GNS SCIENCE

2022 ANNUAL REPORT

PART 1 – HIGHLIGHTS

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

Cover: GNS Science videographer, Jeff Brass, Ngauruhoe.
Inside Cover: Tauira (students) using refractometers to measure groundwater salinity at Ahipara on Te Oneroa-a-Tōhē / Ninety Mile Beach as part of Tūhura Papatūānuku Geo Noho, a marae-based science wānanga.

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 2022.

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

This year has been another successful year for GNS Science as we've responded and adapted to a COVID-19 impacted environment. The uncertainty of COVID-19 and the investment needed in our organisation have meant developing different ways of working and seizing opportunities that have been created.

Our staff have shown commitment and focus in delivering science aimed at making Aotearoa New Zealand Cleaner, Safer and More Prosperous. The global pandemic has continued to constrain international recruits joining us, leading to understaffing in some areas of science capability. Many of our scientists come from overseas and the pandemic has highlighted the need for Aotearoa New Zealand to grow more of its own talent. We continue to play our part by encouraging more Māori into science through Ahunuku Scholarships in association with Te Herenga Waka—Victoria University of Wellington, and hosting interns in our science teams during the universities' summer break.

There can be no denying the continuing impact of COVID-19 on our financial performance, and on our ability to get some work underway within anticipated timeframes because immigration and border restrictions affect our international workforce. However, the resilience of our organisation is evidenced by the fact we continue to deliver a solid performance with excellent results, which is testament to the hard work of all our staff.

GNS Science recorded a pleasing financial result for the year. Total revenue of $108.3 million was up 5% on the prior year, excluding the Government's one-time COVID-19 grant received in 2020/21. Despite the impacts of COVID-19 on our projects, research and commercial revenue strengthened by $6 million compared to the previous year.

While GNS Science recorded a $1.0 million loss after tax for the 2021/22 year, this included a one-off investment of $3.6 million on a much-needed Enterprise system to replace our Human Resource, Finance and Project Management systems. This system will deliver improvements to the underlying operations of GNS Science, including enhanced information for decision-making, contributing to the delivery of our long-term strategic goals. Excluding this one-time cost, the underlying profit before tax was $2.3 million, a strong result given the impact of the difficult operating environment caused by the COVID pandemic.

Strategic direction

This year we released two very important documents, both of which provide the foundation for our future work – influencing and determining our future path. The GNS Science Roadmap builds on the work done in our strategic review process to align our strategic direction with government priorities and the needs of our stakeholders, industry partners and iwi/Māori interests. It describes our future science direction and focus to 2032 and will ensure our outcome-focused Science Themes are driving the delivery of impactful and relevant science for Aotearoa New Zealand.

We also celebrated the release of Te Punawai o Rangiātea, our new Māori Strategy, in 2022. Developed in consultation with staff and guided by the key principles of the Treaty of Waitangi, being participation, protection, and partnership, Te Punawai o Rangiātea provides critical guidance and direction to enable GNS Science to create enduring and sustainable relationships with tangata whenua – iwi, hapū, whānau and Māori.

This year, the Government started a discussion on the future of Aotearoa New Zealand's Research, Science and Innovation sector with the release of Te Ara Paerangi – Future Pathways Green Paper.

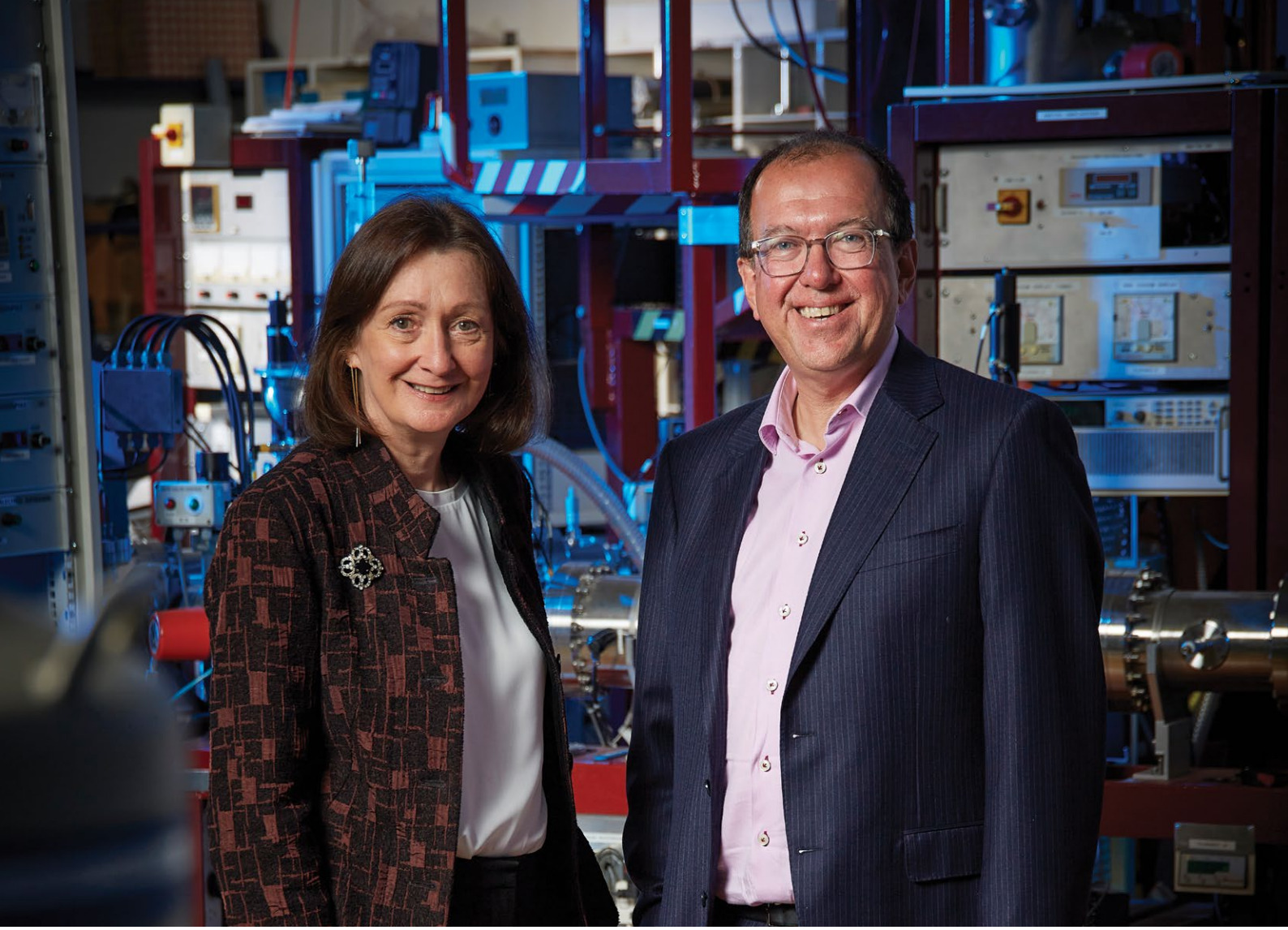
We support the vision of a modern, future–focused research system that is adaptable, resilient and connected, and the direction provided in our new strategy documents means that we are well placed to work with the Government and other science organisations to shape the future of science. Our submission addressed current barriers and challenges in the Research, Science and Innovation System, provided ideas on how the system could be more responsive and support better decision-making across the sector, as well as helping meet Māori aspirations.

Investment

Alongside the implementation of the Science Roadmap, we have continued to invest in people and infrastructure to maintain capability and capacity in key areas. Ensuring we have modern facilities to enable the delivery of great science, minimise health and safety risks to our staff, and bring people together to enable connection, collaboration, and innovation continues to be a priority.

Progressing the GNS Science Property Strategy has been an area of focus, with the Government releasing its preliminary report for Aotearoa New Zealand's Research, Science and Innovation Property Strategy. This has implications for the future location of our Wellington region facilities, and we are working to engage with relevant partners, including mana whenua, other science system actors and government agencies, to ensure that co-location possibilities are considered and that all of our property plans present a coherent picture for the Wellington region in line with the review.

The concept design for a new facility for our Wairakei campus, along with the associated single stage business case, was completed and submitted to the Minister, and provisional approval was received. In addition, we are preparing a proposal for a Geothermal Innovation Centre as a second stage of development for the campus.



During the year we replaced our Finance, Human Resources and Project Management systems with 'Workday', a new Enterprise resource planning tool. This work was done in collaboration with ESR, reducing implementation costs and ongoing licensing fees for both organisations.

We have also had discussions with other science organisations about the potential for further cooperation in mutually beneficial investments in property and infrastructure.

Our science

The calendar year started with our team responding to the unprecedented eruption of Hunga Tonga-Hunga Ha'apai in January. Our scientists supported the National Emergency Management Agency with the Aotearoa New Zealand response, and the Ministry of Foreign Affairs and Trade, and international partners and stakeholders, with the wider international response.

While the violent eruption and ensuing tsunami will be studied for years to come, both reinforce the critical role science and research plays in understanding natural hazards and the risks we have on our doorstep.

GNS Science has a vital supporting role during hazard events such as the Hunga Tonga-Hunga Ha'apai eruption, and this work is a reminder of the 2019 Whakaari White Island eruption, which tragically took the lives of 22 people and seriously injured many others.

This event has had a significant ongoing impact on the organisation, and we continue to prepare for the prosecution resulting from the WorkSafe investigation into the eruption and response. The trial is scheduled to be heard in 2023.

Climate Change has become the truly defining phenomenon of our generation. Already this year, we have seen temperatures soar across Europe and the United States, generating massive wildfires and causing thousands of heat-related deaths across both continents.

Closer to home, torrential rainstorms in July 2021, and again in August 2022, caused widespread flooding and evacuations along the South Island's West Coast, in the Tasman District and the Marlborough Region. Aotearoa New Zealand's understanding of, and response to, climate change is hugely influenced by the work undertaken here at GNS Science.

We are trusted advisors to government, and local and regional councils, and our work is increasingly influencing policy direction and decision-making.

The esteem in which our research is held was further demonstrated during the COP26 Summit, which took place in Glasgow in November 2021. The event saw world leaders assembling to reaffirm their commitment to combatting climate change. Their discussions were influenced by the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6, which was developed collaboratively by leading researchers from around the globe, including from GNS Science. With over 30 citations of GNS Science authors within the IPCC report, this was a demonstration of just how much valuable work is happening at GNS Science to further global understanding of the climate system.

Left to right: Dr Nicola Crauford and Ian Simpson.

Recognition

More recently, the RiskScape team were named winners of the Best Hi-Tech Solution for the Public Good in the NZ Hi-Tech Awards. The award celebrates not-for-profit tech innovations that are focused on improving the lives of the people they serve, and this award is a well-deserved recognition of the impact that RiskScape makes in helping Aotearoa New Zealand understand the risk of, and build resilience to, natural hazards. It's the outcome of years of hard work by GNS Science and our partners at NIWA, as well as our collaborators Toka Tū Ake EQC and Catalyst.

The value of our international relationships and our reputation as the 'energy CRI' was acknowledged with an invitation to join the Prime Minister's Trade Delegation to Japan and Singapore in April. This visit provided the opportunity for GNS Science to reinforce its position as the partner of choice in Japan and Singapore when it comes to energy futures, particularly geothermal and hydrogen, and to cement our profile as global leaders in geohazards. During the trip, Ian Simpson and the Prime Minister officially announced the new 'on the ground' presence of GNS Science in Japan – part of a new geothermal coalition with Aotearoa New Zealand geothermal innovation company Geo40, in a co-investment model with New Zealand Trade and Enterprise.

This year, we also welcomed two new Board members, Wendy Venter and Andrew Cordner. Both bring extensive corporate, commercial and governance experience to GNS Science and we look forward to their positive contribution.

I would also like to acknowledge the recent resignation of our CEO, Ian Simpson. During his five-year tenure, Ian has delivered a strategic review, focussing our efforts on science areas where we have strength, significant influence, and where there is room to grow our capability and impact for New Zealand.

Ian's leadership has strengthened GNS Science partnerships, and our stakeholder and strategic relationships, ensuring we are nationally and internationally respected for the excellence of our science.

In closing, we would like to acknowledge 30 years of GNS Science. Whilst we have been delivering scientific excellence since 1865 (in our role as The New Zealand Geological Survey), 1 July 2022 marked 30 years since Aotearoa New Zealand's science sector was reshaped into the ten Crown Research Institutes, and thus GNS Science was born.

As an organisation, we have grown and adapted over the decades – from an early focus on fossil fuels to now working to understand and address two of the greatest issues New Zealanders will face – the impacts of climate change and the move to a carbon zero economy.

We have no doubt that over the next 30 years, and beyond, GNS Science will continue to deliver on its vision to create a Cleaner, Safer, More Prosperous Aotearoa New Zealand.

Dr Nicola Crauford
Chair
September 2022

Ian Simpson
Chief Executive
September 2022

Top: Ian Simpson with GNS Science staff.

HONOURS AND AWARDS

GNS Science Excellence Awards 2021

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 the winners of the eight categories.

Excellence in Creating an Impact:
Bill Fry

Bill is a seismologist whose research has had a fundamental impact on how Aotearoa New Zealand communities prepare for, manage and respond to natural hazards. This award acknowledges Bill's role in connecting excellent earthquake and tsunami science, and delivering authoritative science advice to a wide range of stakeholders during the 5 March 2021 triple tsunami event, which occurred in the Hikurangi Subduction Zone.

Creating Awareness:
The E Tūhura Explore Zealandia team

The E Tūhura Explore Zealandia team has created an accessible, creative website that gives insights into the amazing forces that shaped Aotearoa New Zealand and the mostly-submerged continent of Te Riu-a-Māui / Zealandia on which New Zealand sits. The maps are a taonga and enable GNS Science to communicate our work to colleagues, stakeholders, educators and the public.

Working Together:
The Aqua Intel Aotearoa team

This award acknowledges the collaborative efforts of this national science platform. As part of their water storage research, they have worked with regional councils, stakeholders and local communities, alongside hydrogeologists, numerical modellers, planners, social scientists, stakeholder relations experts, project managers and coordinators, financial and administration professionals and senior management representatives.

Early Career Achievement:
Cécile Massiot

Cécile is a geothermal geoscientist whose work has improved understanding of how underground hot fluids flow through fractured rocks, which helps in the development of geothermal energy. This award acknowledges her leadership, commitment and drive to lead a team of scientists from GNS Science, Aotearoa New Zealand universities and overseas researchers, in a pre-proposal to the International Continental Drilling Program (ICDP) for scientific drilling at the Okataina Volcanic Centre.

Vision Mātauranga:
The Lakes380 team

The Lakes380 programme is the biggest scientific study of lakes in Aotearoa New Zealand ever undertaken. The team received this award for its engagement with multiple iwi, hapū, and other Māori organisations, enriching our understanding of the environmental, social and cultural histories of many of Aotearoa New Zealand's lakes. The team upholds and exceeds the principles of Vision Mātauranga.

Making a Difference:
Juliette Bowater and the Career Development Framework team

Juliette is an organisational development and capability specialist. This award celebrates her role in the collaborative development and introduction of a career progression framework for specialist staff.

Health and Safety:
Sonja Bermudez

Sonja is the Geological Research Laboratories and Collections Manager, responsible for overseeing the activities of a number of our specialist research laboratory and facilities. This award acknowledges her leadership in empowering her teams to integrate health and safety in their work processes.

Deep Partnering:
German Orozco

In his role as Earth Resources and Materials Manager, German leads a highly skilled and diverse team of Earth and materials science specialists with a strong focus on the energy industry. German received the award for his leadership and ability to engage with stakeholders, and in particular for his work for the Tauhara geothermal power station development.

National and international honours and awards

Science New Zealand Awards

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

Top: Dr Dan Lowry.
Bottom: Dr Simon Cox.
Right: Hikurangi Subduction Margin Project Team.

Early Career Researcher Award – Dr Dan Lowry

Dan is recognised as a world-class ice sheet modeller. His scientific credentials, achievements and reputation are impressive given his very early career status. His work underpins research to improve ice sheet and sea level projections, which support coastal communities so they can better plan for, and adapt to, climate change. He has represented Aotearoa New Zealand's ice sheet and sea level research community through his work on the Intergovernmental Panel on Climate Change Assessment Report 6. This report considers all available international climate change research, and therefore is a major acknowledgement of the quality and relevance of his work.

Individual/Lifetime Achievement Award – Dr Simon Cox

Simon is a structural geologist, with professional expertise in the fields of geological mapping, structural geology, tectonics and fluid flow. His wide-reaching research has played a transformative role in advancing geological knowledge of the South Island and Antarctica.

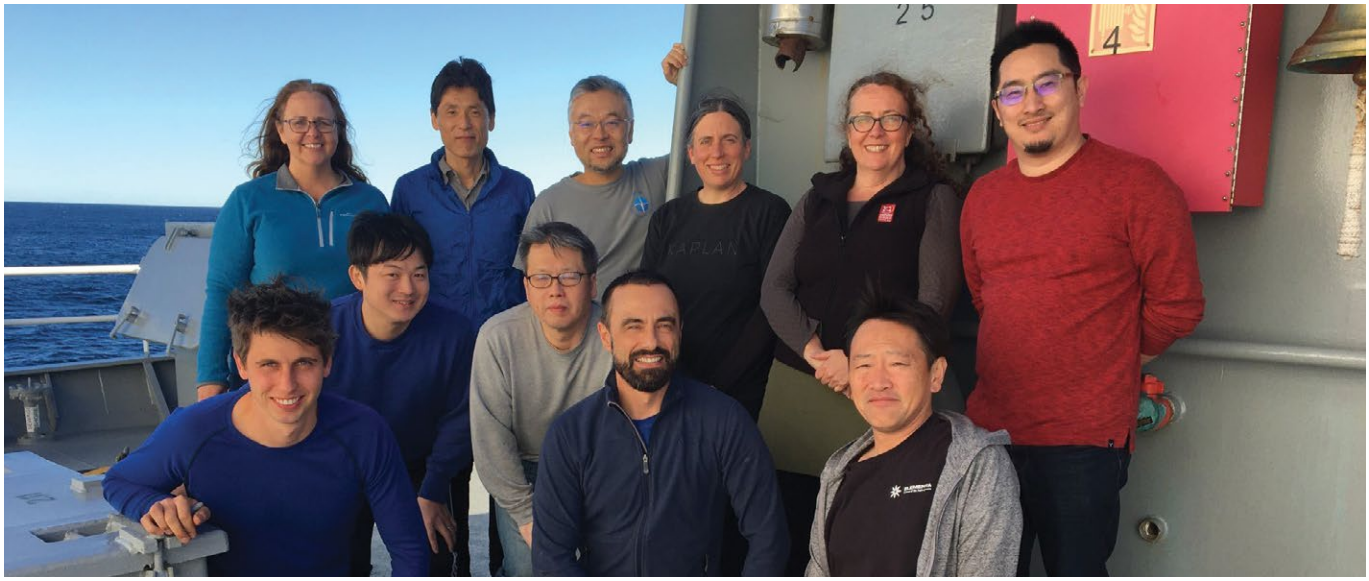
Simon introduced the topic of Earthquake Hydrology to Aotearoa New Zealand, exploring the far-field effects earthquakes can have on groundwater. Recently he led a major international initiative to build a digital geological map dataset of Antarctica. His research on pounamu directly supports iwi/Māori and is part of a broader package of pure and applied work characterising landscape evolution and hazards from groundwater, earthquakes, landslides, and erosion.

The impact of Simon's work is recognised in Aotearoa New Zealand and globally, as are his ongoing efforts to help communities develop resilience to the effects of natural hazards and climate change.

