing public reporting of felt earthquakes, surveys of school teachers and a variety of website traffic statistics. Public expectations for rapid access to emergency information are also high. International examples show that planning and testing for very high traffic volumes is essential if services are to continue without interruption. The high visibility of the GeoNet website presents an excellent opportunity to educate the general public, about their risk of injury and loss in future geologic events, as well as the steps they should take to improve the safety of their families, reduce their risk of property loss, and help build resiliency in their communities. These objectives align with EQC's and suggest a tie-in with EQC's own web presence.

4. Enhancements that would improve the wider operation of GeoNet

This section deliberately focuses on those recommendations that will extend GeoNet above and beyond the current level of baseline support within the existing scope. Unless additional funding is provided, the following highly important activities – many of which have been requested by stakeholders - will not be possible with the current baseline level of funding support.

As in the previous section we have grouped our recommendations under two categories: technical improvements and relationships. Given the number of these enhancements we have also identified first and second order priorities for attention. The recommendations marked (*) below are our suggested first priority. The others are second priority.

a. Technical improvements that would be warranted include:

- **(*) Faster serving of earthquake event information.** We recommend a goal to reduce the performance target to 2 minutes (rather than current 20 minutes) and placing more reliance on automatic systems to greatly speed response. The current practice of having a seismologist review every result extends the time and an automated system for issuing first notices could reduce the time to a few minutes. GeoNet is already setting the global standard for real time shaking on the website. It should be possible with some new effort to provide an epicenter good to 10 kilometres and magnitude good to ¼ unit.

- **(*) Additional support for routine provision of requested/required higher-level data products.** A seismicity catalog that is complete and current must be maintained, even in the event of greatly increased activity, such as an energetic swarm or aftershock sequence. Equally precisely re-located event catalogs should be routinely provided. GNS could also usefully develop further collaborations and expertise among academic researchers so they can work from the available data products.

- **(*) Improved data access tools for research scientists.** The Panel recommends that GeoNet adopt or uphold international standard data formats when possible. This will ensure documentation is sufficient to allow complete reproducibility of results obtained from the raw data that are also being provided.

- **(*) Increase instrumentation and upgrade networks and monitoring, especially at Mount Taranaki,** in particular for those parameters that might foretell of sector collapse (giant landslide). This could include deep wells for research and monitoring, drilled into the Egmont aquifer, so that sensors could detect anticipated large pore pressure changes.

- **Faster serving of higher-sampling-rate GPS data** so that displacement data may be used in near real-time to support finite-fault source model inversion. Existing GPS sites may require telemetry upgrades to support this, and possibly this can be funded by LINZ for some stations.

- **Increase the density of GPS station spacing** throughout areas of currently sparse coverage, especially in the South Island. In possible partnership with GPS vendors, increase density of GPS stations in urban areas at risk; for example, along the Wellington fault.

- **Increase the use of geodetic data, such as GPS-derived site velocities**. Notably by explicitly including the GPS velocity field in the National Seismic Hazard Maps and by using GPS to quickly derive coseismic displacement vectors that allow for accurate modeling of the fault rupture soon after the shaking stops.

b. Activities that strengthen the relationships between the scientific and technical staff of GeoNet and the users of GeoNet information. There are already excellent examples of collaborations between GeoNet and other users of data. The Panel identified possibilities to enhance collaborations with:

  - **(*) Education sector** by connecting with the Science Learning Hub. The Hub provides curriculum based science resources for teachers and is run by the University of Waikato on behalf of the Ministry of Research, Science and Technology. Usage by teachers of GeoNet is already high, but apparently ad hoc. EQC and/or GNS could explore with the Ministry of Education whether there would be benefit to incorporating GeoNet data explicitly into curricula, as it is clear that students are excited and encouraged by opportunities to work with real data from their own localities. This might include help from GNS scientists during curriculum development workshops, continuing education/summer classes for teachers, etc.

  - **(*) DOC conservancies** by extending the relationship with DOC in Taupo/Tongariro to other conservancies and the national DOC office**.** This development is already underway in the Auckland conservancy and there are promising signs that it will be picked up at the national DOC office.

  - **Research users** by creating research user groups to deepen access to and use of the GeoNet database**.** Recent organisation of regional "seismic and volcanic advisory groups" as in Auckland and Taranaki are also an excellent way to strengthen research and emergency management connections. One particularly important role for joint GNS-University organisational umbrellas arises during crises, when there will be a clamor both from scientists to be heard and from the public to hear from scientists.

