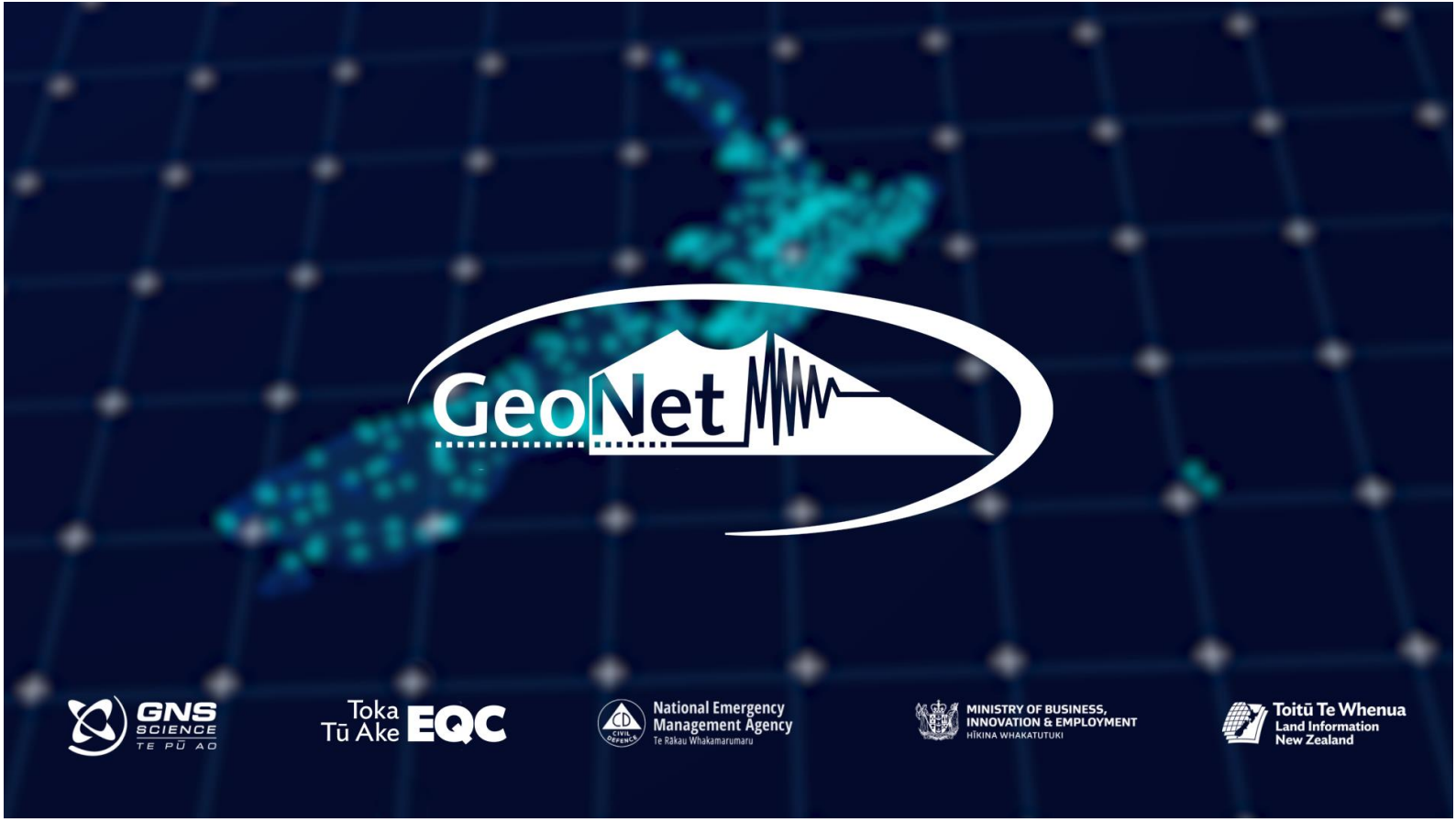


GeoNet Strategic Review 2022

7 October 2022

Rev 1.0

GEONET STRATEGIC REVIEW 2022

07 OCTOBER 2022

Executive Summary

GeoNet uses networks of sensors to gather scientific data on four geohazards: earthquakes, tsunami, volcanoes and landslides. The data is made available to all users at no cost. To date, GeoNet has been substantially funded by Toka Tū Ake – EQC, with LINZ also a long-time contributor. Funding has been tied to the original purpose[1] and the delivery of services defined in contracts between GeoNet and the funders. Initiatives underway to establish a new funding model may lead to some shifts in what GeoNet delivers. This strategic review highlights the possibilities.

GeoNet has, in many respects, exceeded the original vision of its creators and become the victim of its own success. The data that it captures has enabled New Zealanders to better understand and manage Aotearoa New Zealand's geohazards. It has also played a vital role in supporting scientists during geohazard events. Emergency managers have come to depend on GeoNet data and want even more products, services and interpretation from it. Adding new services incurs costs, including the costs associated with development of the core data acquisition and processing. Eroding the quality of the fundamental data to provide more services is a fool's errand. GeoNet needs to identify a path forward that allows for the development of new services within the constraints of the future funding envelope.

GeoNet's 21-year evolution has been shaped by multiple geohazard events, experience gained by scientists about the risk of geohazard events and advances in technology. The GeoNet app gave GeoNet a high profile with the public following the Canterbury earthquakes in 2010 and 2011. The introduction of the National Geohazard Monitoring Centre (NGMC) in 2018 saw another shift in GeoNet's outputs. Through it all, GeoNet has continued to operate to its original purpose.

Delivering on some of the review findings might require changes to the philosophy of GeoNet. The philosophy of GeoNet has been guided by the funders, and funding arrangements are currently under review. The expanded possibilities created by advances in science and technology, combined with new funding arrangements and the development of a 10-year strategic plan, will lay a foundation for the opportunities discussed in this strategic review.

The GeoNet Products and Services Catalogue sets out how the user products and services are organised:

- *Core services* required to support all products and services.
- *Product Suites* define five distinct ways that GeoNet data are organised.
- *Supporting Services* describe how GeoNet data are put to use, including the NGMC.

At issue for the strategic review is that the core services must be maintained to support existing products and services. Often, adding new services incurs a cost for developing the core service to support it. For the Review Panel, the cost of maintaining the core services or upgrading them to support new services is a funding issue, whereas they were focused on the strategic opportunities. The Panel agreed on a single theme for the review:

The future is an open, adaptive, and automated GeoNet, built on a stable and sustained core system.

The panel has made recommendations in five distinct themes:

1. A more open and adaptive GeoNet

The Panel recognises that a key element of GeoNet's success has been its free and open data policy[2], allowing any party, from local and international scientists studying geohazards to the international

1 To provide a nationwide integrated hazards monitoring system for the benefit of the New Zealand public.

2 Refer to Principle 4 of the GeoNet Objectives and principles as shown in Appendix 2.

re-insurance community, to access its data feeds. The Panel endorses the principle but remains open to exploration of three related elements:

- The potential for integrating relevant data feeds from non-GeoNet sensors.
- The potential to utilise experimental, low-cost sensors on parts of the network.
- The potential to draw on more 'citizen science' input.

The Panel supports more development and evolution but sees the process as adaptive rather than revolutionary. A move toward a more open and adaptive environment would require a re-architecting and would enable new pathways to deliver impact.

2. A more automated GeoNet through data science innovations

GeoNet data and services offer insights into complex, time-sensitive and high-stakes decision making, especially during and following an event. GeoNet weighs the importance of data being verified and validated through expert review with the sense of urgency in the moment.

Advances in artificial intelligence (AI), deep learning (DL) and machine learning (ML) techniques lend themselves to an increasing role in geoscience for machine versus human analyses, the rapid understanding of geohazard events and, possibly, input into determining appropriate warnings to the public. GeoNet is in a good position to provide data training sets for this purpose, and AI/DL/ML may well have a role in some of the services that it currently provides.

3. Adding impact-based forecasting and advice to event reporting

There is a global trend toward impact-based advisory products and forecasting alongside geohazard event reporting. This reflects both emerging science capabilities to better model impacts and the value of such products to inform more timely and effective disaster responses by individuals, communities and organisations. An element of impact-based forecasting is near-real-time information products that:

- Provide detailed hazard impact information for hazard events.
- Provide forecasts of likely evolving impacts, e.g. operational aftershock forecasts updated to integrate deformation changes or, for volcanic events, the shifting direction of intensity of ashfall impacts.

This potential development has been acknowledged by GeoNet with work underway to establish future impact-based (and other advisory) products in the next few years.

4. A more connected GeoNet through engagement and partnership

Having built GeoNet's core capability and expanded its focal point of product and service delivery, existing users and other potential users can see new and extended possibilities. GeoNet needs to manage this through wider engagement by the programme to ensure that it provides value to the parts of the community that can benefit from it the most.

Three areas where engagement work is pressing are: (1) the science and engineering community, (2) iwi and the Te Ao Māori perspectives and (3) the Civil Defence and Emergency Management (CDEM) community. Engagement with the science, engineering and emergency management sectors will be helped by the establishment of a Technical Advisory Panel. Structured engagement will also support a collective approach to development of an appropriately trained workforce to sustain GeoNet's operations.

The review panel noted that data made available for free to users is not the same as products and services being provided at no cost to the funders. Greater engagement and partnering will ensure that GeoNet provides the greatest benefit to key users that will, in turn, reinforce the value that it provides for the funders.

5. The National Geohazards Monitoring Centre

The NGMC is a real-time geohazard monitoring service developed in response to the Kaikōura earthquakes in 2016. It was established to ensure that active monitoring for events is continuous, events are detected as soon as possible, relevant data is made available and experts are coordinated so that the course of events and their aftermath can be managed as best as possible.

The NGMC has become a high-profile part of the product and service suite. This is reflected in users' expectations about science advice products and services available through the NGMC and the way that the core GeoNet system enables it.

