GNS SCIENCE

2021 ANNUAL REPORT

PART 1 – HIGHLIGHTS

Our science delivers tangible benefits to help Aotearoa New Zealand move towards a Cleaner, Safer, More Prosperous future.

Cover image and inside front cover image: GNS Science staff install seismic equipment in coastal southern Hawke's Bay to record small earthquakes associated with a slow-slip event on the Hikurangi subduction zone under the east coast of the North Island.
See story on page 45.

OUR ACHIEVEMENTS

OUR SCIENCE

OUR ORGANISATION

Presented to the House of Representatives pursuant to the Crown Research Institutes Act 1992.

Our Annual Report is presented in two parts – Highlights (Part 1) and Reports and Financial Statements (Part 2). Together, these documents fulfil our annual reporting responsibilities under the Crown Research Institutes Act 1992 for the year ended 30 June 2021.

The Reports and Financial Statements (Part 2) includes performance indicators, the report of the directors, financial statements, and independent auditor's report.

Our Annual Report is also available in digital format at www.gns.cri.nz

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www.gns.cri.nz

FROM THE CHAIR AND CHIEF EXECUTIVE

On 1 July 2020, like many other organisations, we were unsure what the new financial year would bring.

Early economic modelling had assumed Aotearoa New Zealand would have a slow recovery from the local disruptions caused by the COVID-19 pandemic. Independently, we also expected the effect of our own health and safety policy ruling out overseas travel to have a material effect on our international business revenue.

As it happened, neither of those eventualities occurred – the Aotearoa New Zealand economy remained resilient (acknowledging that the tourism and hospitality sectors are still affected) and our international business continued online rather than in person.

We are incredibly proud of how our people have responded to what has been an unusual and challenging year. They have been both resilient and adaptable. We thank all our people – our researchers, those working in applied science, our business development team and our corporate staff – for their commitment and focus on delivering science aimed at making Aotearoa New Zealand Safer, Cleaner and More Prosperous. However, the global pandemic has also constrained international recruits joining us, leading to understaffing in some areas of science capability. Nearly half of our scientists come from overseas and the pandemic has again highlighted Aotearoa New Zealand's need to grow more of its own talent. We are doing our part by encouraging more Māori into science through Ahunuku Scholarships in association with Te Herenga Waka – Victoria University of Wellington and hosting several interns in our science teams during the universities' summer break.

Despite the challenges we have faced over the last year we delivered a solid performance, which is a testament to the hard work of all our staff.

The energy CRI

We continued to cement our position as the energy CRI for Aotearoa New Zealand, utilising our materials science expertise to create ways for Aotearoa New Zealand to be both cleaner and more prosperous.

We received MBIE Endeavour funding for *Powering New Zealand's green hydrogen economy: Next generation electrocatalytic systems for energy production and storage*. This research addresses the scientific, engineering, economic and socio-technical challenges associated with the integration of sustainable hydrogen production and chemical storage systems for power, heavy transport fuel, or as a large-scale export commodity.

Subsequently, we were also confirmed as the host of the MBIE Advanced Energy Technology Platform – a $9.2 million contract over six and a half years for next generation green hydrogen – to support the delivery of a sustainable zero-carbon energy future for Aotearoa New Zealand. Working with university and industry partners, the platform focuses on researching hydrogen generation from non-pure water sources (including seawater) and new ways to produce hydrogen using solar-driven electrolysers. The green hydrogen platform is exciting, innovative research that strategically complements our environment and climate research to further measure and understand the impacts of climate change locally in Aotearoa New Zealand, the Pacific, and globally.

We also anticipate an increased role for geothermal power generation in Aotearoa New Zealand's energy future, and as such, we continue to expand our research into supercritical geothermal fluids – fluids that are much hotter and deeper than the fluids currently used – and offer 10 times more energy than present systems.

In the current energy market, we are providing our expertise to commercial geothermal activities, including key geology and modelling for 3D geological models that will help optimise well sightings and orientations. We also successfully introduced lab-based brine polymerisation tests to replace field-based testing, which is expected to save clients millions of dollars over the years.

Mātauranga Māori

We continue to work in partnership with iwi and Māori to assist Māori economic development and inspire rangatahi to develop careers in science.

Ngāti Tahu iwi aim to revitalise their land and economy in an area close to Ohaaki geothermal field; an economic, eco-papakāinga model is their preferred approach.

GNS scientists worked with the owners of Tahorakuri A1 Section 30 land block to address future risks to this land and its surrounding landscapes. We assessed potential risks such as land subsidence and inundation by collating existing geological knowledge (and models), geophysical datasets, groundwater datasets, historical photography and Waikato River data associated with the land and the Waikato River.

In parallel, local hapū compiled their histories and traditions (including oral) interpreting the voices and memories

of people, communities, and participants' knowledge passed down through the generations. Together, GNS scientists and hapū provided an understanding of the land that allows for future development.

With our partners from the Woods Hole Oceanographic Institution in the US, we released a new bathymetric map of Lake Rotomahana, showing the likely locations of the remnants of Te Otukapuarangi and Te Tarata (the Pink and White Terraces), destroyed by the 1886 eruption of Mount Tarawera. Post-Treaty-settlement iwi governance entities Tūhourangi and Ngāti Rangitihi are thrilled with the new map, which shows dozens of geological features not seen before.

A four-day event, Te Rarawa Noho Taiao wānanga, was led and delivered in Northland to 60 high school-aged students affiliated to Te Rarawa iwi. Hosted by Taiao Marae, Pawarenga, Whangapē Harbour, activities were organised around the Runaruna mud volcano, forams and molluscs from Hokianga Harbour cores, the rocks that make up Te Tai Tokerau/Northland, groundwater and salinity, and the impacts of sea-level rise.

In addition to our experienced scientists, three GNS Ahunuku Scholars attended the event, co-leading activities and acting as tuākana for the six groups of students. In return, we welcomed Te Rarawa, including four rangatahi, to Wellington – the first time an iwi has visited us in Wellington. It was a wonderful experience to host them, after they have hosted us so many times, and to show them how we analyse the Hokianga Harbour core samples for environmental changes. Kōrero from Te Rarawa programme leaders was exceptionally positive about the relationship between GNS Science and Te Rarawa.

Collaboration across the science sector

Taking onboard the cues from our shareholder, this year has seen us expand our existing collaborations beyond research partnerships into business partnerships.

We have signed an agreement with ESR to jointly implement an enterprise resource planning system to manage the finance, human resources and project management systems of both organisations.

We have also started discussions with other science organisations about the potential for cooperating on mutually beneficial investments in property and infrastructure.

The collaboration with ESR occurred after discovering both organisations were investigating new business process systems. After independently choosing the same preferred option we formally set up a co-licensing agreement, which is expected to reduce implementation costs and ongoing licence fees.

Our property issues have become quite urgent, with land instability affecting our Wairakei site, the laboratories and National Ice Core Facility at Gracefield housed in end-of-life buildings, and parts of our Avalon building being earthquake prone. We have been unable to invest in infrastructure, facilities and equipment for a couple of decades and need the right facilities to support our science.

Consequently, we have developed a property master plan which aims over the next 5 –10 years to redevelop our Wairakei site and consolidate our Lower Hutt activities at our Gracefield site.

As part of the Gracefield redevelopment, we are discussing future infrastructure plans with other Wellington-based science organisations to discover if it's possible to combine with others to realise the best investment value for the region and the country.

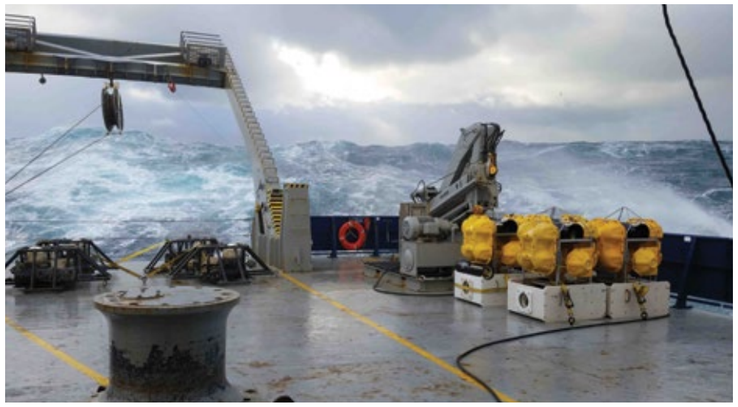
GeoNet asset transfer

On 1 July 2021, the GeoNet programme celebrated its 20th anniversary and the transfer of its assets from EQC to GNS Science.

Thanks to our partners at EQC, the National Emergency Management Agency (NEMA), Toitū Te Whenua Land Information New Zealand (LINZ) and MBIE we continue providing the infrastructure and scientific expertise that has a vital role in Aotearoa New Zealand's natural hazard monitoring and response.

Originally resourced for a research role, GeoNet's purpose has grown to providing real-time monitoring and response to natural hazard events such as earthquakes, eruptions and tsunami. It was central in providing real-time information to NEMA and the Minister of Civil Defence on 5 March 2021, when three large earthquakes in the Kermadec Islands triggered tsunami warnings for our largest population centre, Auckland, and other coastal areas.

After two decades of multi-party funding, we have begun working with our stakeholders to develop secure, dedicated funding from central government for the GeoNet programme to ensure ongoing sustainability of a the programme comprising more than 1000 monitoring instruments, the 24/7 National Geohazards Monitoring Centre / Te Puna Mōrearea i te Rū, and scientific advice to inform geohazard emergencies.



In our view, it is crucial that vital national infrastructure like GeoNet, essential to public safety and resilience planning, is adequately funded for its modern role.

Response to the WorkSafe prosecution

During the year, WorkSafe charged GNS Science with two alleged health and safety offences relating to activities prior to the eruption of Whakaari/White Island on 9 December 2019, which tragically took the lives of 22 people and seriously injured many others.

We anticipate that the prosecution will take some time, possibly years, and note that the Coroner's hearing will begin after the WorkSafe proceedings are concluded. The prosecution has resulted in increased expenditure on legal fees and has slowed some research and business activities while staff are working on our response.

Carbonreduce at GNS Science

Last year, we made the strategic and ethical decision to measure and then reduce the carbon emissions we create by doing business. As one of Aotearoa New Zealand's leading environmental research agencies it is appropriate that we take a strong lead.

The first step, an independent audit by Toitū of the non-COVID disrupted 2018/19 year, set our baseline emissions at the equivalent of 3,218.44 tonnes of CO_2 per year. About a quarter of that (more than 800 tonnes) is staff commute to our five sites.

Our goal is to reduce our emissions by 4 percent per year, aiming for a cumulative 20 percent decrease from our baseline year by 2025. This target is in line with our research, government policy and Intergovernmental Panel on Climate Change advice.

We have replaced part of our fleet with a combination of EV and hybrid vehicles and will be completing gas and electricity audits at Wairakei, Avalon and Gracefield to find where we can become more efficient.

Financial result

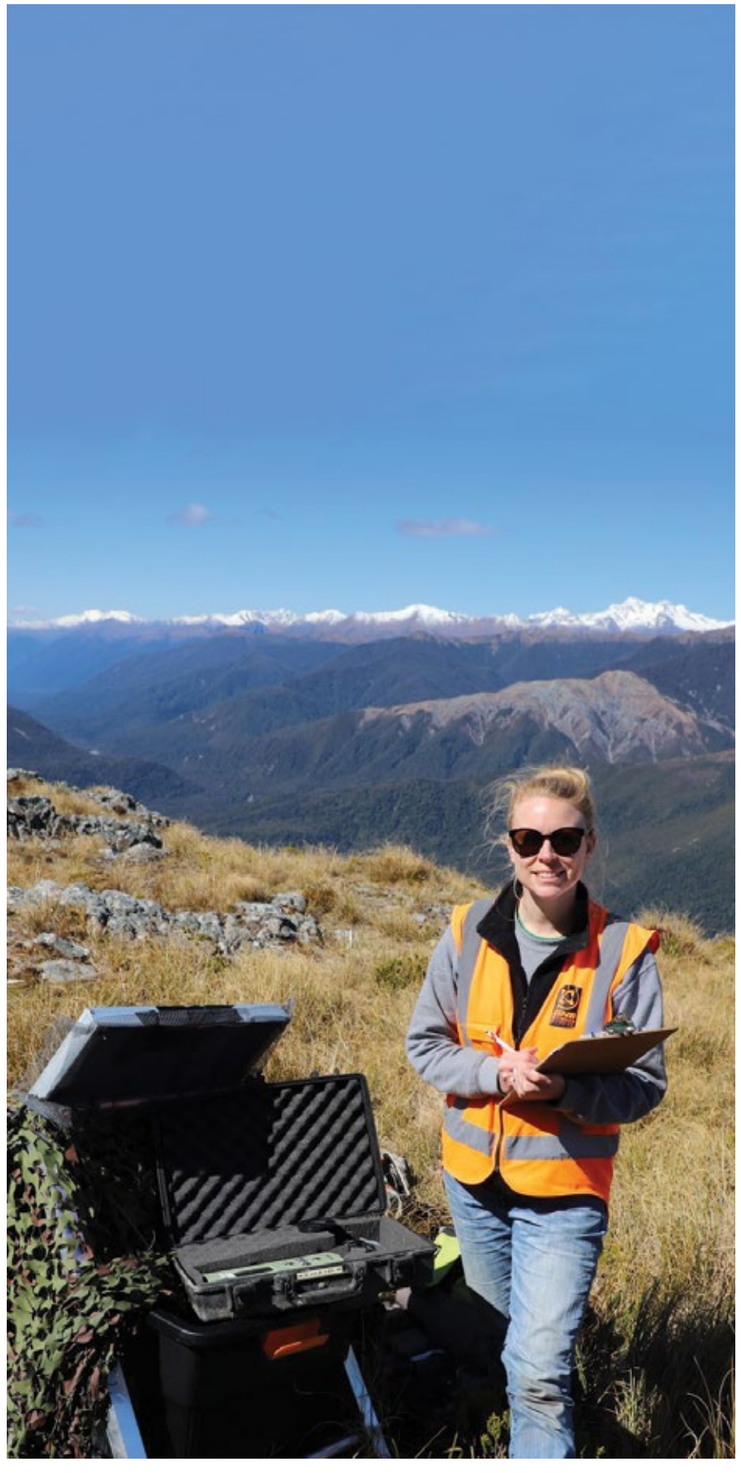
Our financial performance was stronger than we forecast as a result of a better than expected recovery from COVID-19. GNS Science recorded a net profit after tax of $6.1 million for the year to 30 June 2021, up $5.7 million on budget. This includes a COVID-19 grant made in anticipation of the pandemic adversely affecting our business. The $4 million grant from the Ministry for Business, Innovation and Employment (MBIE) offset losses incurred as a result of the COVID-19 pandemic.

In closing, we would like to thank Sarah Haydon and Chris Bush who retired from the Board during the year, and general manager Justine Daw who resigned during the year, all of whom have made great contributions to GNS Science's ongoing success.

Dr Nicola Crauford
Chair
September 2021

Ian Simpson
Chief Executive
September 2021

Left: Seafloor pressure gauges on the US research ship *Roger Revelle* during a GNS Science-led voyage to study the Hikurangi subduction zone off the North Island's east coast. Story pages 44 & 45.
Right: GNS Science seismologist Emily Warren-Smith servicing seismic equipment in South Westland.



HONOURS AND AWARDS

GNS Science Excellence Awards 2020

Every year GNS Science presents awards to celebrate outstanding staff achievements and contributions. Staff are nominated by their peers and a group of senior staff select winners of the seven categories.

Creating an Impact:
Our Rising Tide Team

The Our Rising Tide team was recognised for its vast array of climate change research and project work. This work has focused on two main topics – the Antarctic Ice Sheet response to climate change, and projections and consequences of sea level rise in Aotearoa New Zealand.

Creating Awareness:
The Great Greenhouse Grassoff Team

This team took advantage of a unique event – the first COVID-19 Level 4 lockdown – to collaborate with NIWA and Ministry for the Environment to encourage 'citizen scientists' to take grass samples from within their 'bubble' and send them to GNS Science, providing the team with an opportunity to collect and record changes in fossil fuel produced CO_2 during lockdown.

Vision Mātauranga:
Te Hiku Engagement Team

Over several years, the Te Hiku Engagement Team has been fostering, growing, and strengthening relationships with iwi groups and communities in the Te Hiku area of Te Tai Tokerau, Far North, Aotearoa. This began with education initiatives that targeted the region's rangatahi and has grown to include active research projects and plans for future collaborative research endeavours.

Working Together:
Early Career Staff Network Council

The Early Career Staff Network Council was established in 2019 with the aim of making GNS Science a great place to work for early career professionals. The network is made up of a diverse mix of staff from across all company sites. It is open to anyone who identifies as being in their early career, and includes scientists, specialists, technicians, non-science staff, management and more.

Deep Partnering:
Zara Rawlinson

Hydro-geophysicist Zara Rawlinson was recognised for creating a strong, trusted relationship between GNS Science and Hawke's Bay Regional Council's science team over several years. She has done this through regular engagement, sharing of ideas, taking the time to understand the challenges faced by the Council, and clearly articulating to the Council how and why the work of GNS Science can help them.

Early Career Achievement:
Lucy Kaiser

Lucy is an early career researcher and tuākana to emerging Māori researchers. Between 2018–2020, she led a research project in partnership with East Coast LAB to develop seismic hazard education activities from a Māori-centred kaupapa approach for kura and schools. These activities are designed to encourage tuākana-tāina mentorship, and increase the knowledge and preparedness of ākonga (students) in the Hawke's Bay and Wellington regions.

Making a Difference:
The GNS Facilities Management Team

The pandemic put many organisations around the world into a state of flux. At GNS Science, the Facilities Management Team stepped up to the challenge and worked around the clock to ensure facilities across all sites were kept safe and clean, and enabled essential services to keep functioning.

National and international honours and awards

GNS Science staff make extraordinary contributions to Aotearoa New Zealand. During the year, many of our staff were recognised for their outstanding work.


1.


2.

1. Lucy Kaiser
2. Nick Mortimer

Science NZ National Awards 2020

GNS Science, along with the other CRIs and Callaghan Innovation, celebrated its best and brightest at the 2020 Science New Zealand National Awards at Parliament in December 2020. These annual awards recognise outstanding achievements in science that produce benefits for Aotearoa New Zealand. Twenty-four awards were presented across three categories – Early Career, Lifetime Achievement, and Team.

Our awardee in the Team category was the **Our Rising Tide Team**, which investigates the response of the Antarctic Ice Sheet to climate change and examines the impact of sea level rise in Aotearoa New Zealand. Findings are shared with coastal communities so we can better adapt to our changing world and the team's impact extends into social, cultural, economic and political domains.

Team members have contributed to reports by the Intergovernmental Panel on Climate Change; participated in Aotearoa New Zealand's Coastal Hazards and Climate Change risk and adaptation assessment; provided reports on the potential impact of sea level rise for national and local government bodies; and worked with the Ministry of Foreign Affairs and Trade to develop a project to evaluate flooding hazard due to sea level rise in the Pacific.