Team Award – Hikurangi Subduction Margin programme team

The Hikurangi Subduction Zone, where the Pacific Plate subducts beneath the North Island, is Aotearoa New Zealand's least understood and largest source of geohazards. Knowledge about Hikurangi subduction earthquake potential, acquired since October 2016, is already enabling more reliable forecasts of the hazard and risk the subduction zone poses to Aotearoa New Zealand. The research outcomes have contributed to the development of the East Coast Hikurangi Response Plan and are used to advise central government on the impact of widespread slow slip events.

Thus far, the project has produced more than 50 peer-reviewed publications in international journals, with 11 of these in prestigious, high-impact journals *Nature, Nature Geoscience, Science Advances*, and *Geology*. The team also invests great effort in outreach and education, including a public roadshow of its findings to 11 communities, and supporting two community-led, marae-based research projects to gain an understanding of earthquake and tsunami risk grounded in mātauranga Māori.



Our Chief Scientist, and General Manager Research Strategy and Partnerships, **Gary Wilson**, was awarded the Thomson Medal by Royal Society Te Apārangi. This award recognises his outstanding contributions to the organisation, support and application of science, technology and the humanities, and his leadership in developing Aotearoa New Zealand's international profile in Antarctic research.

Uwe Morgenstern was the recipient of the Outstanding Achievement in Hydrology Award at the New Zealand Hydrological Society Annual Conference. This award acknowledges his pioneering use of age tracers in hydrology, his contribution to significant scientific advances within the international hydrological community, and his support for end-users in groundwater management.

At the Geoscience Society of New Zealand Awards, **Donna Eberhart-Phillips, Susan Ellis and Stephen Bannister** were awarded the 2021 New Zealand Geophysics Prize for a paper examining properties in the crust surrounding the faults that ruptured in the 2016 Kaikōura earthquake using new seismic imaging methods.

GNS Science has been one of the key science organisations engaging with **Te Kura Taumata O Panguru (Panguru Area School, Northland)** who won the 2021 Prime Minister's Education Excellence Award Excellence in Engaging category. We have engaged with the school since 2017 on a number of activities, including the Northland GeoCamps series.

Martha Gabriela Gomez Vasconcelos, a former PhD student at Massey University, co-supervised by GNS Science's **Pilar Villamor**, has received the 2021 National Award to Women in Science 'Emerging Talents' award – awarded by L´Oréal México, United Nations Educational, Scientific and Cultural Organization (UNESCO), Mexica Academy of Sciences (AMC) and the Mexican Commission for cooperation with UNESCO (CONALMEX).

Emily Warren-Smith was awarded the American Geophysical Union's 2021 Editor's Citation for Excellence in Reviewing for the *Journal of Geophysical Research: Solid Earth.*

Nancy Bertler has been appointed to Chair the Independent Science Panel of 'Securing Antarctica's Environmental Future' (SAEF) project, led by Prof. Steven Chown, former President of the Scientific Committee on Antarctic Research, and hosted by Monash University.

Sebastian Naeher has been appointed Chair of the American Geophysical Union Waldo E. Smith Award selection committee for 2022-23. The Waldo E. Smith Award is an award given biennially to a senior scientist in recognition of extraordinary service to Earth and space science.

Sam McColl has taken on a new leadership role for the Geoscience Society of New Zealand, as Vice President. He continues to serve on the Australia and New Zealand Geomorphology Group Executive Committee.

Kyle Bland continues as guest Associate Editor for the *New Zealand Journal of Geology and Geophysics* in relation to the two-volume special issue 'Understanding Sedimentary Systems and Processes of the Hikurangi Subduction Margin; from Trench to Back-Arc'.

Jérôme Leveneur was appointed as a panelist on the Royal Society Te Apārangi Marsden Fund Engineering and Interdisciplinary panel.

The Integrated Global Greenhouse Gas Information System, of which **Jocelyn Turnbull** is co-chair, has been quoted as one of ten highlights in the US Global Change Research Program 2021 report.

Sally Potter was invited to join the World Meteorological Organization (WMO) 'Tiger Team' on water-related research. She was also selected by the Research Board to serve as a 'focal point' for the WMO Standing Committee on Services for Disaster Risk Reduction and Public Services (SC-DRR). The SC-DRR has members from around the world, and connecting GNS Science to this network provides a pathway for global uptake of, and impact from, our social and behavioural science research.

OUR SCIENCE ROADMAP TO 2032

Our ambition – and it's a bold one – is to be the scientific cornerstone of a society empowered to live sustainably and resiliently in the face of the changes and challenges of the Earth and environmental system here in Aotearoa New Zealand.

Our new Science Roadmap will help us achieve this outcome. It will guide the conversations, interactions and engagement we have with government, iwi and Māori partners, industry leaders, academic and research partners and community leaders. This document is a living entity – it will be influenced by societal and natural challenges, and it will change as the future changes, whether by policy, innovation, new technology or new thinking.

"While the Roadmap's primary role is to aid GNS Science in developing its future research direction, it will also be useful for our shareholder, our partners and our myriad stakeholders to see the shared societal challenges we're focusing on," says Chief Scientist, Gary Wilson. "The Roadmap is essentially about people. We want to use it to ignite conversations about how important our science and research is for society and for the future wellbeing of our communities."

The Science Roadmap identifies four key challenges, based on GNS' science themes.

You can access the Science Roadmap on our website: www.gns.cri.nz

Toitū te kupu, toitū te mana, toitū te whenua. We anchor our planning and thinking as we look to the future wellbeing for Aotearoa New Zealand.

CELEBRATING TE PUNAWAI O RANGIĀTEA – OUR NEW MĀORI STRATEGY

GNS Science is genuinely committed to increasing our understanding of Māori science needs and expectations. To support this outcome, earlier this year we released Te Punawai o Rangiātea, our new Māori Strategy.

Meaning 'the flourishing pool of knowledge', Te Punawai o Rangiātea provides critical guidance and direction to enable GNS Science to create enduring and sustainable relationships with tangata whenua – iwi, hapū, whānau and Māori. It details our shared moemoea (vision), whainga (mission), tikanga (values), kawa (actions) and kaupapa (outcomes).

Developed with GNS Science staff and reflective of the organisation's Science Roadmap and Theme Plans, Te Punawai o Rangiātea guides our approach to engagement and establishes 'MAHIA', a GNS Science Māori cultural model to support staff in their engagement with iwi-Māori.

By explicitly weaving the future interests of iwi-Māori into our Science Roadmap, building Vision Mātauranga into our research and actively using mātauranga Māori in our work, we are demonstrating our genuine commitment to the principles of participation, protection, and partnership.

"Te Punawai o Rangiātea will help us to work more effectively with iwi/Māori within the fabric of the research system" said General Manager Māori and Stakeholder Relations Tania Gerrard. "It will help us deliver research that is more responsive to Māori aspirations, it will make the science system more accessible, better protect mātauranga Māori, and strengthen Māori knowledge and practice, which will be to the ultimate benefit of all New Zealanders."

Mahia Framework

Manaaki

Showing respect, support, care, generosity and protection for others.

Our Iwi-Māori relationships demonstrate a robust Māori engagement process while implementing our long-term science direction.

Ara

Awaken the past, rise, path, be open with purpose.
Acknowledge and enable mātauranga Māori-led, GNS Science-enabled research development activities to shape Vision Mātauranga outcomes that produce world-class research.

Hinengaro

Thoughts, ideas, mind, heart, feelings.

Describe how we engage with Iwi-Māori to develop research, technical and cultural expertise to recognise and support mātauranga Māori and shared outcomes with and for our ongoing relationships with Iwi-Māori.

Āhua

Character, nature, condition, appearance.
Enable innovative approaches that enhance both internal and external expertise and capability in Earth sciences, Te Pū Ao me te Ao Māori.

Ihi

Essential, dynamic force and excitement.
Develop our people and processes with Iwi-Māori through increased research, technical and cultural skills to support both mātauranga Māori and science thought leadership outcomes through our relationships.

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.

Photo: Paleoseismology Technician, Regine Morgenstern, and Engineering Geology Surveyor, Jason Farr, planning flight parameters for the M600 LiDAR drone.

SCIENCE THEMES

Providing excellent science, where it matters most

How these impact Aotearoa New Zealand and its people

Research priority areas:
- Understanding Geohazards Processes
- Stewardship of National Capability
- Trusted Science Advice
- Knowledge Exchange
- Building Community Resilience
- Natural Hazard Risk Management System Improvement

How people impact the Earth

Research priority areas:
- Freshwater Security and Quality
- Antarctic Climate and Ice Dynamics
- Ecosystems and Biodiversity
- Our Climate System through Time
- Carbon Cycle and Atmospheric Emissions
- Sea Level Rise and Coastal Change
- Contaminant Pathways in the Earth System

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

Research priority areas:
- Growing the Use of Geothermal Energy, with a Particular Focus on New Resources such as Supercritical Fluids
- Growing an Aotearoa New Zealand Hydrogen Economy
- Developing New Clean Technology Industries based on Advanced Materials Research
- Using the Earth for New Energy Storage
- Modelling and Analysing Aotearoa New Zealand's Energy System

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
- Shared Solutions

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.

Our tohu (icon above) – named Moko – for this theme is a combination of a koru, a well-known symbol of growth and development in te ao Māori, and a close-up look at the skin of mokomoko (lizards/skinks). Lizards are an icon of caution throughout the Pacific, and represent being alert and paying attention to the many signals and signs nature can offer us. Together these designs embody our goal to develop and further our ability to detect, understand and prepare.

NATURAL HAZARDS AND RISK: OUR RESPONSE TO THE HUNGA TONGA-HUNGA HA'APAI VOLCANIC ERUPTION AND TSUNAMI

On 15 January 2022, the Hunga Tonga-Hunga Ha'apai underwater volcano erupted, triggering a devastating tsunami and causing significant damage to Tonga's infrastructure.

This event was, according to our scientists, "unparalleled on Earth for almost 140 years."

The tsunami was observed at coastal gauges and DART® (Deep-ocean Assessment and Reporting of Tsunamis) buoys around the world and its impacts were felt from as far away as the west coast of the USA, Peru, Japan and Aotearoa New Zealand.

GNS Science researchers supported the National Emergency Management Agency and the Ministry of Foreign Affairs and Trade response to the disaster and we worked closely with the Tongan Government disaster management ministry. We also partnered with Geoscience Australia and the United States Geological Survey to help design improved monitoring capabilities in-country.

Despite the unprecedented scale of the disaster, the Government of Tonga, with Aotearoa New Zealand's support, responded rapidly and effectively to the emergency, and is now focusing on recovery and reconstruction.

A snapshot of the Hunga Tonga-Hunga Ha'apai Volcanic Eruption and Tsunami:

- The material ejected in the eruption was about twice that of the Mount St Helens, USA, eruption in 1980; initial assessments indicate that up to one cubic kilometre of material was emitted from the volcano.
- The eruption produced a plume that reached a height of 58km, the tallest volcanic plume ever recorded.
- It generated something that scientists hadn't seen in more than half a century: a shockwave in the atmosphere. The shockwave, travelling at the speed of sound, circled Earth for several days.
- Another rarity of this eruption was that it generated tsunami waves that impacted thousands of kilometres away from the volcano. The pressure wave from the explosion connected with the surfaces of multiple oceans and seas, transferring energy to the water, and creating a spate of small tsunamis around the world.
- The eruption now holds the world record for being heard so far from the volcano. Audible booming could be heard in Iceland and Alaska.
- It has also been confirmed as the biggest explosion ever recorded in the atmosphere by modern instrumentation.

DART® network proves invaluable in assessing tsunami threat following the Hunga Tonga-Hunga Ha'apai eruption

Aotearoa New Zealand's network of DART® buoys proved vital as tsunami experts raced to analyse the tsunami threat to our coastlines following the eruption of the Hunga Tonga-Hunga Ha'apai submarine volcano in Tonga.

"The first sign of unusual activity came when the Aotearoa New Zealand DART® buoy closest to Tonga triggered at 5:48pm. We could see that a significant signal had been picked up by the sensor. This was about 30 minutes after the eruption and we were pretty confident that this was a volcanic-source tsunami," said Earthquake and Tsunami Duty Officer, Elizabeth Abbott.

Anything abnormal detected by a DART® buoy immediately alerts GNS Science's National Geohazards Monitoring Centre (NGMC) who swing into action, activating the GeoNet duty response team and a panel of scientists from GNS Science and partner research organisations, known as the Tsunami Experts' Panel. Data were recorded at more of the DART® buoys, as well as coastal tsunami gauges around the Pacific. GNS Science used the data to build a picture of what threat there might be to Aotearoa New Zealand to provide advice to the National Emergency Management Agency (NEMA).

> **"Following the Hunga eruption, the rapid detection, assessment and reporting of the tsunami threat by GNS Science meant that we were able to issue a National Advisory alerting people to the threat of tsunami activity more quickly and accurately than we otherwise would have been able to for this type of unpredictable and rare event".**
>
> Gary Knowles,
> Director Civil Defence
> Emergency Management, National
> Emergency Management Agency

"Assessing this tsunami was completely different from assessing earthquake-source tsunamis that we're more used to seeing,"said Dr Bill Fry, GNS Science Principal Scientist and Tsunami Experts' Panel member.

"In this event, we were fortunate to have real time observations from the DART® buoys. Based on tsunami measurements from the buoys, we were able to make assessments about when and where the tsunami might arrive, as well as its amplitude, despite having very little information about the volcanic eruption itself."

The global tsunami response community and the Pacific Tsunami Warning Center in Hawaii quickly recognised the importance of Aotearoa New Zealand's DART® buoys and established interim tsunami early warning protocols in the event of further Hunga Tonga-Hunga Ha'apai eruptions. These protocols, largely designed by GNS Science, have been ratified by the United Nations Intergovernmental Oceanographic Commission, are still in effect and are primarily underpinned by data from the DART® network.

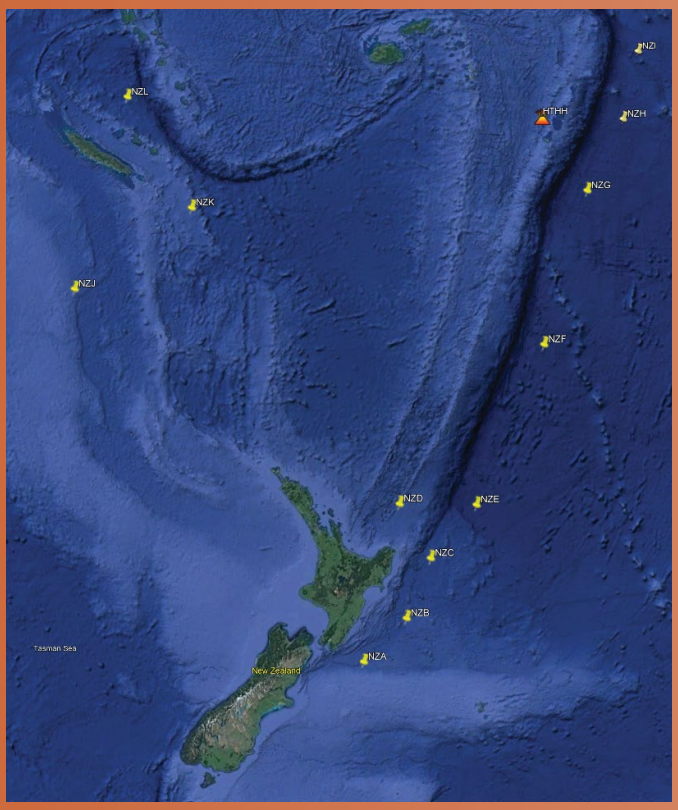
NIWA hydrodynamics scientist and Tsunami Experts' Panel member, Dr Emily Lane says, "If this had happened three years ago, before we had the DART® network, we would have had no idea that there was a tsunami heading our way until it arrived at our coasts and was picked up by our coastal tsunami gauges.

"The network not only helps protect the people of New Zealand, it also fills what had previously been a gap in the global DART® buoy network, providing warning information for our neighbouring countries in the Southwest Pacific too."

Gary Knowles, Director Civil Defence Emergency Management, National Emergency Management Agency says the DART® network has once again proved to be invaluable.

"Following the Hunga eruption, the rapid detection, assessment and reporting of the tsunami threat by GNS Science meant that we were able to issue a National Advisory alerting people to the threat of tsunami activity more quickly and accurately than we otherwise would have been able to for this type of unpredictable and rare event".

DART® (Deep-ocean Assessment and Reporting of Tsunami) buoys are deep-ocean instruments that monitor changes in sea level. They detect tsunami by measuring changes in water pressure via sea floor sensors. Right now, they are the only accurate way we can rapidly confirm a tsunami has been generated before it reaches our coast.



Left & Top: Deploying DART buoys.
Bottom: DART® buoy locations.

NATURAL HAZARDS AND RISKS

RiskScape® – Aotearoa New Zealand's Next-gen modelling tool "vital for our physical and economic security"

Natural hazards are part of Aotearoa New Zealand's DNA – and climate change is increasing both the risks and the impacts of hazard events. Managing our increasing exposure to these natural hazards is critical to our future wellbeing and prosperity – and that's where RiskScape® comes in.

RiskScape® was developed by GNS Science, NIWA and Catalyst IT. It is a software application for analysing natural hazard consequences, providing a risk analysis framework for calculating consequences to people, buildings, infrastructure, the environment and other elements exposed to any natural hazard type. It improves our understanding of natural hazard risk and enables us to make risk-based decisions and implement cost-effective risk reduction.

One of our key stakeholders, Toka Tū Ake EQC, has embraced RiskScape®, which they say has boosted their ability to plan for future natural disasters and respond to them when they happen.

"RiskScape® allows Toka Tū Ake to continuously bring its wealth of research and insurance data into its risk modelling, creating an increasingly comprehensive picture following an event, as well as improving our ability to model and plan for future disasters," says Head of Risk Modelling, Andrea Gluyas.

Gluyas says that as the relevant science develops, with the new tool we will be able to model losses from other perils such as tsunamis and volcanoes. "It will help us to better plan for future events as well as providing critical information immediately after an event to help us best prioritise assistance to the most affected communities."

In 2021, the Queenstown Lakes District Council commissioned GNS Science to undertake a study to estimate the financial loss and damage from debris flow and rockfall scenarios in Queenstown. RiskScape® was used to understand the impact of three alternative district plan policy options and proposed engineering solutions. It also provided quantitative evidence to support the Council's consultation on the best land use policy option to adopt.

GNS Science Project Lead, Nick Horspool, says "This study provides a good example of how RiskScape® can be used to inform land use decision-making to improve natural hazard risk management outcomes in Aotearoa New Zealand. RiskScape's® flexible design allows many sectors, such as land-use planners, asset managers, emergency managers and insurance providers, to better manage the significant risks from natural hazards that Aotearoa faces now and into the future."

RiskScape® named **Best Hi-Tech Solution for the Public Good** at the 2022 NZ Hi-Tech Awards!

"This award is the outcome of years of hard work across GNS, and with our partners at NIWA, Toka Tū Ake EQC, and Catalyst. I'm so pleased to see our collaborative efforts rewarded," said GNS Science CEO, Ian Simpson. "To be able to celebrate surrounded by amazing innovators, and with the Prime Minister there to present the award, it felt like an evening that reflected the true value and impact of the work we do, and how many people benefit from it."

Top: RiskScape® named Best Hi-Tech Solution for the Public Good at the 2022 NZ Hi-Tech Awards!

SNAPSHOT

RiskScape® was developed by GNS Science, NIWA and Catalyst IT

RiskScape® named Best Hi-Tech Solution for the Public Good at the 2022 NZ Hi-Tech Awards!