GeoNet learned from the development of the NGMC that the core GeoNet system has to be strengthened to accommodate most new services, especially for very high-reliability, time-critical emergency response capability. Latterly, the National Emergency Management Agency (NEMA) has established its own 24/7 Monitoring, Alerting and Reporting (MAR) Centre. It will be important to calibrate the role and operation of the NGMC so that the work of the NGMC and MAR are optimised.

Introducing a Technical Advisory Panel

The establishment of a Technical Advisory Panel (TAP) will ensure that GeoNet restores the formal input from the science community and other users (i.e. not just existing funders) and prioritises work on both core-service capability and new products and services. The review panel proposes the following purpose for the TAP:

- To provide scientific, technical and user advice to ensure that the GeoNet investment and products and services are informed by trends in science and technology to serve the needs of the various GeoNet user communities to the extent practicable within funding constraints.
- To provide input to the development pathway and prioritisation process for new products with the aim of supporting efficient science-to-operations feedback loops.

Investment principles

The review has revealed a wide range of expectations and a lack of understanding of how GeoNet makes investment and prioritisation developments (and the constraints it is under, which dictate most choices). Engagement with users would be improved with better understanding of how GeoNet makes investment decisions and what it is doing. The Panel recommends that GeoNet work with funders and GNS Science (and potentially the TAP) to establish a set of investment principles.

An optimistic outlook

The Review Panel is optimistic for the future of GeoNet. The possibilities highlighted by the review are exciting. The Panel wants GeoNet to continue to be taonga ā-motu, a national treasure, and, while they want it to realise its full potential, this should not be to the detriment of the attributes that have made it so successful over the last 21 years.

Purpose of the Review

The purpose of this Strategic Review, as set out in the Terms of Reference (Appendix 1), is to provide assurance to the GNS Science Board and GeoNet stakeholders that:

1. The direction of the development of GeoNet's products and services is:
   - future-focused.
   - structured to deliver maximum impact for New Zealand, and
   - aligned to modern science approaches (including big data).
2. The development of the GeoNet 10 Year Strategic Plan is grounded in stakeholder and scientific insights.

The review panel was asked to address three questions. In service of national and international geohazards research and national geohazards response:

- What are the possible future products and services that the GeoNet sensing network will be required to support?
- How might the way we gather, make sense of and learn from data on geological hazards change over time?
- How would a GeoNet Technical Advisory Panel be best structured and engaged to ensure that GeoNet remains in tune with emerging research and response needs?

Strategic Review Panel Process

Over the course of three workshops, the Panel heard from GeoNet team members, staff from other parts of GNS Science whose work is linked with GeoNet, and a range of external users. The Panel heard requests for future products and services from presenters who are not direct funders. They also heard about trends in geohazard monitoring globally and how the iteration between GeoNet and the science community on the best approaches could be improved.

The findings of this review, therefore, place greater emphasis on the way that we gather, make sense of and learn from data on geological hazards than on lists of requests for new products and services. Essentially, the challenge is how GeoNet keeps doing what GeoNet was set up to do in the face of scientific, technological and commercial developments in geohazard monitoring.

Background and Context of GeoNet

At GeoNet's inception, GNS Science and the funding partners understood the importance and value of making quality data on four geohazards (volcanoes, seismic activity, tsunami and landslides) freely available for science, research and multiple uses in the resilience system in New Zealand and internationally. GeoNet is operated by GNS Science and has been historically funded by Toka Tū Ake – EQC and LINZ. The inspiration for setting up GeoNet in 2001 was to enhance and formalise the gathering of data on geohazards for the public good (see GeoNet's Objectives and Principles in Appendix 2).

As a first-order priority, GeoNet serves its funders and their statutory obligations as provided for through contracts with GNS Science. It leverages partnerships with other organisations that have similar needs (e.g. LINZ – where geodetic infrastructure needs to provide a service to surveyors is also what GeoNet needs to understand the deformation of New Zealand for natural hazards).

The key benefit of GeoNet is to improve our understanding of geohazards and their impacts so that New Zealand will be more resilient than would otherwise be the case. The vision is to make New Zealand a safer place through the provision of data, and it is doing that.

GeoNet is designed to collect, monitor and analyse scientific data on geohazards that the science, insurance, infrastructure and emergency management sectors can rely on to better understand, plan for and respond to geohazard events in New Zealand for the public benefit.

It is a geoscience-led programme, but it relies on data science and information technology to deliver its functionality. GeoNet provides expert advice to NEMA to support New Zealand's response to geohazard events.

GeoNet is a highly trusted source of information and education to the public to build understanding of our geohazards and encourage preparedness.

In short, GeoNet is an enabler for the best possible geohazard hazard risk management in New Zealand.

Functionally, GeoNet gathers data and makes it available through the process shown below. The data collection and dissemination can be live-streamed, near live or manually collected.

While the GeoNet Products and Services rely on GNS Science Information Services for desktop hardware and office productivity software, all specialised applications and infrastructure are managed by separate technology teams within the GNS Science Data Science and Geohazards Monitoring Department, located primarily at the Avalon site.

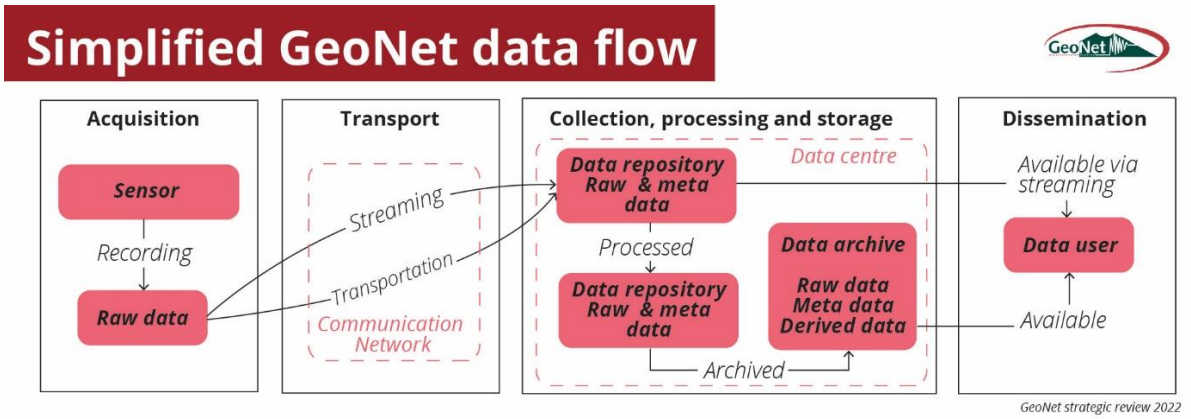


Figure 1 GeoNet core services in a data flow.

GeoNet data is collected by several means. See Figure 2 below. Some examples include:

- Seismometers to measure the magnitude, location and characteristics of earthquakes.
- Global Navigation Satellite System (GNSS) equipment to pinpoint where strain is building up or being released in the earth's crust.
- Seismic, geochemical, GPS survey and remote-sensing techniques for early detection and monitoring of volcanic unrest.
- Survey equipment and mobilisation of resources for a nationwide landslide monitoring and response team.
- Strong-motion recorders for buildings and bridges that monitor how structures move in earthquakes.
- Water-pressure sensors to detect the arrival and height of tsunami waves.

Round-the-clock operation of the monitoring system and a modern data-management centre.

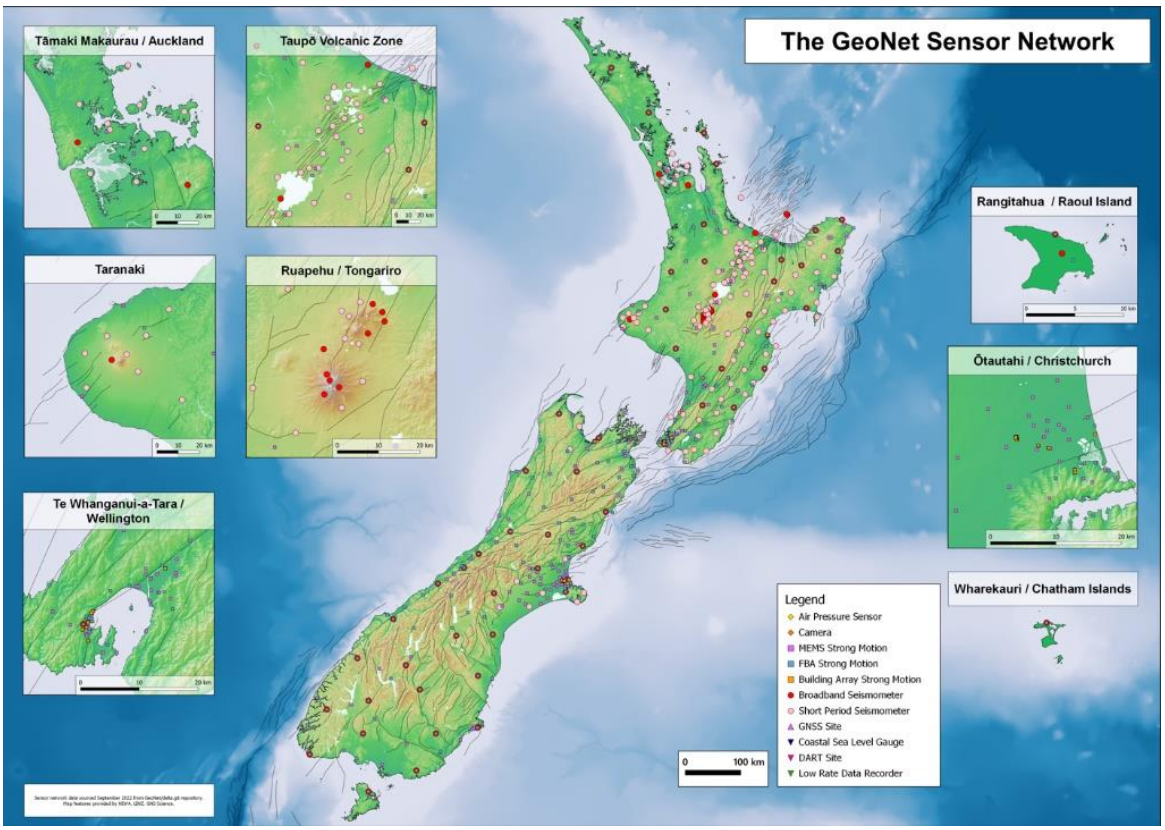


Figure 2 The GeoNet Sensor Network.