Our Early Career Researcher in these awards was **Lucy Kaiser** (left – Kāi Tahu, Kāti Māmoe, Waitaha) who is a driving force for the inclusion of communities, especially indigenous communities, in emergency management and natural hazard research. Building resilience to earthquakes, tsunami, and climate change are key areas for her. Lucy's work is notable for its strong grounding in both western science and Kaupapa Māori, and her ability to effectively blend different knowledge strands and bi-cultural perspectives. She has been acknowledged for her innovation both in Aotearoa New Zealand and through international forums, including the United Nations.

Our awardee in the Lifetime Achievement category was **Nick Mortimer** (left), a prolific and inspiring geologist who has helped to change the way we think about Aotearoa New Zealand geology and tectonics. He is best known for his role in leading the project concerning Te Riu-a-Maui / Zealandia – Earth's eighth continent. During his career with GNS Science, Nick has done consulting work for industry, hydro power operators, government agencies, and overseas geological survey organisations. He has also been an influential figure in the Aotearoa New Zealand Earth science community and is a Fellow of the Royal Society of New Zealand Te Apārangi. He is active in outreach having written popular books, provided expert advice to museums, and given many public talks.

Marine geophysicist **Jenny Barretto** received a commendation from the Congress of the Philippines for her 'extraordinary contribution' to scientific research in recognising a 150km-wide caldera on the seafloor at the Benham Rise in the Philippine Sea.

Paleoclimatologist **Nancy Bertler** was appointed Director of the Antarctic Science Platform for a second four-year term.

Geothermal scientist **Chris Bromley** was awarded a New Zealand Geothermal Association Contribution Award for services to the Aotearoa New Zealand and international geothermal industry. This included chairing international energy bodies and editorship of the *Geothermics* journal.

Minerals geologist **Tony Christie** received an Honorary Fellowship Award from the Australasian Institute of Mining and Metallurgy for exceptional achievement, service or contribution to the resources sector. Tony is one of only three New Zealanders to have received this prestigious award.

Paleoclimate scientist **Giuseppe Cortese** was appointed a panellist for the Marsden Fund, Earth Science and Astronomy Panel.

Geodynamic modeller **Susan Ellis** won the Geoscience Society of New Zealand McKay Hammer Award for the most meritorious contribution to geology published in the previous three calendar years.

Seismologist **Bill Fry** was elected to the Secretariat of the American Geophysical Union's Natural Hazards Section, which has a membership of about 6,700 natural hazards professionals. The body is the world's largest group of natural hazards scientists and has considerable influence over the direction of natural hazards research and application.

Geothermal scientist **Duncan Graham** was awarded a New Zealand Geothermal Association Contribution Award for 42 years of dedicated work advancing geophysical and geochemical monitoring and sampling methods in geothermal fields, and developing new techniques for improving efficiencies in geothermal power plants.

Climate and coastal processes scientist **Georgia Grant** won the Hatherton Award for her paper on sea level rise 'The amplitude and origin of sea-level variability during the Pliocene epoch' which outlines the implications of sea level rise in Aotearoa New Zealand from Antarctic ice sheet retreat occurring under 2°C warming.

Geothermal scientists **Sophie Pearson-Grant, Anya Seward, Brian Carey,** and **John Burnell** were awarded best direct use paper at the 2020 New Zealand Geothermal Workshop.

The Endeavour funded **Hikurangi subduction earthquakes and slip behaviour** (HSM) project team, led by GNS Science, was awarded the inaugural Hayward Geo-communication award for the most meritorious communications in Aotearoa New Zealand in the previous three years.

Principal scientist and micropaleontologist **Chris Hollis** was appointed an expert reviewer for the Intergovernmental Panel on Climate Change Sixth Assessment Report released this year.

Ice sheet modeller **Dan Lowry** was appointed a co-author on the Intergovernmental Panel on Climate Change Sixth Assessment Report.

Social scientists and hazard researchers **Lucy Kaiser, Kristie-Lee Thomas**, and **Emily Campbell** won the inaugural QuakeCoRE Te Hīkina o Rūaumoko Mātauranga Māori Research Award for excellence in mātauranga Māori earthquake resilience research and collaboration. Lucy was also part of a team that won an award at the EMPA (Emergency Media and Public Affairs) awards for the Napier Hill Evacuee research project.

Hazard and risk management scientist **Sally Potter** was invited to co-chair the World Meteorological Organization's High Impact Weather research programme.

Engineering geologist and emeritus scientist **Stuart Read** was awarded Life Membership of the New Zealand Geotechnical Society in recognition of outstanding service to the society and the geotechnical community.

Geophysicist **Fabio Caratori Tontini** and co-authors won the New Zealand Geophysics Prize for the most meritorious publication in the field of geophysics published in the previous two calendar years.

Seismic engineer **SR Uma** was elected to the management committee of the New Zealand Society for Earthquake Engineering, a body that advances the science and practice of earthquake engineering.

ABOUT GNS SCIENCE

About us

GNS Science, Te Pū Ao, is an Aotearoa New Zealand Crown Research Institute that unlocks environmental, social, cultural and economic benefits through its work across four Science Themes:

- Natural Hazards and Risks
- Environment and Climate
- Energy Futures
- Land and Marine Geoscience

Our focus on outcomes means an interdisciplinary approach to our research. Our work combines physical sciences with expertise in Data Science, Vision Mātauranga and Social Science. This approach enables a more sustainable environment and better quality of life for New Zealanders.

We connect with stakeholders and collaborators from research, government and industry to build and deliver fit-for-purpose science. This includes partnering with iwi/Māori to explore the science and innovation potential of Māori knowledge, resources and people to benefit all New Zealanders.

Our impacts

Our expertise contributes to a Cleaner, Safer, More Prosperous Aotearoa New Zealand by:

- building intergenerational wealth and wellbeing through wise custodianship of Aotearoa New Zealand's freshwater, energy and mineral resources
- reducing the physical, economic and societal impacts of geological hazards, including through 'early warning' systems, improved hazard awareness and preparedness, enhanced geohazards monitoring, and enabling more resilient communities, buildings and infrastructure
- understanding past climates to improve global models that predict the future impacts of a changing climate
- developing and applying novel materials and new catalysts to improve the efficiency of green hydrogen production and storage, and improving understanding of geothermal systems for sustainable use of geothermal energy, both contributing to a low-emissions energy future and creating new value for industry.

How we work

Through trusted partnerships with our key stakeholders we:

- provide expert scientific input to policy, regulation, standards, and guidance
- provide advice and tools to decision-makers on the effective management of Aotearoa New Zealand's natural hazards, the environment, groundwater, and energy requirements
- work with business to encourage innovation and productivity, and develop new knowledge-intensive technologies
- contribute to national and global collaborative science initiatives to enhance capability and science value
- build on our host role for the Resilience to Nature's Challenges Kia manawaroa – Ngā Ākina o Te Ao Tūroa National Science Challenge to strengthen our contribution to the Challenge and aligned research.

SCIENCE THEMES

Providing excellent science, where it matters most

How these impact Aotearoa New Zealand and its people

Research priority areas:

- Managing Risk to the Four Capitals*
- Enabled and Informed Public, Community and Business
- Effective Early Warnings and Forecasts
- Improved Response Decision-Making and Recovery Planning
- Improved Risk Governance

How people impact the Earth

Research priority areas:

- Our Groundwater Systems
- Antarctica in a 2°C Warmer World
- Ecosystem Response to a Warming World
- Revealing the Drivers of Our Climate
- Carbon Cycle Dynamics
- Our Rising Tide

How we use Earth's resources sustainably and generate new value for Aotearoa New Zealand

Research priority areas:

- Improved Understanding of Geothermal Systems
- Improved Sustainable use of Geothermal Energy
- New and Improved Technologies for Producing and Storing Green Hydrogen
- New and Improved Technologies for Energy Efficiency and Storage

Underpinning knowledge of Aotearoa New Zealand's geology and how the Earth works

Research priority areas:

- Improved Resilience to Natural Hazards
- Adapting to Changing Climate
- Managing Natural Resources Sustainably
- Wider use of Collections and Databases
- Vision Mātauranga

*The **Four Capitals** (natural, human, social, and financial/physical) are the pillars of the NZ Treasury's Living Standards Framework. Together they generate wellbeing now and into the future.

OUR SCIENCE

Our data, discoveries and innovations over the past year enable more informed decisions to meet Aotearoa New Zealand's current and future needs.

Left: Sunset at Aoraki/Mt Cook, partly masked by low cloud on the horizon, as seen from the Hooker Valley.

SCIENCE THEME

NATURAL HAZARDS AND RISKS

We have a national leadership role for monitoring and research on the causes, risks and consequences of geological hazards in Aotearoa New Zealand. By applying our social science capabilities, we help increase community resilience, communication of risks and hazard preparedness.

CELEBRATING TWO DECADES OF GEONET

Twenty years of monitoring geohazards, informing research and reassuring New Zealanders that yes, that was an earthquake – our national geohazards monitoring system, GeoNet, has much to celebrate. It is a triumph of ingenuity and practicality that is often held up as an international exemplar. The scope and complexity of its operations and the expectation of what it can do have grown substantially, and GeoNet is continually improving to meet that challenge.

"GeoNet is a core part of our national infrastructure. It's grown into a fundamental component of the country's natural hazards monitoring platform – keeping New Zealand informed and safe. The fact that the GeoNet app sits on so many people's phones says a lot about how people value it – science connecting with people every day."

Paul Stocks, Deputy Secretary, MBIE

"GeoNet is a world-leading monitoring network that gives us huge insight into our natural hazards so we can understand the impacts they could have. As the international reinsurers say to us every year when we go to the market – 'you understand your risk better than anybody'."

Sid Miller, Chief Executive, EQC

GeoNet came into being in 2001 when the Earthquake Commission (EQC), GNS Science, and Toitū Te Whenua Land Information New Zealand formed an alliance to substantially upgrade and expand Aotearoa New Zealand's geohazard monitoring networks, which are operated by GNS Science.

Before this, monitoring equipment was sparse, and it could take days to get a location, depth and magnitude of an earthquake. Now it happens in minutes – sometimes in under a minute.

With EQC on board as the principal funder, change came rapidly with scores of new instruments sending real-time information to data hubs at GNS Science offices in Wairakei and Lower Hutt. There are now nearly 700 GeoNet instrument sites across the country, recording and locating between 20,000 and 30,000 earthquakes every year.

From the very first day of GeoNet's operation, all the data on earthquakes, volcanoes, landslides, and tsunami has been made freely available to everyone. A global community of scientists has built up around our data. The research undertaken by this community – with our data – benefits Aotearoa New Zealand, and more broadly our understanding of international geological hazards, immensely.

On the back of EQC support, we have been able to leverage other investment and in 2018 we opened the National Geohazards Monitoring Centre (NGMC) / Te Puna Mōrearea i te Rū, which provides round-the-clock monitoring of major geological hazards to help keep New Zealanders informed and safe. The information NGMC provides is crucial in helping the National Emergency Management Agency (NEMA) make decisions on warnings and advisories as major geohazard events unfold.

"GNS Science and GeoNet represent one of our most important relationships, because of the way the Department of Conservation relies on the data from GeoNet to help us make decisions about public safety during periods of volcanic unrest."

Hollei Gabrielsen, Lead Volcanologist, Department of Conservation

GeoNet came into being in 2001

There are now nearly 700 GeoNet instrument sites across the country

The network locates between 20,000 and 30,000 earthquakes every year

Further to this, last year we worked with NIWA, NEMA, MBIE and MFAT to implement the phased deployment of 12 deep ocean sensors called DART (Deep-ocean Assessment and Reporting of Tsunamis) buoys to the north and east of the country to increase our ability to detect and respond to approaching tsunami. The deployment represents the biggest single growth in tsunami monitoring in this part of the Pacific region in decades.

These vastly improved capabilities could not have been imagined when GeoNet started operating in 2001. They have been built on the solid foundations of the last 20 years.

The reach of GeoNet is such that there have been 250,000 downloads of the GeoNet app, and in the minutes following widely felt earthquakes tens of thousands of people go to the GeoNet website for authoritative information.

It is no exaggeration to say that GeoNet's network sits at the heart of Aotearoa New Zealand's resilience and hazard risk management systems.

As a result of the high quality data collected by GeoNet, scientists understand vastly more about the mechanisms of earthquakes, tsunami, volcanic eruptions, and landslides than we did 20 years ago.

In parallel to these advances, GeoNet has created something special – a community where New Zealanders better understand geological hazards and share their experiences.

What started 20 years ago as a geohazards monitoring network has evolved into a critical piece of national infrastructure. GeoNet is very much focused on the future and the next 20 years will see continued development of its capabilities.

Left: GNS Science technicians upgrade GPS equipment at Annette Plateau in Aoraki / Mt Cook National Park.
Right: A GeoNet communications hub at Mount Price, Whataroa, West Coast, South Island.

"MetService operates one of the nine volcanic ash advisory centres in the world and GeoNet data allows us to monitor the New Zealand-based volcanoes, and this is very important particularly for the aviation community."

Marcel Roux, Manager Aviation Weather Services, MetService

"We couldn't do our job without GeoNet. Through the National Geohazards Monitoring Centre, GeoNet provides us with the advice we need when we have to make decisions about public advisories and warnings."

Kevin Fenaughty, Team Leader Hazard Risk Management & Analysis, National Emergency Management Agency (NEMA)

NATURAL HAZARDS AND RISKS

Resilience to Nature's Challenges

GNS Science is proud to host Resilience to Nature's Challenges Kia manawaroa – Ngā Ākina o Te Ao Tūroa (RNC). The Challenge uses a 'co-creation' approach to bring scientists, economists, mātauranga Māori experts and engineers together with users of their research. The aim: finding new knowledge and solutions to accelerate Aotearoa New Zealand's resilience to ever-changing natural hazards.

This year RNC has consolidated its progress so far and built its linkages across the resilience system. As well as progressing its 10 research programmes, this year RNC has been focusing on deepening its commitment to leadership in mātauranga Māori, and managing the significant impacts and opportunities associated with COVID-19.

Key science progress this year includes:

- completing the first synthetic earthquake catalogue for Aotearoa New Zealand – to inform a new generation of earthquake hazard models and ultimately feed into the national Building Code
- improving severe weather impact models by establishing storm tracks for simulated ex-tropical cyclones impacting Auckland, and modelling severe snow events
- applying the Dynamic Adaptive Pathway Planning approach to planning managed infrastructure retreat in vulnerable coastal locations
- developing new probabilistic models to assess impacts of earthquakes, volcanic ash and tsunami, which will provide improved evidence for community and infrastructure planning and mitigation.

Key challenge impacts this year include:

- integrating disaster scenario impacts into key national and local agencies' emergency planning: for example, Alpine Fault planning for Fire and Emergency New Zealand, emergency housing planning by the Ministry of Business, Innovation and Employment, and Napier City Council's tsunami evacuation plans
- assessing the vulnerability of coastal marae to coastal hazards, and applying mātauranga Māori to tsunami and volcanic hazard assessment
- integrating coastal managed retreat research into policy considerations for national legislative reforms.

Changes are underway in key resilience-related national legislation and agencies, so the next few years present a huge opportunity for our research to inform national policy and accelerate resilience for Aotearoa New Zealand. With this in mind, RNC – supported by host organisation GNS Science – is working with other National Science Challenges and other hazard research programmes to make it easier for research users to connect with science that is relevant to them. This joint approach aims to ensure engagement is coordinated and targeted in the right way, at the right time, for the widest benefit.

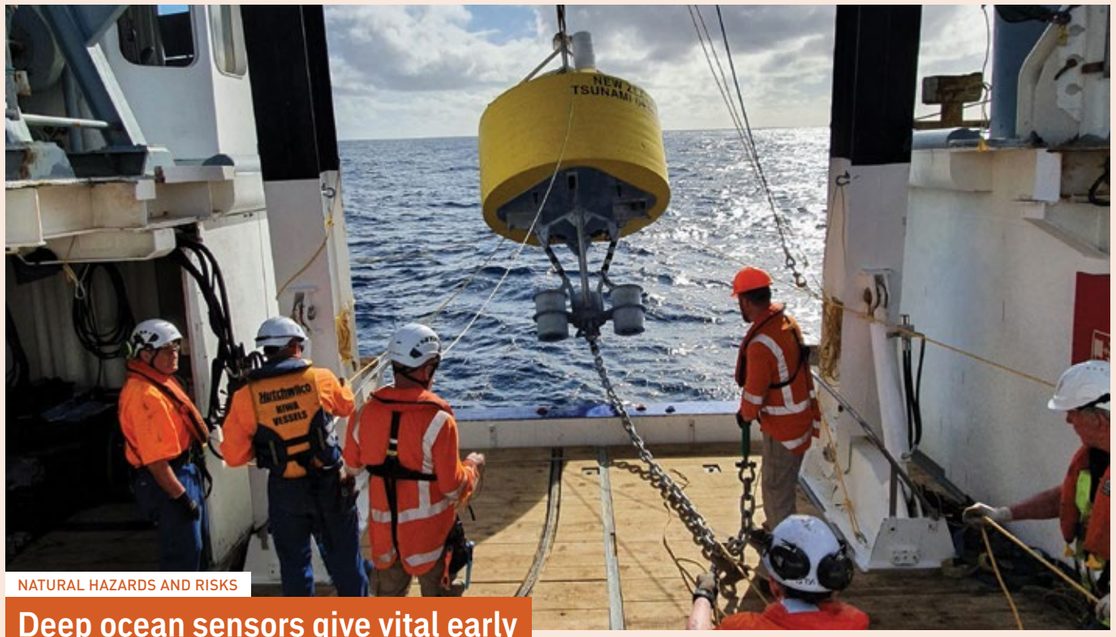
Top: Josh Te Kani (Ngāi Te Rangi, Ngāti Ranginui, Ngāti Pūkenga), the Resilience Challenge's Vision Mātauranga Knowledge Broker, speaking at 'Growing Kai under Increasing Dry' – a primary sector drought resilience symposium co-produced by Resilience to Nature's Challenges, Deep South, and Our Land and Water National Science Challenges. The event was held at Te Papa in May 2021.

SNAPSHOT

The Challenge uses a 'co-creation' approach

RNC has been focusing on deepening its commitment to leadership in mātauranga Māori

The first synthetic earthquake catalogue for Aotearoa New Zealand has been completed



NATURAL HAZARDS AND RISKS

Deep ocean sensors give vital early information on tsunamis

Aotearoa New Zealand's new network of deep ocean tsunami sensors proved invaluable during a series of earthquakes and tsunami off East Cape and Raoul Island in early March. This sequence of three offshore magnitude 7-plus quakes on 5 March generated a complex series of tsunami that were recorded right around the Aotearoa New Zealand coast.

The 5 March sequence was an excellent test of our tsunami monitoring systems. Data from the network of DART (Deep-ocean Assessment and Reporting of Tsunamis) buoys added confidence to estimates of size, location, and timing of the tsunami waves as they approached our coast. This meant the National Emergency Management Agency (NEMA) was able to cancel its initial tsunami warning sooner than would have been possible by relying on coastal tide gauges alone.