It is very helpful to all outside users (MCDEM, utilities and transportation, the general public, etc) if scientists who might not already be close collaborators can work as a single team during crises, debating interpretations behind closed doors and then speaking with a single voice to the public. EQC, through GeoNet could facilitate "buy-in" to such coordinated response.

- **24/7 organisations such as fire and utilities** to look for opportunities to improve response times.

- **Regional government** by developing further regional roadshows to raise awareness of GeoNet and GNS. We are particularly keen to see the types of engagement in Taranaki and Auckland extended to others with high-hazard, tectonically/volcanically active areas.

- **International counterparts through** exchanges - "technical sabbaticals" – between GeoNet technical staff and their counterparts in other countries. We recommend targeted international secondments into GeoNet in areas where its capability needs strengthening with specialized technicans and software developers.

- T**he international volcano monitoring community**, through active participation in the WOVOdat initiative of the World Organization of Volcano Observatories. WOVOdat is an open, fledgling, web-based historical database of worldwide volcanic unrest, intended as an "epidemiological" tool for reference during volcanic crises and in research on specific types of unrest or preeruption processes. Preliminary discussions with GNS staff indicate a strong interest in participating in development of WOVOdat.

These relationships sit within the wider research context. The panel was interested to hear of steps to co-ordinate data and effort among all the hazards research programmes. The complementary investment by the Foundation for Research, Science and Technology is vital to improve the knowledge of the long-term behaviour of New Zealand's faults and volcanoes.

The written history is very short when measured against the recurrence intervals of major geologic events. For example, the Wellington fault ruptures about every 700-800 years, on average. Geologic studies aimed at measuring the rate of fault slippage, the dates and frequency of earthquakes on them, and the size of fault offsets in those earthquakes underpin the earthquake hazard models. Similarly, the past rate and size of volcanic activity is the key to understanding eruption potential in the future. Taranaki Volcano, for example, has a long history of catastrophic summit collapses that devastate the countryside for many miles from the volcano. Its summit is currently highly oversteepened. But what is the probability of its collapse?

The importance of targeted geologic and monitoring studies that answers such questions was clear to the Panel. The EQC currently contributes about $300,000 annually to the study of the Wellington Fault through the "It's Our Fault" project. A greater effort in paleoseismology and paleovolcanology will play great dividends in reducing the uncertainty in present earthquake and volcano hazard models.

As seen in other regions, hazard and loss models depend crucially on recurrence models of the low probability, high consequence events. Improved information from paleoseismology on slip per event and event chronology will lead to significant further improvements in these models. Although already world-class research is being done, there are a few areas where enhancements would meet international standards. Much additional radiocarbon dating will be required to refine dates of the most recent prehistoric earthquakes, at different localities along the major faults. If it can be afforded, airborne LiDAR or otherwise densely surveyed topographic maps are also needed, to quantify and correlate past fault movement along strike. Recently developed statistical methods should be applied to event correlations.

To support all the collaborations outlined the Panel identified a number of specific opportunities to improve the type of material generally available. These included:

- Extending **public information products** for use in visitor centres and museums. In doing so it will need to be able to communicate with a wide range of different audiences, including Maori and cultural minorities and people for whom English is a second language. GeoNet may need to seek advice on how to tailor its communications accordingly. To complete the loop, it would be valuable for GeoNet to contribute with EQC and GNS to a survey on public awareness of GeoNet and GNS outputs, to assist in design of effective public education in the future.

- **Developing scenarios** beyond testing the capabilities of the responders towards involving media and public in active participation and learning about emergency management. Learning from scenarios could also be increased by the participation of people who had participated in actual disaster management operations in other jurisdictions to participate in or act as resources for scenario exercises in New Zealand.

- Consider funding or co-funding some further **research uptake** initiatives. It is in EQC's interests to see as wide as possible an uptake of GeoNet data and data products to the research community and to hazard management specialists for example in regional government. One vehicle to consider could be competitive research grants for academic researchers making use of GeoNet datasets or derivatives; another could be partnering or matching grants with regional government on hazard-related research drawing upon GeoNet data products.

5. Stretch opportunities that would give GeoNet a world leading position

While the dominant conclusions of this review are that the current scope and performance of the GeoNet contract are excellent, we see several good opportunities for expanded dialogue and investment. In some, EQC could facilitate dialogue; in others, EQC could facilitate through both dialogue and investment.