GeoNet is run as a programme within GNS Science, managing geological hazard data from acquisition through to distribution to users as a range of data and advisory products and services.

The GeoNet Core Services shown in Figure 1 above underpin product suites and supporting services to deliver value to funding stakeholders, the research community and a range of government and community stakeholders.

The GeoNet Products and Services Catalogue describes the core services, product suites and supporting services shown below (a more fulsome description of each item is provided in Appendix 3):

- **Core services required to support all products and services:**
  - Sensor Network, i.e. data acquisition
  - Data transportation
  - GeoNet backbone data, i.e. data acquisition, processing and storage.
- **Product Suites define five distinct ways that GeoNet data is organised:**
  - GeoNet Rapid
  - GeoNet Data
  - GeoNet Data International
  - GeoNet Data Casting
  - GeoNet Eruption Detection Systems.
- **Supporting Services describe how GeoNet data are put to use:**
  - Data Access Services
  - Information dissemination
  - Expert monitoring tailored advice and support
  - National Geohazards Monitoring Centre (NGMC)
  - Communications, education and outreach.

Use of GeoNet data, advances in science, responding to events, adopting experience from events and emerging technology have led to greater demands of GeoNet. Significant step-changes in users' knowledge and expectations of GeoNet occurred with: (1) the introduction of the mobile app for providing 'felt' reports, along with effective communications and social science research during the Christchurch earthquakes; and (2) the establishment of the NGMC after the November 2016 Kaikōura earthquake. These shifts in GeoNet's outputs saw more visibility of its work in emergency management, the development of more users and the emergence of more potential users. The timeline of GeoNet's evolution and significant geohazard events is shown in Figure 3.

In 2017, a governance review recommended a single common contract for core services with all funders and the ability to contract for individual services as well. Following this review, the GeoNet Advisory Panel (GAP) was set up with senior representatives from all funding partners and NEMA. A GeoNet Steering Group was established in 2019 to take a more detailed and technical view of GeoNet's planning documents and unfolding issues. These arrangements will be augmented by the establishment of the Technical Advisory Panel (TAP) discussed in this review document. Appendix 4 describes the GeoNet contracting, oversight and governance arrangements in more detail.

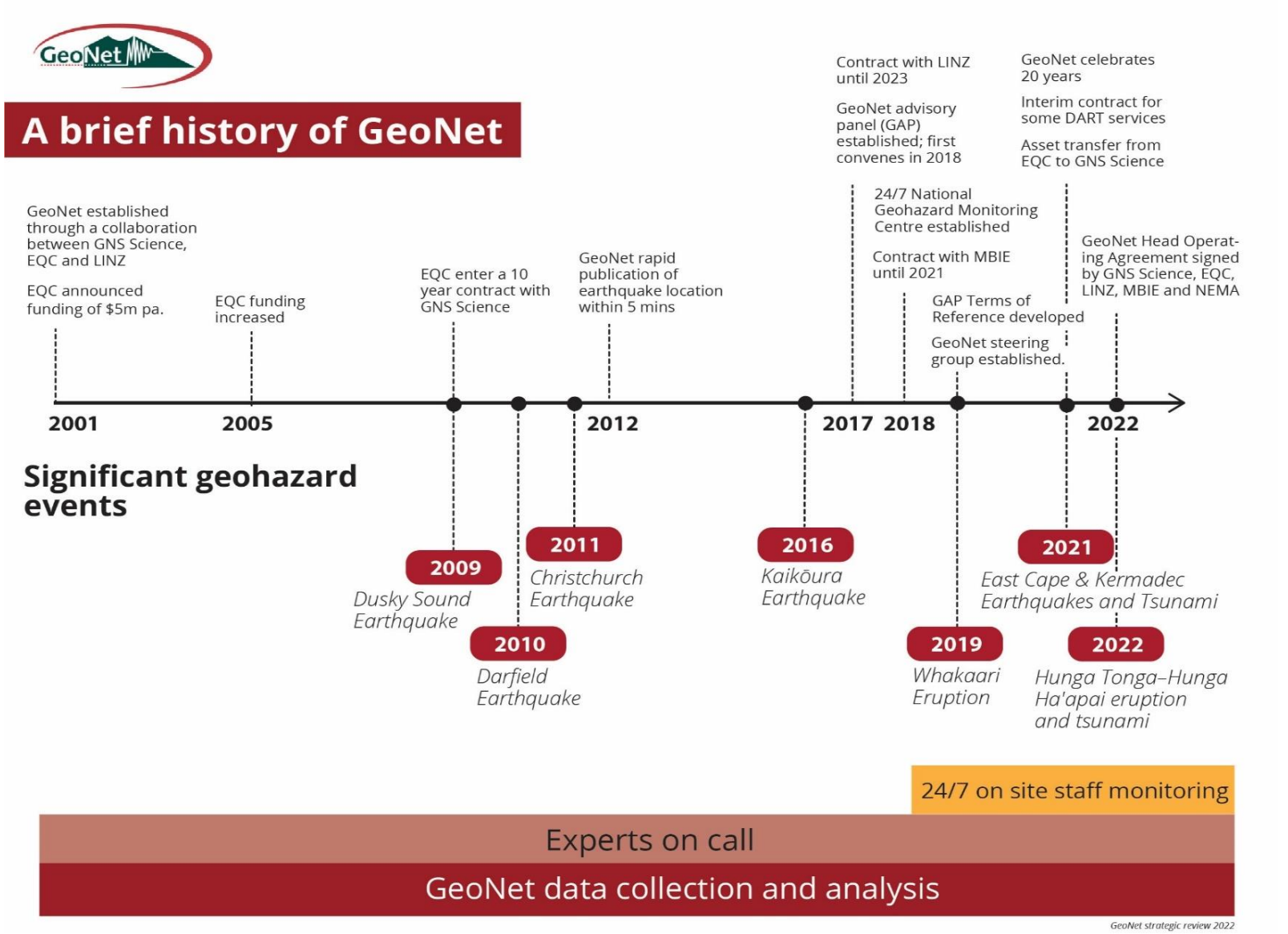


Figure 3 GeoNet's evolution and some of the events that have shaped it.

Findings of the Review: Strategic Imperatives

In addressing the purpose of the review, the Panel has landed on the following strategic imperative for GeoNet.

The future is an open, adaptive and automated GeoNet, built on a stable and sustained core system.

GeoNet has, in many respects, exceeded the original vision of its creators. The wealth of data that GeoNet captures, the range of products and advisory services it now delivers and the collective capability developed over the last 21 years means that New Zealand has accelerated geohazard science, better understands its geohazards and is better able to assess and manage the consequences of its extensive and disruptive geohazards.

As scientists and other users learn more about geohazards from the stream of GeoNet data, all parts of the geohazard science, emergency management and engineering communities learn from geohazard events, and, as technology advances, so the potential increases to innovate and be even better prepared than would otherwise be the case.

GeoNet has responded to events, supported geohazard science and innovated so that its products and services have changed and expanded, and it is relied on by a far greater breadth of users and uses than was originally conceived. New products and services rely on the core services, and these must be maintained to support the extended and derivative uses.

Staff at GeoNet say they can see how they could engage with more users and develop new products and services if there were no constraints. Panel members and presenters to the Panel have talked about enhancements to the core services, additional engagement and new products and services that they would like to see. So, the future of GeoNet is bright if funding arrangements can be secured to support its evolution.

The lack of fulsome engagement with the science and engineering community and users outside the funders (e.g. local government) has been identified as a shortcoming in GeoNet's current arrangements. This would in part be addressed by the establishment of a TAP. Our terms of reference ask how it would be best structured and engaged to ensure that GeoNet remains in tune with emerging research and response needs. We have proposed a purpose, membership composition and draft Terms of Reference that reflect this need and fill the direction in our Terms of Reference. Our recommendations rely on the establishment of the TAP and refer to work that could be sent to it based on our recommended Terms of Reference.

Otherwise, this review finds **five phenomena** that have changed since the last Strategic Review in 2013. These must be considered when we think about how GeoNet could evolve from this point:

1. **Establishment of the National Geohazards Monitoring Centre (NGMC)**

   The NGMC is a real-time geohazard monitoring service developed in response to the Kaikōura earthquakes in 2016. It was established to ensure that active monitoring for events is continuous, events are detected as soon as possible, relevant data is made available and experts are coordinated so that the course of the events and their aftermath can be managed as best as possible.

   The demands on the system, i.e. delivery of the core services, was dramatically changed by the addition in 2018 of the NGMC – Te Puna Mōrearea i te Rū – under the Ministry of Business, Innovation & Employment (MBIE)-funded Enhanced Geohazards Monitoring programme initiated in 2017. That service (as designed) was not able to be added onto the existing GeoNet system without incurring additional cost and putting additional burden on the delivery of core services. Further recent developments are the establishment of the offshore DART tsunami buoy

network[3] and the establishment of a NEMA 24/7 monitoring centre. The sustainable future of GeoNet and its continuing ability to deliver strategic value to national geohazard risk management requires careful balancing of demands across all of the areas that it services.