NATURAL HAZARDS AND RISKS

Tsunami Detectives – preparing for 'the big one'

Earthquake Geologist, Kate Clark, has co-authored a new study, which details the risk of a major earthquake at the southern end of the Hikurangi Subduction Zone and could help communities prepare for 'the big one'.

Working alongside PhD student, Charlotte Pizer, and Dr Jamie Howarth of Te Herenga Waka—Victoria University of Wellington, the study looked at sediment cores from Lake Grassmere Kāpara Te Hau, which contained prehistorical tsunami deposits, to get insight into past earthquakes.

They then combined this physical evidence with radiocarbon dating and sophisticated tsunami modelling techniques, which determined the probability of an earthquake of at least magnitude 8 on the southern end of the Hikurangi Subduction Zone (HSZ) in the next 50 years at about 26%.

Clark says that whilst scientists have known for some time that a large quake on the HSZ could generate a tsunami that would have a major impact on Aotearoa New Zealand, this is the first time they have been able to come up with a probability for large earthquakes.

"This research helps us better understand our largest fault, and the likelihood of tsunamis produced by this fault – and the more information we have, the better we can inform local communities about how to be prepared and resilient."

Core samples of the sediment layers at Lake Grassmere Kāpara Te Hau showed unusual shell layers, indicating deposits from several large-scale tsunamis, which were caused by large subduction earthquakes in the last 2000 years.

"Geological records are essential for assessing the risk of earthquakes and tsunamis, but they're difficult to obtain at transitional plate boundaries like this," Ms Pizer says. "This is a rare opportunity to gain knowledge from past earthquakes and tsunamis–helping us to best prepare for the future."

The paper on the research, published in *The Seismic Record*, confirmed a high tsunami hazard for central Aotearoa New Zealand if a large subduction earthquake were to occur. It also pointed to a high likelihood that ruptures extended well into Cook Strait, notably increasing tsunami hazard for the north-eastern South Island, including Christchurch.

The proximity to Wellington and high likelihood of a tsunami across the Cook Strait area meant a subduction earthquake would probably have "significant environmental and societal impacts".

This project is a joint study between GNS Science, Durham University and Te Herenga Waka—Victoria University of Wellington. It was supported by the 'It's Our Fault Programme' (funded by Toka Tū Ake EQC, Wellington City Council and Greater Wellington Regional Council) and the Understanding Zealandia Te Riu-a-Māui Strategic Science Investment Fund Programme.

Top: 'Tsunami detectives' at work.

SNAPSHOT

The probability of an earthquake of at least magnitude 8 on the southern end of the Hikurangi Subduction Zone in the next 50 years is about 26%

This research helps us better understand our largest fault

NATURAL HAZARDS AND RISKS

Watching over Vietnam's dams

Over the past decade, GNS Science has been supporting the Government of Vietnam to reduce the impact of dam-related flood risk on its communities.

Vietnam has one of the world's most extensive networks of dams, many of which are multi-purpose and support irrigation, hydropower, flood regulation, aquaculture and bulk water supply. However, ageing infrastructure, increased demand resulting from rapid economic development and impacts associated with a changing climate, is putting the infrastructure itself, and the communities it serves, at increasing risk.

That's where GNS Science comes in.

The Vietnam-New Zealand Dam Safety Project was launched in 2012 as a collaborative project between the Governments of Vietnam and Aotearoa New Zealand. Delivered in partnership between GNS Science, Damwatch and Thuyloi University, the project aims to deliver evidence-based decision-making for dam safety management, upgrading dams and improving community-based disaster risk management.

GNS Science's primary role in the project is to provide seismic and landslide hazard assessment, consequence modelling and disaster risk management advice. These specialist skills were identified as one of the key success factors to help solve Vietnam's critical dam safety problem through transferring knowledge and skills on whole-of-river basin management.

In 2022, GNS Science researchers embarked on phase three of the project – having completed phase one (developing guidelines for dam safety assessment methodology) and phase two (applying the methodology across 150 dams in the Ca River System and improving dam safety capability and capacity).

Phase three has seen the GNS Science team embark on a 'scaling up' process to roll out the dam safety assessment methodology to other provinces, and to update and upgrade it to address climate change and social inclusion issues in the disaster risk management process.

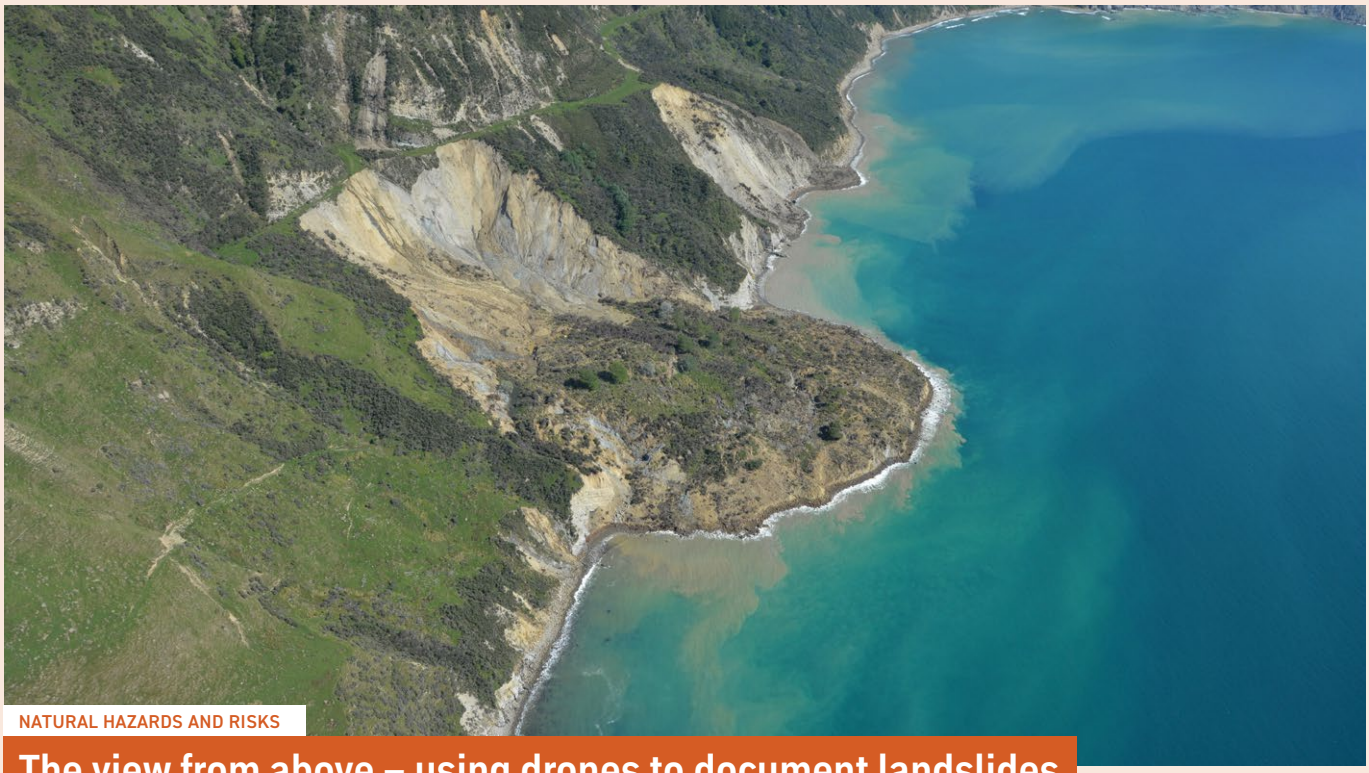
See more about the project here: https://www.youtube.com/watch?v=RcVoTQ_IwW4&t=9s

Top: Ban Ve hydropower dam in Nghe An province, Vietnam.

SNAPSHOT

Vietnam has one of the world's most extensive networks of dams

Phase 3 of the project involves a 'scaling up' process to roll out the methodology to other provinces



NATURAL HAZARDS AND RISKS

The view from above – using drones to document landslides

A wild November storm in Tairāwhiti created one of the largest and most rapid rain-triggered landslides in the Gisborne area. GNS Science initiated a Landslide Response and our engineering geologists teamed up with the Gisborne District Council and Ngāi Tāmanuhiri to determine the scale of damage and the implications it may have for the region's future.

As well as causing widespread flooding and damage to homes in Gisborne, the rain triggered a number of landslides. The largest, at Whareongaonga, and others adjacent, undermined the already-damaged Wairoa to Gisborne rail line and buried several wāhi tapu, including a historic Ngāi Tāmanuhiri pā site, Māra kai (food gardens) and Taunga ika (fishing grounds).

"The size of the Whareongaonga landslide is extreme for a rainfall-induced landslide. There are many large relict (old) landslides in the landscape in the Gisborne area but until now we had thought that they were triggered by large earthquakes" said Engineering Geomorphologist, Brenda Rosser. "This makes this landslide of high scientific value to our team, as we are not aware of such a large, rapid landslide being triggered by rainfall in the region for a very long time."

The GNS Science team took to the skies to survey the Whareongaonga landslide. Using a new drone, the scientists undertook a LiDAR (Light Detection and Ranging) survey, which is a remote sensing method that uses light in the form of a pulsed laser to measure distances to the Earth's surface, enabling them to build a high resolution, 3D model of the ground surface.

"LiDAR data will be used to determine the volume of material involved in the landslide — both the volume evacuated from the source area and deposited down slope and in the sea — and to interpret the processes involved in the landslide initiation and movement. The survey data will also be used as a baseline to map the landslide and tension cracks surrounding the slip, and to monitor changes in the landslide and its deposits over time," said Rosser.

Preliminary results from the 3D difference model showed that the volume of material removed by the landslide was approximately 1.3 million cubic metres; the volume of sediment deposited in the sea was approximately 1 million cubic metres.

Between our initial survey in November 2021 and when we returned to survey the site with the LiDAR drone in late December, the toe (lower part) of the landslide had been eroded by the sea by approximately 50 metres — equivalent to at least 115,000 cubic metres of material.

Top: Whareongaonga landslide near Gisborne.

SNAPSHOT

Using a new drone, the scientists undertook a LiDAR (Light Detection and Ranging) survey

The volume of material removed by the landslide was approximately 1.3 million cubic metres

Approximately 1 million cubic metres of sediment was deposited in the sea

NATURAL HAZARDS AND RISKS

Resilience to Nature's Challenges

GNS Science is proud to host the Resilience to Nature's Challenges National Science Challenge | Kia manawaroa – Ngā Ākina o Te Ao Tūroa (RNC). RNC researchers collaborate with numerous partners to develop better models and understanding of the risks we face from volcanoes, earthquakes, tsunamis, landslides, high-impact weather events, wildfires and coastal change. Our aim is to develop tools that enable agencies, councils, mana whenua, businesses and communities to reduce the impact of hazardous natural events and promote faster and more thorough recovery.

A vital component of resilience is having realistic and meaningful forecasts of events and their impacts. Dr Sally Potter and Dr Sara Harrison of our Weather & Wildfire team have been investigating impact-based weather warnings to determine whether they are more meaningful for the public, and to identify challenges and data needs so they can be implemented. Meanwhile, Dr Melody Whitehead and our Volcanoes team completed an assessment of six different methods of eruption forecasting as they progress toward Aotearoa New Zealand's first operational eruption forecasting system. Similarly, the Earthquake & Tsunami team have completed a review of Earthquake Early Warning systems around the world to assess what kind of system might be best here. Aligned with this work – and another highlight of the year – has been the publication of Dr Bill Fry and Prof Andy Nicol's findings from Aotearoa New Zealand's first earthquake cycle simulator.

A highlight of RNC's efforts this year has been the co-delivery of several 'science to policy' workshops for Ministry for the Environment policy staff working on new adaptation legislation. RNC case studies have also been included in the government's National Adaptation Plan. Meanwhile, Prof Jon Procter and Dr Danielle Charlton of our Volcanoes team worked with the Taranaki Civil Defence & Emergency Management Group Office to develop a poster series about volcanic processes associated with Taranaki Mounga, delivering key messages about how to stay safe in the event of an eruption.

Another key focus of the Challenge is supporting and empowering kaupapa Māori researchers and research. Critical to this mahi is exploration of te ao Māori approaches to resilience, which this year has meant shedding light on a decolonised approach to managed retreat for coastal marae; development of an iwi-led approach to monitoring the volcanic activity of Ruapehu Maunga; and investigation of whānau-centred methods of upgrading earthquake-prone marae buildings for their safe and continued use.

With just two years left to go of the Challenge, and all of RNC's researchers – including 80+ postgraduate students – bringing numerous projects through to fruition, it promises to be an exciting time!

Find out more about RNC: www.resiliencechallenge.nz

RESILIENCE TO NATURE'S CHALLENGES | Kia manawaroa – Ngā Ākina o Te Ao Tūroa | National Science Challenges

SNAPSHOT

Co-delivery of several 'science to policy' workshops for Ministry for the Environment policy staff working on new adaptation legislation

Significant progress made towards Aotearoa New Zealand's first operational eruption forecasting system

Key Theme Outputs

	Research output 2021/22	What we have achieved
1	Improved understanding of earthquake rupture processes, ground motions, frequency and magnitude characteristics, spatial and temporal distributions and interactions, and the underlying tectonic processes operating in New Zealand to inform the refresh of the National Seismic Hazard Model (NSHM).	Multiple new journal papers detailing our improved understanding about the tectonic processes under Aotearoa New Zealand were published this year. Components of the NSHM including the Community Fault Model, revised Earthquake Catalogue, Paleoseismic Database, Ground Motion Database and Geodetic Strain Rate Model were completed, along with Seismicity and Ground Motion models. This improved modelling has been incorporated into the refresh of the NSHM.
2	Deliver improved laboratory and field-based models of submarine landslides, rainfall triggering thresholds for New Zealand debris flows and site-specific conditions and performance of fill slope urban areas under earthquake and rainfall.	New journal papers and reports produced that demonstrate improved models include a study (including risk modelling) for rainfall triggering of debris flows in the Franz Josef Glacier and Fox Glacier valleys, and a review of geomechanical data for greywacke in the Wellington region related to fill slopes.
3	Continue to develop and refine conceptual and numerical models of New Zealand volcanoes which, along with field data, will inform hazard maps and decision support tools for life safety and asset management decision-making.	Conceptual models for both Whakaari/White Island and Ruapehu were updated and are helping to constrain interpretations of volcanic activity. Ruapehu model development was used to support evaluation of unrest at that volcano in early 2022. A Bayesian network for Ruapehu was also completed and is being used by the Volcano Monitoring Group to assess the probability of eruption.
4	Socialise a minor update of the National Tsunami Hazard Model (NTHM) among the stakeholder community, and plan for a major revision of the NTHM by 2024.	The minor update of the NTHM was completed and used to inform assessment of tsunami risk for clients. The plan for the full revision of the NTHM was socialised this year with the New Zealand Tsunami Research Group and external agencies MBIE, DOC, NIWA, Toka Tū Ake EQC and MetService. A tsunami cross-agency 5-year plan was developed to map and further socialise the application of this model and preliminary costings were completed.
5	Continue RiskScape 2.0 product development, improve multi-hazard and probabilistic capabilities and investigate interoperability capability of the platform with other domestic and global risk tools.	RiskScape software has been released publicly, including an open-source licence for research use, and is now being fully utilised by Toka Tū Ake EQC. The RiskScape Governance Group (NIWA and GNS Science) is now working with Toka Tū Ake EQC as a project partner to aid in the further development of the software, which is allowing for more rapid development and delivering significant impact for Aotearoa New Zealand.
6	Deepen understanding of interdependencies between critical infrastructures which may result in compounding hazard impacts, using Wellington and Hawke's Bay as case studies.	Work to account for cascading hazards has been completed as planned. Work is now required to incorporate these new methods into RiskScape so that quantification of hazard and risk can be calculated.
7	Develop and test a protocol to assess iwi management plans for their natural hazard and risk provisions.	Iwi consultation, which has been challenging due to COVID restrictions, has led to new protocols being developed to assess iwi management plans for their natural hazard and risk provisions. The focus for next year will be to deploy the protocols to other partner iwi.
8	Support the translation of science into accessible forms to enable community understanding, risk management and resilience through the development of visual tools and information products.	A comprehensive science advice product catalogue and workplan was completed and we have developed dashboard prototypes to improve communication of our research. The unrest at Ruapehu enabled us to deploy our research methods in a real scenario. The production of hazard and risk maps enabled DOC to determine the summit exclusion zone for that volcano.
9	Deliver improved monitoring capability in line with the outcomes specified in the Enhanced Geohazards Monitoring Contract.	The Enhanced Geohazards Monitoring Contract has been extended for a year as GeoNet transitions to a new Head Operating Agreement. Bridging funding has been approved by Cabinet and initiatives to maintain capability are being prioritised with stakeholders. A 2023/24 (and beyond) budget bid will be submitted to government for ongoing sustainable funding.
10	Landslide forecast models will be incorporated into National Geohazards Monitoring Centre (NGMC) advice to stakeholders, allowing the near-real time forecasting of landslide occurrence and severity in future earthquakes.	The Earthquake Induced Landslide Forecaster is now operational within our NGMC. In addition, we developed a Wellington region pilot of the Rainfall Induced Landslide Forecast Tool – this will be further developed for wider use across Aotearoa New Zealand in 2022/23.
11	Refine and secure enduring governance, contracting and funding arrangements for the GeoNet programme. This includes stakeholder agreement to the GeoNet product and service catalogue and service level measurement.	The GeoNet Head Operating Agreement is being executed by the parties, GNS Science, Ministry of Business, Innovation and Employment (MBIE), Toka Tū Ake EQC, National Emergency Management Agency (NEMA) and Toitū Te Whenua Land Information New Zealand (LINZ). The Agreement creates a solid platform from which the parties can evolve future funding, contracting and governance arrangements. NEMA, with the assistance of MBIE, is leading a budget bid (Natural Hazards Platform) which is intended to secure future funding for GeoNet, the National Seismic Hazard Model and seed funding to develop a business case for funding other hazard models.

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.

Our tohu (icon above) – named Rauru – represents Te Ao Hurihuri, our ever-changingworld. Adaptation over time, survival, change and self-management are central to the Climate and Adaptation theme. In this tohu, built from a rauru, opposing but connected spirals evolve as they get closer to the centre, shown in the pītau (the bumps on the white spirals). The spirals change shape and form as they come together.

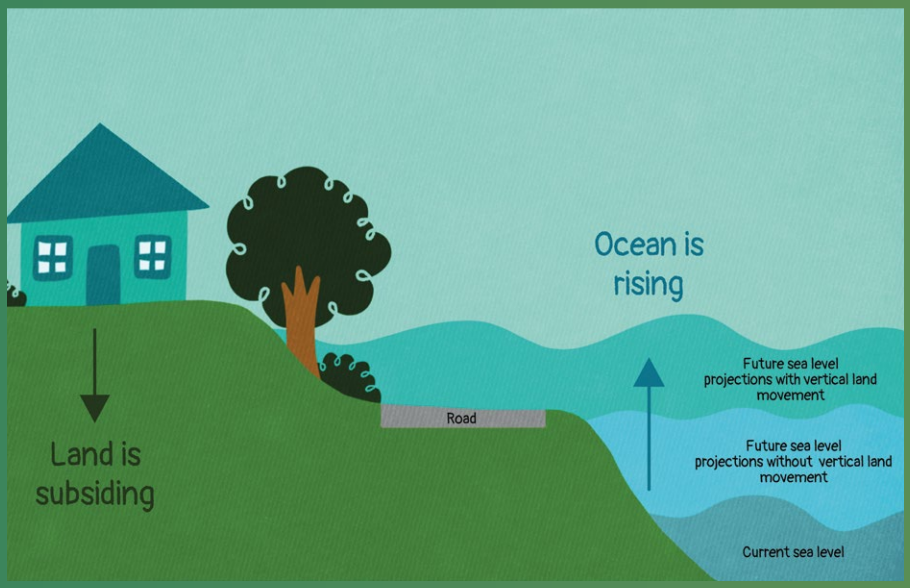
MAKING THE CONNECTION – HOW SCIENCE PARTNERSHIPS ARE HELPING TO SOLVE OUR BIGGEST ENVIRONMENTAL ISSUES

By its very nature, Papatūānuku the Earth, and the Earth System, is vast and intricately connected. So, it follows that the work we do must also be connected – to Aotearoa New Zealand's wider science system, to government policy priorities and direction, to our Māori and iwi partners, to industry stakeholders, and to Aotearoa New Zealand communities.