These are grouped into three categories: technical improvements, relationships, and outreach.

a. Technical improvements

- **Automated, preliminary moment tensor solutions for tsunami warnings.** The hazard of tsunamis from distant sources is well covered in current or scheduled instrumentation and relationships. The hazard of locally generated tsunamis is not as well addressed – not forgotten, but technically quite difficult. If the earthquake is felt, coastal residents can move to high ground immediately. However, if there is a tsunami-generating "slow earthquake" that is not felt, GeoNet instruments will be critical for its detection, characterization, and translation into an immediate warning. How to do this so that people can get off the beach in 20-30 minutes is a technical challenge on which GeoNet could provide world leadership. The solution will probably be in automated, preliminary moment tensor solutions coupled to MCDEM and other warning systems.

- **Installation of "zipper arrays" of seismometers and GPS along major faults** (eg Alpine, Wellington, Wairarapa), for three purposes – to capture information about rupture propagation that can guide emergency response; to get high-quality information about the fault slip that is important for scientific understanding of the exact sense and magnitude of slip; and information about near-source attenuation of ground shaking that is needed by engineers for design of structures and for loss-modeling.

- **Additional data products:** Along with time series files that are already available and well-documented, GPS daily solution files (SINEX) could also be provided (self-documenting with embedded meta-data) along with a well documented work flow. This would require further support for development of the capability and ongoing support for additional quality assurance of this product and the demand from researchers for this product needs to be assessed.

b. Relationships

We encourage EQC and GNS to explore synergies between GeoNet and:

- **NIWA and the MetService for their monitoring of rainfall, other environmental parameters, and rivers.** This could involve potential sharing of multipurpose sensors, communications nodes and maintenance. For an example of multi-use sensors, the precision of GPS data can be enhanced by having real-time, coupled weather information from the same station (atmospheric moisture causes apparent shifts in GPS by as much as several centimeters!), and conversely, GPS data might eventually help NIWA and the MetService in quantifying moisture content through the atmosphere. Both of these uses are at the stage of developmental research. GNS could also provide information about major injections of volcanic sediment into runoff that might clog or at the least change calibration for river gauges, NIWA and the MetService could provide GNS with heads-up information on rainfall that would be useful for landslide researchers, and other matters. GNS and NIWA already have a joint Hazards Center; this suggestion pertains specifically to greater use of GeoNet and comparable NIWA/MetService monitoring data. This is consistent with a growing international trend toward multi-hazard, multi-sensor monitoring.

- **GeoNet/GNS counterparts in neighboring countries, through the Ministry of Foreign Affairs and NZAid.** In principle, there is already communication of ash hazard from Vanuatu, Solomon Islands, and other Pacific volcanoes to the Wellington Volcanic Ash Advisory Center (VAAC, operated by MetService), but in practice this communication is sometimes compromised by difficulties in communication, network maintenance, and even network coverage on remote volcanoes. In principle, too, New Zealand scientists are always learning from earthquakes, eruptions and the like in neighboring countries, but in reality this is greatly facilitated by exchange visits. While we do not propose that EQC or GeoNet undertake expansion into neighboring countries, we do think there are opportunities for EQC dialogue with NZAid, as potential co-investors, to explore relatively low-cost, win-win engagements between GNS, their counterparts in neighboring countries, and New Zealand universities. Examples of such engagement might include opportunities for university training, on-the-job or short-course training for technicians from neighboring countries, and modest assistance before, during, and after major events in neighboring countries. A key here is that such exchanges be recognized not solely as academic research but equally as practical help for all parties. EQC could provide partial support to GNS to second a scientist over to NZAid as a Geoscience advisor, as is presently done to good effect in Australia and the US. A common misperception in AID agencies, worldwide, is that scientists are looking only for another pocket to fund research that might have little benefit in poverty reduction. Our perspective is that while some research is indeed technical and of longer-term rather than immediate payback for poor communities, much of the GeoNet work is very practical and leads to immediate reduction of vulnerability. Perhaps EQC could explore with NZAid how modest joint investment for GeoNet to engage with neighbors would bring good payback to all parties.

- **Providers of** visualization tools to present for GeoNet data and related research results. Typically, graphics in scientific papers serve scientists much better than lay users, and uptake of GeoNet data would be helped considerably by collaboration with those who specialize in data visualization.