2. The ongoing cumulative impact of event responses

Every major geohazard event through the Canterbury earthquakes, Cook Strait earthquakes, Kaikōura, and many others, have drawn very heavily on GeoNet and GNS Science. The result has been agile scientific responses in the national interest, innovation, experience gained and accumulation of technical debt for GeoNet. 'Technical debt' refers to the backlog of maintenance and development that is created when limited resources are necessarily re-deployed to focus on events. In short, GeoNet is still catching up on the backlog of technical debt; the cost of managing technical debt must be recognised in funding a sustainable system, and it's harder to catch up if new events occur.

3. Increasing demand for new products and services

GeoNet's successful delivery through major geohazard events, plus improving technologies and the experience and capabilities gained by a wide range of users, has led to a huge pent-up demand for more (and faster delivery of) products and services. The strategic plan that follows this review and the allocation of future funding will have to address the ability for core services to continue to support all recommendations from this review that are taken up.

4. Private sensor networks and datasets

Third-party networks and data sources have experienced significant growth and will continue to develop at speed. There is a demand for this data and for it to be available and in an aggregated format. This proliferation of new players and datasets is leading to changing expectations on GeoNet and NEMA (e.g. through Google Earthquake Early Warning). This is addressed in the first of the five strategic themes.

5. Advances in Machine-Learning techniques

Advances in Artificial Intelligence (AI) and Machine-Learning (ML) techniques indicate an increasing role in geoscience for machine-based analyses and solutions to support provision of timely scientific advice. An increased focus in this area may provide partial solutions to the challenge for GeoNet to meet increasing expectations for faster products and services.

To remain relevant, GeoNet cannot lapse into some sort of steady state. It has marked out its place as a highly-trusted information source for geohazards in New Zealand. There will continue to be events, technology will continue to advance, users will continue to ask for more products and services, public expectations will continue to grow, and the core services will always have to be able to support all of this. GeoNet's role is to be the enabler for science to improve our understanding of New Zealand's geohazards, and our ability to learn about them advances to the extent that the ongoing funding arrangements allow it to do so.

The strategic imperative for this review is to recognise the demands that have been put on the system and understand the potential to evolve GeoNet from the point we are at now, the scope for new products and services that can develop through greater engagement with user communities and the implications of doing more on the sustainability of the core services.

3 The New Zealand Deep-Ocean Assessment and Reporting on Tsunami (DART) network is distributed across the southwestern Pacific Ocean to support detection and analysis of potential tsunami in the Pacific, with a specific focus on the Hikurangi, Kermadec, Tonga and Vanuatu (formerly New Hebrides) trenches.

Strategic Opportunities for the Future of GeoNet

From the strategic imperatives, the panel identified strategic opportunities, grouped under five main themes:

1. **A more open and adaptive GeoNet**
2. **A more automated GeoNet through data science innovations**
3. **Adding impact-based forecasting to event reporting**
4. **A more connected GeoNet through engagement and partnerships**
5. **The impact of the National Geohazard Monitoring Centre.**

Additionally, the Panel has offered commentary on a range of topics that have the potential to block future development and need to be addressed through collective action by GeoNet funders, users and supporters. The matters include:

- Funding decisions matched to agreed collective national needs.
- Hazard risk assessment workforce development. The Panel notes the challenge of the capacity of the workforce and attractiveness of retaining staff at GeoNet, including shift workers in the NGMC.
- Expectations continuing to exceed resourcing.
- The need for more clarity on roles and responsibilities across the New Zealand Hazard Risk Management system.
- Emerging risks (and opportunities) from global technology platforms (e.g. Google's Earthquake Early Warning (EEW) system poses some governance and reputational risks, as well as offering benefits. There is no other operational EEW in New Zealand currently).

Operational matters that arose through multiple submitters have been grouped separately and addressed where relevant to the Terms of Reference of the review, as well as the recommendations about the form and function of an external **Technical Advisory Panel.**

The Panel's findings are more about strategic direction for evolution than about specific future products and services. Choices over strategic direction reflect trends in the way that we might gather, make sense of and learn from data on geological hazards over time.

1. A more open and adaptive GeoNet

The Panel heard from several submitters that GeoNet is perceived by some to be relatively closed, both in the sense of its capacity to engage fully with all potential users and of the network itself and its operation. The Panel is of the opinion that a more open GeoNet would deliver greater benefits over time through greater capacity for innovation in geohazard monitoring; increased ability to adapt the network to changing requirements or evolving technologies, at least at the margins; and the building of support for GeoNet through a community of contributors and partners. The Panel notes that the GeoNet Programme has a wish to engage more widely but has been constrained by funding, and the challenge of raising expectations for new products and services or un-costed network changes. The issue of engagement and partnership is picked up separately under Strategic Theme 4.

The Panel recognises that a key element of GeoNet's success has been its free and open data policy[4], allowing any party, from local and international scientists studying geohazards to the international re-insurance community to access its data feeds. This has underpinned a range of scientific discoveries,

4 Refer to Principle 4 of the GeoNet Objectives and principles as shown in Appendix 2.

leveraged global collaborations and supported public and private sector understanding of New Zealand geohazards. The Panel endorses this principle and is of the view that the future for GeoNet is a more open database or possibly a system of tiered instrumentation, as well as open data, to deliver the benefits described above of greater capacity for adaptation and innovation.

The Panel sees this in terms of three related opportunities set out below. In each case, at issue is whether opening GeoNet to greater flexibility could be done without compromising delivery of core services, sustaining the free and open data approach and meeting its objectives and principles. They would also have to be introduced either without additional costs or with funding.

1. **The potential for integrating relevant data feeds from non-GeoNet sensors.** The Panel heard from several submitters about the opportunities for diversifying and supplementing existing GeoNet sensor-derived data through integrating relevant remote-sensing data or by taking feeds from third-party sensor networks, such as those used by engineers to understand variations in ground-shaking effects for individual buildings. There are risks that GeoNet's current 'closed' model may not be able to compete with the burgeoning low-cost, private networks and other 'big tech' players such as Google, or is missing opportunities to routinely access cost-effective, relevant remote-sensing data feeds (e.g. datasets from Canterbury Seismic Instruments Ltd (CSI)'s sentinel network; InSAR for ground deformation; and a range of different sensors for volcano monitoring, etc.).

   If this approach is advanced, it should not undermine GeoNet's current approach in which scientific data is for the benefit of all users, and the additional infrastructure and delivery costs (and quality assurance and security requirements) for such a service would have to be outweighed by the benefits (or funded separately by those deriving direct benefit). The Panel acknowledges that routine integration of InSAR data, for instance, would be expensive and a major undertaking, with potentially significant implications for the design of the network and its core services.

2. **The potential to utilise experimental, low-cost sensors on parts of the network.** This could provide a way to cost-effectively increase sensor density in areas of interest, and, with the right development environment on the system, allow third-party researchers to conduct research development of relevance to GeoNet (e.g. experimental volcano monitoring technologies). This approach could also include hosting third-party products that may add to a suite of tools for either research or geohazard response. An additional benefit of selectively utilising low-cost sensors could be the simpler integration of campaign monitoring by third parties into the network, which would reduce demands on GeoNet resources during major event responses or large science campaigns. As with the other ideas about 'opening up', this may create additional costs for safe and reliable operation of the core GeoNet systems, but such additional service of this kind would have both great potential for enabling innovation and as a partial solution to the science push for extending or 'densifying' the network.

3. **The potential to draw on more citizen science input.** This could build on the successful routine felt reports for earthquakes and campaign-based 'Dob in a landslide' and 'Dob in a tsunami' to include a wider range of geohazard observations. New Zealanders are familiar with the GeoNet brand and app, and there may be scope for other ways to deploy the app in support of this activity, with both science and engagement benefits. Pursuing this avenue could help GeoNet advance its role of helping New Zealanders live with their natural hazards but not at the expense of its overall purpose and delivery of core services.

   There are active research projects in New Zealand on best practise for integrating citizen science that could support development of an enhanced approach by GeoNet over time. Such data inputs could, over time, contribute to the development and refinement of impact forecasting for geohazard events.

Opening the GeoNet system in this way would obviously create a range of operational, security and privacy risks and could incur material additional core-system costs, at least in set-up. Consideration could be given to GeoNet operating with different tiers of service or more than one level of security or business-continuity robustness. Consideration would have to be given to how the critical components of the network and core could be protected, with more open layers or nodes for connection of third-party sensors or tools (e.g. for experimental volcano monitoring) or hosting software tools in a development environment. Unlocking the opportunities of these changes would require investment in robust, reliable and adaptive system architecture and processes.

The Panel supports more development and evolution but sees the process as adaptive rather than revolutionary. That is, adapting to advancing science, dealing with climate change[5] and advancing technology. There needs to be a balance between evolving GeoNet to fulfil its purpose better and being led by possibilities that could undermine GeoNet's stated objective, purpose and principles.

Recommendations

1.1 GNS Science should, in consultation with the TAP and other stakeholders, test whether the system architecture and processes are robust, reliable and adaptive enough to unlock synergies across these opportunities.

1.2 The GeoNet Programme should explore and develop options, with input from the TAP, for routinely integrating relevant remote-sensing data streams from sources other than the GeoNet sensing network to supplement current data collection methods across all geohazards.

1.3 The GeoNet Programme should explore the feasibility for 'tiered' access to the network that would enable connection to third-party networks or utilisation of third-party sensors, where these can add value to GeoNet's objectives and investment principles.

1.4 The GeoNet Programme, with the support of the TAP, should explore the feasibility of utilising a wider range of sensor types, including lower-cost technologies.

1.5 The GeoNet Programme, with the support of the TAP, should explore the feasibility of creation of a development environment to enable research of novel new monitoring technologies, in partnership with others.

1.6 The GeoNet Programme, with the support of the TAP and the GNS Science Social science team, should explore the feasibility to extend the range of 'citizen science' contributions to GeoNet impacts data collection.