The twelve DART buoys measure a tsunami in the open ocean – far away from the complicating effects of coastlines, and typically long before tsunami waves reach land. Data from the buoys is sent via satellite in near real-time to GNS Science and to the Pacific Tsunami Warning Center in Hawaii. Analysts in our National Geohazards Monitoring Centre evaluate the data and, along with experts from GNS Science and other tsunami scientists across Aotearoa New Zealand, they provide advice to NEMA so it can issue advisories and warnings to the public.

Conversely, the DART buoys can tell us when no tsunami has been generated by an earthquake, allowing quicker stand down of warnings. They also detect tsunami generated by uncommon sources such as seafloor landslides or underwater volcanic eruptions, which are not always associated with large earthquakes.

GNS Science worked closely with NEMA, NIWA, the Ministry of Business, Innovation and Employment and the Ministry of Foreign Affairs and Trade in the deployment of the DART buoys. The network provides improved safety to all countries bordering the Pacific Ocean, especially Aotearoa New Zealand and southwest Pacific nations.

In the deep ocean, tsunami waves travel at up to 800km/h, which means that a tsunami generated near Raoul Island will reach the New Zealand coast in about an hour. Deploying the DART buoys is the biggest step forward for tsunami monitoring in this part of the globe in decades – and in the event of a tsunami, they help keep us and our Pacific neighbours safer.

Top: Crew on NIWA's research ship *Tangaroa* deploy a DART buoy to the north of Aotearoa New Zealand.

SNAPSHOT

7-plus
The sequence of three offshore magnitude 7-plus quakes on 5 March generated a complex series of tsunami

Data from the DART buoys added confidence to estimates of size, location, and timing of the tsunami waves

800km/h
In the deep ocean, tsunami waves travel at up to 800km/h

NATURAL HAZARDS AND RISKS

Getting to know your geological hazard

Sometimes, in order to find out more about an active fault, you need to get up close. Digging trenches and probing active faults tells us more about their history and their potential threat – and it helps communities make decisions on how to be better prepared for earthquake hazards.

Every year, we dig numerous trenches to examine faults first-hand. Near Morrinsville this year we dug three trenches across the Te Puninga Fault to expose soil layers displaced during earthquakes over the past 20,000 years. We took samples from each layer so that experts at the University of Waikato and in Spain could date the fault ruptures. The fault is subtle in the landscape and only came to our attention recently thanks to improved aerial mapping techniques.

As part of an initiative to improve the knowledge of risk in parts of the country traditionally seen as low seismicity areas, the Earthquake Commission (EQC) funded us to investigate the fault. Preliminary estimates indicate the fault is capable of generating a magnitude 6-plus quake – important knowledge given that it is only 27km from Hamilton. Our analysis will give a clearer picture of how frequently it ruptures, when it last ruptured, and how big future quakes could be.

Similarly, in Feilding, the Manawatū District Council gained EQC funding and commissioned us to investigate the Rauoterangi Fault, which passes through the western part of the town. The fault was believed to be inactive until a regional geological mapping exercise in 2020 reclassified it as active. This means there is enough evidence that it has ruptured at least once in the past 125,000 years.

Our preliminary estimate was that the fault could potentially generate an earthquake once every 5,000 to 10,000 years. However, the Council wanted a clearer indication of the fault's earthquake potential to help inform future decision-making. We dug a trench across the fault and found evidence of past fault movements in the trench walls. We collected material for radiocarbon dating which will paint a more detailed picture of the history of the fault.

> **"We're incredibly grateful to both GNS Science and EQC for enabling this trench work to take place. There's obviously community interest in the outcomes of this work given the faultline's presence in Feilding. It's important that we know what hazards are in our district for future development and the information we get from this report will be valuable for our planners and land development team."**
>
> Helen Worboys, Mayor, Manawatū District Council

The findings of investigations like these will give the Council and the local community a clearer picture of the fault behaviour so they can make decisions about how to manage the risk it poses. People living in these regions need access to the best possible information, and our research plays an important role in helping to inform community decisions about appropriate risk management, including land use planning.

Top: Earthquake geologists Pilar Villamor, Kelvin Berryman and Kate Clark examine evidence of past ruptures of the Te Puninga Fault near Morrinsville to learn more about its earthquake potential.

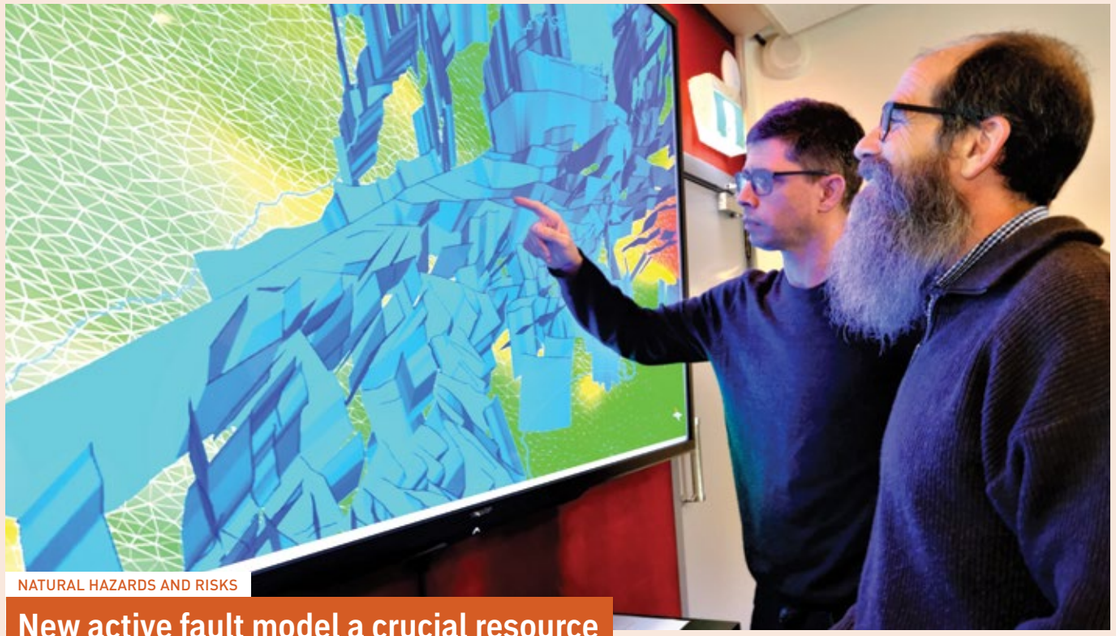
SNAPSHOT

We dug three trenches across the Te Puninga Fault

6-plus
The fault is capable of generating a magnitude 6-plus quake

125,000
The Rauoterangi Fault has ruptured at least once in the past 125,000 years

The fault could potentially generate an earthquake once every 5,000 to 10,000 years



NATURAL HAZARDS AND RISKS

New active fault model a crucial resource

All of Aotearoa New Zealand's known active faults have been captured in a multi-agency collaboration led by GNS Science. More than 50 earth scientists and engineers have contributed to the Community Fault Model, which catalogues all the faults across the country which could potentially generate an earthquake.

The 3D model is an important information source for applications such as the National Seismic Hazard Model, tsunami hazard evaluation, earthquake ground-motion simulations for engineers, and for other earthquake research projects. So far, 2D information has been collected for 880 on-shore and offshore faults, and by the end of this calendar year the model will show the faults in three dimensions to seismogenic depths – about 20km.

As well as known active faults, the model will include faults that fall outside the traditional definition of active – having ruptured once in the past 125,000 years – but could be capable of generating an earthquake. This will include faults that contributed to events such as the 2016 magnitude 7.8 Kaikōura earthquake.

GNS Science's Russ Van Dissen, who is the co-lead compiler, says being slightly more expansive about the definition of an 'active fault' puts us a step forward. It is a major update that incorporates many advances made in the past 15 years and consolidates them in one place. The more we know about all Aotearoa New Zealand's faults – both currently active and potentially active – the better decisions we can make about building locations, engineering design and community resilience.

Top: Geologists Hannu Seebeck and Russ Van Dissen, co-lead compilers of the Community Fault Model project, discuss three-dimensional fault structures along the Marlborough Fault System in the northern South Island.

SNAPSHOT

50
More than 50 earth scientists and engineers have contributed to the Community Fault Model

880
So far, 2D information has been collected for 880 on-shore and offshore faults

By the end of the year the model will show the faults in three dimensions to seismogenic depths

The model will include faults that fall outside the traditional definition of active, but could be capable of generating an earthquake

NATURAL HAZARDS AND RISKS

A better base for increased resilience to earthquakes

Aotearoa New Zealand experiences between 20,000 and 30,000 earthquakes every year, and a GNS Science-led revision to the National Seismic Hazard Model (NSHM) will give us one of the most advanced hazard models in the world.

On its completion in 2022, the revised NSHM will provide a greatly enhanced picture of the likely strength of ground-shaking at any given point in the country over given time periods. The update will mean improved information for decision-makers and the reinsurance industry, as well as central and local government agencies, structural and geotechnical engineers, the insurance sector, seismic hazard consultants, and risk modelling specialists.

The first part of the revision will provide improved estimates of magnitude, location, and frequency of earthquakes throughout the country, while the second part will see better estimates of ground-shaking in future earthquakes, as well as quantifying uncertainty in a way that decision-makers can use.

The revision incorporates a fundamental change in the way scientists model earthquakes on known faults. In the past, it was common to consider a Wellington Fault earthquake as a singular event. However, the updated model will have numerous Wellington Fault rupture events to cover many possibilities – including how a single fault might interact with other nearby faults. As the Kaikōura earthquake in 2016 showed us, earthquake ruptures don't necessarily stop at discrete boundaries marked on a map, as many faults can participate in a single earthquake.

For complex events, the gains will be even greater. The previous version of the NSHM incorporated fewer than 10 rupture scenarios for the Hikurangi subduction zone east of the North Island, whereas the new version will have more than 10,000 – all with different ground-shaking implications.

We are adding large amounts of data to the NSHM as part of the revision – including seismic data from 6,000 earthquakes of magnitude 3.0 and above that have occurred throughout the country during the past 30 years. This will lead to improved understanding of the way the seismic waves travel through the Earth and how that translates to ground-shaking at the surface. By modelling this data, we can reduce the uncertainty in how much any one earthquake will cause the ground to shake.

Scientists will then adjust models to account for regional variations in geology. The revision will also highlight new areas for research – like how geological basins amplify seismic energy, as most of our main cities are built on basins.

The update is a joint initiative being led by GNS Science, the Ministry of Business, Innovation and Employment, and the Earthquake Commission. It involves the collective knowledge and skills of a large team of national and international scientists and end-users.

Top: Programme lead of the National Seismic Hazard Model revision Matt Gerstenberger (centre), with core team members Kiran Thingbaijam (left) and Anna Kaiser (right) in GNS Science's National Geohazards Monitoring Centre.

SNAPSHOT

The updated National Seismic Hazard Model will provide significantly improved earthquake occurrence and ground-motion models

The revision will account for complex faults, including possible rupture of multiple faults during a single earthquake

The revision will incorporate improved understanding of seismic wave propagation to better estimate ground-shaking levels

NATURAL HAZARDS AND RISKS

RiskScape software at the heart of risk modelling

2021 has seen a major update for our world-leading risk modelling tool, RiskScape. Developed in partnership with NIWA and the Earthquake Commission (EQC), RiskScape 2.0 provides a modern software platform, underpinned by the very latest scientific research.

RiskScape software enables users to assess risk to buildings, infrastructure and people from natural hazards such as earthquakes, tsunami, volcanic eruptions, landslides and floods. It is being used increasingly for central and local government agencies and infrastructure operators, and this enables a wider understanding of the potential costs of natural hazards.

EQC is in the process of transitioning to RiskScape 2.0 to replace its existing risk modelling tool, Minerva, which it has used since the late 1990s. EQC relies on sophisticated risk and loss modelling to understand the potential losses from a range of natural hazard events. International reinsurance companies depend on the quality of these models to assess the level of cover they provide for Aotearoa New Zealand.

EQC needs to provide an Aotearoa New Zealand-specific view of our risks and to maintain the high level of trust it has developed with the reinsurance industry. Understanding our natural hazards and their potential impact is vital for Aotearoa New Zealand's physical and economic security. RiskScape 2.0 is a modern software platform that will enable EQC to expand its capabilities.

Having models underpinned by the latest scientific research gives reinsurers confidence and reduces undue uncertainty. This results in better pricing for Aotearoa New Zealand's natural hazard reinsurance and, in the long run, helps EQC keep its insurance premiums lower for New Zealanders.

Beyond EQC, RiskScape has a wide range of applications. They include cost-benefit analysis for infrastructure options, understanding the impact of future natural hazard events, emergency management response and planning, impact assessment for insurers, and land-use planning and policy development.

Top: Our RiskScape risk modelling software is increasingly being used for central and local government agencies and infrastructure operators to provide a better understanding of the potential cost of natural hazard events.

SNAPSHOT

RiskScape 2.0 provides a modern software platform, underpinned by the very latest scientific research

RiskScape software enables users to assess risk to buildings, infrastructure and people from natural hazards

The Earthquake Commission needs to provide a New Zealand-specific view of our risks and maintain the high level of trust it has developed with the reinsurance industry

SCIENCE THEME

ENVIRONMENT AND CLIMATE

Our research focuses on groundwater resources, sea level rise, the carbon cycle and climate change impacts on ecosystems. Working with our major partners, we have designed our programmes to meet their current and future needs.

MUCH NEEDED BOOST FOR OUR LAKES

A globally unique research project co-led by GNS Science is moving into a new phase – analysing cores of sediment taken from lake beds all over Aotearoa New Zealand in order to monitor their health and guide their restoration.

Left: Lakes380 co-leader Marcus Vandergoes of GNS Science prepares a sediment corer for deployment in South Mavora Lake, Southland.
Right: Jamie Howarth of Victoria University of Wellington, Marc Schallenberg of the University of Otago and Tim Deitrich of Cawthron Institute collect a sediment core from Lake Ione in Fiordland.

GNS Science and Cawthron Institute co-lead the project, titled, Our lakes' health – past, present and future (Lakes380). It's a highly collaborative project, and the biggest scientific study of Aotearoa New Zealand's lakes ever undertaken.

Many of our lakes are deteriorating in health, and prior to this project there was very little scientific knowledge about their current and historic health at a national scale. At the heart of this research is the lake-bed sediment, which is laid down continuously and records environmental change over millennia. It's like opening a history book: the cores provide new insights into how and why the health of our lakes has changed over the centuries, even before human arrival.

Each lake has its own unique story and has been impacted by a mix of natural events such as storms, volcanoes and earthquakes, and human-induced pressures including vegetation change and the introduction of exotic flora and fauna.

The project team has travelled the length of the country – including the Chatham Islands – collecting four sediment cores from each of their targeted lakes. They have collected samples from about 10 percent of the country's 3,200 naturally occurring lakes. The new knowledge gleaned from these cores is helping assess lake health and guide restoration and management work undertaken by councils, iwi, the Department of Conservation, and other interested parties.

The team has also collected samples of surface water and of the lakebed surface, and this is providing a huge amount of information on current biodiversity and water quality. Cutting-edge techniques have revealed new insights: environmental DNA detects taonga species including tuna (eel) and kākahi (freshwater mussels), while hyperspectral imaging assesses algae abundance.

"Our relationship with the team from Lakes380 has been one that has really taken us on another pathway and one that has been really exciting. The longterm value of this work is that we're going to be able to go back in history and learn in-depth about exactly what our lake looked like, what the health of the lake was, and what we can learn to be able to get our lake back to what we want it to be."
Robert Martin, Chairman, Ngā Puna Rau o Rangitīkei

Recently the team has developed a new method to estimate lake water quality using bacterial DNA. This will enable the health of Aotearoa New Zealand's lakes to be determined at a resolution and scale not previously possible. For some lakes, we have found that their pre-human water quality was not as good as previously thought. For these lakes, trying to get them back to a pristine state is unrealistic. This new information is assisting in setting achievable lake restoration targets.

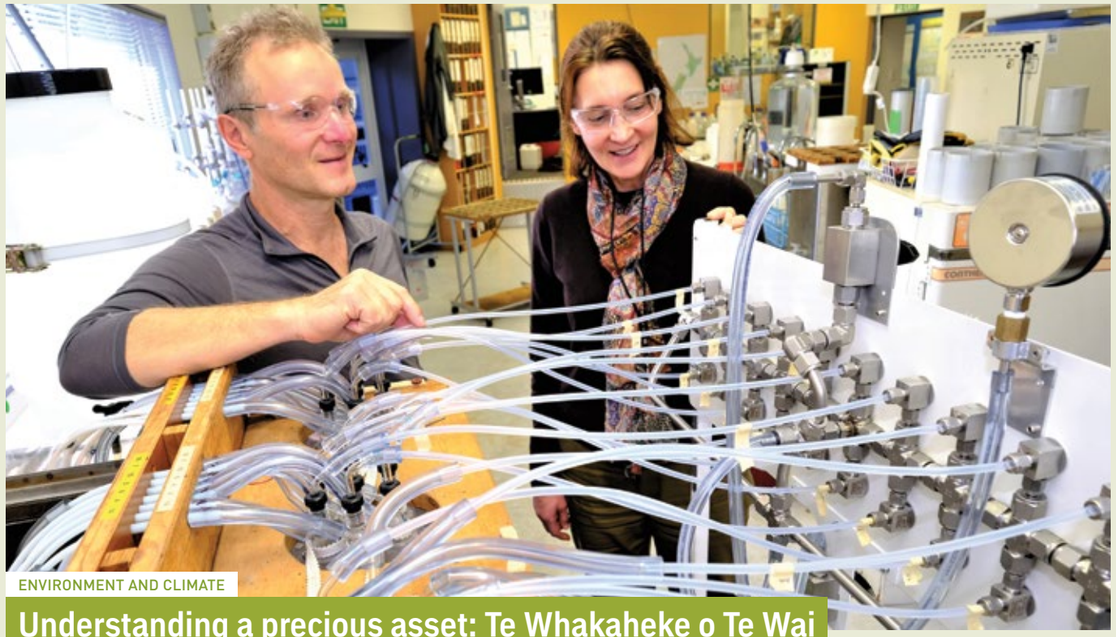
Throughout the field sampling campaign, the team has worked closely with iwi. In four areas – Wairarapa Moana, Rangitīkei, Rangitoto ki te Tonga/D'Urville Island and Otago – they have worked in partnership with iwi to weave mātauranga Māori with scientific data to enhance knowledge on lake mauri (wellbeing) and assist with restoration. They have produced a range of audio-visual platforms, including documentaries and augmented reality displays.

These are helping reconnect whānau globally with their roto (lakes) and to convey stories of the lakes and aspirations for their future.

The project relies on strong research partnerships with Victoria University of Wellington, University of Otago, Waka Taurua Ltd, Matana Consulting, Ngā Puna Rau o Rangitīkei, Ngāti Kahungunu ki Wairarapa, The University of Auckland, more than 10 international organisations, and iwi around the country.