An example of this approach in action is the New Zealand SeaRise: Te Tai Pari O Aotearoa programme. It's an inter-disciplinary, integrated programme, with each partner making a critical contribution to solving one of Aotearoa New Zealand's most pressing environmental issues.

"Science is all about connections," says NZ SeaRise co-lead, Richard Levy. "We each have specialist skills in different fields and disciplines, yet our work is intricately connected because Earth systems are connected. The NZ SeaRise programme demonstrates that when we create a community of learning, we can solve problems on a much bigger scale than if we were working independently."

Levy describes GNS Science's key contributions to the NZ SeaRise programme as being about "ice, space, coast and people". The research team has gathered data and information about the Antarctic Ice Sheet and connected this to data on vertical land movement across Aotearoa New Zealand. They've then shared the information with social science and planning experts to help build a picture of how much sea level will rise along our coastlines and how these changes might affect our land and people.



Left: Infographic showing impact of vertical land movement on sea level rise.
Right: NZ SeaRise co-lead, and Environment and Climate Theme Leader, Richard Levy, Friis Hills, Antarctica.

Let's start with ice

Antarctica is a recorder of climate change; it harbours information about our climate past and its response to future warming will have major impacts across the globe.

"We are striving to understand as much as we can about the role Antarctica and its ice sheets will play in a warming world – because what happens in Antarctica will shape what happens everywhere on the planet", says Levy.

Late last year, Climate Scientist, Dan Lowry, released a study which used a new approach to understanding Antarctic Ice Sheet change. By combining traditional, numerical-based ice sheet models and adding a statistical emulator based on the data of hundreds of ice sheet models, scientists are now more certain about the interactions between the warming oceans surrounding Antarctica and its massive ice sheets.

"This method paves the way for clearer projections of the future of the Antarctic Ice Sheet," says Lowry. "The results from our study highlight the urgency of reducing carbon emissions and the long-term consequences of failing to do so."

Next – vertical land movement (and space)

Ice melt in Antarctica affects the whole planet, but vertical land movement is key to understanding future sea level rise at a local scale. Most regional coastal management plans have assumed that sea level would generally rise the same amount everywhere around our coastline. But recent space-based measurements show our coastlines are sinking and rising by varying amounts. And in places where our coastline is sinking, sea level will rise faster than previously assumed.

GNS Science Geodesists, Ian Hamling and Sigrun Hreinsdottir, alongside their colleagues, have been researching the impacts of vertical land movement (VLM) on sea level rise. Their work clearly demonstrates how these movements affect the entire coastline and this insight has been a key contribution to the new sea level projections produced by NZ SeaRise.

"With around 15,000 kilometres of coastline, we knew traditional approaches to measuring vertical land movement were impossible. To overcome this, we combined observations from Interferometric Synthetic Aperture Radar (InSAR) and GPS stations to

increase the breadth and density of vertical land movement estimates. The ability to identify VLM at high spatial resolution is a game-changer in our understanding of rising sea levels," says Hamling.

Hamling, Hreinsdottir and their team have created a high resolution, systematic map of country wide vertical land movement, allowing NZ SeaRise to produce bespoke sea level rise projections for every two-kilometre stretch of our coastline; projections which will provide invaluable insight for decision-makers as they plan to adapt to a changing climate.

"Understanding the impact of vertical land movement on sea level rise significantly changes the time we have to plan for its impacts. The amount of sea level rise we might expect to occur in 50 to 60 years could actually happen in two or three decades," says Levy.

And finally, what about the people?

The data we have collected will help us all to make better decisions about how to manage the consequences of rising seas in Aotearoa New Zealand. The new NZ SeaRise projections will inform the Ministry for the Environment's national adaptation plan. They are currently being used to update coastal hazards guidance for local government, helping communities, planners, businesses and infrastructure providers across the country adapt to the unavoidable impacts of coastal hazards and climate change.

"Most New Zealanders accept that climate change and warming temperatures are causing sea levels to rise," says Hamling. "What they didn't know, up until very recently, was how much local sea level rise around the coast of Aotearoa was affected by the up and down movements of our land. We're very aware when these vertical land movements occur in large jumps during earthquakes, but less obvious to us are the smaller shifts that occur continuously in between large seismic events. These small but continuous changes add up, and in areas that are going down (subsiding) the annual rate of sea level rise can double."

The NZ SeaRise programme

The NZ SeaRise: Te Tai Pari O Aotearoa programme has released location-specific sea level rise projections out to the year 2300, at locations for every two kms along the coast of Aotearoa New Zealand. These projections are available to explore through an online interactive map developed by Takiwā, a data management and analytics platform: www.searise.nz/maps-2.

NZ SeaRise is a five-year research programme supported by the Ministry of Business, Innovation and Employment Endeavour Fund. It brings together over 30 local and international experts from GNS Science, Te Herenga Waka—Victoria University of Wellington, NIWA, University of Otago and the Antarctic Science Platform to improve projections of sea level rise in Aotearoa New Zealand. The sea level projection and mapping tool was developed by Takiwā, a Māori-owned data management and analytics platform.

ENVIRONMENT AND CLIMATE

GNS Science on the global stage

The COP26 Summit in November 2021, saw world leaders coming together to reaffirm their commitment to combatting climate change and keeping global temperature rise of 1.5°C within reach.

These global negotiations were driven by findings in the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6, which was developed collaboratively by leading researchers from around the globe, including from GNS Science.

GNS Science had two contributing authors and more than 30 citations of our published research.

GNS Science's Environment and Climate Theme Leader, Dr Richard Levy, says that IPCC reports give a comprehensive account of the latest climate research – while also revealing areas where more work is needed; work which he says GNS Science is well placed to fill with our proven climate expertise.

"Carbon sources and sinks, the impacts of sea level rise, and regional water cycles are all areas that need further exploration. And there remain large uncertainties regarding the response of the Antarctic Ice Sheet to warming, particularly if we fail to achieve emissions targets outlined in the Paris Agreement".

"We also need to understand how clean energy options – like hydrogen – may impact our environment, climate, and society. And we need to keep unravelling the interconnectedness of climate processes and feedbacks to understand how everything fits together, so that we can identify the likely consequences of change and adapt to, and thrive in, an evolving future."

> **"GNS Science has much to offer as we fill these knowledge gaps alongside our partners in Aotearoa New Zealand and around the world".**
>
> Dr Richard Levy

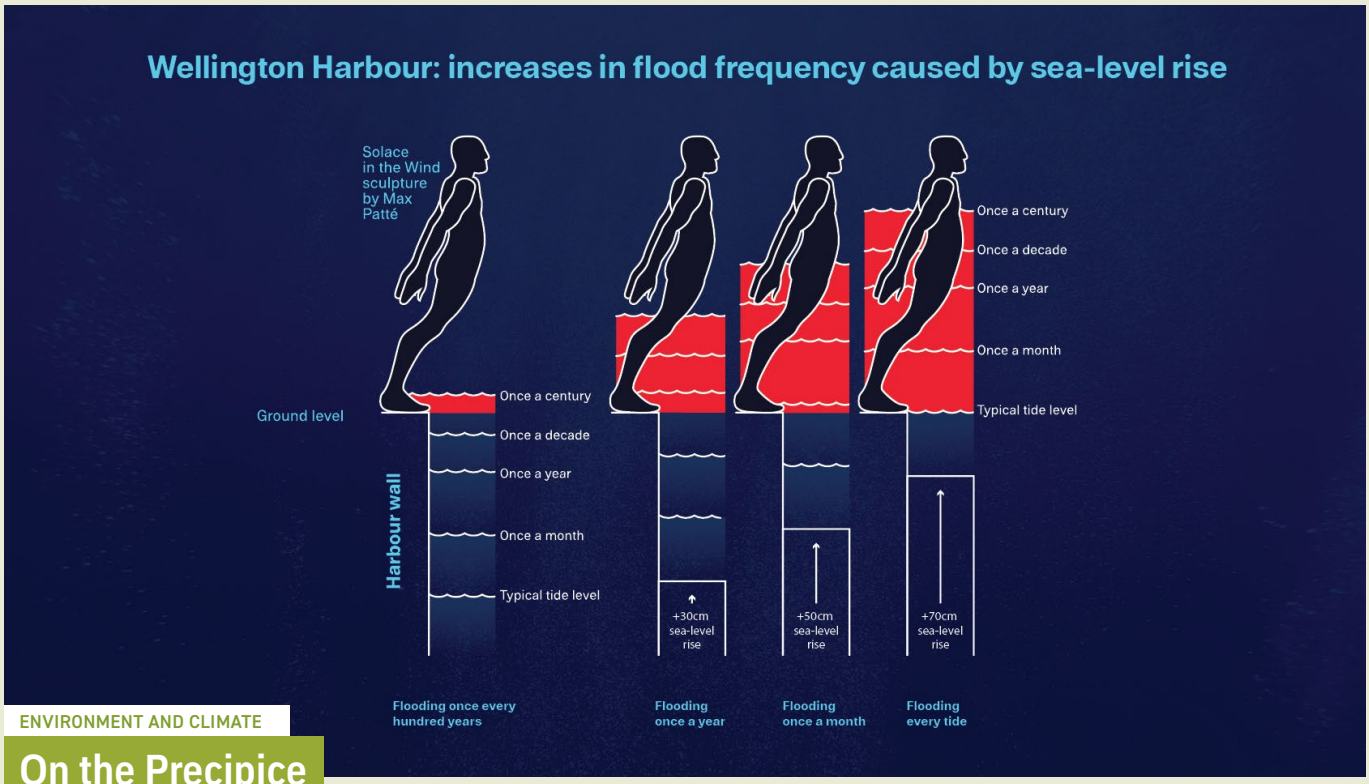
You can read the full Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6 (AR6) – Working Group I (WGI) The Physical Science Basis here: www.ukcop26.org

Top: Storm surge, Eastbourne, Wellington, July 2022.

SNAPSHOT

World leaders came together to reaffirm their commitment to combatting climate change and keeping global temperature rise of 1.5°C within reach

GNS Science had two contributing authors and more than 30 citations of our published research in the IPCC Assessment Report 6



ENVIRONMENT AND CLIMATE

On the Precipice

"The numbers are sharp and the repercussions alarming — but it's not too late. We still have a chance to curb CO_2 emissions before we reach a climate tipping point," said GNS Science socio-economic policy specialist, Celia Wells.

Wells was speaking at the launch of the GNS Science-commissioned report, *On the Precipice – the climate change target that humanity cannot afford to miss.* The report draws on work by GNS Science, Te Herenga Waka—Victoria University of Wellington, the Antarctic Science Platform, international researchers, and the Intergovernmental Panel on Climate Change (IPCC).

> **"Sea level rise poses one of the greatest risks to our economic security and the welfare of our communities. We know from the science that we need to act now if we want to slow global warming and curb the worst of its effects. We have a responsibility to act now to protect our planet for future generations. This is our moment to make a difference."**

On The Precipice includes data, research and modelling from a range of Aotearoa New Zealand and international scientists. It concludes that we must take "urgent action for a salvageable future" and that our best chance of avoiding the worst impacts of climate change is to limit further warming immediately.

"We can, and should, act now to limit sea level rise by urgently limiting greenhouse gas emissions. The work we're doing in Antarctica now will influence future government policy. Community leaders and decision-makers are seeking out science to help them prepare for the changes ahead," said Wells.

"Climate change is the greatest issue most of us will face in our lifetime. We know from the science that we need to act now if we want to slow global warming and curb the worst of its effects. This is our moment to change."

On the Precipice can be accessed here: www.gns.cri.nz

Top: Using Matt Patte's 'Solace in the Wind' sculpture on Wellington harbour to depict potential impacts of sea level rise.

SNAPSHOT

On The Precipice includes data, research and modelling from a range of Aotearoa New Zealand and international scientists

We can, and should, act now to limit sea level rise by urgently limiting greenhouse gas emissions

Climate change is the greatest issue most of us will face in our lifetime

ENVIRONMENT AND CLIMATE

Lakes380 – a merging of mātauranga Māori and science

The Lakes380 team, including programme co-leader and GNS Science Paleoecologist, Marcus Vandergoes, has been working alongside Ngā Puna Rau o Rangitīkei, to uncover the environmental history of Lake Oporoa.

They have documented historic environmental change through the analysis of lake sediment cores and their discoveries correspond with oral histories that have been passed down through generations. The identification of Raupō (bull rush) in the sediment core is both culturally and environmentally significant, so too is the discovery of kowhai seeds deep within the sediment. Both discoveries match the oral histories recounting the journey taken by Matangi — an early Māori explorer who traversed and named places in the Rangitīkei. He followed a flock of tui which were drawn to the kowhai trees near the lake, which is how Lake Oporoa was discovered.

"Core sediments are a way for the lake to tell its own story. The analysis of the core samples from Lake Oporoa tell us when humans first interacted with the lake, when Europeans arrived and the subsequent impact of introduced species and agricultural practices," said Vandergoes. "It was a unique experience for us to be able to interweave biophysical data with cultural knowledge. It's a combination that will ultimately provide a richer understanding of the value and health of our lakes."

He Reo nō te Puehu – a virtual experience

In partnership with Ngāti Koata and the Department of Conservation, the Lakes380 team have created a unique way for people to engage with the past, present and future of Lake Moawhitu.

In April 2022, the Lakes380 team launched its cutting-edge virtual experience of Lake Moawhitu on Rangitoto ki te Tonga/D'Urville Island. Informed by mātauranga Māori and biophysical data, viewers can travel backward and forward through time to gain a deeper appreciation of how lake, landscape and human interactions have changed over 1,000 years – and importantly, discover what it could look like 100 years from now.

The virtual reality experience is an excellent example of the science communication approaches being championed through Lakes380. "Transformation of lake management in Aotearoa New Zealand requires wider changes in society. We have placed working with iwi, educating the community, and science communication at the forefront of our efforts to ensure our science empowers people, inspires engagement, and drives societal change," Vandergoes said.

Lakes380 data update: Predicting the water quality of all lakes in Aotearoa New Zealand

The Lakes380 team developed a method to evaluate lake trophic status using bacterial environmental DNA in lake surface sediment. They coupled this DNA 'tool' with statistical techniques to predict the trophic levels (a metric of water quality) of all lakes in Aotearoa New Zealand. Worryingly, the model estimates that over 45% of our lakes are in 'poor or worse than poor' condition.

The team have developed an app so you can explore the water quality of your favourite lakes: https://lakes380.upshift.co.nz/

Top: GNS Science's Marcus Vandergoes and Adelaine Moody examining a core sediment.

SNAPSHOT

The identification of Raupō (bull rush) in the sediment core at Lake Oporoa is both culturally and environmentally significant, so too is the discovery of kowhai seeds deep within the sediment

In April 2022, the Lakes380 team launched its cutting-edge, virtual experience of Lake Moawhitu

The team have developed an app so you can explore the water quality of your favourite lakes: https://lakes380.upshift.co.nz/

ENVIRONMENT AND CLIMATE

What's the future for South Dunedin?

Structural Geologist and Principal Scientist, Dr Simon Cox, has spent the past few years discovering what lies beneath the community of South Dunedin. His observation-based models of groundwater are being used by local government to help determine the future of the community.

South Dunedin is home to around 10,000 people. It's a flat, low-lying coastal area, surrounded by steep hills and built on reclaimed land with shallow groundwater. Prior to 2019, little was known about what lay below its subsurface.

In 2020, a consortium led by GNS Science and Otago Regional Council and supported by NZ SeaRise (see page 26) , began a programme of drilling and groundwater monitoring. Drill cores, some as deep as 60 metres below the surface, were used to create a 3D model defining the geological architecture beneath South Dunedin. Groundwater was monitored at 27 sites, to reveal an 'ultrasound-like' look of how the groundwater behaves. A detailed aerial LiDAR (Light Detection and Ranging) survey was also captured in 2022, the first in more than a decade, which adds even further clarity to future issues faced by the city. LiDAR is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses – combined with other data recorded by the airborne system – generate three-dimensional information about the shape of the Earth and its surface characteristics.

While a barrier of sand dunes protects low-lying properties from direct inundation by the sea, the area remains vulnerable because of its lack of natural drainage and shallow groundwater that sits only a metre or so below the streets and houses. Shallow groundwater causes all sorts of problems – it can damage foundations, cause dampness in homes, impede access to roading networks and damage other infrastructure.

Working alongside Phil Glassey and Lee Chambers, Cox's research revealed that the sediment beneath much of the City has low permeability, and volumes of groundwater flow are small, which is good news for a community seen as extremely vulnerable to the effects of sea level rise.

"There may be 'a bit more time' with less immediate rise of groundwater than if the ground had high-permeability with extensive tidal flow of seawater in and out of the shallow sediment – as had been widely rumoured prior to the study. But once sea level rises to 30 or 50cm, due to climate change, then the city will be faced with a need to make some hard decisions. It may be that we have to eventually retreat from this land, but in the meantime there's an awful lot of living to do," said Cox.

Given sea rise is likely to start impacting communities within decades, rather than centuries, plans to adapt need to start now. Cox's discoveries are already being used by decision-makers to guide their future planning. Dunedin is also being used as a case study to understand the effects of urban development and sea level rise on groundwater systems.

Top: Structural Geologist, Simon Cox, using an electronic tape to measure the depth to groundwater at a monitoring borehole in South Dunedin.