2. A more automated GeoNet through data science innovations

Data Science brings together Computer Science, the study of computing, with the scientific approach and statistics. A big part of Data Science is AI (Artificial Intelligence), of which Deep Learning (DL) and Machine Learning (ML) (classification, recognising patterns, data generation) are subsets, as well as computational statistical methods and formal approaches to searching and optimisation problems. The emergence of Data Science as a strategic theme is partly a response to the increasing specialised application of computational methods to science problems. Data Science leverages off and needs big digital datasets that are available today. These need to be managed and processed efficiently. Therefore, Data Science relies on modern computational and data pipeline technology (High Performance Computing (HPC), Cloud, etc.) and is not only the development of algorithms.

5 The Panel was not invited to review the perils included or excluded from GeoNet's scope. The question of whether other perils should be included or the existing perils monitored will change as a result of climate change was not explicitly considered. While it is the case that climate change may lead to more landslips, the nature of geohazards is that events could take place in any of the four. Decisions around monitoring levels would include the influence of climate change.

Advances in DL/ML techniques lend themselves to an increasing role in geoscience for machine versus human analyses, the rapid understanding of geohazard events and, possibly, input into determining appropriate warnings to the public. GeoNet is in a good position to provide data for Data Science because of its data pipeline technology and architecture. GeoNet staff are always working on improving this, and DL/ML may well have a role in some of the products and services it currently provides. As noted previously, the future for GeoNet needs to reflect the opportunities and practices in the wider data-management and data-utilisation fields, as well as anticipating trends in hazard risk management. The Panel has identified the important potential for increased utilisation of software tools to enable greater automation of routine data-processing tasks and to more quickly adapt to new advisory and information products and services. Increased automation for GeoNet products and services has the potential to:

- Enable more efficient and timely delivery of data and information products and enable GeoNet to 'do the routine better' (for instance, moment-tensor solutions and an earthquake catalogue that does not require re-work to be used for hazard assessment modelling).
- Increase the efficiency of NGMC workflows and the role of Geohazard Analysts, Science Duty Officers, Seismology Intelligence Panel and Tsunami Experts Panel during critical, time-dependent phases of event responses (for example, for issuing tsunami threat and impact assessments).
- Support innovation (by GeoNet and partners) in a development environment of new data and advisory products, including exploring novel approaches to data visualisation.

Greater investment is likely warranted in development of software-based tools for use in monitoring and advisory functions of GeoNet (including, and perhaps especially, the NGMC, including Duty Officers). Investment in this area might require re-prioritisation of existing people resources.

More structured engagement with science contributors and researchers and a collective view of the development pipeline is essential to ensure a joined-up science to operations pathway. GeoNet needs to be resourced to identify and potentially (further) develop the most useful data-science approaches. Data-science approaches need to be implemented efficiently so that users will be ready and able to use new tools. Internationally, the science-to-operations pathway is an ever-present challenge and field of active development. We are not aware of any one organisation that has been able to demonstrate an accepted best-practise approach to solving this problem. In that, GNS Science and GeoNet could be world-leading by demonstrating this approach.

Development of a structured science-to-operations process leading to a development pipeline will need time and resources and would ideally leverage off existing resources in GeoNet, GNS Science and elsewhere (see the shaking layer example below). The GeoNet/RCET collaboration to develop and deliver shaking layer products is an example of a successful science-to-operations collaboration between GeoNet and a science programme. Perhaps it is a model for future collaborations.

Shaking Layers Project – a model for successful collaboration?

The Shaking Layers Project (January 2021 – June 2023) is a multi-disciplinary project funded by GeoNet and the RCET Endeavour Programme, providing near-real-time ground-shaking maps to end-users within a few minutes from an earthquake of magnitude 4 or above in New Zealand. The model combines observed ground motions from strong-motion stations with ground-motion models to produce spatial estimates of ground shaking for each intensity metric type.

The Shaking Layers tool constitutes a great step beyond available maps on the GeoNet website, as it provides shaking information covering the entire country and not only at observed locations. These maps have been of high demand by engineers, emergency respondents and councils in the last 10 years, as it provides them with invaluable information to prioritise interventions.

The project was developed in a way where efforts could be combined between GeoNet developers and GNS Science scientists, creating a unique bridge of collaboration between the two groups. Moreover, to ensure that the tool was also scientifically robust and fit-for-purpose, the Shaking Layers Project was developed together with a Science Advisory Panel and End-User Advisory Panel, with members including representatives from NEMA, Toka Tū Ake EQC, CDEM, KiwiRail, Fire and Emergency New Zealand and city councils, amongst others. The project is innovative, as it involved these end users' and external scientists' perspectives and feedback from the very start. This is the first time that a project has been designed this way at GNS Science. Technical end users were invited to be part of a monthly panel, the public was surveyed (over 1600 respondents) and user personas developed. The feedback provided was fed directly into the design process.

ICT disciplines continue to advance and specialise at pace. There is now a large knowledge gap between university-qualified ICT staff and traditional science staff who write code, which was not present 20 years ago. This gap is a risk for science-to-operations initiatives and makes the necessary onboarding of science experts into GeoNet delivery hard. A new model for GeoNet of shared collaboration/responsibility is needed. The Data Science discipline and the data scientists that are born out of it present an opportunity to help bridge this gap.

Recommendations:

2.1 GeoNet, in consultation with the TAP, should review the science-to-operations pathway and determine if the process could be better articulated and implementation more effective.

2.2 The GeoNet Programme should work with the TAP to identify areas for priority development of automated, software-based tools for use in monitoring and advisory functions of GeoNet, especially the NGMC services, including Duty Officers' functions.

2.3 The GeoNet Programme should work with the TAP to develop a collective view of the development 'pipeline' to ensure a joined-up research-to-science-operations pathway.

2.4 GNS Science, with the support of the TAP, should engage with relevant university and technology partners to address the gap in skills and capabilities required to support geohazard monitoring system operation and development, including in AI/ML (see later on workforce constraints).

3. Adding impact-based forecasting to event reporting

The Panel heard from a number of submitters about global trends in adding impact-based advisory products and forecasting to reporting of geohazard event reporting. This demand reflects both emerging science capabilities to better model impacts and the enhanced value of such products to inform more timely and effective disaster responses by individuals, communities and organisations. The potential to deliver impact-based information has already been acknowledged by GeoNet and others, and the Panel was impressed by the depth and scope of work underway to establish future impact-based (and other advisory) products in the next few years. The Panel endorses these developments and supports this as an area of continued focus for GeoNet.

There is a strong desire from the emergency management community for near-real-time information products that:

- Provide detailed hazard impact information (likely extent and types of physical damage; and likely disruption to people, communities and infrastructure) for hazard events.
- Provide forecasts of likely evolving impacts, e.g. operational aftershock forecasts as routine, and updated to integrate deformation changes (e.g. slow slip and post-earthquake deformation). For volcanic events, this might include impact forecasts that build on the routine ashfall modelling that provide sector-based forecasts of disruption (e.g. to transport networks, wastewater systems, agriculture, human health, etc.).

Development of these types of products requires processing beyond description of the magnitude and intensity of an event, so requires a shift in what GeoNet currently provides routinely (see the shaking layer example). These developments align strongly with the opportunities (in Strategic Theme 2) to increase automation and enhance data utilisation, which have potential to change and substantially streamline monitoring advice provided by the NGMC across all hazard types. While heavily orientated around the role of GeoNet in supporting emergency responses, the development of routine impact-based products is also potentially useful for research purposes.

Evolution along these lines must not undermine GeoNet's fundamental purpose and organisation. Strategically, if the addition of impact-based forecasting for emergency response can be accommodated alongside delivering core services for all users, this would be a welcome development. In the crisis-response domain, care would need to be taken to avoid affecting GeoNet's reputation as a trusted voice. Development of new impact-forecasting products will need careful management to avoid new dependencies and risk of failure at an inopportune time.

Recommendations:

3.1 GNS Science, with the support of stakeholders and a subset of users, should develop a prioritised plan for development of impact-based forecast products in the near- and longer-term to complement event reporting. The plan should clarify the development pathway from research to GeoNet operations, including how any new products are prioritised and the associated data governance.

3.2 NEMA should work with GNS Science, with the support of the GAP, to develop a training plan for responding agencies to interpret and utilise these new products.

4. A more connected GeoNet through engagement and partnership

The Panel heard a strong appetite for more connection to GeoNet from a range of users, reflecting the challenge for GeoNet as its successes drive increasing demand. Stronger connection with, and better understanding of, key users would ensure that the architecture of GeoNet better serves the needs of its user community. Having built its core capability and expanded the focal point of product and service delivery, existing users and new users can see new and extended possibilities, driving a strong push for more and wider engagement by the GeoNet Programme.

A clear plan/strategy is needed for deeper and sustained connections to strengthen relationships and linkages that enable GeoNet to better understand and serve the needs of stakeholders and partners. Areas of focus for engagement include:

- **Meaningful partnerships with iwi and hapū Māori**
  - GeoNet (enabled by GNS Science) should clarify its partnerships with iwi and hapū and confirm its Te Tiriti context.
  - Explore data and knowledge exchange with iwi/hapū as monitoring partners.
  - View matters of data sovereignty through a Te Ao Māori lens.
- **Deeper partnerships with science and engineering communities for:**
  - Establishing data-specification needs to inform network design, expansion and product and service requirements.
  - Potentially developing a 'test bed' development environment, enabling collaboration on tool and product development and supporting campaign monitoring (as noted in Rec. 1.5).
  - Actively mobilising research by others of benefit to GeoNet's operations.

- Formalising an approach for third-party input into technique and tool development and network design, for both science and event-response needs.