The five-year project is a great example of how we work with local communities and how our science can make a real difference. The project is now into its fourth year and is funded through the Ministry of Business, Innovation and Employment's Endeavour Fund with support from our Strategic Science Investment Fund (SSIF) funding.

For more information visit: Lakes380.com



ENVIRONMENT AND CLIMATE

Understanding a precious asset: Te Whakaheke o Te Wai

Freshwater is central to every aspect of life, and a greater and deeper understanding of its movement through the Earth is the cornerstone of a multi-year project led by GNS Science. Our aim: boosting freshwater quality and security of supply to benefit drinking water safety, cultural values and sustainability for agriculture, tourism, and regional economies.

The GNS Science-led project – Te Whakaheke o Te Wai – will produce a world-first series of maps showing flow paths of freshwater in Aotearoa New Zealand's aquifers. Nationally there are 20 major aquifers plus more than 100 lesser ones. This project focuses on the aquifer under the Heretaunga Plains in Hawke's Bay and it tracks the entire hydrological cycle: from when water falls as rain, its pathways through aquifers, to when it is taken from wells for households and other uses.

About 19 billion cubic metres of rain falls in Hawke's Bay each year. More than half goes straight out to sea and the rest moves through the region's aquifers. In the north, the aquifer system is river-fed, with water moving rapidly at first but slowing down considerably by the time it reaches the coast. In the south of the plains, the groundwater is recharged from rain.

Our research has shown the oldest groundwater in this system is about 4,000 years old and is found at a depth of about 250m underground. However, most of the water drawn off for household use, agriculture, and industry has been travelling through the aquifers for less than 10 years. Modelling these complex underground flow paths will predict the outcome of different management scenarios.

This will incorporate chemical data, as well as the effects of geology, seasonality, and interaction with streams and rivers.

Mātauranga Māori is central to this project. Combining western science with indigenous knowledge will promote a collective understanding of the whakaheke of water, its relationship to whakapapa, and its role in empowering kaitiakitanga.

> **"As a result of this research, we will be able to manage our water resources more rapidly and effectively: from a local level, including complex water resource issues at Bridge Pa that affect local hapū, to the entire Heretaunga Plains and other regional aquifer systems. More broadly, having these tools that can be applied nationally will help the whole country deal with some of the problems we are facing with water resource management."**
>
> Dr Jeff Smith, Manager – Science, Hawke's Bay Regional Council

The outputs from Te Whakaheke o Te Wai will support decision-making from the national scale through to smaller scale areas to guide the development of national policies, manage contaminant inflows to groundwater-fed rivers, and protect drinking water supplies.

GNS Science leads this project in collaboration with multiple organisations, including major partners NIWA and ESR. Funding has been provided by the Ministry of Business, Innovation and Employment's Endeavour Programme contestable fund.

SNAPSHOT

20
Nationally there are 20 major aquifers plus more than 100 lesser ones

2.5D
All New Zealand coastal aquifers have now been mapped in 2.5D

19 billion
About 19 billion cubic metres of rain falls in Hawke's Bay each year

4,000 years
The oldest groundwater in this system is about 4,000 years old

250m
It is found at a depth of about 250m underground

Top: Co-leaders of the Te Whakaheke o Te Wai project Uwe Morgenstern and Catherine Moore in GNS Science's Water Dating Laboratory.

ENVIRONMENT AND CLIMATE

Lessons from the Amazon help NZ's carbon accounting

Meeting our atmospheric carbon emission targets requires heavy-duty science – and the first step is measurement. Working out our carbon budget involves estimating how much carbon goes into the atmosphere – and how much is taken up by the land. GNS Science has brought in expertise from Brazil to help work out how current carbon accounting rules line up with what's happening in the real world.

Brazilian scientist Lucas Domingues has joined our team fresh from helping to determine how much carbon is being taken up by the Amazon rainforest. The Amazon has long been considered the world's largest 'land carbon sink'. But Lucas' work contributed to recent findings showing that due to fires and deforestation the south-eastern part of the Amazon is no longer taking up carbon and is now a net carbon emitter. This major finding has global significance.

As Aotearoa New Zealand considers how to reach its goal of net-zero carbon emissions by 2050, assessing the size of our own 'land carbon sink' will be crucial. In Auckland, as part of the multi-organisation CarbonWatch programme, we are measuring fossil fuel emissions and, at the same time, trying to understand the land carbon uptake. Scientists suspect urban environments could be a significant carbon sink, but this has not been measured in a systematic way.

Lucas' expertise is crucial to the project in Auckland. He has helped set up sophisticated monitoring sites that continuously record the amount of carbon dioxide, carbon monoxide, water vapour, and methane in Auckland's air. His team also designed a flask sampler which autonomously collects air samples that are subjected to a range of analyses back in the lab that can reveal much about the way urban environments 'breathe'.

> **"Auckland has a target of halving carbon emissions by 2030 and reaching net-zero emissions by 2050. Auckland Council is taking many actions to support Auckland to achieve the goal. Measuring greenhouse gas emissions provides robust evidence to evaluate our progress and inform future policy development."**
>
> Dr Shanju Xie, Senior Scientist, Kaipūtaiao Matua Research & Evaluation Unit (RIMU), Auckland Council

GNS Science and policy-makers have worked closely together in designing this project. When we fully understand how much emitted carbon is being absorbed back into the Earth, carbon credits can accurately reflect what is actually happening in our biosphere.

SNAPSHOT

Working out our carbon budget involves estimating how much carbon goes into the atmosphere – and how much is absorbed into the Earth

The Amazon has long been considered the world's largest 'land carbon sink'

Monitoring sites record the amount of carbon dioxide, carbon monoxide, water vapour, and methane in Auckland's air

Top: Carbon Cycle Scientist Lucas Domingues with a read out from one of the high precision greenhouse gas analysers installed in Auckland.

ENVIRONMENT AND CLIMATE

Drastic emissions cuts will curb worst effects of ice melt

The evidence continues to mount: cutting emissions is essential if we are to limit the most damaging effects of climate change. GNS Science ice sheet modeller Dan Lowry contributed to a major international study this year, which showed that limiting global warming to 1.5 degrees Celsius could reduce sea level rise from polar ice melt from 25cm to 13cm by 2100.

The study was published in *Nature* and it is the latest and best forecast relating to rising oceans. It clearly illustrates both the benefits to be gained from a sharp cut in emissions of carbon dioxide and other heat-trapping gases, and the dangers of failing to do so: more flooding, costly modifications to coastal infrastructure, and displacement of coastal communities.

The scenario-based land-ice projections are being used by the award-winning NZ SeaRise programme, led by GNS Science and Victoria University of Wellington, to determine how Aotearoa New Zealand coastlines will be impacted at the local level.

The 1.5ºC target is the stricter of the two targets set by the 2015 Paris agreement to combat climate change.

However, the world has already warmed about 1.1ºC since 1900 and is not on course to meet the 1.5ºC target, or even the higher Paris goal of 2ºC.

Even if drastic steps are taken – efforts to remove carbon dioxide from the atmosphere, for example – warming is projected to remain at a level where not enough new ice can accumulate to replace what is lost. Melting of ice currently accounts for about half of sea level rise and most of the remainder is a result of expansion of ocean water as it warms.

The findings have informed the United Nations Intergovernmental Panel on Climate Change's Sixth Assessment Report, and the data will be incorporated into the next Ministry for the Environment report on coastal hazards and climate change.

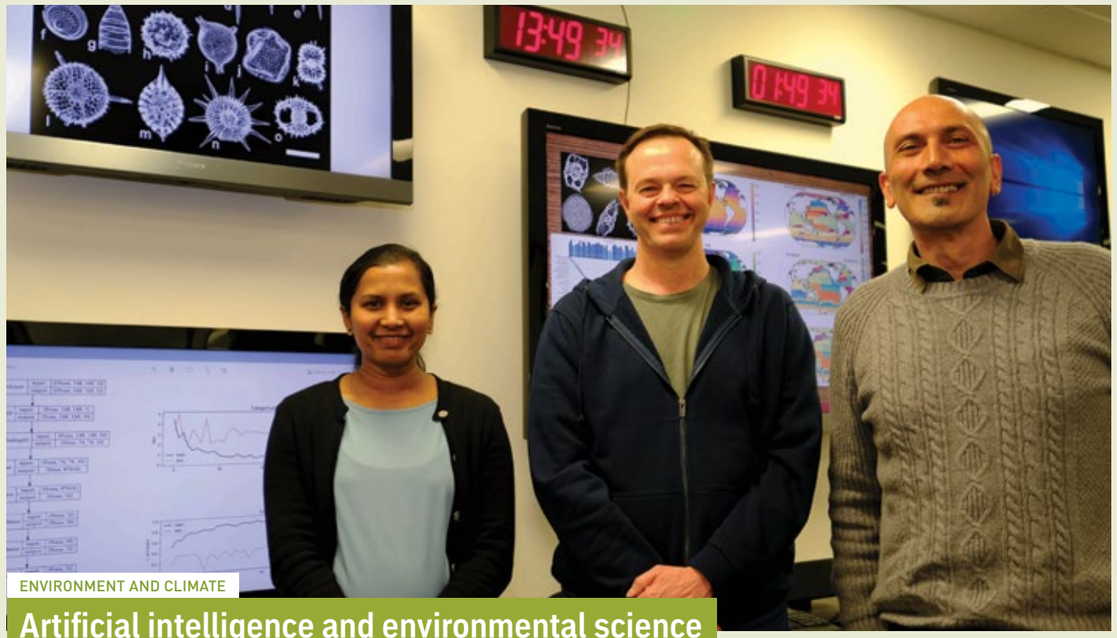
Top: Ice sheet modeller Dan Lowry on the Ross Ice Shelf in Antarctica installing GPS stations to monitor seasonal changes in ice flow velocity.

SNAPSHOT

1.5ºC
Limiting global warming to 1.5ºC could reduce sea level rise from polar ice melt from 25cm to 13cm by 2100

1.1ºC
The world has already warmed about 1.1ºC since 1900

1.5ºC
The world is not on course to meet the 1.5ºC target, or even the higher Paris goal of 2ºC



ENVIRONMENT AND CLIMATE

Artificial intelligence and environmental science

How can artificial intelligence contribute to environmental science? The answer lies in technology that's very similar to Facebook's face recognition software – and it could help predict future climate behaviour.

Data science techniques like machine learning and artificial intelligence help GNS Science extract meaningful information from large Earth science datasets to predict future patterns for a range of applications. Artificial Neural Networks drive face recognition on Facebook and in security cameras – and GNS Science has designed algorithms that automatically capture, classify and store images of microscopic plankton fossils.

Fossilised plankton is a rich treasure trove of information which tells us how climate changed in the past. This helps us understand what processes drove the observed change, and by looking back, we can refine the models we use to forecast future change. These will help shape our climate adaptation policies and increase Aotearoa New Zealand's resilience.

When combined with ecosystem models, the plankton data helps us model different climate scenarios and how they might interact with the planet's natural cycles. For example, our scientists are combining data science, paleontology and marine ecosystem studies to explore historic large changes at the base of the oceanic food chain that occurred during past warm climates.

Under the regional council-driven scheme Envirolink, we have worked closely with a number of councils to show how satellite data of land, soil, vegetation and inland waterways can be used to improve environmental management. The technical solutions, co-designed with councils to meet their needs through interactive stakeholder workshops, have equipped councils with a powerful tool that has given them a sounder footing for developing their environmental management plans.

Elsewhere, we use satellite radar imaging data (InSAR) to measure the deformation of the Earth's surface to better understand volcanic and seismic activity. Artificial intelligence methods allow us to analyse this data to assess the potential for landslides after earthquakes and heavy rainfall. We also use machine learning to identify previously unrecognised faults in the landscape from LiDAR images.

Data science and artificial intelligence methods enable GNS Science to use data-rich, complex Earth science datasets to get high-impact results for Aotearoa New Zealand.

Top: Scientists Sapthala Karalliyadda, Christof Mueller, and Giuseppe Cortese all use artificial intelligence and data science in their various research disciplines at GNS Science.

SNAPSHOT

Designed algorithms that automatically capture, classify and store images of microscopic plankton fossils

Fossilised plankton tells us how climate changed in the past

Satellite radar imaging data is used to measure the deformation of the Earth's surface to better understand volcanic and seismic activity

SCIENCE THEME

ENERGY FUTURES

As 'the Energy Crown Research Institute', GNS Science plays a major role in enabling Aotearoa New Zealand's transition to a low-carbon energy future. Our research aims to increase opportunities to use renewable energy resources, make efficiency gains, and grow the country's energy resource security.

GREEN HYDROGEN

GNS Science's green hydrogen research could transform the way New Zealanders produce, use and store energy in the future. We are leading a team of national researchers in an ambitious research programme which centres on new ways to produce and store green hydrogen, as well as building capability in the hydrogen industry.

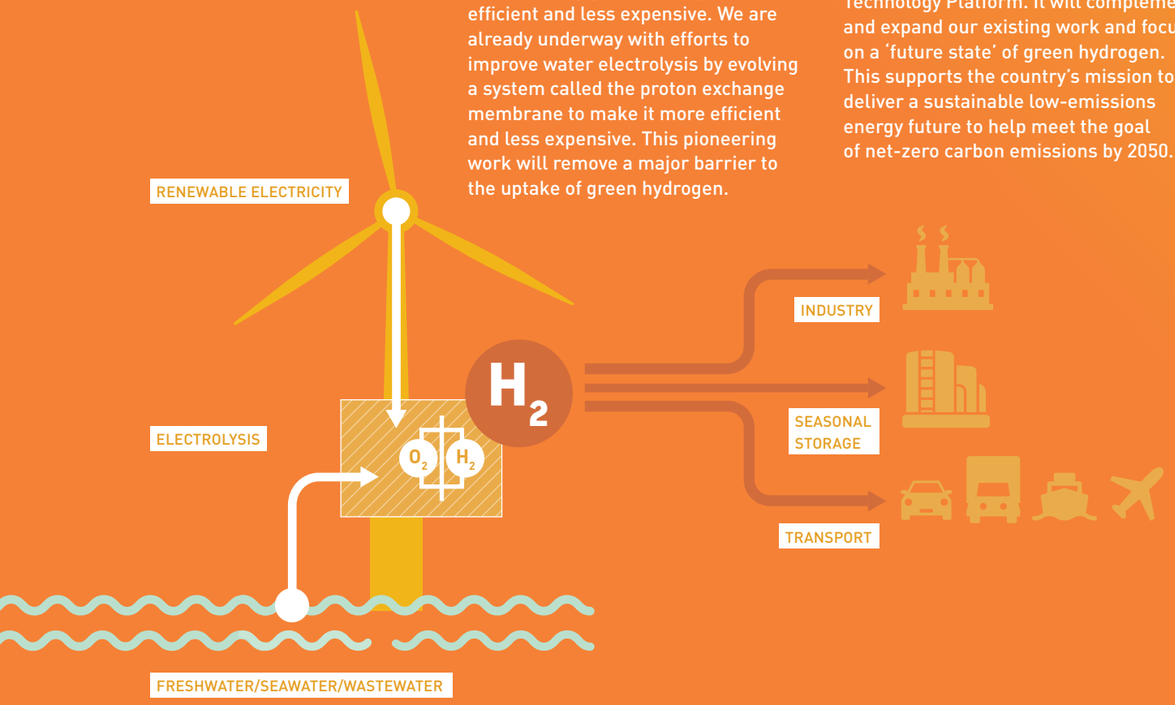
Nearly all of the hydrogen produced around the world is 'brown' hydrogen, created using energy generated from coal and natural gas. Green hydrogen is made with electricity from renewable energy sources, using electrolysis to split water into hydrogen and oxygen without any carbon by-product.

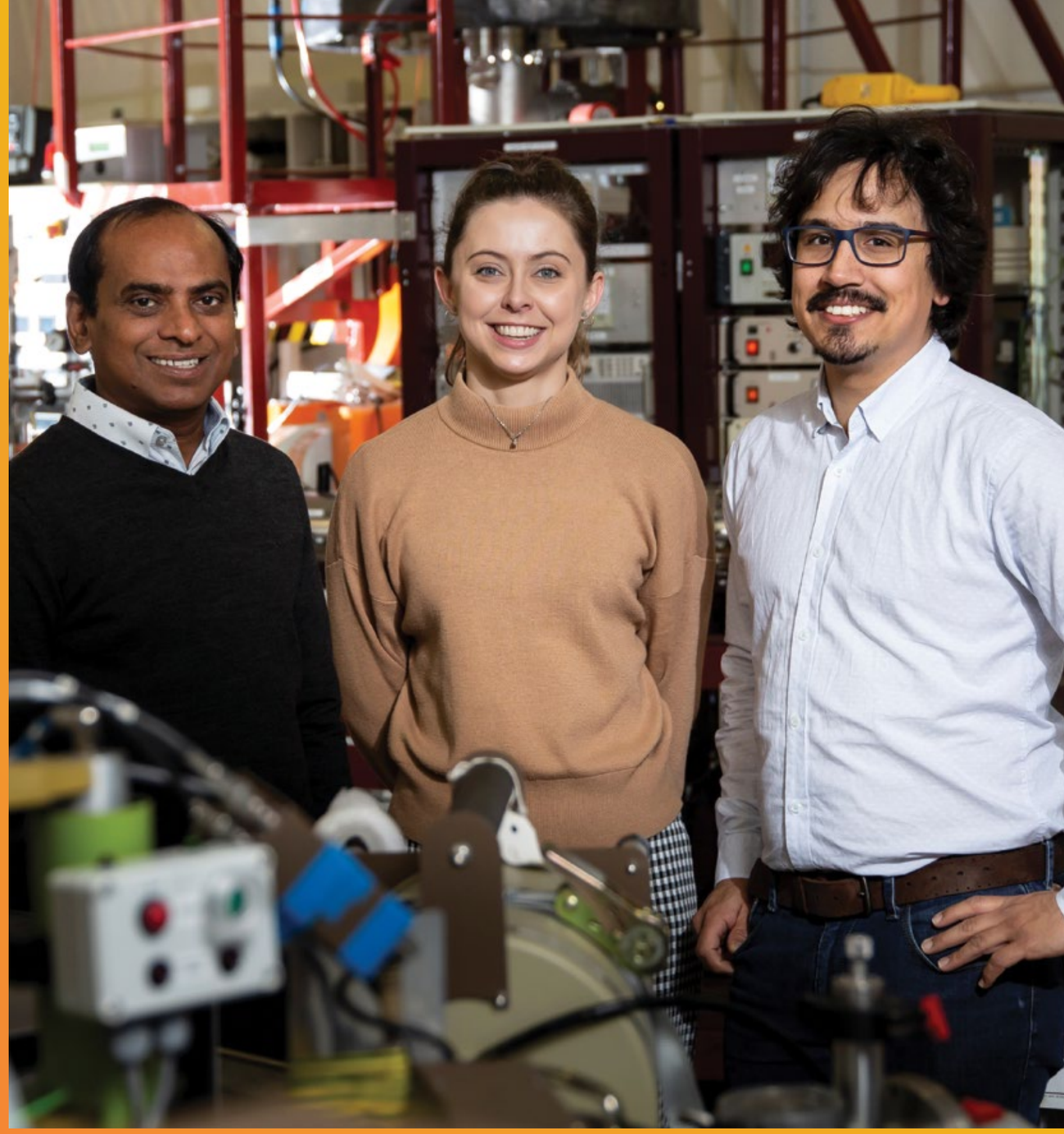
Green hydrogen could be a vital component in Aotearoa New Zealand's clean energy mix. The project's goal is to develop transformative technologies that facilitate the sustainable production of green hydrogen to replace fossil fuels for stationary power and transport industries, which currently contribute about 40 percent of the country's greenhouse gas emissions.