SNAPSHOT

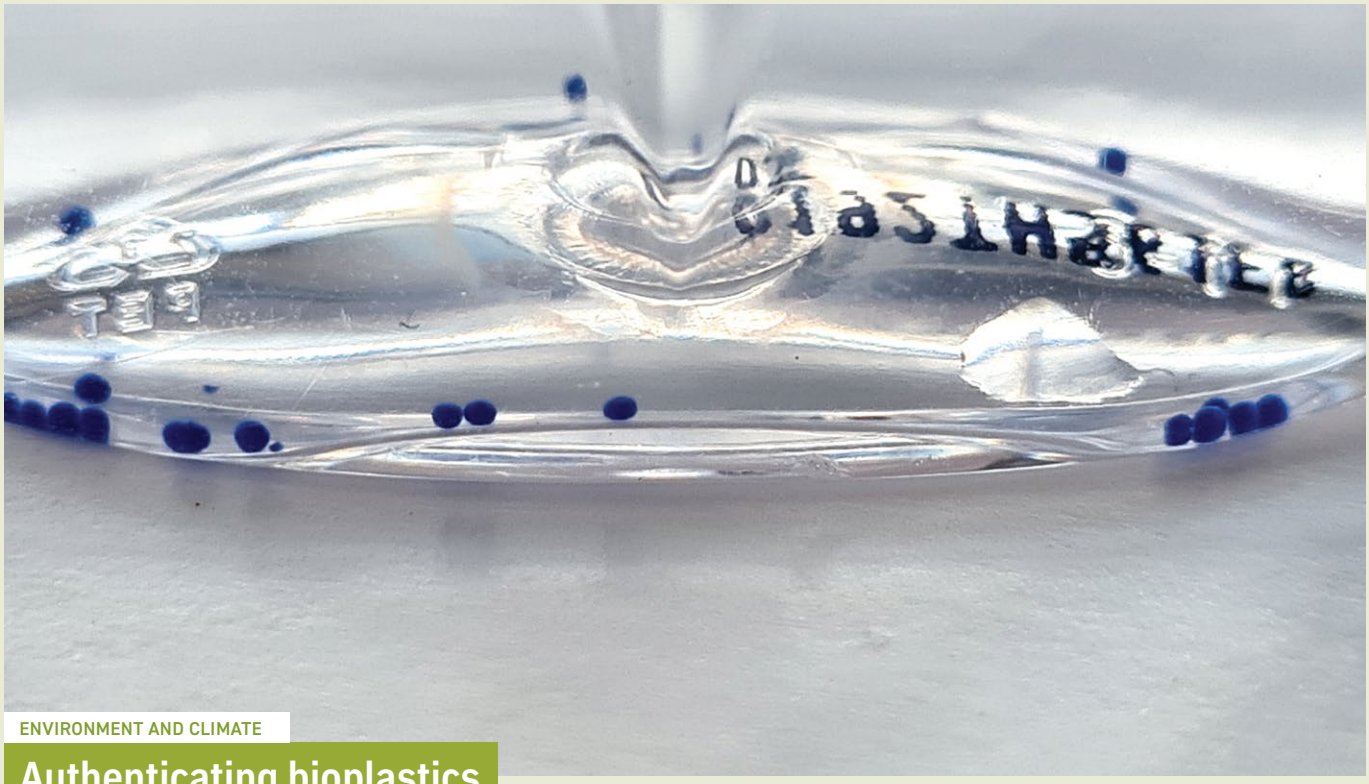
60 metres

Drill cores, some as deep as 60 metres below the surface, were used to create a 3D model defining the geological architecture beneath South Dunedin

27 sites

Groundwater was monitored at 27 sites, to reveal an 'ultrasound-like' look of how the groundwater behaves

Once sea level rises to 30 or 50cm, due to climate change, then the City will be faced with a need to make some hard decisions



ENVIRONMENT AND CLIMATE

Authenticating bioplastics

If you buy plastic or plastic-wrapped items, you may have noticed many products now come embossed with claims of "sustainably sourced", "compost-friendly" or "made from plants".

Despite these promising developments and the honest efforts by businesses to improve transparency for consumers, profit sharks are riding, and hiding, in the wake of this green wave.

A recent study by GNS Science researchers, in collaboration with Scion and the Zhejiang Academy of Agricultural Science (Hangzhou, China), revealed that 50% of in-market bioplastics don't meet their eco-friendly claims.

The study used carbon and hydrogen stable isotopes for the first time to verify a range of plasticware samples from Aotearoa New Zealand and China. It found that very few of the bioplastic-claimed samples were 100% bioplastic, with most around 30%, and some as low as 6%.

Previously, to counter dishonesty in the supply chain, radiocarbon (14C) dating has been internationally employed for bioplastic authentication. Measurements of the radioactive decay of carbon can verify whether the plastic is fossil fuel, petroleum polymer, or plant-based by the age of the material. "It's one of the bread-and-butter tasks for GNS Science's Rafter Radiocarbon Lab," says Jocelyn Turnbull.

For now, the authentication of bioplastics is not covered by a worldwide standard, and the definitions and policies surrounding bioplastic vary significantly. For Aotearoa New Zealand, this means both consumers and manufacturers rely on external certifications of bioplastic.

The study proposes a new way to use rapid, low-cost authentication analyses that could increase the ability of routine testing and checking of bioclaims.

During the study, Karyne Rogers, Jocelyn Turnbull, and the Rafter Radiocarbon and Stable Isotope laboratories applied stable isotope analysis for a new and novel test of bioplastic status. It is a cheaper and faster diagnostic tool than radiocarbon dating, serving well as an initial screening tool.

GNS Science also collaborated with Scion to apply tritium analyses to bioplastics for the first time. The concept is to use the same principle used for radiocarbon authentication, but in this case targeting the hydrogen rather than carbon in the plastics. The tritium method is still under development and is not yet a routine measurement.

"We are world-leading in using stable isotopes (both carbon and hydrogen) to authenticate bioplastics and develop criteria for their identification. Our methods ensure that the bioplastics industry remains accountable for their products and claims, and that scientific evidence is available to detect and prevent fraud," Karyne Rogers says.

Scion's Dr Stefan Hill says GNS Science has shown effective methodology and he would like to see these two tests adopted alongside radiocarbon dating as international standards. "We want them [consumers and businesses] to be aware these methods are available at GNS," Dr Hill says.

Top: Buyer Beware! Check your purchases really are bioplastic.

SNAPSHOT

50%
50% of in-market bioplastics don't meet their eco-friendly claims

6%
Some bioplastic-claimed samples were as low as 6% bioplastic

Authentication of bioplastics is not covered by a worldwide standard, and the definitions and policies surrounding bioplastic vary significantly

Key Theme Outputs

	Measure of Success 2021/22	How did we measure up?
	By June 2022, 30% of our (~150) coastal aquifers have been mapped, measured, and modelled.	Over 30% of our coastal aquifers have been mapped, measured and modelled. A 2.5D stacked hydrogeological units map has been completed for the North Island, the focus is now on completing the South Island and converting these stacked polygons into 3D facies (rock characteristics) maps.
	Research output 2021/22	**What we have achieved**
1	National Groundwater Recharge Model resolution has been enhanced using state of the art data science techniques (e.g., Google Earth Engine).	The National groundwater recharge model has been enhanced including: 1) variable resolution input (from daily to monthly data, from 15m to 5km); 2) analyses routines and interface for comparison of model outputs to ground observations (lysimeters); 3) incorporating the ability to ingest multiple sets of long-term data of rainfall and evaporation into the Google Earth Engine coding environment.
2	At least four staff members have been trained to use DELFT3D modelling tools. These staff will work on projects that aim to examine sedimentary processes under changing environmental conditions in a variety of coastal settings in Aotearoa New Zealand.	Following on from introductory training, five staff members are now engaged in various stages of applying DELFT3D to the investigation of real-world coastal sediment processes, including: identifying suitable study sites (Taranaki, Abel Tasman National Park), data input and model set up (Greymouth, West Coast region), and preliminary modelling (Hokianga Harbour).
3	National scale sample collection from over 300 lakes from Aotearoa is completed and associated environmental histories of lake health are developed for 50% of the sites.	Data collection and analysis has been completed for 50% of sites. Analysis for some of these sites has been incorporated into recent publications and public information sheets. See our Lakes380 story in the Environment and Climate Theme and www.lakes380.com.
4	New international partnership for drilling at the grounding zone of the West Antarctic Ice Sheet is established.	An international consortium (New Zealand, US, UK, Germany, Australia, South Korea, Japan and Italy) for the SWAIS 2C drilling project has been established, with funding also secured from the International Continental Drilling Program.
5	Automated microscopy is implemented and improved to help mitigate loss of key skill sets due to staff retirement and to enhance efficiency in paleoecological data acquisition.	Key capability was recruited this year and a business case for a new automated microscopy capture and classification system was developed. Internal capability was also explored through our Artificial Intelligence (AI) and Advanced Analytics Team. An internal automated capture and classification project was supported resulting in a journal paper.
6	A new groundwater model for South Dunedin is developed and has been used to assess changes in inundation probability due to sea level rise.	A groundwater model for the South Dunedin area has been set up and used to assess changes in water table height under four sea level rise scenarios using projections from the NZ Sea Rise programme.
7	The first estimate of Auckland's full carbon budget is provided.	The Mahuika-Auckland fossil fuel CO_2 data product was completed, along with the urban application of a carbon flux Vegetation Photosynthesis Respiration Model. We are now working on a publication that evaluates these models with observations.
8	Co-designed field-based activities to enhance iwi involvement in Geosciences are completed and led to a new iwi-led research partnership that aims to investigate climate change impacts on local communities in Northland.	A week long Northland based Geo Noho (marae-based wānanga or science camp) for Year 7-9 students took place in May. It incorporated mātauranga Māori (Māori knowledge) and te reo Māori (Māori language) with Western science concepts. Northland-specific iwi-led and co-designed research projects were completed and incorporated into an MBIE Endeavour Programme bid.

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.

Our tohu (icon above) – named Te Rā – has the sun, Tama-nui-te-rā, at its heart. The sun is a central figure of energy for most lifeforms here on earth, a symbol of hope, as with each new day comes potential and growth. Energy Futures looks forward, it is hopeful and carries the possibility for a better tomorrow. The two koru are the sun's rays representing growth and expansion. This tohu speaks of hope, growth and potential.

GLOBAL PARTNERSHIPS HELPING TO CREATE BETTER ENERGY FUTURES

GNS Science's reputation as a global leader in renewable energy research was acknowledged when our Chief Executive, Ian Simpson, was invited to join the Prime Minister's trade delegation to Japan and Singapore.

> **"If we are going to meet our climate commitments, and help our global partners meet theirs, it is vital that we invest in research, science, innovation and technologies that can drive that success."**
>
> Dr John Burnell, GNS Science Energy Futures Theme Lead

The visit provided GNS Science with an opportunity to further secure its profile in Japan and Singapore as the global leaders in geohazards and build our reputation as the partner of choice when it comes to creating sustainable energy futures, particularly geothermal and hydrogen research and commercialisation.

"New Zealand, Japan and Singapore face an urgent need to increase the generation of energy from renewable, sustainable, resilient, low-carbon sources. Our respective governments have set ambitious targets for renewable energy generation and GNS Science is well-positioned to support achieving these targets," said Simpson.

GNS Science has long-standing relationships in Japan; they are important partners and collaborators for our geothermal, future hydrogen activity, geohazards and environment and climate change research.

As a small, resource-constrained country, Singapore is a significant growth opportunity for GNS Science with their country having a 99% fossil fuel energy system currently, making it likely hydrogen and geothermal will be a strong focus for their future.

"The beauty of these international partnerships is that we get to research, design and create solutions that have the potential to provide clean, reliable, and sustainable energy generation. As well as exporting these solutions, we can also use them to create better energy options for New Zealand communities."

日本へようこそ
Welcome to Japan!

During April's Trade Delegation, GNS Science announced a geothermal coalition, which will see us establish a physical presence in Tokyo, alongside geothermal innovation company, Geo40. The move to open an office in Japan demonstrates the strength of Aotearoa New Zealand's expertise in the geothermal space and builds on GNS Science's long-standing partnerships in Japan.

The initiative will operate under a co-investment model, with half of the cost being met by New Zealand Trade and Enterprise's International Growth Fund, and the remainder coming from the GNS Science and Geo40 geothermal coalition.

"It's a brilliant illustration of our commitment to deep partnering – we're building a gateway for collaboration that is of benefit not only to GNS, but also to the wider New Zealand research, science, and innovation system," said Ian Simpson. The expansion in Japan comes as the energy sectors of both countries sharpen their focus, as governments grapple with how they can meet changing demands for energy, without causing irreversible impact to the environment.

"It's a major science challenge. How do we produce more renewable energy in a way that increases the overall security of our power supply? That's what Japan and New Zealand are both trying to solve," says Dr John Burnell, Energy Futures Theme Lead, and Senior Geothermal Modeller.

Maximising the reliable and plentiful geothermal power source is vital for both countries if they are to achieve their visions for carbon-neutral economies by 2050.

Japan is estimated to have the third largest source in the world of geothermal energy beneath its surface, capable of producing around 23,470 megawatts. With only twenty or so geothermal plants operating in Japan, outputting around 535 MW, the country has vast opportunities for expansion.

The coalition will be supported from Aotearoa New Zealand by GNS Science's world-leading New Zealand Geothermal Analytical Laboratory (NZGAL), which provides commercial geothermal and groundwater analysis services to companies all over the world.

"We have a number of research programmes underway including the Geothermal: the next generation Endeavour programme researching ultra-hot – supercritical geothermal resources, which envisages drilling deeper to access more energy, and we are working with industry on geothermal carbon capture, which is currently being trialled in New Zealand," said Dr Burnell. "Our geothermal exploration and geothermal systems research, coupled with learnings from New Zealand developments, can add considerable value for Japan."Geo40 bring new extraction technologies to the coalition, their world-first commercial-scale plant can recover high-value minerals from geothermal fluids to get value out of by-products such as silica. This is used in everything from papermaking to permeation grouting and could also help sustainably source low-carbon lithium for electric transport in the future.

Back home, GNS Science will continue to focus on modelling, geology, geophysics, geochemistry, and other work to unlock even more of our geothermal resource. Our Wairakei location in a geothermal area in the Taupō Volcanic Zone is the nexus for solving industry challenges around geothermal energy and brings together leading researchers, industry partners and key stakeholders, including central and local government and iwi/Māori.

"If we are going to meet our climate commitments, and help our global partners meet theirs, it is vital that we invest in research, science, innovation and technologies that can drive that success," Dr Burnell says.

Top: Left to right: Yuki Sadamitsu, Director-General, Natural Resources and Fuel Department, Ministry of Economy, Trade and Industry (METI), Minister for Trade Damien O'Connor, Haruo Hayashi, President of the National Research Institute for Earth Science and Disaster Resilience (NIED), Haruya Nakata, President of Geothermal Energy Research and Development Co., Ltd. (GERD), Tetsuhiro Hosono, Chairman and Chief Executive Officer, Japan Oil, Gas and Metals National Corporation (JOGMEC), Shin Maeda, President, Tokyo Tower, Prime Minister Jacinda Ardern, and GNS Science Chief Executive Ian Simpson.

ENERGY FUTURES

Kaitiakitanga of geothermal eco-systems

The partnership between Ngati Tahu-Ngati Whaoa Runanga Trust and GNS Science has demonstrated how combining indigenous knowledge and western science can benefit present and future generations.

The project, *'Kaitiakitanga of geothermal ecosystems through joint scientific and Matauranga-a-iwi approaches*', uses the Waiotapu Geothermal Field as a case study area.

Ngati Tahu-Ngati Whaoa has a strong historical, cultural and contemporary association with geothermal resources within their rohe. Such resources were used for cooking, bathing, preserving, healing and trading.

Ngati Tahu-Ngati Whaoa Runanga Trust are the mandated iwi authority for the Ngati Tahu-Ngati Whaoa people. The Runanga, through iwi feedback, recognised that due to multiple factors, Ngati Tahu-Ngati Whaoa mātauranga regarding geothermal taonga had eroded over time, and this loss of cultural knowledge presented a key threat to their ability to actively practise kaitiakitanga and uphold the values of the geothermal resources in their rohe for ongoing protection and restoration.

"Our partnership and the research generated from it has helped Ngati Tahu-Ngati Whaoa address the erosion of cultural knowledge and provided them with a knowledge resource to effectively advocate for sustainable management of their geothermal taonga" said GNS Science Geophysicist and report co-author, Robert Reeves.

"The project has been very successful in strengthening relationships between GNS Science and Ngati Tahu-Ngati Whaoa Runanga Trust and I believe that was due to the fact that both knowledge bases recognise and respect the inherent values and differences between knowledge systems."

The research included capturing oral histories and the recounting of stories from local elders and iwi members, sharing values and mātauranga regarding their geothermal taonga, integrated with geothermal surface feature and vegetation data and a range of scientific information on the Waiotapu Geothermal Field.

Importantly, says Reeves, the work generated from the partnership provides a comprehensive review of the cultural and scientific aspects of an Aotearoa New Zealand geothermal field, which can be used as a template for other geothermal field reviews.

"These types of reports can be used to help assess baseline conditions, assess changes over time, and to consider cultural values in resource development situations. This approach will ultimately help to preserve and protect our environment and improve resource use, which will deliver greater economic value, improve environmental sustainability and deliver shared prosperity for our communities."

Top: Kokowai (red ochre or haematite) could be dug from the ground and was an important mineral that was used for customary trade with other iwi by the Ngati Tahu-Ngati Whaoa people (photo from Te Ara with permission from Te Papa Tongarewa the Museum of New Zealand).

SNAPSHOT

The partnership between Ngati Tahu-Ngati Whaoa Runanga Trust and GNS Science has demonstrated how combining indigenous knowledge and western science can benefit present and future generations

The work generated from the partnership provides a comprehensive review of the cultural and scientific aspects of an Aotearoa New Zealand geothermal field

ENERGY FUTURES

Green hydrogen for a carbon zero future

Over the past 12 months, GNS Science has taken the lead in driving hydrogen research in Aotearoa New Zealand and in doing so, cemented its position as the 'energy CRI'.

"Urgent response to climate change is one of the biggest challenges facing society right now and restructuring our energy sector is going to be a means to achieving that," says Energy Futures Theme Lead, John Burnell. "Green hydrogen is an energy solution that will play a key role in our carbon neutral future."

Currently 95% of hydrogen produced globally is 'brown hydrogen', produced from coal and natural gas, and it is responsible for CO_2 emissions. Green hydrogen, produced by splitting water into hydrogen and oxygen using electrolysis from renewable energy sources, is carbon-neutral but remains expensive to make.

GNS Science researchers are currently exploring ways to make green hydrogen affordable and more widely adopted as a viable energy carrier and fuel. The key to doing this is in increasing the efficiency of the catalytic process used in splitting water into its component molecules of oxygen and hydrogen.

Over the past 12 months, GNS Science has hosted and participated in a number of national and international green hydrogen-related events, which has provided the opportunity to share our scientific progress and to discuss the latest directions and trends in national and international research.

Collaboration is the key to unlocking the potential of green hydrogen, and we will continue to lead conversations and share ideas around efficiency of production and storage, how to capture green hydrogen's range of applications and discuss the socio- and techno-economic factors that will enable its uptake in Aotearoa New Zealand.

GNS Science is also establishing a Green Hydrogen Laboratory – an electrocatalytic testing facility for researchers and industries to test materials for hydrogen production. It will be the only independent facility in Aotearoa New Zealand capable of testing green hydrogen provenance and quality to meet international standards for hydrogen use in fuel cells. This facility will complement our range of laboratories and testing services, which are used to support high value research and industry development.

"GNS has years of experience working with energy sector leaders. This, coupled with our unique capabilities in geothermal and materials science, will enable us to build an industry that will help New Zealand shift to a low carbon future," said Burnell.

"Our research is helping Aotearoa New Zealand respond to the challenge of decarbonising its energy sector and meet its international commitments to reduce greenhouse gas emissions."

SNAPSHOT

Currently 95% of hydrogen produced globally is 'brown hydrogen', produced from coal and natural gas, and it is responsible for CO_2 emissions

GNS Science is establishing a Green Hydrogen Laboratory – an electrocatalytic testing facility for researchers and industries to test materials for hydrogen production

ENERGY FUTURES

The first step to a circular economy for batteries in Aotearoa New Zealand

Batteries lie at the heart of a renewable energy future: powering electric cars, storing solar-generated electricity and much more besides. But how to tackle the problem of their limited lifespan? GNS Science Energy Future experts are on the case.

Aotearoa New Zealand's objective of electrifying its transport infrastructure carries with it an environmental consequence – in the form of a growing waste stream of used rechargeable batteries. In August, GNS Science hosted a group of influencers from the energy, recycling and transport sectors along with a group of government officials. Their shared aim: to lay the foundations for a reuse and recycling path for Aotearoa New Zealand.