- **Engagement with the Emergency Management sector**
  - Develop a clear, integrated view of national and regional needs and service expectations.
  - Ensure that product and service needs are aligned with funding arrangements.
- **Engagement with the growing user community**
  - Greater engagement is required with specific users of data, information and advice products and services, e.g. risk and loss model developers, National Seismic Hazard Model, RiskScape, the engineering and critical infrastructure sectors, to ensure that strategic data needs for hazard risk management inform GeoNet's network design and product and service specifications.
- **Engagement with Education and Training providers**
  - Support the continued development of an appropriately trained workforce to support GeoNet's operation (see reference to workforce development in the Systems Barriers section).

More transparency with stakeholders and users in investment decisions is needed. The review has revealed a wide range of expectations and a lack of understanding of how GeoNet makes investment and prioritisation decisions (and the constraints it is under, which dictate most choices). Engagement with the categories of stakeholders and users would be improved with better understanding of how GeoNet makes investment decisions and what it is doing. In part, this might be addressed by engagement within the TAP (or similar) and establishing a set of investment principles (as agreed by the funders and GNS Science and discussed in the section Principles for Investment) that can be publicly shared.

The opportunity to pursue these developments will be dependent on funding and priorities set by the GAP members and could be informed by a TAP.

Stakeholder input to network design and enhancement

In addition to the main strategic themes, there were several drivers identified related to potential network design to support enhanced monitoring or a wider range of future products and services, including:

- **Offshore network expansion** as a logical step for the national system. However, this would require considerable investment, utilisation of new technologies and close partnering with other technology-provider partners (e.g. fibre-optic companies). The Panel recommends that consideration be given to the scope for this expansion as part of future funding business cases.
- **More sensor and data streams for tsunami** to improve the value for tsunami geoscience and support more effective science response. While recent advances such as DART have been a significant step up, there is a range of other data sources that could be considered, including infrasound, offshore fibreoptic cables and remote sensing.
- **A wider range of routine sensor types for volcano monitoring** (e.g. near-real-time geochemistry, integration of INSAR and other remote-sensing data to supplement ground-based sensors (as previously noted).
- **Expand the use of boreholes** to improve data quality in sites of high science value.
- **Increase the density of GNSS sites**, especially close to major faults in the South Island.
- Accelerate planning **considerations for capturing the next Alpine Fault event**.

In September 2022, the future network design of GeoNet was the subject of a researcher-led workshop. The outputs of this work will likely inform the development of the GeoNet 10-year strategic plan.

Recommendations:

4.1 GeoNet should seek to maximise the value of GeoNet through a comprehensive structured stakeholder engagement programme.

4.2 GNS Science should establish a Te Tiriti o Waitangi context for GeoNet and its partnership approach with Iwi Māori.

4.3 GNS Science, with the support of the GAP members, should develop a clear plan for deeper and sustained connection across the system to strengthen relationships and linkages (identified above) that enable GeoNet to better serve the needs of stakeholders and partners and continue its strong record of enabling science opportunities.

4.4 The GAP members should be urged to lead engagement across government to ensure wider understanding of the strategic value of GeoNet data in development and maintenance of tools for national hazard risk assessment and management (such as the National Seismic Hazard Model).

4.5 GNS Science should work with the GAP to develop a collective view of priority needs for products and services to inform the GeoNet strategic plan.

4.6 GNS Science should work with the GAP to develop and agree upon a set of investment principles for GeoNet (see proposed set of principles in this document) as part of the next GeoNet strategic plan.

4.7 NEMA, MBIE, EQC, LINZ and GNS Science should work collaboratively to ensure that the 2023 budget bid for GeoNet funding reflects cost to sustainably deliver priority near-term new products and services and the development required to build adaptive capacity and automation.

4.8 The TAP agenda should include consideration and prioritisation of the potential network design drivers identified in this section.

5. The impact of the National Geohazards Monitoring Centre

The NGMC is a high-profile service provided by GeoNet, added to its existing platform in 2018, delivering specific 24/7 products and services for NEMA. While the specific function of the NGMC was not an explicit focus of the review, users' expectations about science-advice products and services and the way that the core GeoNet system enables it were traversed in the review. The review heard a strong call for a wider set of needs/demands (speed, product types) from the national and regional emergency managers that would be delivered through the NGMC capability by the GeoNet Programme and wider GNS Science technology and science capability, with an emphasis on faster response, impact-based forecasts and direct communication of advice and alerts to the public. Key points that the Panel heard include:

- Standing up NGMC has had cost and system impacts on the core GeoNet system. GeoNet may have work to do to strengthen the core system to accommodate a wider set of future needs/demands, especially for very high-reliability, time-critical emergency response.
- NEMA establishing its own 24/7 Monitoring, Alerting and Reporting (MAR) Centre (established during the period of this review) clearly calls for re-examination of the role and operation of the NGMC. It is important that the roles of the two 24/7 operations minimise duplication, avoid creating gaps in information and maximise the value of the combined investment.
- There is an outstanding question (beyond the scope of this review) of whether GeoNet (on behalf of GNS Science) stays strictly a geohazard science advice function or whether there is logic for it to become the issuer of formal (and time-critical) public geohazard warnings.

- Independent of this question, there is an opportunity to explore how best to support improved integration within the assessment/warning chain ahead of any change in assignment of responsibility for issuing hazard warnings (given that any legislative change likely to be many years off).

Recommendations:

5.1 NEMA, with the support of the GAP members, should work with GNS Science to review roles and functions between the current NGMC and NEMA's MAR to maximise the efficiency of information flows and value of the combined investment to deliver system benefits.

6. Operational Matters

While programme operations performance was outside the scope of the review, several science submitters referred to the need to:

- Improve metadata accuracy for all sensor locations.
- Improve the quality and consistency of the earthquake catalogue (and some other products, e.g. moment tensor solutions) to reduce the need to undertake re-work by researchers and other technical users. Note that submitters commended GeoNet for the work they have done on data access/Application Programming Interfaces (API's) and high-quality guidance for use of the various search and data download tools.

Recommendation:

6.1 These operational matters should be addressed as part of the agenda for the TAP.

7. System Barriers

While wider governance, management or system issues were not a focus of this review, the issue of obstacles and barriers regularly came up in Panel discussions. Many of those obstacles and barriers are beyond GeoNet's control. The GAP represents key funders and NEMA, while the GNS Science Board is ultimately accountable for GeoNet's performance. The GAP member agencies all have statutory obligations and have agreed GeoNet's objectives and principles (as set out in Appendix 2). There are several matters that could free GeoNet up if they were resolved.

- Clarity on roles and responsibilities for GeoNet (including NGMC specialist functions), GNS Science, various science advisory groups and NEMA in relation to advances in event forecasting (mainly seismic) and warning and advice across all the perils.
- Funding and governance to be better aligned to collective national public benefits of the system.
- A collective approach to workforce development.
  - There were two main aspects to this: (1) lack of formal training programmes and no clear career-development pathways for specialist roles such as the Geohazard Analysts in the NGMC; and (2) challenges of recruitment and retention of specialist technical skills across a range of areas, including geohazard science, data science and Information and Communications Technology (ICT) to enable GeoNet to continue to deliver and innovate.
  - An allied aspect to this is that, as new advisory products or tools are developed (e.g. impact-based forecasts), additional training by users will be needed to ensure their successful utilisation (see Rec. 3.2).

Recommendations:

7.1 NEMA, with the support of the GAP, should work with GNS Science and others to clarify roles and functions between them in relation to event forecasting and warning and advice.

7.2 Consideration should be given, by the GAP members, to establishing an 'inter-departmental executive board' that would support greater coordination and alignment of effort and resources across the range of portfolio areas relevant to national hazard risk management.

7.3 The GAP should clearly articulate the national strategic capability requirements for GeoNet.

7.4 GNS Science and the GAP should work collectively to ensure that sustainable funding for GeoNet matches the costs of delivering the identified capability.

7.5 GNS Science should work with NEMA, MetService and university partners to develop training programmes that ensure the rights skills and capabilities are available to enable GeoNet to meet its objectives.

Technical Advisory Panel (TAP)

As per the scope of the review, the Panel has considered how a GeoNet TAP would be best structured and engaged to ensure that GeoNet remains in tune with emerging research and response needs. It proposes the following:

- Purpose
- Membership and composition
- Draft Terms of Reference.

Purpose

- To provide scientific, technical and user advice [to the GAP and the GeoNet Steering Group] to ensure that the GeoNet investment and products and services are informed by trends in science, technology and monitoring uses to serve the needs of the GeoNet user communities to the extent practicable within funding constraints
- Provide input to the development pathway and prioritisation process for new products, with the aim of supporting efficient science-to-operations feedback loops

Membership

- Up to nine members
- Mix of science, technology, emergency management user representatives
- Independent Chair
- Meet six-monthly (or more regularly, as required)
- Report to the GAP.

DRAFT Terms of Reference

1. Overall Purpose

1.1 The GeoNet Technical Advisory Panel (TAP) supports the GeoNet Advisory Panel (GAP) in meeting its primary objective of maximising the long-term contribution of GeoNet to New Zealand, with a focus on resilience to geohazards and realising the full potential of geospatial technologies.

1.2 The primary purpose of the TAP is to provide scientific, technical and user advice to the GAP and the GeoNet Steering Group to ensure the GeoNet investment and the products and services are informed by trends in science, technology, and monitoring uses to serve the needs of the various GeoNet user communities to the extent practicable within funding constraints.

1.3 The TAP will provide input to the development pathway and prioritisation process for new products with the aim of supporting efficient feedback loops that support science-to-operations feedback loops.

1.4 Depending on its areas of focus, the TAP may choose to establish working groups to address particular issues.

2. Authority

2.1 The TAP will perform activities and provide advice to the GAP and the GeoNet Steering Group within the scope of this Terms of Reference.