GNS Science's materials science experts aim to make the process for producing green hydrogen more efficient and less expensive. We are already underway with efforts to improve water electrolysis by evolving a system called the proton exchange membrane to make it more efficient and less expensive. This pioneering work will remove a major barrier to the uptake of green hydrogen.

A key part of the project is the development of technologies that will make it possible to produce green hydrogen from modified solar power. At present, green hydrogen production uses electricity from wind and solar. But a direct sunlight-to-hydrogen catalysis system will enable off-grid hydrogen production for smaller and more isolated communities. And for additional efficiencies, our scientists are working on ways to use wastewater and seawater in the catalysis process. Currently only pure freshwater is used to produce green hydrogen.

We are also aiming to build capability in the hydrogen industry. In 2021 GNS Science was awarded $9.2 million to host a six-year research programme in the Ministry of Business, Innovation and Employment's Advanced Energy Technology Platform. It will complement and expand our existing work and focus on a 'future state' of green hydrogen. This supports the country's mission to deliver a sustainable low-emissions energy future to help meet the goal of net-zero carbon emissions by 2050.



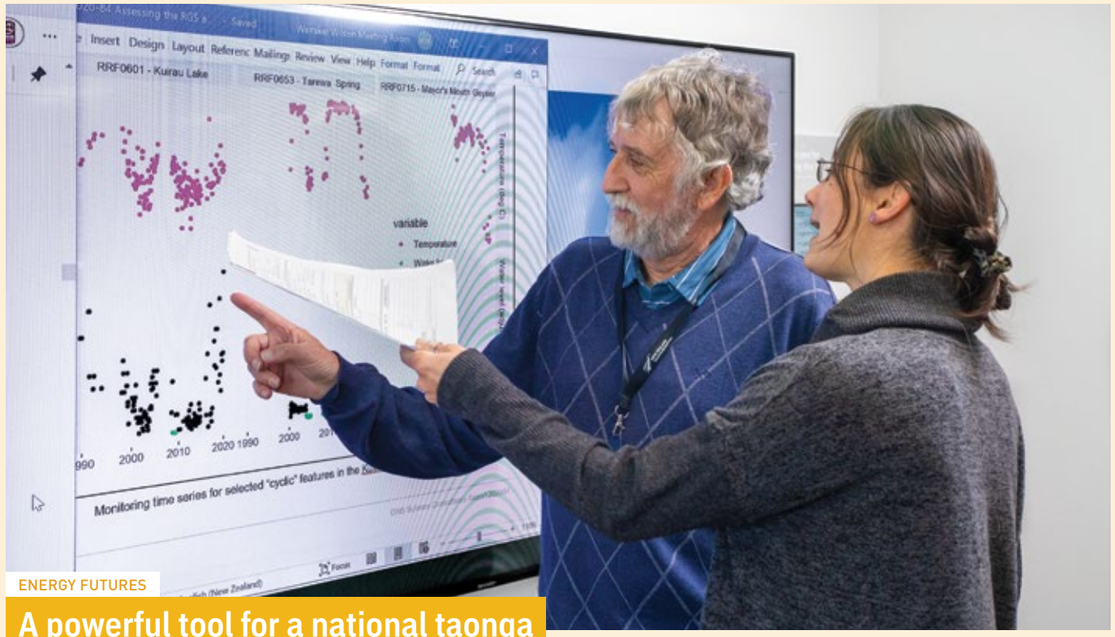


The project is built on a consortium-style model that connects industry, science and education to produce benefits across society, the economy, and the environment.

GNS Science will partner with iwi and wānanga to support the learning and development of Māori in the energy sector. We are planning to offer grants, scholarships, and placements to open up career pathways for scientists, engineers, and technicians to ensure that qualified people are available to fill jobs as the industry grows. This will help build green hydrogen into a resilient, net-zero carbon energy system for Aotearoa New Zealand.

The programme is led by GNS Science and includes collaborations with Victoria University of Wellington, The University of Auckland, University of Canterbury, University of Otago and the MacDiarmid Institute, as well as industry and private companies.

Top: Key members of the Aotearoa New Zealand Green Hydrogen Technology Platform at GNS Science John Kennedy, Michelle Cook and Jérôme Leveneur.



ENERGY FUTURES

A powerful tool for a national taonga

The Rotorua Geothermal System is a taonga. It's one of New Zealand's foremost tourist attractions, with a subsurface system that covers about 12 square kilometres in and around Rotorua, and is home to many of Aotearoa New Zealand's remaining geysers, large hot springs and mud pools. It is therefore culturally, environmentally and economically important to the nation.

Our partnership with the Bay of Plenty Regional Council is helping to ensure the long term health of this globally important geothermal system. We monitor about 40 of its 1,500 geothermal surface features bimonthly for the Council, and the Council also collects data from a number of shallow geothermal and groundwater monitoring wells.

In the 1980s the government initiated a bore closure programme due to a serious decline of surface features. The system responded positively to the closures, and more recently this has been boosted by an active management under the Rotorua Geothermal Regional Plan.

A recent GNS Science report summarising four decades of monitoring data has given the Council a sound platform from which to fine tune its management plans for the future. The report marks the first time we have analysed the full 40 years of data to examine long-term trends. It provides a fuller understanding of the relationships between the current uses, characteristics of the geothermal reservoir, groundwater systems, and the status of surface geothermal features such as geysers and hot springs.

The report highlights that the system is not bullet proof and will need careful management to remain healthy. One of the findings highlights the importance of long term rainfall trends in the health of the system – meaning small changes in the long term climate trends could impact the status of the shallow underground reservoir.

The report also reinforced that while many features have recovered to a pre-exploitation state and are stable, others are still improving or are fluctuating. Today there are about 140 consented geothermal takes for water and space heating for private homes, bathing, hospitals, schools, motels and other industrial uses. These all have limits set under the Rotorua Geothermal Regional Plan. Management of the geothermal system remains complex with so many different users and differing views on significance among the Rotorua community.

The report concludes by making a series of recommendations to improve the monitoring and understanding of the geothermal system so that use can continue, while maintaining the world-renowned geothermal surface activity.

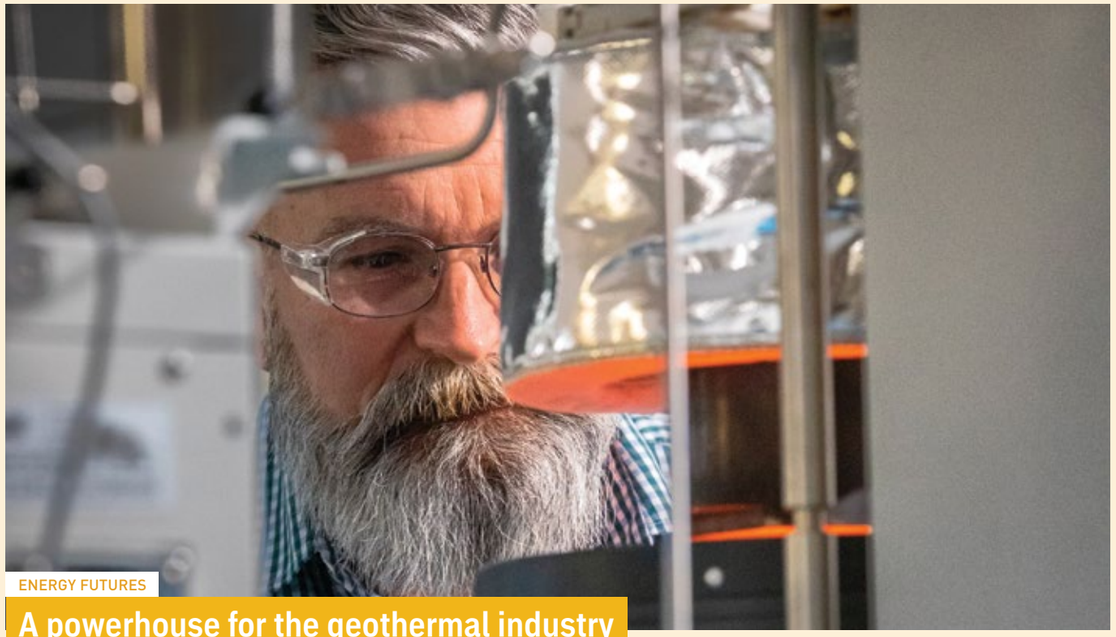
Top: Report authors Brad Scott and Magali Moreau discuss 40 years of monitoring data from Kuirau Lake hot spring in Rotorua, as part of a comprehensive review for the Bay of Plenty Regional Council.

SNAPSHOT

12km²
Rotorua Geothermal System covers about 12 square kilometres in and around Rotorua

40/1500
We monitor about 40 of Rotorua's 1500 geothermal surface features bimonthly for the Council

Small changes in long-term climate trends could impact the status of the shallow underground reservoir



ENERGY FUTURES

A powerhouse for the geothermal industry

The GNS Science experimental geochemistry lab at our Wairakei campus was already one of the best in the business, but it is now unique in the world. A recent upgrade has extended its capabilities, with new equipment that replicates the high pressures and temperatures found in geothermal reservoirs up to 7km below the surface.

The laboratory's research work is focused on geochemistry questions in geothermal environments, while its commercial work helps geothermal energy operators better understand the subsurface environments in which they operate. It helps our clients solve problems and improve the productivity and sustainability of their geothermal plants.

The facility now has four high temperature and pressure reactors. They are designed to study chemical reactions between water-based fluids and rocks at depth. The upgraded equipment can operate at temperatures up to 700°C and 300 atmospheres to simulate extreme conditions found in the deepest geothermal environments in the world. Three-hundred atmospheres is 300 times the pressure you would feel at sea level.

The lab specialises in predicting the effects of fluid re-injection in geothermal reservoirs and testing the effectiveness of compounds added to water to prevent deposits that can clog pipes. It also helps in combatting corrosion inside geothermal power stations and helps operators choose the best materials for different parts of their power plants. While geothermal simulations form the bulk of its work, the facility can also be used to study the formation of mineral deposits in the subsurface.

In order to realise the energy available at greater depths, we need to understand the chemical and physical conditions in these environments. As the geothermal industry explores deeper environments in pursuit of more energy at the surface, the laboratory will be an important partner.

Top: Lead Scientist in the Experimental Geochemistry Laboratory at Wairakei, Bruce Mountain, working with ultra-high temperature apparatus which can simulate fluid-rock interactions deep within the Earth.

SNAPSHOT

7km
New equipment replicates the high pressures and temperatures found in geothermal reservoirs up to 7km below the surface

700°C
The upgraded equipment can operate at temperatures up to 700°C and 300 atmospheres

The lab tests the effectiveness of compounds added to water to prevent deposits that can clog pipes

ENERGY FUTURES

Super hot, super deep, supercritical

Supercritical geothermal is uncharted territory. The reservoirs are more than 5km deep, and the fluid temperatures are above 400ºC – capable of producing many times more energy than conventional geothermal wells. GNS Science is working with colleagues in Japan to explore these 'supercritical' fluids, which could hold the key to meeting our future energy needs.

While several countries are working towards this goal, no-one has managed to successfully harness deep geothermal resources yet. At supercritical temperatures and pressures, fluid becomes a different beast and behaves more like a gas. It transfers energy much more efficiently than conventional fluids in geothermal systems, but extreme pressures and corrosiveness encountered in these deeper environments can overwhelm conventional well and power station technologies. Sharing knowledge and expertise with Japanese colleagues is an important part of overcoming the technical and engineering challenges in this quest.

Japan has an ambitious energy plan to double the renewable energy component of its national energy mix. Geothermal is seen as a crucial part of this, including supercritical resources. Our Japanese colleagues have strong capabilities in engineering and knowledge of rock properties, and they are also planning to drill deep geothermal wells to intercept supercritical fluids. Combined with GNS Science's expertise in geochemistry, geophysics, and modelling, the sharing of knowledge from this drilling initiative will benefit both countries.

With increasing demand for low-emissions electricity and increasing pressures on our water resources, conventional and supercritical geothermal are seen as an attractive option for future renewable energy sources. Conventional geothermal energy, which currently supplies 17 percent of our national electricity needs, could be teamed up with supercritical to provide a reliable 24/7 source of electricity. This baseload is currently provided by hydro-electric generation, which can struggle in dry years, and thermal (fossil fuel) generation.

Our recently upgraded experimental geochemistry laboratory, based at our Wairakei facility, is already contributing significantly to supercritical research by simulating conditions at extreme depths. It is currently working with international partners to help in the development of well drilling and power station materials capable of dealing with the extremes of supercritical fluids.

Top: Leader of the multi-organisation project to investigate the feasibility of deep geothermal energy, Isabelle Chambefort of GNS Science, studying the link between magmas and hydrothermal fluids at depths beyond conventional geothermal reservoirs.

SNAPSHOT

5km
The geothermal reservoirs are more than 5km deep

Fluid temperatures are above 400ºC

Our Japanese colleagues have strong capabilities in engineering and knowledge of rock properties

17%
Conventional geothermal energy supplies 17 percent of our national electricity needs

A draft energy research strategy and roadmap have been developed

Right: GNS Science provides specialist scientific services to the geothermal energy industry in Aotearoa New Zealand. Pictured is the Ngā Awa Pūrua Geothermal Power Station, northeast of Taupō. Mercury Energy operates the power station in a joint venture partnership with Tauhara North No.2 Trust. The plant is notable for having the largest single-shaft geothermal turbine in the world.

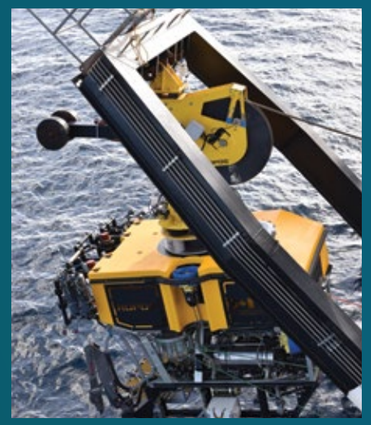
SCIENCE THEME

LAND AND MARINE GEOSCIENCE

Our research is addressing fundamental questions about the composition and architecture of the continent Te Riu-a-Māui / Zealandia and the geological processes that have shaped it. The geoscience data we collect contributes to improved resilience to geohazards, managing natural resources sustainably, and adapting to a changing climate.

A FRONT-ROW SEAT TO THE INTERNAL WORKINGS OF NZ'S LARGEST FAULT

Aotearoa New Zealand's unique geography is yielding insights into the behaviour of subduction faults – both the Hikurangi subduction zone off the east coast of the North Island, and others around the world.



Left: The Canadian-built ROPOS submersible was used for the first time in Aotearoa New Zealand this year to investigate the Hikurangi subduction zone during a GNS Science-led voyage on NIWA's research ship *Tangaroa*.
Right: Scientists watch a live video feed from cameras on the Canadian-built ROPOS submersible as it explores the seabed above the Hikurangi subduction zone off the North Island's east coast.

The Hikurangi plate boundary is where the Pacific tectonic plate subducts – or dives underneath – the Australian plate. Subduction faults are responsible for some of the largest and most powerful earthquakes and tsunami in the world, so understanding their internal workings is crucial to communities along the east coast.

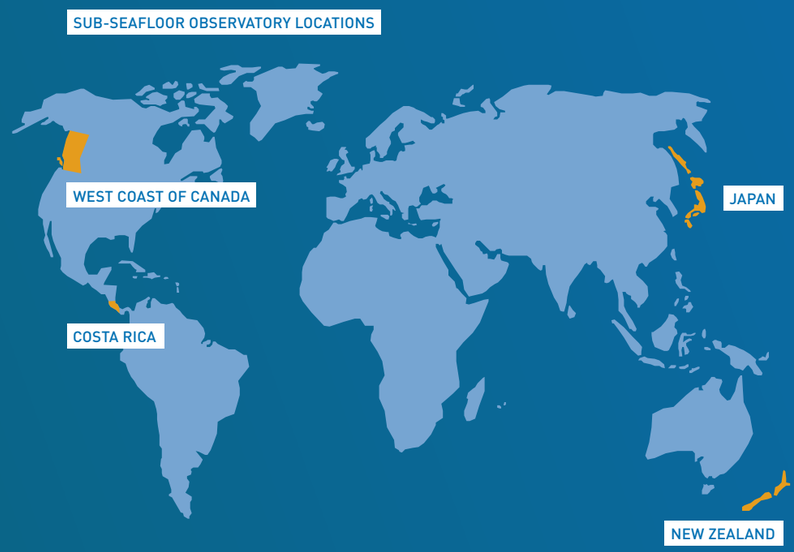
Two seafloor observatories were installed east of Gisborne in early 2021, continuously recording a range of physical and chemical changes inside the fault including the enigmatic 'slow-slip' events common on the fault. One is installed 40km off the Gisborne coast 1,000m below the sea surface, and the other sits 80km off the Gisborne coast in water depths of 2,500m.

They sit right on top of the fault, recording very high resolution data – which is then collected by the Canadian-built ROPOS Remotely Operated Vehicle, which docks with the seabed observatories and downloads their recorded data. Scientists can clearly see two large slow-slip events plus at least half a dozen smaller ones. Only two of these events had been clearly visible in the data recorded by onshore GPS instruments. The new data enabled scientists to observe how Hikurangi slow-slip earthquakes evolve in much greater detail than any other types of data they have used before.

Aotearoa New Zealand is one of only four places in the world where these hi-tech sub-seafloor observatories are keeping tabs on offshore plate boundaries. Others operate off Japan, Costa Rica, and Canada's west coast. With on-board batteries designed to last for a decade, the observatories record valuable data round the clock and all year round. They extend down 400m below the seabed to give scientists an intimate view of the plate boundary fault.

Information acquired from the seabed observatories will add to scientists' growing understanding of the Hikurangi subduction zone and the earthquake and tsunami risk it poses to Aotearoa New Zealand. The voyage to service the observatories took place on NIWA's research ship *Tangaroa* and included scientists and engineers from GNS Science, NIWA, the University of Washington, the Canadian Scientific Submersible Facility, Victoria University of Wellington, and The University of Auckland.

The voyage was supported by funding from the Ministry of Business, Innovation and Employment, and by the United States National Science Foundation. The two seafloor observatories were funded by the National Science Foundation and the International Ocean Discovery Program.