Creating a circular economy for batteries in Aotearoa New Zealand would be a big step towards an environmentally sustainable low-carbon future. Workshop participants shared ideas about technology and industry needs and agreed on GNS Science's proposed outcome-focused approach. They devised a roadmap for the next steps – apply for Research and Development funding to discover a non-destructive way to revitalise batteries for electric vehicles, as well as research the bigger picture of battery reuse and recycling in Aotearoa New Zealand.

Commercial viability will be central to these research outcomes, so industry input will be crucial. We've had some great feedback from the battery industry, car manufacturers and transport infrastructure agencies keen to get involved – watch this space.

> **Creating a circular economy for batteries in Aotearoa New Zealand would be a big step towards an environmentally sustainable low-carbon future.**

Based on the takeaways from this workshop, we are co-designing with key stakeholders to develop battery revitalisation strategies towards a circular economy of batteries in Aotearoa. We are also working with researchers and industries to develop new research ideas targeting different funding opportunities.

SNAPSHOT

Workshop participants shared ideas about technology and industry needs and agreed on GNS Science's proposed outcome-focused approach

We've had some great feedback from the battery industry, car manufacturers and transport infrastructure agencies keen to get involved

ENERGY FUTURES

Will geothermal and hydrogen fuel future Kiwi BBQs and our homes?

As part of Tech Week 2022, GNS Science played a leading role in bringing people together to explore the importance of geothermal energy and how it fits with the Government's vision for a renewable, clean energy future for Aotearoa New Zealand.

GNS Science researchers teamed up with industry, green tech reps and iwi to host the 'Back to the (Energy) Future' panel discussion. Billed as a 'future-focused retrospective', the panel discussed Aotearoa New Zealand's energy transition and our progress towards a zero-carbon 2050.

> **"This is where having energy options is important. You need a good mix of different energy types that provide consistent and reliable energy generation."**
> Michelle Cook

"The conversations we're having now – about energy transition, the climate emergency and zero-carbon 2050 – will be the retrospective conversations our families, communities and scientists will have in the future," said Energy Materials Scientist, Michelle Cook. "We wanted to get people thinking about what we need to do now to ensure we can meet those targets in 2050."

The gathered crowd was posed questions like 'what new tech have we created along the way?', 'what opportunities did we create and take advantage of', 'what problems have we solved and what problems remain?' and importantly, 'what's changed about how we live and work?'

Science to help Aotearoa New Zealand transition to a carbon-neutral economy is progressing at a rapid pace, but according to Cook, "as a country we are not getting our emissions down fast enough."

Science, she says, holds the key to reducing emissions. GNS Science is looking for ways to get more out of hydrogen, as well as geothermal energy, and developing better technology to access clean energy in future, including green hydrogen, supercritical geothermal and other renewable sources like wind, sun and water generation.

"This is where having energy options is important. You need a good mix of different energy types that provide consistent and reliable energy generation."

SNAPSHOT

GNS Science researchers teamed up with industry, green tech reps and iwi to host the 'Back to the (Energy) Future' panel discussion

The gathered crowd was posed questions like 'what new tech have we created along the way?', 'what opportunities did we create and take advantage of?'

ENERGY FUTURES

Looking to the past and the future to create eco-friendly papakāinga

GNS Science is working with the Tahorakuri A1 Section 30 Ahuwhenua Trust local land trust at Ohaki to establish an eco-friendly papakāinga (housing settlement) in degraded geothermal environments.

The project aims to reconnect the community with the geothermal land, unlock and protect the value of resources of the land and explore resilient composite building materials. GNS Science Senior Māori Advisor, Diane Bradshaw, says the project is using past knowledge to create future solutions.

"A sustainable future relies upon sustainable future minerals. The blending of mātauranga-a-hapū and technical learning aims to investigate rocks materials and provide insights into Māori architectural and philosophical worldviews," said Bradshaw.

MacDiarmid Institute Research Assistant, Dr Oliver McLeod, is analysing the mineralogy of geological materials to assess their physical and chemical suitability for the development of different building materials, like cut stone blocks, pumice-ash based composites and silica glazes.

"A project of such significance requires a bold and, at the same time, sensitive and gradual approach to the use of whānau and hapū resources," said Bradshaw. "Māori land and buildings are independently the largest fixed asset and investment in tribal estates, so the importance of an economical and sustainable building process is enhanced."

The study focuses specifically on mineral extraction in the Taupō Volcanic Zone (TVZ). It will explore the material uses of geothermal silica in eco-papakāinga development and identifying opportunities from silica extraction and refinement. Lessons from this project will inform good practice on Māori engagement, social licensing and renewable energy transitions in the geothermal industry.

The project will identify pathways to utilise geothermal resources to reduce carbon footprints, combined with locally-sourced materials; recognise barriers to producing building materials using components derived from geothermal brine; and define tikanga-based pathways for mineral assessment or preparation of best practice applications.

"We are fortunate here in Aotearoa New Zealand to have a world-class scientific community alongside an innovative 'problem solving' culture. When you combine geoscience with mātauranga-a-hapū you get a much better understanding of the land, its history and cultural significance. When we apply this all together, we can deliver benefits across the economy and to the whole of society."

He papā te whatitiri, hikohiko te uira, kia kotahi ai ngā maunga. Ngā tohu me nga mahitahi ngā e ki ai I te tangata he rangatira. We acknowledge the land as a gateway, a journey that can develop and unite minds across many disciplines to increase Māori research capability in unlocking the potential of Māori people, knowledge and resources. Leadership and empowerment are based on traditional values and a Te Ao Māori worldview.

Top: Ohaki.

SNAPSHOT

A sustainable future relies upon sustainable future minerals

The project will identify pathways to utilise geothermal resources to reduce carbon footprints

Key Theme Outputs

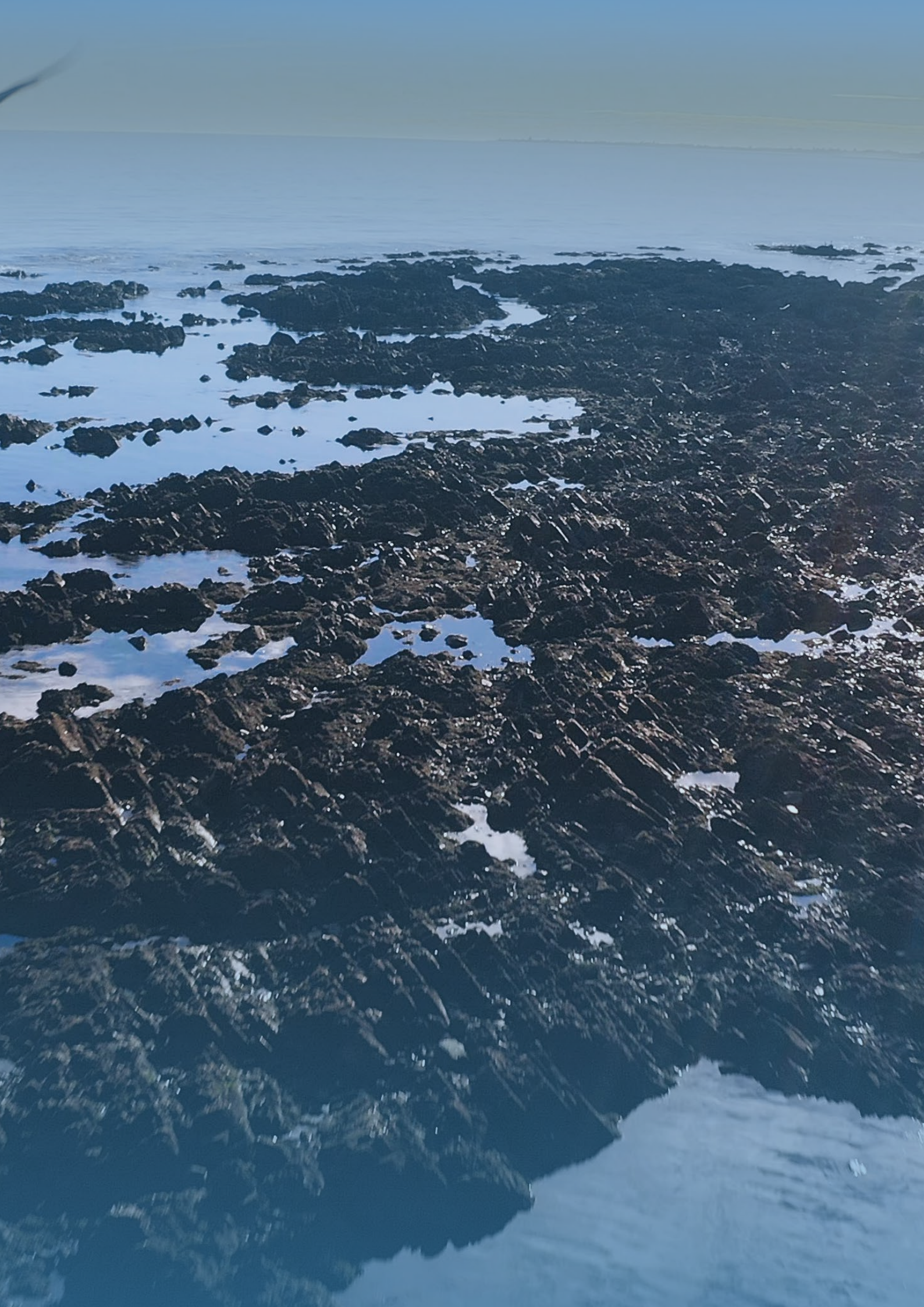
	Measure of Success 2021/22	How did we measure up?
	By June 2022, a new resource assessment model is being used to increase renewable electricity generation from geothermal energy.	GNS Science has updated the Tauhara 3D geological model which is being used for resource assessment by Contact Energy as part of the planning of the new Tauhara II geothermal development. This is a new 168 MW power station.
	Research output 2021/22	**What we have achieved**
1	New insights on the factors that influence the source and location of Aotearoa New Zealand's geothermal systems are obtained from integrating findings from geochemistry, geology geophysics and modelling.	The Geothermal: the next generation MBIE funded Endeavour programme has advanced this quarter, with data acquisition completed and progress made towards manuscript publication. The manuscript is focusing on detailed study of the key factors controlling hydrothermal circulation in the Taupō Volcanic Zone, Aotearoa New Zealand.
2	New understandings of the consequences of different model representations of the energy source of a geothermal system are obtained.	A study developed simple numerical experiments which demonstrated that numerical models of geothermal systems commonly capture only the top of a reservoir and do not produce the correct model behaviour in comparison to a model that captures the entire convecting domain with a heat flux only. A paper was published with the results.
3	An assessment of environmental impacts is undertaken to support the resource consenting of a geothermal power company.	Multiple geoscience and effects reports were produced and reviewed before submission to Waikato Regional Council in support of the reconsenting of a geothermal power company.
4	GNS Science will organise and contribute to a workshop focused on implementing direct heat infrastructure in Taupō that will demonstrate the value of geothermal energy to the Taupō public, government and developers.	Engagement with Taupō District Council, which included a workshop, has been very positive. Currently the plans for implementing the infrastructure for a district heating scheme from ground source heat pump technology is sitting with Council with further feasibility investigation underway for possible development to commence in 2024. We are also supporting iwi groups, and in particular Te Manatōpū Hau Kāinga o Ōhinemutu (Te Arawa iwi), in relation to ground sourced heating initiatives in Rotorua.
5	An electrocatalytic testing facility is developed for researchers and industries to test materials for hydrogen production.	We have received consent for an electrocatalytic testing facility. Work on the facility is underway and is expected to finish before the end of October 2022.
6	Integrated capability will be developed in the field of thermal materials and engineering that will enable research and industry consultancy to improve energy efficiency and renewable energy utilisation.	A control system for the wind tunnel for testing our modified surface materials in condensation/freezing environments has been set up and the equipment is ready for experimental work in the coming year. We also completed a first round of experimental work on anisotropic wetting surfaces. In addition, we are engaging, through NZ Product Accelerator, with a New Zealand manufacturer to reduce life cycle emissions from their products.

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.

Our tohu (icon above) – named Puhoro – is a meeting of stratigraphy and puhoro, a traditional Māori design found in kōwhaiwhai and tāmoko. Tāmoko is traditionally carved, as is the land by natural processes over the ages. Movement and whakapapa (genealogy and literal memory of the earth) are carried in this design.



GNS SCIENCE RESEARCHERS HELPING TO USHER IN 'A NEW ERA' OF EARTHQUAKE SCIENCE

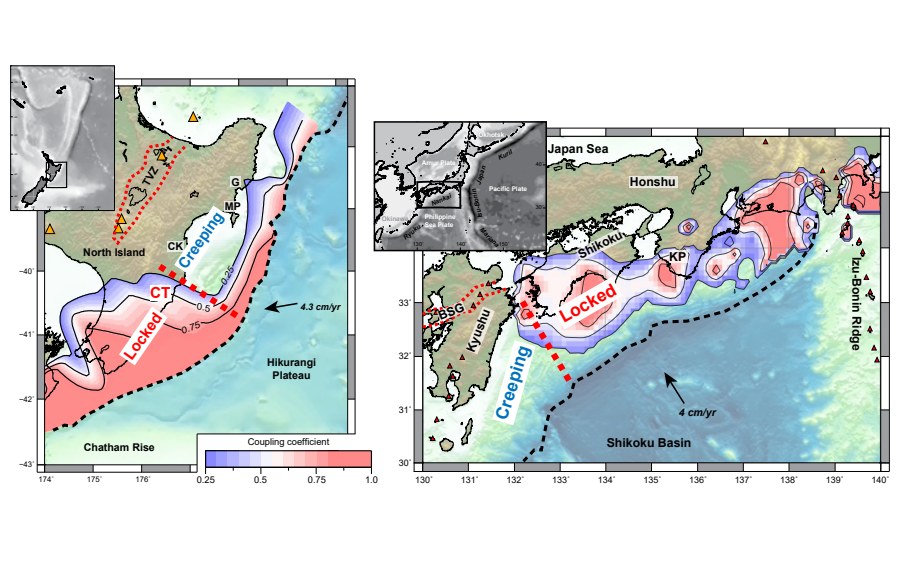
GNS Science Marine Geophysicist, Dan Bassett, is leading an international team working to understand how the structure of subduction zones impacts the size and location of our largest earthquakes.

Working with scientists from the University of Texas, the Japan Agency for Marine-Earth Science and Technology and Scripps Institution of Oceanography in San Diego, and using supercomputers at the Texas Advanced Computing Center, Bassett has helped create a new data-driven imaging technique that gives the most complete picture yet of a major earthquake fault system.

The team has been working in the Nankai Trough, a subduction zone off the southern coast of Japan. Seismically speaking, the coast of Japan is one of the best-monitored places in the world; the Nankai Trough region has been blanketed with seafloor monitors and has the densest array of borehole seismometers on the planet.

The researchers were able to process a "gigantic dataset" of seismic recordings going back 20 years – into the first single high-definition, three-dimensional model of an entire subduction zone. What they found was quite unexpected – a mountain-sized fist of super dense rock miles beneath the coast was forcing the Philippine Sea Plate to subduct with a trajectory that is a factor-of-two steeper than adjacent regions.

"Most research on subduction zones relates the geometry of subduction faults to the age and thickness of the plate that's diving beneath the surface, but it doesn't consider the plate sitting over it. The new findings indicate that the slab of crust overlying the megathrust may be more important than anyone realised," said Bassett.



It's thought that the rocky abnormality, known as the Kumano Pluton, is diverting tectonic energy into points along its flanks where several of the region's largest earthquakes are known to have originated.

Insights from the study were published in *Nature Geoscience* earlier this year and, according to Bassett, they will have significant science implications, both for Japan and for our own broader understanding of how subduction zones work.

"This study produced the highest resolution regional model for any subduction zone on Earth. There are many striking similarities between the Nankai Trough and the Hikurangi Subduction Zone. It is New Zealand's closest tectonic analogue, so much of what we have learnt in Japan is applicable in the New Zealand context," he said.

The research team now plans to build three-dimensional models of the subduction zone in northeastern Japan, where the giant 2011 Tohoku earthquake originated, and Aotearoa New Zealand North Island's Hikurangi Subduction Zone.

> **"Being able to compare high-resolution 3D models of Earth structures across three subduction zones should enable us to think more carefully about how the structure of subduction zones is impacting earthquake behaviour."**
>
> Marine Geophysicist, Dan Bassett

Right: Installing a seismometer in Central Hawke's Bay as part of the PULSE network.

Checking the PULSE of the Hikurangi Subduction Zone

In 2021, a group of GNS Science researchers pulled on their gumboots and went digging up in the hills across the Pōrangahau region. Their mission was to install 50 temporary seismic and geodetic (GPS) instruments as part of the PULSE project – Physical processes UnderLying Slow Earthquakes – to record signals related to slow slip earthquakes and help us better understand how and why they happen.

Slow slip events are common along the Hikurangi Subduction Zone, where the Pacific Plate is subducting under the Australian Plate. During a slow slip event, the energy is discharged slowly, over weeks to months, not through a sharp jolt emitted by a typical earthquake.

"Because these slow slip earthquakes happen so slowly, they don't produce vibrations or ground shaking, and that means that we can't record them or know that they're happening with normal seismic instrumentation," said seismologist and project co-leader, Dr Emily Warren-Smith.

The best way to identify them is using GPS sensors, which sit at ground level and can tell us how points on the Earth's surface are moving very gradually through time. This slow deformation of subduction zone rocks subsequently creates many smaller earthquakes, which can then be felt and detected using seismometers.

The seismometers are buried below the surface, and they record the vibrations from these smaller earthquakes. Scientists then analyse the small earthquakes occurring both before and during a Pōrangahau slow slip event, giving them the opportunity to test their ideas around how these slow slip events happen.

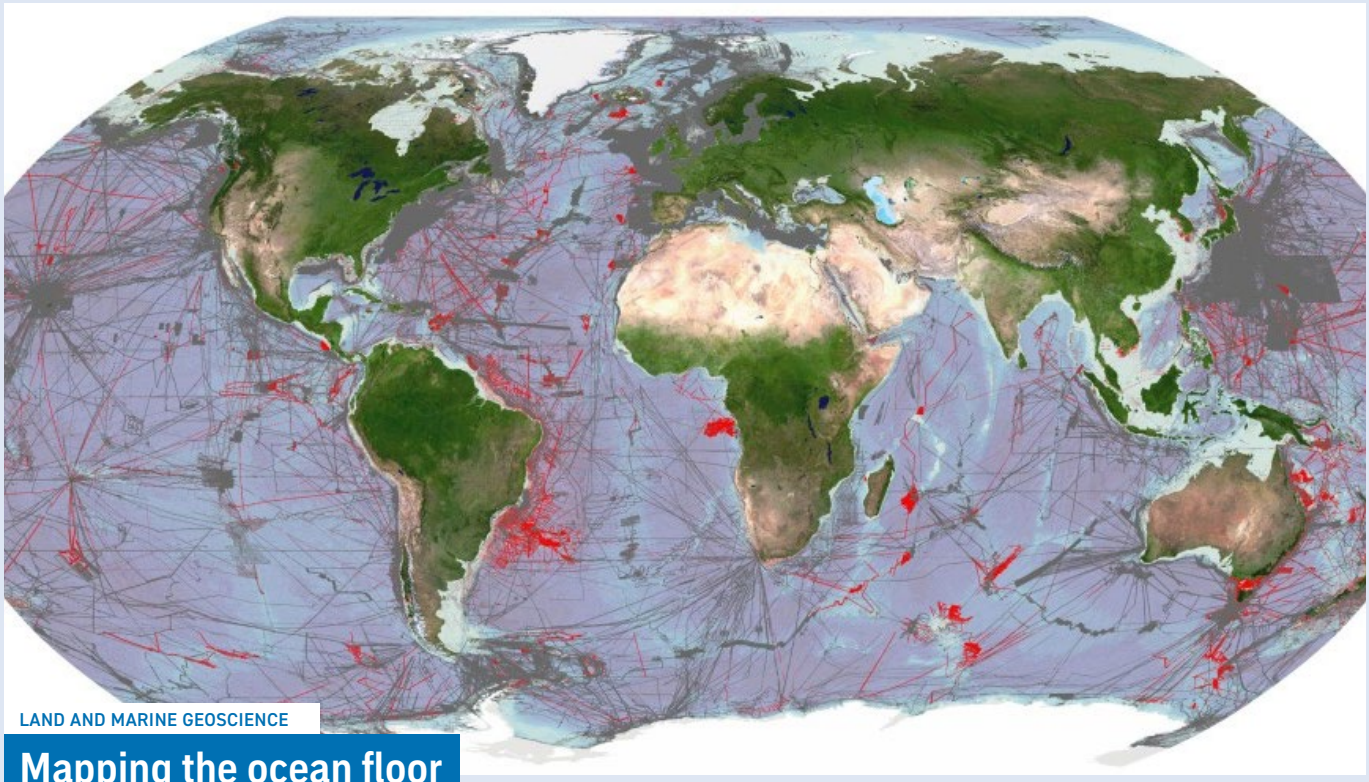
"The PULSE project will help us determine whether there are any observable changes in the Hikurangi Subduction Zone that could be used as future monitoring tools to better forecast large earthquakes. Our work is really all about helping communities prepare and build resilience," says Warren-Smith.