- **Colleagues from GeoNet counterparts from around the world who might assist in case of major earthquakes or volcanic eruptions.** Though very capable, the combined GNS and New Zealand university groups are still likely to be overwhelmed in a major event, and would do well to pre-arrange with selected colleagues for backup assistance if needed. Pre-arrangement will also make it easier to manage uninvited and potentially disruptive scientific visitors.

c. Outreach

We see opportunities in making the work of how GeoNet supports the 4 Rs – Reduction, Readiness, Response and Recovery - more visible by commissioning:

- **A business analysis of how GeoNet data have reduced uncertainty and thus lowered EQC's re-insurance costs.** The case of how developing MINERVA and underlying data helped EQC argue for NZ $10M/y is impressive; we suspect that there could be further savings if new data are used to update earthquake loss models, and if GeoNet data are also used for loss models of volcanic and other hazards. Some of this work is already in progress (indeed, world-leading), and we think expanded EQC support will be money well spent.

- **An economic analysis of how GeoNet data save money for New Zealand communities, for the Government, and for New Zealand business.** Too often, one reads reports of past or future losses. More to the point for investment decisions is information about whether and how investment in hazard mitigation reduces losses. Though many scientists are skeptical that economic analysis could capture the value of their work, and loth to put dollar values on lives saved, many decision makers think in terms of returns on their investments. A pragmatic approach would be to ask economists to do CBA on tangible costs and benefits of GeoNet, and then note the intangibles in addition.

Conclusion: The table below summarises the actions recommended

Targeted Improvements	Critical	Enhancements ***First order priority**	Stretch
Additional reduction in uncertainty for low-probability yet high-consequence events	Increase investment in the area of urban strong motion instrumentation including representative structures. Improve strong motion coverage along selected, major fault lines in the South Island. Extend regular surveying of volcanic centers using InSAR and diffuse CO2 Monitoring. Install a small network of tiltmeters high on Ruapehu	Increase instrumentation and upgrade networks and monitoring, especially at Mount Taranaki (*). Increase the density of GPS station spacing.	Installation of "zipper arrays" of seismometers and GPS along major faults. Explore synergies between NIWA and the MetService for their monitoring of rainfall, other environmental parameters, and rivers.
Additional education on translating data and information into action and need efficient web tools and proven robust web service	Improve the capacity of the website to serve information. Increase the skill level of tsunami interpretation for GeoNet on-duty officers.	Connect with the 'Science Learning Hub. (*) Extend the relationship with DOC in Taupo/Tongariro to other conservancies and the national DOC office. (*) Develop further regional roadshows to raise awareness of GeoNet and GNS. Develop international sabbatical exchanges for GeoNet technicians and software developers, in areas where its capability needs strengthening.	Forge relationships between GeoNet/GNS counterparts in neighboring countries, through the Ministry of Foreign Affairs and NZAid. Provide partial support to GNS to second a scientist over to NZAid. Strengthen ties with colleagues from GeoNet counterparts from around the world who might assist in case of major earthquakes or volcanic eruptions.

		Encourage participation of GeoNet staff in development of WOVOdat, an epidemiological database of worldwide volcanic unrest.	
Faster and even more complete access to raw data sets, work flow documentation and to higher-level data products		Additional support for routine provision of requested/required higher-level data products. (*) Improved data access tools for research scientists and engineers. (*) Faster serving of higher-sampling-rate real-time GPS data. Increase the use of longer-term geodetic data, such as GPS-derived site velocities. Link with providers of visualization tools.	Additional data products such as SINEX files.
More timely reporting: e.g. aim for 2 minutes earthquake response time and overall improved training for responders.	Priority test the information delivery systems for emergency managers at all levels of government.	Faster serving of earthquake event information. (*) Look for opportunities to improve response times by connecting with 24/7 organisations such as fire and utilities.	Automated, preliminary moment tensor solutions for tsunami warnings.

Annex One: Terms of Reference

1. Undertake a review of GeoNet's development to date against original objectives, and its current fitness for purpose, including:

    - Functionality
    - Management, staffing and skills
    - Investment Controls, procurement and system redundancy
    - Alternatives and technology obsolescence

After consultation with stakeholders:

2. Review in relation to international practice and the New Zealand context, present policies governing the scope of the GeoNet Project, including but not limited to, the criteria for its geographic coverage, national versus local monitoring, dissemination of research data and public information; ascertain the need or otherwise, for any changes or amplification of current directions.