Capturing the moment

In June this year our scientists deployed nearly 50 short term seismic and GPS instruments in southern Hawke's Bay and the Wairarapa to capture data on a slow-slip event that was happening under that region. Data from the network will greatly improve our understanding of how and why these slow earthquakes occur so regularly, and what causes them to happen in the first place.

Slow-slip events are common along the Hikurangi subduction zone and, as the name suggests, the energy is released over weeks to months, rather than as a sharp jolt in a more 'conventional' earthquake. They occur when the boundary between Australian and Pacific tectonic plates becomes temporarily 'unstuck', and the plates begin creeping past each other.

Humans can't feel slow-slip earthquakes as they happen so slowly. They are also too slow to be picked up by seismometers, so they have to be recorded with special GPS equipment that can measure the slow movement of the land.

Pōrangahau is at the centre of the project because it experiences slow-slip earthquakes every four years. The temporary network will enable scientists to capture information on the slow-slip event, and its associated small earthquakes, in much greater detail.

The short-term deployment is in addition to an array of seabed seismic instruments specially deployed last year, and the data continually collected by the nationwide GeoNet network. All together, this will provide a clearer picture of how energy builds up and gets released.

We've observed previously that small quake earthquake behaviour changes both before and during slow-slip events, but not in enough detail to fully understand why. Armed with the data from the land-based and offshore networks, scientists hope to see if changes in the subduction zone could help forecast large earthquakes.

LAND AND MARINE GEOSCIENCE

Showcasing homegrown geology to the world – virtually

Imagine travelling through a pre-historic landscape and learning about major geological features – all from the comfort of your laptop screen. When COVID-19 made running conferences impossible, scientists moved their events online, including field trips. But how do scientists recreate the experience of being out on location?

Like many events in 2020, the Ninth International Symposium on Submarine Mass Movements and Their Consequences – otherwise known as underwater landslides – had to be held virtually. The organisers invited us to make an online field trip for conference participants that was both entertaining and informative. The ideal solution: a virtual visit to the magnificent onshore pre-historic examples of these preserved in the landscape of northern Taranaki.

Taking GNS Science's expertise at organising and hosting physical fieldtrips, we tackled the assignment head on. The challenge was to capture not just the information, but the feeling of being out in the field.

The result is a self-guided virtual trip comprising videos, 3D models of geological outcrops, field photos, and drone footage – all in a digital platform that enables viewers to immerse themselves and 'explore' the landforms at their own pace. We wanted participants to have the experience of an actual field trip and share the encounter with colleagues.

The pandemic has accelerated the need for new digital learning models, and it has forced scientists to get creative with how they convey complex concepts and ideas. We are keen to develop these powerful tools as part of our geoscience and communication portfolios. It gives us a way of bringing understanding of our unique landscape and geology to a wide audience – enabling access to remote sites and geological features.

Top: Geologists and virtual tour guides Suzanne Bull and Malcolm Arnot at Jam Roll Bay on the north Taranaki coast, one of the sites that features in our first virtual field trip.

SNAPSHOT

The organisers invited us to make an online field trip for conference participants

The digital platform enables viewers to immerse themselves and 'explore' the landforms at their own pace

The pandemic has accelerated the need for new digital learning models

LAND AND MARINE GEOSCIENCE

Mapping our urban foundations

A new set of geological maps for some of Aotearoa New Zealand's fastest-growing regions will help decision-makers plan for the future.

GNS Science's urban geological mapping programme aims to provide geological information that will contribute to planning and infrastructure development in rapidly growing areas. The map sets typically include geological and geomorphological maps, a 3D model, borehole information, and geotechnical information.

As well as helping to manage and mitigate geological hazards, these maps aid management of geological resources such as aggregate and groundwater.

We have completed an urban geological map for Christchurch, and similar maps for Dunedin, Napier-Hastings, and South Auckland are nearing completion. This latter map covers 830sq km of this rapidly growing region – from Papakura in the north to Pokeno in the south, and from Waiuku and Clarks Beach in the west to the Hunua Ranges in the east.

The previous geological map of South Auckland was nearly 30 years old and the new map shows much greater detail. It revises and updates rock classifications and combines recently captured aerial mapping image data with Geographic Information Systems software.

Another Auckland map – covering Silverdale to Warkworth – is our next major product in this urban series. Throughout the production process we involve stakeholders and end-users such as geotechnical consultants and councils.

Top: Looking south over the South Auckland area with new housing developments at Ormiston in the foreground and Manurewa, Takanini, Papakura, and the State Highway 1 corridor in the middle distance.

SNAPSHOT

These geological maps help decision-makers plan for the future

830sq km
The South Auckland map covers 830 sq km of this rapidly growing region

The Silverdale to Warkworth map is the next major project in the series

GNS Science is custodian of eight Nationally Significant Databases and Collections (NSDCs).

These NSDCs provide publicly-accessible geoscientific data for researchers, hazard and risk assessors, resource explorers, resource managers, and land-use planners. Some of the datasets date back to the earliest scientific activities carried out in Aotearoa New Zealand in the mid-19th century.

These databases and collections meet the FAIR Data Principles, enabling our most important underpinning databases and collections to be widely, efficiently and confidently used to deliver new insights and context for applied geoscience, education, policy setting, community engagement and industry benefit. For more information see https://www.gns.cri.nz/Home/Products/Databases/Nationally-Significant-Databases.

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LAND AND MARINE GEOSCIENCE

Hands-on geoscience experience for Kiwi kids

A humble sandbox paired with clever augmented reality technology creates the most immersive and exciting geoscience lesson ever. GNS Science experts have been on tour with this hands-on learning tool that introduces intermediate-aged students to Earth science as a fun and exciting experience.

Known as the Augmented Reality Sandbox, its aim is to engage a wide cross-section of young learners. Using a plywood box filled with sand and a digital projector, a computer displays topographic contours that adjust as sand is moved around inside the box.

> **"The learning opportunities offered through this experience were so engaging that I would recommend it being offered to all schools and would welcome the opportunity to have them return to our school."**
>
> Rose Symes, Teacher, Marotiri School, Mangakino

Tamariki create their own landscapes by digging into the sand to form mountains, valleys, and plains. Augmented reality layers such as elevation colour markings, topographic lines, and bodies of water are projected onto the sand, and adjust in real time as a sensor detects each change. With the wave of a hand, students can create rain, generate tsunami and see how topography controls water movement.

The Sandbox gives a tactile introduction to the way that water flows through different landscapes – and shows how sea level rise will impact our coasts and neighbouring island nations.
Our scientists present students with real-life scenarios and problems that they can investigate such as identifying areas prone to flooding or planning the best route for walking tracks.
The Sandbox also engages students with aspects of STEM (science, technology, engineering and mathematics) beyond geoscience and inspires them to think about ways in which science and technology work together. Students learn to identify landscape features, interpret topographic maps and apply maths concepts – as well as using creative and descriptive language to share their observations.

The project was made possible by Unlocking Curious Minds funding, support from REAP Wairarapa, REAP Central Plateau, and the Partnership Through Collaboration Trust.
A colleague at WelTec designed and built the Sandbox. The concept and software were developed by the University of California Davis W.M. Keck Center for Active Visualization in the Earth Sciences.

Top: Students shape landscapes in the Augmented Reality Sandbox to engage with map elements, water flow concepts and landform features.

SNAPSHOT

Its aim is to engage a wide cross-section of young learners

Tamariki create their own landscapes by digging into the sand to form mountains, valleys, and plains

They can create rain, generate tsunami and see how topography controls water movement

It shows how sea level rise will impact our coasts and neighbouring island nations

LAND AND MARINE GEOSCIENCE

Decision-making support for infrastructure development

Each year Aotearoa New Zealand consumes the equivalent of eight tonnes of aggregate per person across many uses: roading, construction and many other infrastructure projects. The need for aggregate is increasing in high-growth areas, and new and existing quarries will be needed to meet this demand.

GNS Science has produced the first national assessment of aggregate opportunities to help decision-making for infrastructure and land-use planning. Using physical, cultural, and economic criteria it ranks areas in terms of their potential to be a future hard rock or gravel resource.

Aggregate transport costs double in the first 30km and keep increasing with distance, so ideally quarries should be located close to their final market to minimise transport costs and carbon emissions. However, community sensitivities to quarrying can significantly constrain operators. Therefore, planners look for a 'goldilocks zone' that provides high quality raw material and keeps costs down, while also minimising factors such as noise, dust and heavy vehicles near built-up areas.

The study weights different gravel and hard rock opportunities across Aotearoa New Zealand, using spatial computer modelling of rock property information, current and forecast demand, land use, supporting infrastructure, cultural criteria and social licence, and environmental factors. Opportunities for hard rock such as greywacke, sandstone, basalt, and limestone are shown in one map, and another shows unconsolidated material such as river gravels, sand, boulders, and pumice.

> **"The quarry industry hopes this GNS Science study provides a turning-point in the increasingly expensive and frustrating efforts required to secure and maintain supplies of aggregate. As the study notes, transport over distance is the big and avoidable cost in providing the fundamental building block of all infrastructure – aggregate, sand and rock from quarries. I trust central government agencies and councils around the country will now plug this study into their planning and begin some rapid movement towards opening up new quarries in every region. These are urgently required, and I commend GNS Science for this pivotal study."**
>
> Wayne Scott, Chief Executive, Aggregate and Quarry Association

The maps are available as part of a digital data product, as GIS layers and as 21 printable map sheets covering the entire country. They are a powerful tool for council land-use planning, laying out guides for potential future quarry developments and identifying areas that could supply major infrastructure projects. Councils will find the report a valuable resource as they plan for future growth.

The New Zealand Infrastructure Commission Te Waihanga funded this report, and the project has been supported by the Aggregate and Quarry Association.

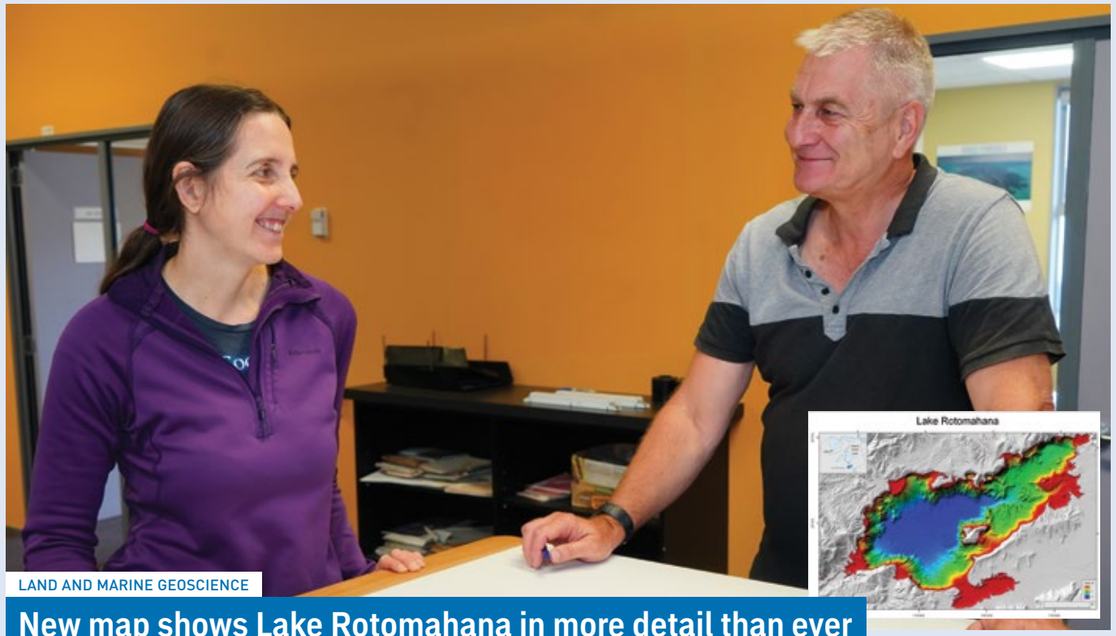
Top: The Rangitīkei Quarry in Manawatū is an example of a quarry that ranks strongly in the GNS Science report based on multiple criteria. The quarry supplies aggregate for roading and infrastructure development in the Manawatū.

SNAPSHOT

8 tonnes
Aotearoa New Zealand consumes the equivalent of eight tonnes of aggregate per person each year across many uses

30km
Aggregate transport costs double in the first 30km and keep increasing with distance

The study assesses different gravel and hard rock opportunities across Aotearoa New Zealand



LAND AND MARINE GEOSCIENCE

New map shows Lake Rotomahana in more detail than ever

The first new map of Lake Rotomahana in four decades reveals features not seen since before the 1886 eruption of Mount Tarawera – including the likely locations of the once-famed Pink and White Terraces.

The new bathymetric map represents nearly a decade of data gathering by GNS Science and our American partners, with resolution that is 400 times better than the previous map.

> **Post-Treaty-settlement iwi governance entities Tūhourangi and Ngāti Rangitihi say they are 'thrilled' with the new map and what it depicts. "The map is significant in that it locates the sites of Ōtūkapuarangi (The Pink Terrace) and Te Tarata (The White Terrace)."**
>
> Rangitihi Pene, Trustee of the Tūhourangi Tribal Authority

The Rotomahana map helps to put all existing information about the 1886 Mount Tarawera eruption and the geothermal systems under the lake into a much better context. It shows lakefloor features and other subtleties that have not been seen for more than a century, before the lake started to fill up immediately after the 1886 eruption.

Cutting edge techniques helped to build this full, high resolution picture. Multi-beam sonar provided a highly detailed view of the lakefloor, while seismic reflection techniques effectively 'stripped off' recent sediment deposits to reveal the surface of the lakefloor immediately after the eruption.

> **"The information GNS Science portrays in its Lake Rotomahana poster will not only elevate our understanding of geological and geothermal processes in the area, but it also provides a platform for greater understanding of lake dynamics."**
>
> Paul Scholes, Senior Environmental Scientist, Bay of Plenty Regional Council

Rotomahana increased to five times its original size after the 1886 eruption, which covered the surrounding countryside in mud and ash up to 40m thick. The blast was so violent, it could be heard as far away as Auckland and Christchurch. The A1-sized map is available from the GNS Science webshop, either as a downloadable PDF version at no cost, or a hard copy poster.

PDF version: https://doi.org/10.21420/E4FK-8P15
Print copy: https://shop.gns.cri.nz/rl-rotomahana/

It is the first of a series of new bathymetric maps of the Rotorua lakes being developed by GNS Science, with support from the Bay of Plenty Regional Council.

Top: Compilers of the Lake Rotomahana map Jenny Black and Cornel de Ronde.

SNAPSHOT

10 years
The new bathymetric map represents nearly a decade of data collection and analysis

400
The resolution is 400 times better than the previous map

100 years
It shows lakefloor features and other subtleties that have not been seen for more than a century

Lake Rotomahana increased to five times its original size after the 1886 eruption

40m
The eruption covered the surrounding countryside in up to 40m of mud and ash

LAND AND MARINE GEOSCIENCE

Marae-based Earth science learning

Tūhura Papatūānuku – or Explore Mother Earth – is the mission behind marae-based science learning camps, where rangatahi get to be 'science detectives' solving some of nature's biggest mysteries.

The three marae-based Geo Noho were run by GNS Science and our partners for intermediate-aged students in Northland. The four-night wānanga or 'science camps' aim to reveal the excitement and possibilities of science prior to students heading off to high school. The wānanga programmes were co-designed and co-delivered with Māori knowledge-holders and educators to incorporate mātauranga and te reo Māori with contemporary science concepts.

Holding these events in a familiar and immersive noho marae (marae stay) setting helps connect science with ancestral learning and community knowledge. Each wānanga begins with students exploring how to use observation and interpretation to answer questions about their environment. They start by asking a question – what is this that I can see? And how did it get here? – and then search for clues to solve the mystery.

The 'science detectives' use scientific equipment, with guidance from GNS Science specialists, to inspect items they collect during the day. The stimulating environment enables students to experience the thrill of learning new things every day.

Using their new skills, rangatahi learn about the geology and biodiversity of the environment around them and what it might have looked like thousands of years ago.

At the Whatuwhiwhi wānanga on the Karikari Peninsula, they explored the remains of ancient fossil forests in their area, learning about the water and carbon cycles, and testing differences between honey sourced from different plant species.

> **"We've found that this is a really powerful way to help our tamariki connect with science while ensuring we maintain a connection with a Te Ao Māori world view."**
>
> Joanne Murray, Kaiwhakapūmau, National Programme Coordinator at Te Aho Tū Roa

At the Geo Noho camps, students make their own discoveries – which helps them to see that anyone can be a scientist. They learn that every rock and every shoreline has a story to tell about how our environment was formed, and how it might change in the future. The confidence they develop helps them to see that they can be change makers in the world.

GNS Science ran the wānanga in partnership with Far North REAP and the Te Aho Tū Roa Programme – a nationwide hands-on learning initiative for young students – with support from the Unlocking Curious Minds contestable fund. We are planning more marae-based 'Explore Mother Earth' science camps this year.

Top: Students at the Whatuwhiwhi Geo Noho use a corer to collect a sample of sediment from Lake Ohia to examine under a microscope to understand the environmental changes within the area.

SNAPSHOT

The science camps aim to reveal the excitement and possibilities of science prior to students heading off to high school

Rangatahi learn about the geology and biodiversity of the environment around them and what it might have looked like thousands of years ago

They learn that every rock and every shoreline has a story to tell about how our environment was formed, and how it might change in the future

OUR ORGANISATION

Over the past year, the excellent work of our people has helped shape decisions that improve the lives of all New Zealanders.

Left: Volcano geochemistry technician Karen Britten collects gas samples from fumaroles on Mt Tongariro during scheduled monitoring of the volcano.

OUR PEOPLE AND CULTURE

Our people are at the heart of GNS Science's capabilities and success. They are central to our mission of delivering a Cleaner, Safer and More Prosperous Aotearoa New Zealand.

GNS Science continues to focus on developing our workforce in order to meet our strategic goals and deliver value to Aotearoa New Zealand.

Our investment in people is evidenced through the delivery of our People and Culture Strategy which focuses on leadership development, strategic workforce planning and capability, and diversity and inclusion. These initiatives are aimed at nurturing talent and ensuring our people feel valued for their work.

Developing our leaders

We continue to invest in building the capability of our leaders, particularly through the Tūhono Leadership Development Programme which began in 2021.

This programme focuses on three aspects: Technical, Performance, and Change Leadership. It is designed to help our people understand their different leadership contributions and is embedded in 'real work', with participants undertaking a signature change project as part of the programme. We continue to focus on improving core people leadership skills through an inhouse programme that traverses a range of topics relevant to our people leaders.

Strategic workforce planning and capability

This year we undertook a comprehensive review of the opportunities and challenges that we face in meeting our workforce capability and capacity requirements. This initial work on strategic workforce planning will help us to identify key initiatives required to secure our workforce of the future.

In June we finalised the design of the Career and Capability Development Framework. It is based on the 'one GNS' concept and is intended to promote satisfying and flexible career options for all of our employees. The Framework consists of a Career Pathways model (to guide career development) and Career and Capability Descriptors, which articulate the performance and behavioural expectations for employees at each stage of their career with us.