Slow slip events happen on other subduction zones around the world, but Aotearoa New Zealand, and the Hikurangi in particular, has really become a magnet for world-leading science in terms of slow slip event understanding in recent years.

"This is because the Hikurangi is in a really unique setting, being so close and so shallow, which means the observations that we make are much clearer than if we were trying to observe things much deeper down in the Earth," says Warren-Smith.

The PULSE project is in collaboration with Te Herenga Waka—Victoria University of Wellington. It is part of a Royal Society Te Apārangi Marsden-funded programme. It was also made possible with generous support from landowners in the Pōrangahau region who enabled GNS Science staff to access and install equipment on their land.

Watch our PULSE team in action: https://www.youtube.com/watch?v=y3y9FtMbDGg



LAND AND MARINE GEOSCIENCE

Mapping the ocean floor

GNS Science researchers are part of the international science community attempting to map the entire ocean floor by the end of this decade. It is, according to its contributors, a monumental task – equal in scale to the space programme.

GNS Science has contributed to the 2022 version of the General Bathymetric Chart of the Oceans (GEBCO) global bathymetry grid, which is a multi-nation, cross-disciplinary, Nippon Foundation – GEBCO Seabed 2030 Project. It has set itself the ambitious target of mapping the entire global ocean by 2030.

So how exactly does one map the entire ocean floor?

"The global project team has divided our 'one ocean' into manageable portions, and then approached researchers and institutions in those areas to contribute their data," says GNS Science Geophysicist, Brook Tozer.

He's part of a team that delivers the base layer for this map by using satellite data to fill in gaps where high-resolution shipboard-sounding data has not yet been collected. He and fellow GNS Science researcher, Jenny Black, are part of a group responsible for delivering the South and West Pacific 'portion' of data to be included in the annual GEBCO Grid. This is a continuous, global terrain model for ocean and land, providing global coverage of elevation data, at a spatial interval of 15 arc seconds (or around 500 metres). It consists of 43200 rows x 86400 columns, giving 3,732,480,000 pixels of data.

GEBCO is an international group of mapping experts, operating under the joint auspices of the International Hydrographic Organization (IHO) and UNESCO's Intergovernmental Oceanographic Commission (IOC). The project is significant because it is a flagship project of the United Nations' Decade of Ocean Science for Sustainable Development (2021-2030).

"The map will have the potential to transform our understanding of how oceans work. Seafloor bathymetry plays a fundamental role in modulating many oceanographic and biological processes, affecting things such as ocean circulation and mixing, ocean acidification, pollution and our climate. It will enable us to map geological hazards and improve tsunami and coastal flooding models. It has the potential to revolutionise scientific exploration and improve the sustainable management of fisheries and minerals," says Tozer.

The GEBCO 2022 Grid contains newly-mapped seafloor equal to the size of continental Europe, and for the first time, it will include data from Greenland and Antarctica.

According to the project leaders, "Oceans are key to our survival, so this project is really a map for the health of the world's oceans. It's a map for our cultural heritage, a map for scientists, politicians, policymakers and people. It's essentially a blueprint for change and sustainability."

You can discover more here: https://seabed2030.org/

Top: Grey regions depict the mapped areas in the 2021 release of the GEBCO Grid, red shows the additional coverage included in the 2022 release.

SNAPSHOT

The goal is to map the entire ocean floor by the end of this decade

The GEBCO 2022 Grid contains newly-mapped seafloor equal to the size of continental Europe

Oceans are key to our survival, so this project is really a map for the health of the world's oceans

LAND AND MARINE GEOSCIENCE

GeoDiscoveryNZ formally established

GNS Science has led the way to formally establish GeoDiscoveryNZ, a partnership between NIWA, Te Herenga Waka—Victoria University of Wellington, University of Otago, University of Auckland and GNS Science.

GeoDiscoveryNZ provides a platform for Aotearoa New Zealand research organisations to take part in scientific drilling through the International Ocean Discovery Program (IODP) and the International Continental Drilling Program (ICDP).

> **"GeoDiscoveryNZ will help us access the benefits of being part of those ambitious global programmes and promote New Zealand interests in scientific drilling. We'll be able to encourage and support opportunities for early career researchers and Māori students – as well as inspiring a wider Oceania perspective of Earth science discovery and exploration,"**
>
> Land and Marine Geoscience Theme Lead, Stuart Henrys

Our continuing international scientific efforts aim to address critical global challenges facing humanity including climate change, improving coastal resilience, mitigating geohazards, and restoring ocean health.

"Together with the Australian and New Zealand International Ocean Discovery Program Consortium (ANZIC), it will enable our researchers to participate and lead globally important, mission-led science that maximizes the impact of addressing critical risks to humanity and creates a more sustainable society. In addition, it will also help strengthen and encourage engagement between scientists, stakeholders and communities," says Henrys.

The inaugural GeoDiscoveryNZ Committee meeting was held in June 2022, which determined the strategic direction for Aotearoa New Zealand's participation in scientific drilling.

Top: *JOIDES Resolution* preparing for voyage.

SNAPSHOT

GeoDiscoveryNZ provides a platform for Aotearoa New Zealand research organisations to take part in scientific drilling

LAND AND MARINE GEOSCIENCE

What lies beneath – unearthing ancient landslides deep beneath the seafloor

Growing our understanding of undersea landslides that can cause tsunami risk for Aotearoa New Zealand will help build our preparedness and event response capability.

"We know about tsunami, tai āniwhaniwha, the great waves that are often caused by earthquakes," said GNS Science Seismic Interpreter, Suzanne Bull. "But we don't know a lot about other tsunami sources, including underwater landslides."

It's hardly surprising, given offshore landslides are challenging to explore, and are often poorly preserved or rapidly buried by younger sediments. But underwater landslides are responsible for about eight percent of tsunamis globally so it is important we learn all we can about them.

With that goal in mind, in 2021 a team of mostly women scientists, led by GNS Science in collaboration with NIWA, Auckland University, University of Newcastle, Australia and Taranaki iwi, Ngāti Tama and Ngāti Mutunga, embarked on a two-year project to assess 'silent tsunamis'.

"We know that the Tasman Sea, has been subject to five million years' worth of mega-scale underwater landslides, which could have generated devastating tsunamis," says Bull.

"These tsunamis likely originated near New Zealand's western coast, travelling more than 2,000 kilometres to also affect Australia. This is particularly intriguing as western New Zealand is not prone to subduction zone seismic activity, which often controls a coastline's vulnerability to tsunamis."

Many of the world's continental margins have been imaged using seismic reflection surveying. These subsurface datasets can help to reveal the secrets of the ancient underwater landslides now buried beneath the seafloor. Subsurface geological mapping has identified six very large landslides – one of them, occurring about 1 million years ago off the coast of Taranaki, at 4,000km^3 in volume, is the largest underwater landslide ever discovered around Aotearoa New Zealand.

What is still unknown is the nature of the tsunami hazards they likely generated, and how frequently they occur. To predict reoccurrence and help build our risk and resilience toolbox, accurate descriptions of the landslides are required.

During two separate voyages, Suzanne and her team mapped nearly 6000km^2 of the Tasman Sea floor. They collected sediment samples, along with subsurface geophysical imaging, and over the next 18 months they will combine this with numerical modelling to help us better understand underwater landslides and their potential to cause tsunamis.

"Our job is to learn all we can about these landslides We hope that our undersea landslide research will go a long way to help us predict if further landslides will occur in this area in future, and how we can best prepare to protect our communities, infrastructure, and built environments."

Top: Voyage Leader Jess Hillman (GNS Science), Voyage Co-lead Sally Watson (NIWA) and Project Lead Suzanne Bull (GNS Science) on the bridge of the *R/V Tangaroa.*

SNAPSHOT

Offshore landslides are challenging to explore

Underwater landslides are responsible for about eight percent of tsunamis globally

Suzanne and her team mapped nearly 6000km^2 of the Tasman Sea floor

LAND AND MARINE GEOSCIENCE

Ka rawe to our friends at Te Kura Taumata o Panguru

We were thrilled to see Te Kura Taumata o Panguru win the Excellence in Engaging category of the 2021 Prime Minister's Education Excellence Award.

GNS Science is fortunate to have worked with Te Kura Taumata o Panguru since 2017, and we've seen the incredible impact of their approach to teaching and learning first-hand.

"We met Mina Pomare-Peita, principal at Te Kura Taumata o Panguru, back in 2017 and we were inspired by her drive and passion for her community and her commitment to their rangatahi," says GNS Science Geologist, Kyle Bland.

Since then, GNS Science has worked closely with Mina, and our other partners in the Far North, to deliver both science mahi and community engagement. This work includes GeoCamp, Tūhura Papatūānuku Geo Noho (marae-based science wānanga), Te Rarawa's Noho Taiao, and school engagement for the Hokianga Harbour sedimentation project – all of which have involved Panguru students.

"Our goal is always to encourage these tamariki to believe that anyone can be a scientist," says Bland.

> **"We want to help empower rangatahi with knowledge to make their own discoveries. We want to teach them 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"**
> GNS Science Geologist, Kyle Bland

The Prime Minister's 'Excellence in Engaging Award' recognises Panguru's inspiring work to connect community for greater good, and their commitment to collaborating with regional and national agencies to support learning in te taiao (the environment) and to empower ākonga (students) with skills in language, business and sustainability.

Top: Tūhura Papatūānuku Geo Noho included Panguru taitamariki and was an opportunity for them to learn about te taiao, supported by Māori knowledge holders and GNS Science experts.

SNAPSHOT

Te Kura Taumata o Panguru win the Excellence in Engaging category of the 2021 Prime Minister's Education Excellence Award

GNS Science is fortunate to have worked with Te Kura Taumata o Panguru since 2017

Our goal is always to encourage these tamariki to believe that anyone can be a scientist

LAND AND MARINE GEOSCIENCE

Are we FAIR and do we CARE?

GNS Science is committed to meeting its obligations to manage data, as outlined in the New Zealand Data and Information Management Principles. We are also dedicated to working with Māori around the sovereignty of science data we hold and science data we intend to acquire.

We apply FAIR principles in our approach to digital data management. These principles, being Findable, Accessible, Interoperable and Reusable, are considered best practice and we have applied them across our Nationally Significant Collections and Databases (NSCDs) to ensure they are used and shared across the science sector and public.

The NSCDs have 27 digital datasets that are able to be measured against FAIR principles. They span geological maps, paleontology, rocks and minerals, volcanoes, earthquakes, groundwater and geomagnetism. Included in the analysis are four other data resources covering landslides, active faults, tsunamis and geodesy. These contain a further 23 high-value natural hazard datasets that are FAIR assessable.

GNS Science's Dataset Catalogue http://data.gns.cri.nz/metadata is a critical metadata information resource that enables good FAIR compliance. The catalogue's metadata can be searched, including through external search engines and data registries, and this ensures our data are Findable. The catalogue describes the Interoperable and Reusable components of the data and points to where our data are Accessible from.

Each dataset has been assessed in terms of its FAIR compliance by adapting a quantitative tool, which was developed in Australia and is based on international criteria.

"The NSCD datasets score highly in the Findable, Accessible and Reusable principles and many are also scoring well for their Interoperable status. The high-value natural hazard datasets also score highly under Findable but are generally lower in terms of the Accessible, Interoperable and Reusable components", says Maria Mavroeidi, GNS Science's Data Management Partner. "The higher FAIR scores for the NSCD datasets reflect the consistent levels of funding directed towards their information management."

The quantitative FAIR compliance analysis method we have applied is globally significant; we described our method to an international forum of geological surveys information managers in June and this has helped spur a work programme around consistent measurement of FAIR compliance of geoscientific data across geological surveys.

The CARE Principles for Indigenous Data Governance refer to Collective Benefit, Authority to Control, Responsibility and Ethics that address sovereignty of data.

We are working with other CRIs through the Māori Data Sovereignty Working Group to assess the sovereignty of science data we hold and establish protocols around how we collect and manage data; these are key components of the value we place on kaitiakitanga and CARE Principles.

Top: GNS Science Lab and Collections Technician, Henry Gard.

SNAPSHOT

FAIR

We apply FAIR principles in our approach to digital data management

GNS has 27 digital datasets that are able to be measured against FAIR principles

GNS Science's Dataset Catalogue data.gns.cri.nz/metadata

Key Theme Outputs

	Measure of Success 2021/22	How did we measure up?
	By June 2022, greatly improved characterisation of potential for Hikurangi subduction earthquakes and their likely impacts is provided for natural hazard risk assessment.	We were among the first globally to use full-waveform inversion of data to generate high-fidelity seismic reflection images of the Hikurangi Subduction Zone. New data collected from land and seafloor seismological and geodetic instrument networks are being used for ongoing analysis of subduction zone slow slip and earthquake events. There has been extensive media coverage of our ground-breaking research and multiple high-impact journal publications.
	Research output 2021/22	**What we have achieved**
1	Refine our knowledge of the underlying processes associated with plate boundary hazards to improve resilience to earthquakes, tsunamis, volcanic eruptions and landslides.	The publication of several research outputs has advanced on the understanding of the processes that drive plate boundary dynamics. Our results show that heterogeneous properties of the plate boundary interface strongly govern deformation, including the localization of fault slip. The results are being incorporated in the next generation earthquake and tsunami hazard models. See Honours and Awards.
2	Develop models that show how heat and magma are generated in the Taupō Volcanic Zone to improve understanding of how renewable geothermal energy can be utilised.	New models developed used an integrated approach combining geodesy, seismology and magnetotellurics to estimate the distribution of melt (magma) beneath the Okataina Volcanic Centre (OVC) near Rotorua. Together, InSAR and GNSS observations show long-term subsidence over the last 15-20 years in and around the OVC. The deformation was modelled as a contracting magma body at depth with implications for geothermal exploration.
3	Quantify how critical elements and materials are distributed in the subsurface through building new workflows for resource assessment.	We have advanced understanding of the transport of metals to the seafloor in the Kermadec arc hydrothermal systems, to provide better context and understanding of the link between tectonism, volcanism and mineralisation in the Taupō Volcanic Zone and its offshore extension. Metals will play a central role in successfully building Aotearoa New Zealand's clean technology value chains and meeting climate goals.
4	Refine our understanding of surface processes in coastal and urban environments through integrated geological, geochemical, and geophysical investigations to inform predictive modelling of sedimentation and erosion.	To help refine our understanding of landslides and coastal erosion processes, virtual outcrops were created and will be used to assess the effects of different climate adaptation options. We also acquired new seismic reflection data across giant-scale landslides buried beneath the seafloor offshore Taranaki. These data are revealing the conditions that led to triggering of past submarine landslides and disclose the possible consequences of slides on communities and infrastructure.
5	Refine the age control of past climate events to improve understanding of the rates and scale of climate impacts.	Recent publications demonstrate progress in using sediment recovered during IODP Expedition 371 to estimate paleolatitudes of the Zealandia continent from 48 to 18 million years ago. These new paleogeographic maps are used to improve past ocean circulation and climate models to infer past environmental change in the SW Pacific.
6	Ensure GNS Science's high-value geoscience databases are increasingly interconnected and interoperable, resulting in a significant upsurge in their use in data science applications.	GNS Science's high-value geoscience datasets are better connected and interoperable through added data and metadata links. Our data are being increasingly used in Data Science applications. Increased use of Digital Object Identifiers (DOI) has also improved interconnections between datasets, metadata, webpage descriptions, and publications.
7	Work closely with international scientific organisations, especially IODP and ICDP, to enhance understanding of global-scale environmental change, variability and impacts and improve predictive capability for hazards and disasters.	GNS Science and the Australian National University signed a Memorandum of Understanding that establishes the Australian and New Zealand International Ocean Discovery Program Consortium (ANZIC) in 2021. Our researchers are working with many international scientific organisations including the IODP and ICDP to advance five scientific drilling missions in our region.
8	Communicate our research, its potential outcomes and impacts in clear, accessible and engaging ways to key stakeholders.	We are communicating our research in many ways to stakeholders. In addition to the workshops, presentations, and media outputs, we have been running scenarios for response situations, virtual fieldtrips, mini-documentaries on YouTube, web map technology, interactive 3D graphics and virtual reality of an undersea volcano.

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: GNS Science staff at Avalon Campus.

OUR PEOPLE AND CULTURE

Our people enable GNS Science to deliver its vision of a cleaner, safer and more prosperous Aotearoa New Zealand. Guided by our People and Culture Strategy we continue to develop our workforce within a COVID-19 environment.

Our staff number increased to 497 at the end of the year following some lean COVID related years with border closures impacting on international recruitment and the resulting tight labour market. Turnover was higher than the previous year and at 30 June 2022 was sitting at a rolling average of 13.5%. We experienced recruitment and retention issues in both the science and non-science roles, particularly the non-science roles. Our gender balance remains largely the same (44% female and 56% male) and we will continue to address this through Workforce Planning and our Pay Equity Plan.

This year we concentrated on supporting our people in the ever-evolving COVID-19 environment. Our people appreciated the support we provided them during this time, including enabling flexible work with significant wrap around support. This appreciation came through strongly in the last two Engagement Survey results.

During the year we focused on growing our workforce's capacity while at the same time commencing a project to implement an enterprise resource planning system (ERP), Workday, that integrates our Human Resource (HR) systems with finance and project management. This required a significant investment of time and resource over the entire financial year with key staff in each of these disciplines seconded to lead this.

We continue to explore ways to reward our people in a challenging fiscal environment and tight labour market. We were able to make some headway for our science staff this year with the introduction of a Career and Capability Development Framework at the beginning of the year. The release of the Science Roadmap this year provides a key focus for the Workforce Strategy going forward.

Developing our leaders

We are seeking an overall lift in leadership capability in order to have a positive impact on the organisation's success. Our focus is now on increasing leadership skills of all staff, with the main vehicle being the Tūhono Leadership Development Programme which began in 2021 and is being rolled out across GNS Science. This year five cohorts, representing 56 people, completed the programme. By year end over 65% of our people leaders had completed this programme. Tūhono focuses on three aspects: Technical, Performance, and Change Leadership. It is designed to help our leaders understand their different leadership contributions and is embedded in 'real work', with participants undertaking a signature change project as part of the programme.