3. Membership

3.1 The Panel will comprise nine members appointed as follows (the 'Members'):

3.2 Science representatives.

3.3 Technology representatives.

3.4 Emergency management user representatives.

3.5 A quorum of any meeting will be two thirds of the Members.

3.6 The Chair will seek to gain a consensus; however, if necessary, each Member will have one vote, and any business of the Panel requiring a decision will be made by a simple majority vote of the members. The Chair will not have a casting vote.

3.7 Members may request approval from the Chair for representatives of their organisations, in addition to themselves, to attend meetings to discuss specific matters. Those additional representatives will have no right to vote on any decision by the Panel.

3.8 Members may also send proxies to meetings with the prior approval of the Chair. Proxies will have voting rights.

4. Technical Advisory Panel Working Groups

4.1 The TAP may appoint working groups to progress issues and advise the TAP. For example, a Working Group may be established to provide a user perspective on improvements to the earthquake location system.

4.2 The TAP will determine the membership, scope and deliverables of any working groups in consultation with the GeoNet Programme.

5. Meetings

5.1 Meetings will be held two times a year, organised around GeoNet's annual cycle of strategy, planning, budgeting and reporting.

5.2 The Chair of the Panel will convene additional meetings on receipt of a request by the GeoNet Programme or by a member of the Panel.

5.3 The Chair, on behalf of the Panel, will report to the GAP and the GeoNet Steering Group with recommendations in relation to matters that require approval from the Board, and to keep the Board informed of the work of the Advisory Panel including the provision of draft and approved minutes of meetings.

6. Conflicts of Interest

6.1 Panel Members (apart from the independent Members) recognise an ongoing conflict of interest in ensuring that their own organisation's GeoNet-related needs are met and that they achieve value for money from their funding contributions, while working together on the Panel to maximise the long-term contribution of GeoNet to New Zealand.

6.2 Members (including the independent members) will raise any additional specific conflicts of interest with the Chair and agree a mechanism for dealing with them at the commencement of a Panel meeting.

7. Review

7.1 These Terms of Reference will be reviewed annually, and any changes will be recommended to the GAP for approval.

7.2 The Panel will confirm annually that they have carried out the responsibilities outlined in this Terms of Reference.

8. Approval

Members of the GeoNet Advisory Panel have accepted these Terms of Reference and are committed to working as a collective to deliver the intent outlined in this document.

Principles for Investment

The Panel deliberations have re-affirmed the challenges for GeoNet in delivering to ever-expanding and often unfunded expectations and the need to balance strategic choices across the range of competing interests among its funders and other users. As noted in discussion of the strategic themes, a collective approach to objective setting would greatly assist GeoNet to achieve funding appropriate for sustainable development.

The Panel propose a set of principles for guiding prioritisation of investment in new products and services or other enhancements of the core system. These are:

- Investments shall always contribute tangibly to consistency of acceptable performance, and enhancements must not compromise the core system.
  - The costs of maintaining and upgrading the core services need to be accounted for in development of new products and services.
  - New products and services should cost-effectively increase adaptability of the system to minimise accumulation of technical debt.
- Collective approach and transparency in priority-setting across the range of purposes.
  - New products and services should seek to achieve balanced outcomes for science knowledge, risk assessment and emergency management response.
  - Strategy for change and enhancements should be informed by all sciences (physical and social, data) and new technologies and regulatory needs.
- GeoNet investments should seek to leverage other investments to maximise the national geohazard monitoring and data capabilities.

Abbreviations

AI – artificial intelligence

API - Application Programming Interfaces

CDEM – Civil Defence and Emergency Management

CSI - Canterbury Seismic Instruments Ltd

DART – Deep-Ocean Assessment and Reporting on Tsunami network

DL – deep learning

EEW – earthquake early warning

EQC – Earthquake Commission: Toka Tū Ake, the foundation from which we stand strong, together

Geohazards – geological hazards

GAP – GeoNet Advisory Panel

GNSS – Global navigation satellite systems

HPC - High Performance Computing

InSAR – Interferometric synthetic aperture radar

ICT – Information and Communications Technology

LINZ – Land Information New Zealand

MAR – Monitoring, Alerting and Reporting Centre

MBIE – Ministry of Business, Innovation & Employment

ML – machine learning

NEMA – National Emergency Management Agency

NGMC – National Geohazard Monitoring Centre

RCET – Rapid Characterisation of Earthquakes and Tsunamis Endeavour Programme

TAP – Technical Advisory Panel

Appendix 1 – Review Panel Membership and Terms of Reference

The panel members are:

- Richard Smith, Resilience Science Challenge – Kia manawaroa – Ngā Ākina o Te Ao Tūroa, Chair
- Sean Audain, Wellington City Council – Me Heke Ki Poneke
- Thomas Wilson, University of Canterbury
- Jonathan Procter, Massey University
- Andrea Gluyas, Toka Tū Ake – EQC
- Cara Gordon, Emergency Management Bay of Plenty
- Emma Hudson-Doyle, Massey University
- Graham Leonard, GNS Science
- John Townend, Victoria University Wellington – Te Herenga Waka
- Roger Fairclough, NZ Lifelines Council

Terms of Reference for the GeoNet Strategic Review

1. Overall purpose

The purpose of this Strategic Review is to advise the GNS Science Board and GeoNet Advisory Panel on:

- The future direction of the development of GeoNet's products and services to ensure that it is future-focused, structured to deliver maximum impact for New Zealand and aligned to modern science approaches (including big data).
- The strategic direction of the GeoNet 10-Year Strategic Plan to ensure that it is future-focused and grounded in user and funder needs and scientific insights.

2. The Strategic Review will consider

In service of national and international geohazards research and national geohazards response:

- What are the possible future products and services that the GeoNet sensing network will be required to support?
- How might the way we gather, make sense of and learn from data on geological hazards change over time?
- How would a GeoNet Technical Advisory Panel be best structured and engaged to ensure that GeoNet remains in tune with emerging research and response needs?

3. Outputs/deliverables

The Review is intended to be user- and science-focused and will deliver a Report to the GeoNet Advisory Panel in September/October 2022.

4. Review to draw on existing resources, including strategic insights and operating shifts from Strategic Review, Part 1

The review panel will be informed by reviews undertaken in recent times, including the Building Instrumentation Review.

5. Out of Scope

- GeoNet contracting, governance and funding sources.
- GNS Science geohazard event response strategy and Incident Management System.
- GeoNet Programme Operating Model. This will be in scope for the GeoNet Tactical Review proposed for FY 22/23.
- Expansion of GeoNet's monitoring scope, i.e. review focus will be limited to monitoring geological hazards.

6. Review Panel commentary

The Review Panel may choose to provide commentary on strategic issues outside of the scope of the Review.

Attributes of Review Panel Members

All Review Panel Members are to demonstrate the ability to bring an open (but informed) mindset, curiosity, relevant expertise and a willingness to work in a constructive and collegial manner with other Panel members and stakeholders.

The combined Panel membership includes local and international expertise in:

- Natural hazards science
- Monitoring
- Social science – including communications and education outreach
- Geodesy
- Supporting infrastructure
- Big data – relationship to science and monitoring environments
- Emergency Response
- Mātauranga Māori.

The Review Panel Chair contributes:

- The ability to chair meetings
- An understanding of the GeoNet operating environment
- The ability to influence others without dominating.

Appendix 2 – GeoNet Objectives and Principles (Schedule to GeoNet Head Operating Agreement)

Overarching GeoNet Objective:

A shared commitment by the Participants[6] to maximise the long-term contribution of GeoNet to New Zealand's wellbeing.

GeoNet Vision:

To make New Zealand a safer place to live.

GeoNet Purpose:

Summarised by four strategic outcomes:

- **GeoNet is a trusted cornerstone of the four 'R's,** providing data and information for risk reduction, event readiness, response and recovery for all geological perils.
- **GeoNet helps New Zealanders live with their natural hazards** by providing information in usable forms and extending the two-way conversation on New Zealand's hazards landscape.
- **GeoNet connects our data to those who create new knowledge** by collecting, analysing, archiving and distributing hazards data for research and helping the community make best use of the data available.
- **GeoNet contributes to a resilient and modern economy** by providing datasets that inform decision makers, are building blocks for hazard and risk models and integrate and enrich other data platforms (e.g. geospatial infrastructure).

Part B: Principles

The Participants acknowledge that, in order to achieve the Objectives, GeoNet will be implemented and operated, and the Participants will exercise their rights, and perform their obligations, under the GeoNet Agreements consistent with the following principles:

1. GeoNet provides a public good and acts on behalf of, and for the benefit of, all New Zealanders, and the Participants share a common interest in the operation of GeoNet and certain Core Services. This is the key interpretive principle to guide the other Principles.
2. GNS Science is motivated to provide the Services, is incentivised to retain appropriate human capital, and all of the Participants share the same beneficial owner. This Agreement provides the framework for the Participants to work together and resolve differences should they arise.
3. All of the Participants will endeavour to ensure that GeoNet is sustained and enduring by continuing to deliver its core capabilities in accordance with internationally validated performance measures and by remaining abreast of evolving technologies through continuous innovation and improvement.
4. GeoNet is intended to provide easily accessible, 'free-to-air' open data in an appropriate and reasonable manner, i.e. in a manner that aligns with the Government ICT Strategy 2015 and associated open-data goals for New Zealand government agencies.

6 'Participants' in this context refers to contractual counterparties.