As part of the initiative to recognise and reward high performers, we have developed a Remuneration and Rewards Strategy, which is slated for implementation this coming financial year.

Diversity and inclusion

We adopted a comprehensive Workforce Diversity & Inclusion (D&I) Policy in August 2020, followed by the release of a resources page on the intranet and unconscious bias training for all staff. The D&I Committee was set up in early 2020 and has been active with events such as Pink Shirt Day, sponsoring women students to attend the AWIS Conference and providing input into the D&I Policy and the Accommodation Strategy.

The Ahunuku Scholarships and Māori intern programmes have been well received and will continue to grow, subject to funding and the availability of spaces. Towards the end of 2021, GNS Science partnered with other CRIs to develop a proposal for a mentoring and talent management programme for rangitahi across the sector. Work will continue on this in the coming year.

Within GNS Science, we continue to support employees in developing their bicultural competence through the provision of Te Reo and Tikanga courses, which were both well received and over-subscribed. A full bicultural competence programme is planned for next year, as part of the implementation of the new Career and Capability Development Framework.

As with other CRIs, GNS Science has traditionally had much greater numbers of men in senior scientist roles than women. This has impacted both our gender pay gap and development opportunities for employees.

A full bicultural competence programme is planned for next year, as part of the implementation of the new Career and Capability Development Framework.

Our Career and Capability Framework, and the associated performance and promotion processes, have been developed under a diversity and inclusion lens.

This has enabled us to identify those unintentional but systemic issues that create disadvantage within organisations. To date, we have overhauled the way we assess promotion, and two years on we have seen more women moving into senior scientist roles. We are implementing further changes to remove systemic barriers to career development for research and laboratory technicians, giving them the same level of career development opportunities as scientists.

Left: Using the ion-implantation system to manipulate the chemical and electronic structure of materials for energy conversion processes, GNS Science National Isotope Centre.
Right: GNS Science staff and participants of the last of our three Tūhura Papatūānuku Geo Noho GeoCamps, Haiti Tai-Marangai Marae, Whatuwhiwhi, Karikari Peninsula, Northland.

Early Career Staff Network

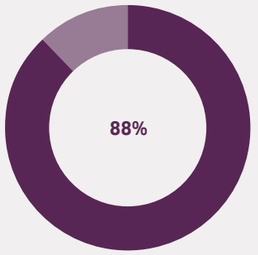
The Early Career Staff Network (ECSN) is a self-identifying group of early career staff lead by a council of its members representing the many aspects of early career life at GNS Science.

The ECSN facilitates the contribution of early career voices to our organisation's strategic decision-making, and provides career development, self-discovery, and social opportunities for early career staff.

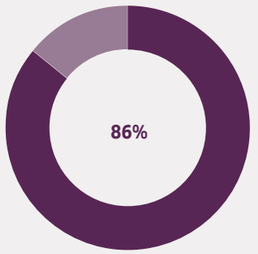
This year, the network grew to more than 120 members, who benefited from a variety of exciting ECSN initiatives.

This year, the network grew to more than 120 members, who benefited from a variety of exciting ECSN initiatives. These included the ECHO 'buddy' system supporting new staff, a series of Lunch n' Learn guest speaker events, an innovation workshop delivered in partnership with CreativeHQ, leadership training, and a new monthly newsletter sent to members offering early career specific news, opportunities and congratulations.

Top: Surveying the lake bed of Lake Roto Kawau to record fault fractures associated with the Wellington Fault, Zealandia Ecosanctuary, Wellington.
Left: Summer Research Scholar Emma de Jong organising samples in GNS Science's Ice Core Facility.
Right: GNS Science provides specialist consultancy and scientific services for the geothermal energy industry in Aotearoa New Zealand and also in Pacific Rim nations.



Participation in full survey



Participation in pulse survey

Our engagement

We conducted two staff engagement surveys this year – one full survey in September 2020 and a pulse survey in April 2021.

Both surveys covered engagement, common purpose and manager effectiveness questions. Some questions which are particularly sensitive at measuring staff engagement at organisation and group level are classified as 'key drivers'. We track 'key drivers' at an organisational level which provides valuable insights into areas we can focus on to ensure GNS Science maintains its ability to produce excellent science.

To support this work, we have expanded our health and safety capability and strengthened our collaborative culture that promotes health and safety as part of everyday work.

The response rate for both surveys was high – 88% for the full survey and 86% for the pulse survey.

In 2020, all key driver questions had favourable increases between 5 and 13 points at the organisation level, and between 2 and 31 points at the Group level.

Results from the full survey showed 72% engagement by staff, and 62% for a sense of common purpose compared to 55% in the previous year. Manager effectiveness is at 74%, an increase of nine percentage points from 2019.

Health and safety

Our staff conducted more than 1400 field trips in the past year across a range of risks including work on volcanoes and in geothermal areas, work in alpine and bush areas, and work in and around water both on the New Zealand mainland and offshore. Sometimes it involved extensive off-road driving and working with helicopters. The broad scope of our mission also means that we occasionally had staff in Antarctica and on Raoul Island. In addition, we undertake a significant amount of lab work with all the attendant risks and protocols that this involves.

To support this work, we have expanded our health and safety capability and strengthened our collaborative culture that promotes health and safety as part of everyday work. As an example, staff helped to develop our new Health and Safety Value Statement via a number of interactive forums. Its cornerstone message is: "Health and safety is at our core, empowering everyone, every day, everywhere."

Notable milestones in the past 12 months have included:

- completed an external review of our Critical Risks and Health and Safety Management Systems. It concluded we mostly meet industry best practice, but identified a few areas for improvement that we are addressing
- developed new procedures and guidance in support of our work such as temporary traffic management, driver safety, field safety, visitor safety, electrical safety, emergency management, water safety, contractor management, and guidance for managers and team leaders
- implemented regular staff engagement using forums and learning teams across all areas of critical risk and fieldwork-related subjects
- introduced technology in support of good health and safety behaviours; this includes our vehicle booking system, GPS devices in all vehicles and all field parties, and our portal for lodging and approving fieldwork plans
- spent more time with staff in the workplace and in the field to better understand our working environments
- developed and delivered health and safety training and workshops covering critical risk management, fieldwork, fieldwork portal, GPS and other safety devices, use of vehicles and driving, job risk analysis, risk registers, electrical safety, chemical handling training, fire safety, CIMS (Coordinated Incident Management System) training, and new staff inductions.

We are planning further health and safety improvements this year, with focus areas including critical risk management framework, contractor management, and ensuring we have the right tools and support for our staff in labs and in the field.

VISION MĀTAURANGA

GNS Science's drive to embed Vision Mātauranga in our work is about unlocking, in partnership with Māori, the science and innovation potential of Māori knowledge, resources and people to benefit all New Zealanders. We are committed to developing partnerships with iwi/Māori interests and entities to identify and deliver primary science needs that best contribute to the social, economic, cultural and environmental wellbeing of Aotearoa New Zealand.

At GNS Science we see engaging with iwi/Māori as an integral part of our work. We work in partnership with Māori where we can – building relationships takes time, but we know that strong relationships will lead to quality outcomes and will place us in the best position to understand the Māori context, obtain quality and robust research, and provide excellent and reputable products. Our engagement approach, guided by our Māori Engagement Strategy, aims to be inclusive and considers the perspectives and cultural values of iwi, hapū, whānau and Māori, and continues to enhance our relationships with iwi/Māori.

Our approach is holistic and is built on having a Te Ao Māori perspective, which is an important component in developing our internal capability. As we continue to increase our visibility and reputation within Māori communities, we are more able to attract emerging Māori science talent.

A welcome cultural outcome of our initiatives is to create pathways for iwi-led research to be more common-place. This is where iwi/Māori decide what and how research approaches are developed and how to apply the findings.

In all of this there are tangible benefits for GNS Science. By integrating our scientific work with the Māori narrative we gain a richer understanding of the Earth.

Career pipeline and Ahunuku Māori Summer Scholarships

We have been systematically building pathways that lower the barriers for young Māori entering the science sector. A number of our research programmes have initiatives aimed at enthusing Māori students at intermediate and secondary level, including Geocamps, and science roadshows (see our *Marae-based Earth science learning* and *Hands-on geoscience experience for Kiwi kids* stories).

Four-day science camp for local students

In January 2021, and in partnership with Te Runanganui o Te Atiawa, many staff from across GNS Science contributed to the first 'Tawhi kia Rehua' Te Kura Whenua wānanga, developed and undertaken for rangatahi (Year 8–13 students) with whakapapa to local iwi. The four-day hands-on event covered a broad range of research topics being undertaken at GNS Science. It was designed to introduce the fundamentals of observation-based science processes, and how they can then be applied to 'real-world' challenges and opportunities.

More than a dozen rangatahi participated in activities that were held at our Avalon and Gracefield sites in Lower Hutt. It included the GeoNet training facility, our National Geohazards Monitoring Centre, the National Ice Core Facility, and the National Paleontological Collection. There were also field trips to geologically and environmentally significant locations in Hutt Valley and Porirua. The students gained practical experience in the observation of landscapes, ecology of estuaries, faultline characterisation, earthquake monitoring and event response, and climate-change related topics.

This project continues our commitment to encouraging the next generation of Māori students into careers within geoscience.

Top: Tawhi kia Rehua participants visiting the Ice Core Facility at GNS Science's National Isotope Centre.

Our support for Māori participation in science has progressed well with the continuation of the Ahunuku Māori Summer Scholarships programme. This programme is designed to help build stronger connections between GNS Science and the academic community, increase the talent pool for future recruitment of scientists, and enhance Māori capacity and capability within our organisation.

GNS Science and Victoria University of Wellington awarded three undergraduate students of Māori descent the Ahunuku Māori Summer Scholarships this year. These Earth/physical science students worked on programmes at GNS Science over the 2020/2021 summer break, providing them with the opportunity to gain valuable experience. We are aiming to extend this partnership to other Aotearoa New Zealand universities in the future.

External relationships

We continue to make progress in building enduring relationships with iwi/Māori, guided by our Māori Engagement Strategy. A key part of this is strengthening our national networks through forums such as Te Ara Pātaiao – the Crown Research Institute Māori Leadership Group, and Māori academic institutions like Te Whare Wānanga o Awanuiārangi. Te Ara Pūtaiao brings together Māori leadership across the CRIs and provides a forum to share knowledge and information and identify opportunities to support Māori growth through science collaborations. While in its infancy, we are working with research staff at Awanuiārangi to discuss options to grow technical pathways that support Iwi-Māori enabled earth science research. We have also further developed our Māori engagement database which makes information about all our Māori and iwi relationships accessible to all our staff, and established a Vision Mātauranga toolkit, which includes information, maps and advice to support staff engagement with Māori and iwi.

Hosting Te Rarawa

We have worked extensively with Te Rarawa iwi in Hokianga in recent years conducting joint environmental research projects and running marae-based wānanga (science learning camps) for school-age students. We reciprocated the hospitality this year by hosting three Te Rarawa partners and four rangatahi (students) to get hands-on science experience at our Lower Hutt facilities. Staff from across GNS Science led our guests through a series of science activities to provide insight into our projects and especially the Tātaihia te Parataiao o Te Wahapū: Hokianga Harbour Sedimentation project. It was great to be able to share the science that goes on between the fieldwork and sharing results.

Te Reo

Our Te Reo training programme, available to all staff, continued this year. This is part of our commitment to develop GNS Science capability and capacity to support Vision Mātauranga (see Our People and Culture section).

Left: Our partners from Te Rūnanga o Te Rarawa in Northland, Wendy Henwood and Joanne Murray, examine sediment samples collected from Hokianga Harbour with guidance from Henry Gard during a visit to GNS Science facilities in Lower Hutt.
Right: Co-leader of the Lakes380 project Marcus Vandergoes of GNS Science at a knowledge-sharing event at Whakakī Lake, Hawke's Bay, with representatives from Hawke's Bay Regional Council and the Whakakī Lake trust.

IMPROVING OUR DELIVERY

Infrastructure

At GNS Science, we know people and ideas need the right environment to thrive. Providing the right tools, equipment, technology and resources is the best way we can help our staff do what they do to the best of their abilities. We have been developing long term plans to make sure our infrastructure is constantly refreshed so we have the specialist facilities, leading-edge equipment and information management systems that we need to deliver world-class science for our customers.

Following a comprehensive review of the current state of our buildings and other infrastructure, and our needs into the future during the 2019/20 year, we have now completed the development of our draft Property Strategy. The Property Strategy provides a high-level planning framework across our portfolio of research laboratories, workshops, office accommodation and public interface property. Preferred options for the future development of our Wellington Region (Avalon and Gracefield) and Wairakei properties have been agreed, and we are now working with other research organisations, including Callaghan Innovation, ESR and Victoria University of Wellington, to ensure that together our property plans present a coherent picture for the Wellington region.

GNS Science is investing in its ICT (Information Communication Technology) systems and infrastructure to ensure that we are well-positioned to take advantage of the growing opportunities across the Aotearoa New Zealand science and innovation system for high-performance computing and associated data science opportunities.

A significant step forward in the implementation of the Information Systems Strategic Plan this year, has been working collaboratively with ESR to identify a common replacement for our enterprise systems, which will address issues with our core capabilities of Financial Management, Human Resources Management, and Contract and Project Management. The procurement process for a new joint system has been completed and it is currently being installed for use. This will result in significant efficiency gains and enable the delivery of timely information and transparency for managers and decision-makers.

We hope that the establishment of a shared system with ESR, will provide a platform that other CRIs will be able to join in future years.

Connectivity and innovation

We continue to roll out new programmes to deliver meaningful value with and for our major stakeholders. This includes implementing a Stakeholder Engagement programme and engaging our major partners and end-users earlier in the research process. GNS Science relies heavily on international research collaborations and partnerships to deliver high quality research outcomes through the leveraging of international capability and large-scale facilities. We continue to maintain this through strategic agreements with other national geoscience and isotope science agencies in Australia, Japan, Germany, Italy and the USA. We also hold strategic national memberships that enable national access to collaborative resources, including the International Ocean Discovery Program (IODP) and the International Continental Drilling Program (ICDP).

The Innovation Hub within GNS Science continues to provide internal mechanisms and incentives to support higher-risk innovation and co-design approaches to develop new research directions. This includes hosting innovation workshops, allocating capability development funds to encourage co-design approaches to new research directions, and allowing higher-risk initiatives to be tested.

COVID-19 has had a significant impact on many of our major stakeholders, particularly our international stakeholders, and the way in which we can engage with them. This year, we have continued our use of digital methods to deliver value to customers and to engage in key international forums, including the use of virtual business trips. We expect these to continue to develop and to become a part of our engagement practices into the future, complementing our 'in person' activities.

We have also been working on a refresh of the GNS Science website purpose, platform, and content, which will enable access to information about GNS Science and the work we do in a more efficient and effective way. An increasing number of face-to-face engagements have also taken place, for example, the first targeted GNS Science Stakeholder Relations roadshows took place at TechWeek in Taranaki this year.

A GNS Science stakeholder survey was completed once again this year. GNS Science aims to deliver excellent, mission-led research, and the survey is a helpful indicator of the relevance of our research and how responsive we are to major stakeholder priorities and needs, across the full science value chain from fundamental to applied research, tools and technologies, and knowledge dissemination.

We have also been working on a refresh of the GNS Science website purpose, platform, and content, which will enable access to information about GNS Science and the work we do in a more efficient and effective way.

Improving processes

With our move to a higher risk, more fundamental, technology-led and data-driven research portfolio, last year we focused on maturing our project-based operating model putting in place greater management oversight of our science themes, and new governance and accountability frameworks, including science and commercial portfolio advisory groups. Our project management specialists are now actively involved in and providing project management services on over 20 major programmes and projects across our SSIF, Contestable and Commercial funding areas. Our project management framework rollout started in November 2020 and will continue into 2021/22, with training of our team leaders, project leaders, and programme leaders ongoing.

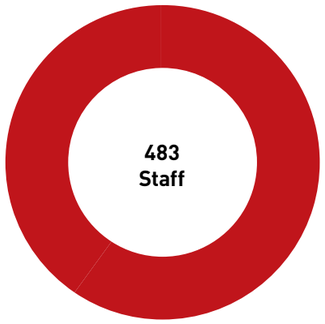
Our resilience, readiness, and response capabilities were tested again this year when a series of tsunamigenic earthquakes on 5 March along the Hikurangi – Kermadec margin prompted a significant GNS Science response.

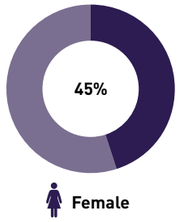
This sequence of earthquakes tested a new GNS Science event response structure, and successfully trialled our improved systems and processes, with our staff providing critical advice and updates to NEMA and the Minister of Emergency Management.

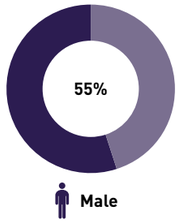
This year we successfully tested our Disaster Recovery process by temporarily moving our Avalon services to Wairakei, increasing our resilience in the event of a major disruption to our IT services in Wellington. We have also been looking at our ICT security and assessing our vulnerability, seeking advice on a variety of information security concerns on the back of the recent ransomware attacks on other organisations, with a view to strengthening our security.

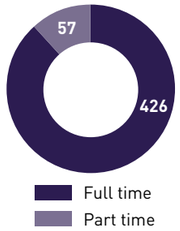
Left: Rangatahi during the Geo Noho camps studying the minerals within rock and beach sand samples they collected near Haiti Tai-Marangai Marae, Whatuwhiwhi, Karikari Peninsula, Northland.
Right: A magnetotelluric survey of Lake Tarawera to determine the nature of geological structures under the lakebed.