3. Assess GeoNet's current ability to respond to major events, given its roles and responsibilities under the existing contract. Recommend any strengthening of the system, organisational capacity requirements, partnerships and other investments necessary to meet stakeholder and functional expectations of GeoNet.

4. Review in relation to international practice and original objectives the capabilities embodied by GeoNet and advise how these can be maintained to assure future delivery of specified outcomes.

5. Review present funding arrangements and potential levels of future expenditure required to maintain the capabilities defined by 3 and 4 in the medium to long term, so as to allow EQC to consider a range of options for any future funding.

9/15/2008

Annex Two: The Panel

Kieran Devine

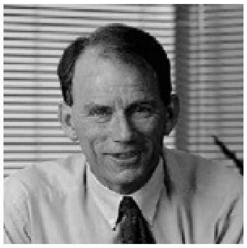
Kieran is a chartered engineer with more than 30 years experience within the electricity industry both in New Zealand and abroad. He is currently General Manager of System Operations for Transpower, the owner/operator of New Zealand's high-voltage electricity transmission grid. Kieran is responsible for real time Scheduling, Despatch, and Security of the New Zealand Power System, together with the management of the Wholesale Electricity Market, as the System Operator. He completed bachelors and masters degrees in engineering at the University of Canterbury, and an MBA with Distinction from Victoria University of Wellington. Kieran is a Fellow of the Institute of Professional Engineers (NEW ZEALAND), and a member of UK and USA counterpart organisations - the IEE and IEEE, respectively. He is also a member of the Institute of Directors of New Zealand, a former director of WEL Networks and past Chairman of the NEW ZEALAND Electricity Market, Rules Committee.

William Ellsworth

William (Bill) is a senior research geophysicist with the U.S Geological Survey in Menlo Park, California. Over the course of a 37 year career with the USGS, he has conducted research on fundamental problems in seismicity, seismotectonics, probabilistic earthquake forecasting, earthquake source processes and earth structure, while contributing leadership and direction to the USGS Earthquake and Volcano Hazards Programs. He received his Bachelors degree in Physics and Masters in Geophysics from Stanford University, and his Ph. D in Geophysics from the Massachusetts Institute of Technology, and is a Consulting Professor of Geophysics at Stanford University. He is currently the President of the Seismological Society of America, a member of the National Earthquake Prediction Evaluation Council, and is the co-principal investigator for the San Andreas Fault Observatory at Depth component of the National Science Foundation's EarthScope project.

Kenneth Hudnut

Ken studies earthquakes as a geophysicist for the U.S Geological Survey in Pasadena, California. He serves as Geodetic Coordinator on the U.S. Earthquake Program Council and leads the Southern San Andreas Fault Evaluation (SoSAFE) Project for the Southern California Earthquake Center. Ken is a former director of the University NAVSTAR Consortium (UNAVCO); he has served four terms as Chair of the Southern California Integrated GPS Network (SCIGN), and is an advisor on spatial referencing to the California Department of Transportation. In recognition for contributions made to the global navigation and positioning industry, he was selected by *GPS World* as one of '50+ Leaders to Watch' in 2007 and for other enhancements to GPS received a Group Achievement Award from NASA in May 2008. Ken is a graduate of Dartmouth College (A. B. and M. Phil) and Columbia University (Ph. D) and is a Visiting Associate in Geophysics on the faculty of the California Institute of Technology.



Rob Laking

Rob is a graduate of Victoria University of Wellington (B. A) and Harvard University (MPA) and a former senior New Zealand public servant and specialist in advice and capacity building in governance, public management and financial management. He has held senior management positions in energy, industry and primary resources policy; reform of public enterprise and financial management reform, serving with the New Zealand Treasury, the Ministry of Housing, Social Welfare and the State Services Commission. Since 1995, Rob has combined consulting with teaching and research at the School of Government, Victoria University of Wellington. He was Director of the Master of Public Management programme from 1997-2002 and has organised several executive programmes including Commonwealth Advanced Seminars on Public Service Reform. Rob has contributed to public sector reviews in defence, education, health, science and welfare, and has served frequently abroad on behalf of the World Bank, the Asian Development Bank, IMF, OECD, UNDP and DfID. Rob's research interests include governance in public organisations, expenditure planning and budgeting, performance management, strategic decision-making in government and public management in the developing world.