5. Transparency and awareness of the resource allocation, progress and constraints on resource use and the use of GeoNet is necessary for GeoNet and the Services to operate as effectively as possible.
6. The Participants must adopt an adaptable and innovative approach to: (a) the provision and use of the Services; and (b) the development, implementation, operation and iteration of the Strategic Plan, Business Plan and Integrated Annual Work Plans to ensure that GeoNet, GNS Science and the Other Participants can maintain critical infrastructure for the purposes for which it is applied, e.g. to respond appropriately to Hazard Events.
7. The Participants, and their use of the Services, must recognise and allow for GNS Science's responsibilities under the National CDEM Plan to manage the GeoNet platform for the detection of specified natural hazards, assessment of related threats (especially tsunami), provisions of scientific advice in relation to those natural hazards and contribution to public information on geological hazards and associated emergencies.
8. Communication and reporting between the Participants is to be early, open, inclusive and non-adversarial, including in relation to variations and resource diversion in response to Hazard Events. The Participants recognise that a good faith and 'no surprises' approach are key to ensuring the success of the arrangements under this Agreement.
9. GeoNet systems and staff are closely integrated with relevant research activities in GNS Science and other New Zealand research organisations.

Appendix 3 – Descriptions of GeoNet Current Products and Services

Core services required to support all products and services

Sensor Network, i.e. data acquisition

Data Acquisition is the infrastructure for continuous measurement of geophysical phenomena and the acquisition of this data for geohazards research, monitoring (e.g. deformation) and response. This service is an amalgamation of many Sensor Networks dispersed across the country, often in remote locations, as well as manual acquisition of data.

Each Sensor Network is assigned a Tier – 1 (high, most critical), 2 or 3 (low, less critical) with regards to their impact on, and contribution to, GeoNet's overall Data Acquisition capability. Tiers are used for design and engineering, asset management planning, maintenance approaches (including response times to outages) and service levels.

Data transportation

The GeoNet Data Transportation Core Service comprises the physical and virtual infrastructure and IT services required to move data between the Sensor Networks and data centres that enable data collection, processing and storage.

Transportation infrastructure is assigned a Tier based on the Sensor Network to which it belongs; Tier 1 (high, most critical), 2 or 3 (low, less critical) with regards to the network's impact on, and contribution to, GeoNet's overall data collection capability. Tiers are used for design and engineering, asset management planning, maintenance approaches (including response times to outages) and service levels.

GeoNet backbone data, i.e. data collection, processing and storage

The technology platform and associated services that aggregate and control GeoNet data upon collection at the data centres, then processes the data into usable forms. Data is then stored (including archival) for access via GeoNet products and supporting services.

Product Suites define five distinct ways that GeoNet data is organised

GeoNet Rapid

GeoNet Rapid distributes trusted near-real-time information for geological hazards in Aotearoa New Zealand.

During widely experienced geological hazard events (earthquake, landslide, tsunami and volcano), there is intense demand for information from GeoNet Rapid. Distribution of products, including advice, in GeoNet Rapid must be highly scalable and, due to the very rapid rise in demand, always 'on'.

This Product suite includes advice products that primarily support government (NEMA) decision-making.

GeoNet Data

The GeoNet Data Product Suite comprises high-quality geophysical and geochemical data, which can be used to create new knowledge and value. The GeoNet Data Product Suite describes data by class (seismic, GNSS, landslide, tsunami, volcano), which include raw and/or basic data, derived data, written observations and data that are required for interpretation of the data.

The goal is to ensure that all datasets are well-curated and abide by the Findable, Accessible, Inter-operable, and Re-usable (FAIR) data principles. This Product Suite differs from GeoNet Rapid in that the data may be distributed more slowly, but it is more complete and of higher quality. The datasets in this Product Suite are those which are archived.

Data are distributed in several ways using community-standard web services, bespoke web services (where no appropriate community standard exists) and other internet protocol-based approaches.

GeoNet Data International

GeoNet Data International is part of Aotearoa New Zealand's contribution to the global geophysical and geological research and monitoring communities.

Products in this Product Suite are ones that are provided to fulfil international obligations or to support international agencies in development of high-quality global geophysical datasets and hazard monitoring activities (e.g. the global terrestrial reference frame and nuclear test monitoring communities).

Use of Aotearoa New Zealand data in an international setting helps to maximise the benefit of GeoNet data to Aotearoa New Zealand and the global community.

GeoNet Data Casting

GeoNet Data Casting enables data to be streamed in real time to many dispersed end-users simultaneously. This data can be used for monitoring, real-time data processing, real-time positioning applications and visualisation by those national and international organisations and agencies who receive it. This supports a range of functions, from precision in global positioning to research, monitoring and response to geohazards.

GeoNet Eruption Detection Systems

Monitoring to detect an explosive volcanic eruption on selected Aotearoa New Zealand volcanoes and notification to customers. Only available on Tongariro and Ruapehu volcanoes.

Supporting Services describe how GeoNet data is put to use

Data Access Services

This Service suite encompasses all public-access mechanisms for GeoNet data (i.e. data products encompassed within the Product Suites).

Services within this suite tend to be systems that make data and metadata available for public use and are referenced in the Product Suites where appropriate.

Information Dissemination

This service suite encompasses services whose systems support the provision of timely, reliable and efficient information to the public. Information can be templated or bespoke (e.g. *ad hoc* from experts) and distribution tends to be web-based. Services are referenced in the Product Suites where appropriate.

Expert Monitoring Tailored Advice and Support

This Service consists of groups of individuals that support readiness for, response to and recovery from event response on behalf of GNS Science through ongoing expert monitoring practices and on-call and on-request specialist advice, expertise and support.

Groups within this service cover a range of scientific expertise for earthquake, landslide, tsunami, volcano, communications and public information and GeoNet systems and services.

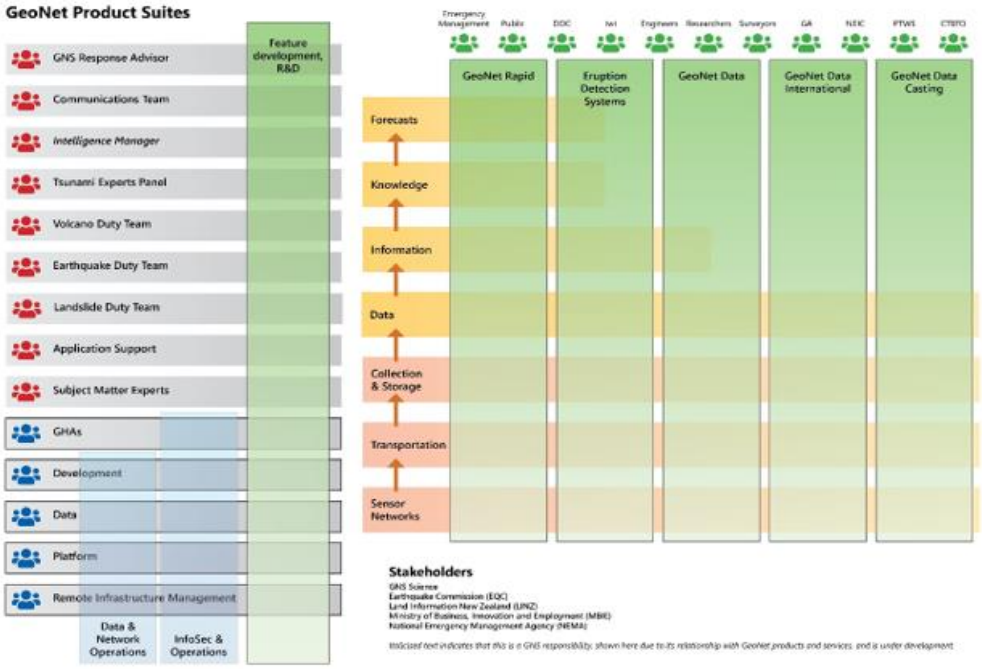
The groups in this service serve as the escalation points for the NGMC and, together with the NGMC, form the nucleus of any science response from GNS Science. As such, they primarily serve the NGMC, NEMA and GNS Science but will support additional communication outside of the organisation to the public, media and key stakeholders (as required).

National Geohazards Monitoring Centre

The NGMC monitors for data and information on earthquake, landslide, tsunami and volcano events 24/7/365. The NGMC distributes rapid information and advice in response to these geohazards events. This information is produced as part of the GeoNet Rapid Product Suite.

Communications, Education and Outreach

This service provides geohazards information, educational materials and engages with the public to improve their understanding of Aotearoa New Zealand's geological hazards.


GeoNet Product Suites
GNS Response Advisor
Communications Team
Intelligence Manager
Tsunami Experts Panel
Volcano Duty Team
Earthquake Duty Team
Landslide Duty Team
Application Support
Subject Matter Experts
GHAs
Development
Data
Platform
Remote Infrastructure Management
Data & Network Operations
InfoSec & Operations
Feature development, R&D
GeoNet Rapid
Eruption Detection Systems
GeoNet Data
GeoNet Data International
GeoNet Data Casting
Forecasts
Knowledge
Information
Data
Collection & Storage
Transportation
Sensor Networks
Stakeholders
GNS Science
Earthquake Commission (EQC)
Land Information New Zealand (LINZ)
Ministry of Business, Innovation and Employment (MBIE)
National Emergency Management Agency (NEMA)
Italicised text indicates that this is a GNS responsibility, shown here due to its relationship with GeoNet products and services, and is under development

Appendix 4 – GeoNet Governance Arrangements

The GeoNet Advisory Group (GAP) was established in 2017 in anticipation of a new multi-lateral contract arrangement designed to bring transparency and alignment across the funders and contracting parties. The GeoNet Head Operating Agreement was finally executed by the parties this year and took effect on 1 July 2022. The GeoNet Head Operating Agreement provides that the GAP and the Steering Group will be augmented by the addition of the TAP.

The GAP is not a decision-making body *per se*. It makes recommendations to the GNS Science Board and provides assurance around stakeholder support and/or concerns around the work of GeoNet. The GAP is supported by a GeoNet Steering Group with the same representation. The Steering Group takes a more detailed and technical view of GeoNet issues, including review of planning documents and quarterly reporting against business plans.

The GNS Science board is ultimately accountable for GeoNet's performance under the contracts. The funders all receive GeoNet services, but so too do the science and engineering communities, local government, and many more user groups.