OUR PEOPLE AT A GLANCE

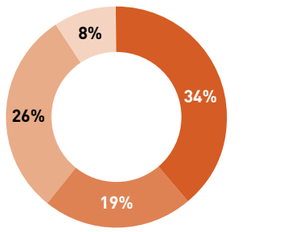




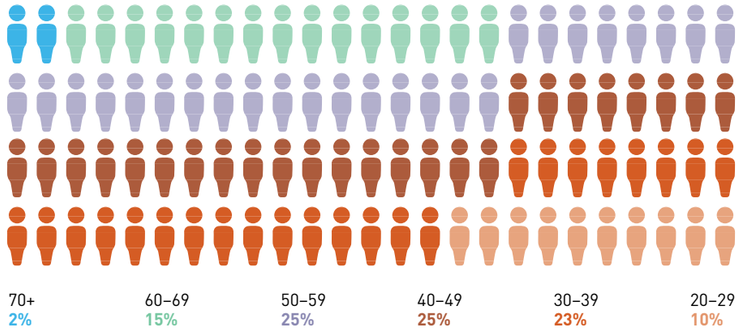




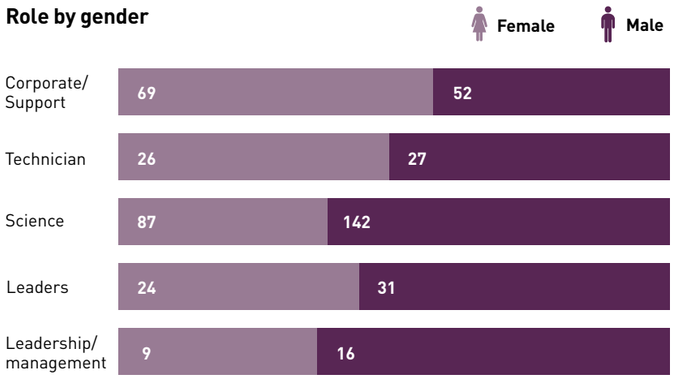
Qualifications



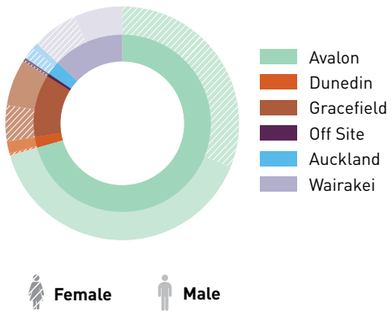
Age



Role by gender

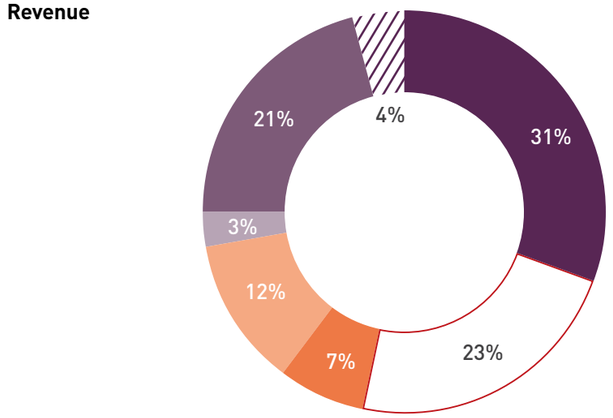


Split of Staff by headcount

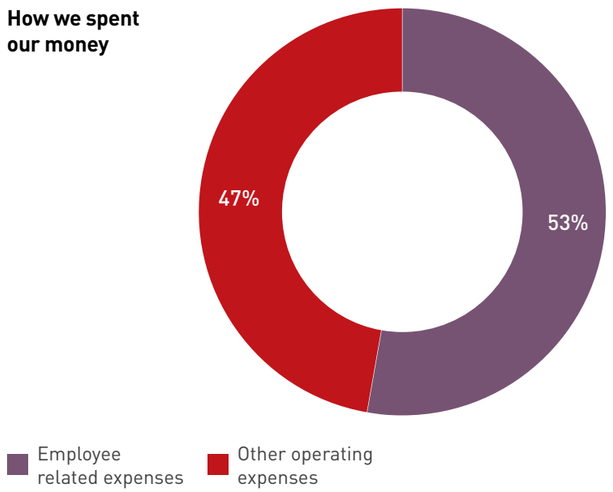


OUR NUMBERS AT A GLANCE

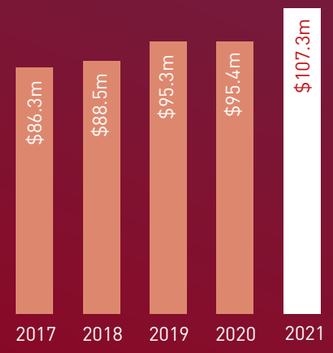
Revenue



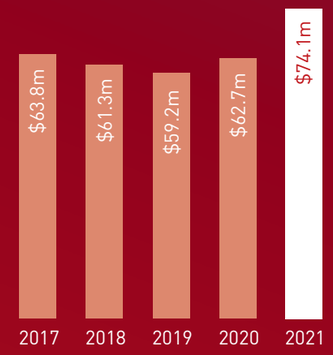
How we spent our money



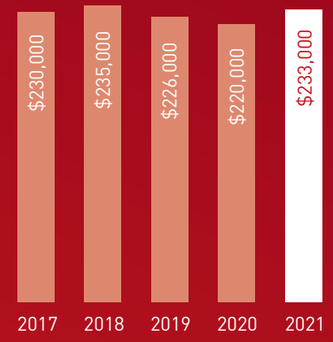
Revenue ($m)



Total assets ($m)



Revenue per FTE ($)



OUR BOARD OF DIRECTORS

Left to right:, Dr Nicola Crauford, Dr John Sharpe, Felicity Evans and Paul White.

Dr Nicola Crauford

Chair
BSc (Hons), PhD, DistFEngNZ, FAICD, CFInstD
Wellington
(Appointed 1 July 2015)

Nicki has extensive governance and senior management experience in energy, water and telecommunications utilities. She brings a combination of technical, commercial and strategic skills to the Board. As well as utilities her governance portfolio has spanned science research and development, fire and emergency management and environmental protection and regulation. Nicki has a degree in chemical engineering from the University of Newcastle upon Tyne and a doctorate in applied science from the University of Southampton. Nicki chairs the Electricity Authority, is a director of Watercare Services and CentrePort, and is a trustee of the Wellington Regional Trust Stadium. She is a Distinguished Fellow of Engineering New Zealand, a Fellow of the Australian Institute of Company Directors, and a Chartered Fellow of the Institute of Directors in New Zealand.

Paul White

B Arch, MBS
Rawene, Hokianga
(Appointed 14 August 2017)

Paul is from the Ngāi Tūpoto hapū of Te Rarawa iwi and has had a 30-year background in Māori development and governance, and wide experience in the public service. He is currently a management and development consultant and professional director and lives in Rawene in the Far North. Over the past 20 years he has served on the boards of Housing New Zealand, Canterbury District Health Board, FITEC, Health Sponsorship Council, Top Energy and the asset holding group of Te Rarawa Iwi. He is currently on the Executive of Te Matapihi – a national Māori housing body, and Heritage NZ's Māori Council. Previously Paul was the Chief Executive of Ngāi Tahu Development Corporation, Regional Director for Te Puni Kōkiri in Te Tai Tokerau, and Regional Manager for the Housing Corporation in Northland.

Dr John Sharpe

BSc, MSc (Tech), PhD, CMInstD
Hamilton
(Appointed 1 September 2016)

John has held a number of executive leadership and director roles in early-to-mid-stage technology companies in Aotearoa New Zealand and the USA. Trained in the physical sciences, he has spent much of his career developing and commercialising biomedical equipment and other sensor technologies with applications in primary industries, life sciences research, and human health. He has also been involved in state-owned and industry research organisations carrying out science and undertaking business development activities.

Felicity Evans

Graduate of the Australian Institute of Company Directors (GAICD)
Wellington
(Appointed 1 July 2018)

Felicity has more than 25 years of experience in the finance industry, including in retail and commercial banking and human resources. She was formerly the General Manager Talent and Culture for ANZ New Zealand and Pacific. She is a graduate of the Australian Institute of Company Directors, a Chartered member of NZ Institute of Directors, an Associate of the Bankers' Institute of New Zealand, a former Trustee of Diversity Works, and a former Director of Global Women NZ.

RETIRING DIRECTORS

Sarah Haydon

Former Deputy Chair
BSc, FCA, CMInstD
Auckland
(Appointed 1 July 2014)

Sarah retired from the Board this year after eight years' service. She is a chartered accountant and has worked for BP in the UK and also on international project work, and was CFO at OfficeMax New Zealand. She is Chairman of The Co-operative Bank Limited and a Director of Ports of Auckland Ltd. Sarah has an extensive background in planning, finance, general management and organisational development.

Chris Bush

BE (Chem)(Hons), CMInstD
New Plymouth
(Appointed 1 January 2016)

Chris retired from the Board during the year after six and a half years' service. He is an experienced oil and gas professional with 30-plus years in both upstream and downstream sectors including roles in New Zealand and overseas. He runs his own consultancy providing strategy and risk management advice to the energy sector and other capital-intensive industries. He has held a number of director roles and was previously Chair of the Petroleum Exploration and Producers Association (PEPANZ) and of the Be Safe Taranaki Trust.

OUR EXECUTIVE TEAM

Ian Simpson

Chief Executive
BSc (Hons), Manchester University
MBA INSEAD, France

Ian joined GNS Science in January 2017. Prior to his appointment he spent seven years as the head of the Earthquake Commission (EQC) where he led the response to the Canterbury earthquake sequence, one of the world's largest natural disaster insurance events. Ian brings 30 years' senior leadership experience in public and private sector roles across a range of industries. After holding corporate finance roles with BP plc and Diageo plc, he emigrated from Britain in 2006 as GM of Finance at the Accident Compensation Corporation.

Tania Gerrard

General Manager, Māori Strategy and Partnerships
Te Whānau a Tāpuhi, Ngāti Porou
BA, University of Otago

Tania joined GNS Science in November 2018 after more than four years with the Ministry for the Environment. Her role at the Ministry was Acting Director of Water, specialising in iwi rights and interests. Her earlier roles included registrar/operations manager at the Waitangi Tribunal and Negotiations Manager with the Office of Treaty Settlements, and Senior Policy Analyst with the Ministry for Primary Industries/ Fisheries. At GNS Science Tania's responsibilities include providing strategic advice and guidance to the Executive Leadership Team and leading Vision Mātauranga activities across the organisation. Tania is currently the Chair of Te Ara Pūtaiao (Crown Research Institute Māori Leadership Group).

Peter Benfell

General Manager, Science
BE (Hons), The University of Auckland
DipBusAdmin, Victoria University of Wellington

Peter joined GNS Science as General Manager, Science in October 2018. He is responsible for the leadership and management of staff within the Science Group as well as the quality and performance of our research and science. Prior to joining GNS Science, Peter was Chief Executive at the Infrastructure Industry Training Organisation Connexis. He previously worked at GNS Science as Group Manager, Environment and Natural Resources Group between 1998 and 2001, and has had over 30 years' experience in research, science and technology and its successful application. Peter has held senior management roles at the Foundation for Research, Science and Technology, AgResearch, and Opus International.

Left to right: Tania Gerrard, Peter Benfell, Greg Holland, Ian Simpson, Gary Wilson, Rose Macfarlane, and Andrew Simpson.

Rose Macfarlane

General Manager, People and Culture
Post Grad Dip. Management Studies, Massey University
Dip. Business Studies, University of Waikato

Rose was appointed General Manager of the human resources, communications, health and safety, and administration departments in July 2018. Prior to taking this role, she was GM, Human Resources at DairyNZ. She has also held positions as Human Resources Manager at Hamilton City Council and the Waikato District Health Board. She has significant experience in managing change, understanding the challenges of differing business environments and dealing with a broad range of organisational culture and people matters.

Greg Holland

Acting General Manager, Stakeholder Relations
BSc and MSc, The University of Auckland
Dip Bus Admin, The University of Auckland

Greg joined GNS Science in 2016 with a background in geothermal and engineering geology. Prior to this, he managed environmental monitoring, natural hazards and strategy units, worked as a consultant engineering geologist and within investment banking focusing on the financial instruments and structures required for engineering and resources companies. Greg leads the strategic direction of the Stakeholder Relations Group, which develops stakeholder and contestable research strategies, maximises business opportunities aligned to our strategic science direction, and explores opportunities for GNS Science's intellectual property.

Andrew Simpson

General Manager, Business Services
BCom, University of Otago, C.A.

Andrew joined GNS Science in 2019 after three years at the University of British Columbia where he held the role of Vice President, Finance and Operations. He is an experienced university leader and advisor, holding previous roles of Chief Operating Officer at Victoria University of Wellington, Vice Principal (Operations & Finance) at Queen's University, Canada, and Chief Operating Officer at the University of Waikato. At GNS Science, Andrew is responsible for leading a wide range of functions including finance, legal, risk and assurance, ICT, property and facilities, project management office, and performance and reporting services.

Gary Wilson

General Manager, Strategy & Chief Scientist
BSc (Hons), BMus, PhD, Victoria University of Wellington

Gary joined GNS Science in May 2019. He is responsible for leading GNS Science's science, research and innovation strategies and he contributes to developing the strategic direction and investment for the organisation. He previously held academic positions at the University of Oxford and University of Otago, where he is still an Honorary Professor in Marine Science. He has held the Byrd Fellowship at Ohio State University and the Blaustein Visiting Professorship to Stanford University.

His research interests are in environmental geophysics and marine geology and he still has active research programmes in Antarctica, the Subantarctic and Aotearoa New Zealand. He is currently the Vice-President of the Scientific Committee on Antarctic Research (SCAR), Chair of the Royal Society Te Apārangi Committee on Antarctic Sciences, and a Trustee of the Sir Peter Blake Trust.

STRATEGIC SCIENTIFIC AND USER ADVISORY PANEL

The Panel provides advice on research to the Board. Its purpose is to ensure our science continues to focus on excellence and that we are well tuned in to national and international trends and associated opportunities. Panel members have broad experience across all our science themes, and provide strong end-user perspectives.

Dr Chris Pigram

Chris is a geologist with over 40 years of experience and was the Chief Executive Officer of Geoscience Australia between 2010 and 2017. He was made a Member of the Order of Australia in 2019 and was elected a Fellow of the Academy of Technological Sciences and Engineering (ATSE) in 2016. He chairs several Australian committees including the Independent Expert Scientific Committee that advises government on water issues related to large coal mines and coal seam gas developments, the MinEX CRC, and CSIRO's Minerals Resources Advisory Committee. He is also Chair of AuScope Limited, and is a member of the Advisory Panel for CSIRO's Deep Earth Imaging Future Science Platform. He was appointed to the Australian Space Agency Advisory Group in 2019.

Professor Rob Dunbar

Rob is the WM Keck Professor of Earth Sciences and a Senior Fellow of the Woods Institute for the Environment at Stanford University. He leads a research group that works on past, present, and future climate change and its impact on oceans and coastal environments. He regularly works with governments as well as the United Nations and several NGOs to help develop and implement solutions to environmental and resource problems. Rob is an experienced field scientist and has led over 70 research expeditions and voyages since 1980 with most focused on Antarctica and Indo-Pacific regions. He has studied the impact of sea ice on local and regional climates as well as unique microbial communities that exist within and beneath sea ice. In 2016, he was awarded the medal of Antarctic Research by the Scientific Committee for Antarctic Research (SCAR). He currently serves on the US National Academies Board on Atmospheric Science and as a Trustee for the Consortium for Ocean Leadership.

Professor Trevor Ireland

Trevor is a Professorial Research Fellow at The University of Queensland. He specialises in SHRIMP microanalysis and applications in geochronology, stable isotopes, and trace element geochemistry, on terrestrial and extraterrestrial samples. He has worked extensively on geochronology of Aotearoa New Zealand, Antarctica and Australia. He is currently involved in the preliminary examination of the samples of asteroid Ryugu returned by the JAXA Hayabusa2 spacecraft and is also an investigator on the NASA Osiris-REx mission, which recently departed from asteroid Bennu. Trevor is the past President of The Meteoritical Society and is a Fellow of the American Geophysical Union and the Geochemical Society.

Dr Lucy Jones

Lucy is the founder of the Dr Lucy Jones Center for Science and Society, with a mission to foster the understanding and application of scientific information in the creation of more resilient communities. She is a Research Associate at the Seismological Laboratory of Caltech and author of *The Big Ones: How Natural Disasters have Shaped Us* (Doubleday, 2018). During her 33 years with the US Geological Survey, she created the first Great ShakeOut drill, now a worldwide event with over 60 million participants in 2018. She also created methodologies for assessing earthquake probability that have been the basis for all earthquake advisories issued by the State of California. Her pioneering science was recognised with the 2015 Samuel J. Heyman Service to America Medal, the Ambassador Award from the American Geophysical Union, the 2016 William Rodgers Distinguished Alumni Award from Brown University, the 2017 Distinguished Lecture Award of the Earthquake Engineering Research Institute, and the 2018 Frank Press Medal from the Seismological Society of America.

Dean Kimpton

Dean runs his own infrastructure strategy and advisory business Tuhura and Partners. Until mid-2019 Dean was Auckland Council's Chief Operating Officer, gaining significant insight into the unique challenges of growth, the built environment, infrastructure strategy, and delivery. Dean is an independent director on the NZ Upgrade Programme advisory board (Waka Kotahi), chairs the Eastern Busway Alliance (Auckland Transport), the Bay of Plenty transport system investment initiative, and MBIE's Building Advisory Panel. He was a member of the RM Reform Panel appointed to review the RMA, a recent past President of Engineering NZ, and former chair of QuakeCoRE. Prior to his role at Auckland Council, he was managing director of engineering consultancy AECOM.

Cameron Madgwick

Cameron is the Chief Executive of Gibson Sheat Lawyers. This role builds on his prior executive leadership roles advocating for the petroleum sector, legal advisory roles in the electricity sector and private practice and governance within the education and justice sectors. Cameron remains active in his community and is the Chair of specialist disability provider Laura Fergusson Wellington. His experience and connections to the energy sector position him to provide a valuable contribution to the work of the Panel. He has a particular interest in science advocacy and communication.

Sarah Stuart-Black, QSO

Sarah is Secretary General of New Zealand Red Cross, a role she has held since December 2020. Prior to this role, she was the Deputy Chief Executive and held the statutory role of Director Civil Defence Emergency Management in the National Emergency Management Agency. She was appointed Executive Director of the Ministry of Civil Defence & Emergency Management in December 2014. Sarah joined the Ministry of Civil Defence & Emergency Management in 2003 and held a number of different roles during her time with the Ministry. She has had a diverse range of experience within New Zealand and England, as well as Ethiopia, Niue and the Solomon Islands. She was a member of the United Nations Disaster Assessment & Coordination Team for nine years and has represented New Zealand at a variety of international forums, bilateral, regional and global meetings, exercises and forums. Sarah has published a number of papers in international journals and has co-edited three books.

Associate Professor Ting Wang

Ting is an Associate Professor in the Department of Mathematics and Statistics and Associate Dean Research (Division of Sciences) at the University of Otago. Her research field is multidisciplinary, centering on the interface of statistics and geosciences. Her main focus has been on the development of statistical models for geophysical hazards such as earthquakes and volcanic eruptions. Ting has led, managed and participated in national and international collaborative multidisciplinary research projects, including projects funded by EQC, Marsden, MBIE, the Natural Hazards Research Platform, and Resilience to Nature's Challenges. She received the Worsley Early Career Research Award from the New Zealand Statistical Association in 2013, and a University of Otago Early Career Award for Distinction in Research in 2017.

Photograph acknowledgements

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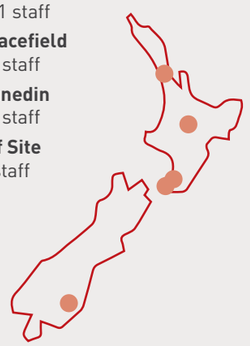
Our office locations and staffing

Auckland
12 staff
Wairakei
62 staff
Avalon
341 staff
Gracefield
55 staff
Dunedin
10 staff
Off Site
3 staff



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Former Deputy Chair
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General Manager,
Strategy & Chief Scientist
Greg Holland
Acting General Manager,
Stakeholder Relations
Peter Benfell
General Manager,
Science
Andrew Simpson
General Manager,
Business Services
Rose Macfarlane
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People and Culture
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