Lesley Middleton

Lesley is the General Manager: Science and Technology at the Ministry of Science and Technology. She is responsible for advising the Minister on new science directions for government and manages staff covering emerging technologies, environmental science, social science and broader science engagement with schools. Lesley has a Masters degree in public policy from the University of Bristol, United Kingdom and has previously worked as a health services researcher in the UK and for the Ministry of Health in New Zealand. Lesley was a member of the Ministerial Committee on Applied Social Science in 1996 (the Hawke Committee), and led an earlier review of social science research for the Office of the Chief Scientist. She has represented New Zealand science in a number of global forums and cross-government working groups, including (as Chair) an interagency steering group established as part of the New Zealand Government's response to the 2004 Indian Ocean tsunami, to monitor and coordinate technical and international issues related to tsunami.

Chris Newhall

Chris is a graduate of the University of California (B. S. and M. S) and Dartmouth College (Ph. D.) with more than 30 years experience of volcano monitoring, crisis response and research on active, explosive volcanism. He worked for many years at the U. S Geological Survey in Seattle, while also teaching at the University of Washington. He now lives in the Philippines and was recently appointed Professor/Volcano Group Leader of the Earth Observatory of Singapore at Nanyang Technological University. Chris played a key role in the scientific response to the 1991 volcanic crisis at Mt Pinatubo, Philippines. His understanding of the build-up to that eruption has been credited as crucial to the successful evacuation of large communities and mitigation of effects. Chris continues to spearhead initiatives to improve volcano hazard assessment and risk mitigation worldwide, and has recently contributed to science programme reviews for the NEW ZEALAND Foundation for Research Science and Technology. He is a past Chairman of the World Organization of Volcano Observatories (WOVO), an emeritus affiliate of the U.S Geological Survey Volcano Hazards Program and affiliate professor at the University of Washington.

Annex Three: Stakeholder Interviews

Representatives of sectors and organizations associated with GeoNet were interviewed, to assist the panel's understanding of the context within which GeoNet is being developed.

- **Department of Conservation**
  - Paul Green, Conservator, Taupo-Tongariro Conservancy
- **Earthquake Commission**
  - David Middleton, Chief Executive
- **Land Information New Zealand**
  - Graeme Blick, Senior Geodetic Advisor, Office of the Surveyor General, Wellington
- **Local Government**
  - Gary Bedford, Director of Resources, Taranaki Regional Council
- **MetService**
  - Ray Thorpe, Manager of Aviation Services
- **Ministry of Civil Defence and Emergency Management**
  - John Hamilton, Director and David Coetzee, National Controller
- **Risk Modelling (Reinsurance Sector)**
  - David Spurr, Consultant
- **University of Canterbury**
  - Jim Cole, Professor of Volcanology
- **Victoria University, Wellington**
  - John Townend, Senior Lecturer in Geophysics

Annex Four: Glossary of Terms

Coseismic displacement vectors	The amount and direction of ground (or fault) displacement that accompanies an earthquake
Fragility curve	In structural engineering, a function that describes the probability of failure of a structure or structural type, for a given applied load of one form or another, e.g., earthquake shaking.
GPS	An acronym for Global Positioning System: A system of satellites and receiving devices developed by the US. Department of Defense and used to compute positions on the Earth. GPS is used in navigation, and its precision supports a wide range of scientific and cadastral applications.
Moment tensor solution	The moment tensor is a mathematical representation of movement on a fault during an earthquake. The seismic moment is a measure of the size of the earthquake derived from the moment tensor. Seismologists use the seismic moment to compute the "moment magnitude", the standard measure of earthquake size.
Pore pressure	Pressure exerted by fluids contained within the pores of rock. Landslides are sometimes triggered by rising pore pressures.
SINEX file	Solution (Software/technique) INdependent EXchange Format
Slow slip earthquake	A slow slip earthquake occurs when fault displacement occurs over a period of hours to months, rather than in seconds as occurs during ordinary ground-shaking earthquakes. More than a dozen slow slip earthquakes have been recorded beneath the North Island since continuous GPS monitoring was expanded with GeoNet in 2002.
Strike	The course or compass direction of a fault (line) across the Earth's surface.
Strong motion instrumentation	Instruments that record the strong shaking of the ground and in structures during earthquakes. The measured shaking may be used immediately after an event to scale and direct the emergency response. Structural measurements are studied after events to analyze and compare the performance of structures against design assumptions.
Zipper array	An array of GPS instruments deployed on either side of a major fault and along its length, used in real-time to detect "unzipping" of the fault during an associated earthquake rupture.