We also run Leader forums, which are held quarterly. These are an opportunity for all our leaders to come together. This year presentations and discussions included our new Science Roadmap, the *Te Ara Paerangi Future Pathways* Green paper, resilience during change and adapting to COVID-19.

Strategic workforce planning and capability

This year we commenced implementation of a Career and Capability Development Framework (discussed above) and a Talent Acquisition Strategy. This included adopting a talent map to identify key areas for capability growth and retaining talented individuals.

Future workforce planning will be a key priority for next year as we align our approach to the new Science Roadmap. GNS Science's workforce draws both from within Aotearoa New Zealand and overseas, especially in the Science roles. COVID-19 caused significant delays to the recruitment and onboarding of overseas staff as a result of border closures and their gradual re opening. The challenges with international recruitment reinforce the need for developing capability within Aotearoa New Zealand, especially at the postgraduate level. Resolving this is not a short-term fix and international recruitment will continue to be a requirement. GNS Science attracts staff from all over the world because of its reputation and also the advantages of living in Aotearoa New Zealand.

System Improvement through a joint initiative with Environmental Science and Research Ltd (ESR)

Over the past year GNS Science and ESR have been working together to deliver an integrated financial, payroll, Human Resources and project management system. The system being implemented in both organisations is 'Workday' and it went live on 1 July 2022, as scheduled. Workday allows us to manage the full worker lifecycle – from staffing, nurturing talent to compensation, using a single intuitive Human Resources system.

Right: Science leadership team on board *RV Tangaroa* relaxing in the sun at the end of a successful voyage.

Diversity and inclusion

Following the completion of an Independent Pay Equity Review early in the year, GNS Science then developed a Pay Equity Plan. The external review advised that our gender pay gap is lower than the average pay gap in the Aotearoa New Zealand labour market overall; however, GNS Science has vertical and occupational issues; with more females in GNS Science found in lower levels of the organisation and males in higher paying job functions and roles. The Pay Equity Plan contains strategies and interventions to both lower the gap and retain the gains already made.

There are some gender differences within departments, with the corporate support area having a higher proportion of females than males, whereas in the science areas 39% of staff identify as female and 61% male. Males continue to outnumber females in leadership roles both in the science and business support areas. Technicians is the occupational group where a gender balance is almost achieved.

Our Diversity and Inclusion Committee continues to be actively involved in organisation-wide initiatives including organising workplace events such as Pink Shirt Day, sponsoring women students to attend the Association for Women in the Sciences (AWIS) Conference and organising a Speaker Series to highlight our diverse workforce. They also provide a unique lens across our policies, procedures, and initiatives. Our Women in Leadership programme has been very popular, including a recent talk by Dr Sue Bidrose, the Chief Executive of AgResearch.

The Ahunuku Scholarships and Māori intern programmes have been well received. We were delighted to welcome an intern from the programme to our permanent staff. Within GNS Science, we continue to support employees in developing their bicultural competence through the provision of Te Reo and Tikanga courses.

Assessing silent tsunami risk in the Tasman Sea/Te Tai-o-Rēhua – our voyage on video

Whether we choose to celebrate the science, the women powering it all, or the sensational collaborative effort, the story of GNS Science's three-week study of underwater landslides off Aotearoa New Zealand's coastline is a compelling one.

The women-dominated team has embraced the concept of collaboration to its fullest. "The voyage is notable not just for the science and discoveries we're making but for the fact that the majority of participants are women, including the Voyage Lead and Co-lead. It's been such an organic, collaborative project. We all feel a sense of pride and ownership and we're all really vested in its outcomes," said GNS Science Project Lead, Suzanne Bull.

Suzanne, Jess Hillman and the team from GNS Science, were joined by NIWA, the University of Auckland and the University of Newcastle in Australia, with the project showcasing the true team effort that is the driving force behind the 'silent tsunami' project. The team is also working alongside iwi in the Taranaki region, Ngāti Mutunga and Ngāti Tama, and includes three early career researchers and a post-doctorate position at the University of Newcastle in Australia.

The 2021 Endeavour Smart Idea project 'Assessing silent tsunami risk in the Tasman Sea/Te Tai-o-Rēhua' continues until the end of 2023.

You can watch the crew at work here: https://vimeo.com/niwanz/taranakivoyage

Early Career Staff Network

GNS Science's Early Career Staff Network (ESCN) aims to empower early career staff within GNS Science. The ESCN aims to increase connections between early career staff within GNS Science, advocate for their interests within and outside GNS Science, and support the development of their careers. They actively contribute to future decision-making, including ensuring the voice of early career staff are represented in GNS Science strategy and focus on empowering GNS Science to grow as a diverse, inclusive, innovative and agile organisation.

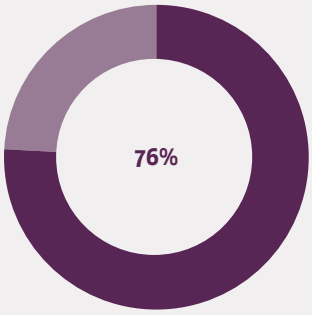
This year there was an increase in enrolment in the Early Career In-House Orientation programme, where new starters are partnered with other early career staff across other parts of the organisation.

The ESCN also hosted two well attended 'lunch and learn' sessions, including a presentation from the National Geohazards Monitoring Centre. The network had successful engagement and consultation around the *Te Ara Paerangi Future Pathway*s Green paper to ensure the early career perspective was represented in the submission.

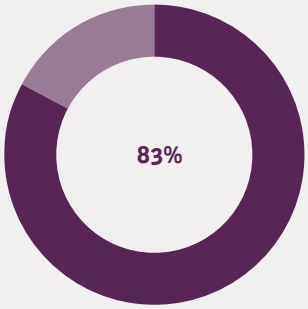
Rachel Lawson on why she joined the ESCN Council this year "I joined the council to represent specialists and technicians who play an important part in the research cycle but may be inadvertently overlooked in early career staff discussions."

Karl Laurence on why early career voices are important to support in GNS Science, "To me, the early career voice is rich with fresh perspectives and novel ideas that can challenge the established ways of working."

Top: GNS Science Technician Te Aomania Te Koha, Geological Research Labs and Collections at our National Isotopes Centre.
Bottom: GNS Science staff.



Participation in September 'Pulse' survey



Participation in May full survey

Our Engagement

We conducted two staff engagement surveys this year, a 'pulse' survey in September 2021 and a full survey in May 2022. Both surveys covered engagement, common purpose and manager effectiveness questions as well as looking at wellbeing, diversity and inclusion, leadership, communication, teamwork and values. The May survey introduced a new methodology, making it easier for managers to review and understand the key drivers of engagement within their teams and allowing them to access their team's results easily. The new methodology provides valuable insights into areas we can focus on to continue to improve our employees' engagement and maintain our ability to produce excellent science.

The response rate for the September survey was 76%, and the May survey was 83%.

Results from the May survey show a 71% engagement score, which is the same as the previous year's survey. We are seeking to increase this score and have developed an action plan to secure this. The survey also identified that staff appreciate the organisation's support during the COVID-19 pandemic, particularly around flexible working.

Health and Safety

GNS Science has undergone a step change in health and safety maturity during the past year. We have increased capability within the Health and Safety team to support our focus on improving our wellbeing, critical risk management, health and safety systems, documented processes, education and training.

This investment has resulted in improved understanding of health and safety and increased levels of leadership, ownership, engagement and collaboration throughout the organisation. Demand for health and safety support has significantly increased, confirming a growing integration of health and safety into our day-to-day work and culture.

The high-risk environments we often work in mean that we face some unique challenges. We have identified our critical risk profile and made significant progress in understanding how to manage these risks. GNS Science regularly works with other organisations, including peer agencies, commercial contractors and members of the public. The Health and Safety at Work Act 2015 requires us to ensure the health and safety of people who enter or are affected by our places of work. A challenge for GNS Science is that not all our people are confined to a conventional workplace such as an office – many of them are regularly on the road, working in the marine environment or in the field. Thus, one of the workstreams for the past year has concentrated on the nature and scope of GNS Science workplaces and progress has been achieved in mapping the overlapping health and safety duties that exist between GNS Science and others. We are also learning how better to use insights from our fleet management tool EROAD in order to keep our people safer on the road.

GNS Science is a data-driven organisation – we measure, we observe, and we learn. This approach extends to ensuring that we monitor what matters in relation to the safety of our people. Good reporting data assist us in developing better predictive health and safety models.

The health and safety reporting system, ecoPortal, continues to evolve, with a view to making forms and processes more intuitive for our people and reducing the administrative load where practicable.

While we face numerous significant physical hazards at GNS Science, there is a psychosocial component that recognises the effects of fatigue, stress and mental health factors on maintenance of safe work practices. The COVID-19 pandemic has re-emphasised the importance of this aspect of our work.

During the year, 14 leader workshops were conducted for team leaders and other managers, which concentrated on the management of psychosocial risks and the promotion of wellbeing. In addition, a number of wellbeing workshops have been conducted for all staff on topics such as stress, sleep science and fatigue management. This area of health and safety will remain a priority during the year to come.

Top: GeoNet site Tai Ping maintenance.

VISION MĀTAURANGA

Te Punawai o Rangiātea, which means 'the flourishing pool of knowledge', is GNS Science's new Māori Strategic Plan which includes a shared vision, mission, values and outcomes, describing how we will engage with iwi-Māori to guide our future work. Te Punawai o Rangiātea complements our Science Roadmap and our research Theme Plans and will be implemented alongside our Stakeholder Relations activities.

Implementation of Te Punawai o Rangiātea will guide our work to embed Vision Mātauranga across the organisation. It defines a cultural values-based framework that sets out best practice guidelines to ensure our research and researchers have a clear approach to unlocking the potential of Māori knowledge and communities.

Training programmes

Our te reo Māori and tikanga courses continue to be popular and we have recently started Te Tiriti o Waitangi two-day workshops with our leadership teams. Further workshops will be made available to staff through the 2022/23 year and will become a core course in our development programmes. A successful workshop outlining our Vision Mātauranga policy and its application to research and working with Māori was held and will become a regular part of our programme.

Career pipeline and Ahunuku Māori Summer Scholarships

We continue to build 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 Tūhura Papatūānuku Geo Noho, marae-based wānanga or science camps. These are supported by the Ministry of Education through Whānau Engagement Funding, and co-designed and co-delivered by Far North REAP, Te Aho Tū Roa, and GNS Science, Geo Noho incorporate mātauranga Māori and te reo Māori with Western science concepts.

GNS Science continues to work with Te Herenga Waka—Victoria University of Wellington (VUW), providing opportunities to undergraduates and graduates in the Earth Sciences to work at GNS Science including through our Ahunuku Māori Scholarship programme, with over 15 Māori students supported in their fields of study. GNS Science and VUW have signed a Memorandum of Understanding to enable both agencies to partner to provide scholarships to graduates of Māori descent specialising in Earth Sciences.

Right: Tūhura Papatūānuku Geo Noho based at Waimamoni Marae (Ngāi Takoto), Far North. **Top 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.

Our ongoing efforts to partner with VUW to grow the Māori science and research workforce continue to produce results, including:

- Four Ahunuku Scholars for this year, three studying science degrees and one in Science Communications.
- Support for a Māori PhD student in Volcanology. GNS Science support includes research stipend and fees for the final 6 months of the PhD, with academic support from both GNS Science and VUW.
- Two Māori Master's Students, (one a previous Ahunuku Scholar) starting their post-graduate studies at VUW in 2022.
- Employment of a previous Ahunuku Scholar full time as a Laboratory Technician. This year GNS Science has developed our research relationship with Te Whare Wānanga o Awanuiārangi (TWOA), to grow mātauranga Māori scholars across our research programmes. Our first Master's mātauranga scholar with TWOA is studying this year, focusing on energy resilient Māori communities.

External relationships

Our work across the Crown Research Institutes (CRI) in regard to Māori continues through Te Ara Pūtaiao (a pan-CRI senior Māori leadership group). This year Te Ara Pūtaiao were awarded Equity, Diversity and Inclusion Capability funding from the Ministry of Business, Innovation and Employment (MBIE) to undertake a project, currently underway, identifying barriers and opportunities for Māori students in the science field. This will enable us to scale up CRI reach and responsiveness activities and increase career pathways to attract Māori into science-based careers and minimise existing barriers. The Fund focuses on collective science and Vision Mātauranga best practice initiatives to enable CRIs to better share and implement research best practice.

We are also working together to establish a joint CRI approach to delivering strategies and/or best practice guidelines that acknowledge and uphold Māori Data Sovereignty in line with Te Tiriti o Waitangi (Te Tiriti) and national obligations.

Te reo

This year we continued our Te Reo training programme of Te Reo Māori and tikanga courses, and introduced workshops on Te Tiriti o Waitangi, and Vision Mātauranga policy and its application to research and working with Māori. These are available to all staff and are part of our commitment to develop GNS Science capability and capacity to support Vision Mātauranga.

Top Left: Mihi whakatau for our 2021-22 summer interns and Ahunuku scholars.

SUSTAINABILITY: WE'RE REDUCING OUR CARBON FOOTPRINT

As one of Aotearoa New Zealand's leading environmental research agencies, GNS Science is committed to acting in an environmentally ethical and responsible manner and supporting an environmentally-conscious culture. As the 'Energy CRI', we also play a major role in enabling Aotearoa New Zealand's transition to a low-carbon future, and our scientists are researching the changing levels of atmospheric CO_2 and determining the impacts those have on our Earth's surface.

TOITŪ CARBON REDUCE

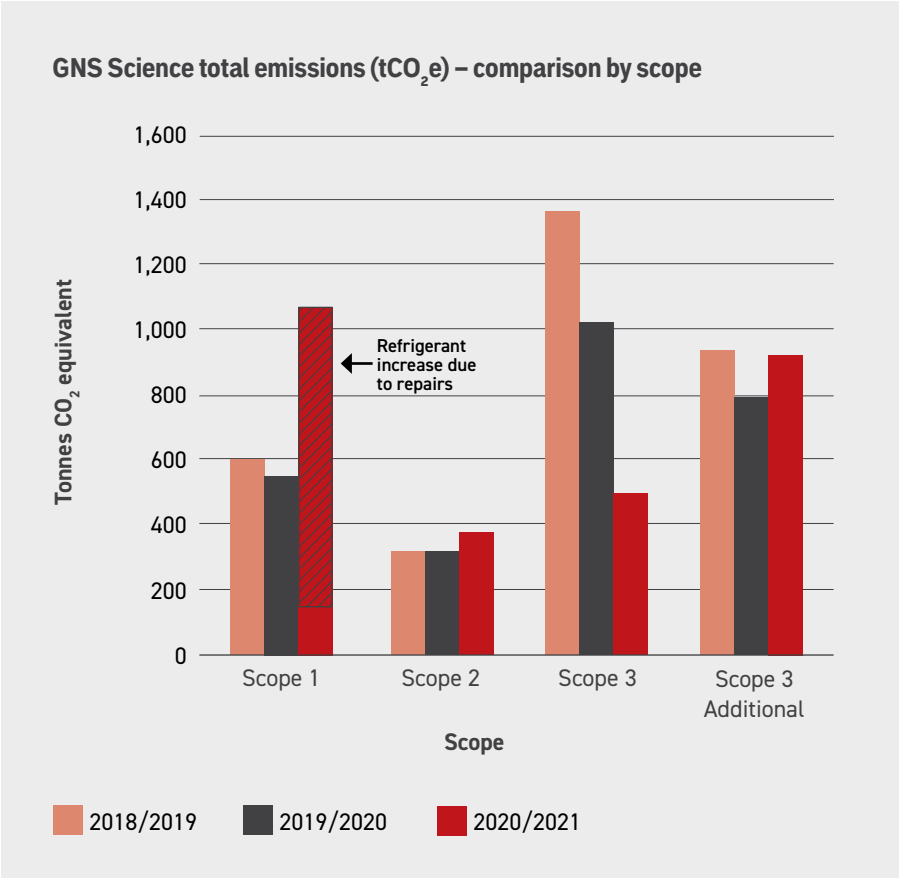
We 'walk the talk' in all that we do and we're careful about minimising and mitigating the impact of our operations on the environment. That's why after almost a decade of monitoring our own emissions, GNS Science made the decision to have our organisational emissions independently audited and measured so that we could track our emissions reduction against national and international standards.

In 2020, we signed up to the Toitū carbonreduce programme, a world-leading certification scheme which helps businesses and organisations measure their direct and indirect greenhouse gas emissions accurately. Following our very first 'carbon audit' in March 2021, we committed to reducing our net carbon emissions by 4% per annum, aiming for a cumulative 20% decrease from our baseline year (2018/2019) by 2025.

What are we doing to meet our goals?

As a first step, we have replaced some of our fleet with a combination of EV and hybrid vehicles. We have also undertaken gas and electricity audits at our three largest sites – Wairakei, Gracefield and Avalon – and we will use this information to then introduce efficiencies in the type and ways we power our facilities. While the travel restrictions associated with COVID-19 have reduced our travel emissions dramatically, we are committed to sustainable business travel and new ways of working (e.g., virtual meetings). Around a quarter of our total emissions come from staff commuting to our five sites around Aotearoa New Zealand, and we are looking at ways to help reduce these emissions where possible.

Top: GNS Science electric car out in the field, Ruapehu.



Scope 1 includes the fuel used in the company vehicles (petrol & diesel), the backup diesel fuel tank at Avalon, refrigerants, gases used in labs (e.g., CO_2, LPG, SF_6).

Scope 2 includes the electricity and natural gas used in the buildings, and to power the GeoNet seismic stations around the country.

Scope 3 includes business travel (flights), rental cars, ferry travel, helicopters, taxis (and Uber, etc), mileage and fuel claims from staff, freight/couriers, waste to landfill, and the transmission and distribution losses from the electricity in Scope 2.

Scope 3 additional includes accommodation related to business travel, the staff commute, and recycling (paper, glass, plastic & aluminium) and bus travel.

See how we're tracking

We publish an annual Toitū carbonreduce Emissions Summary, which demonstrates our efforts and progress towards meeting our targets. You can access our inaugural report on the GNS website: www.gns.cri.nz (search Toitū).

Science for now.
Science for the future.
Science for good.

To date, we have reduced our carbon emissions by around 14%. We were on track for a 34% reduction in our first two years, but unfortunately a refrigerant leak and repair resulted in a one-off large carbon emission. The global pandemic has contributed significantly to our rapid reduction, but we are aware our research requires national and international travel, and we will be working hard to ensure our return to travel is sustainable.

IMPROVING OUR DELIVERY

Infrastructure

Providing our staff with the right tools, equipment, technology and resources is the best way to help them perform to the best of their abilities. This year GNS Science has continued its extensive programme of projects to bring GNS Science infrastructure, systems and processes up to date. Our long-term plans to continually update our offices, specialist facilities, leading-edge equipment and management systems have been progressing over the year.

In 2020/21 we developed our Property Strategy, which provides a high-level planning framework across our portfolio of research laboratories, workshops, office accommodation and public interface property. This year, we have been developing business cases for support of our planned future developments, including the first stage which will be our Wairakei redevelopment. We continue to work with other research organisations, including Callaghan Innovation, ESR and Te Herenga Waka—Victoria University of Wellington, to ensure that together our property plans present a coherent picture for science in the Wellington region.

The refurbished GNS Science Tritium and Water Dating Laboratory at our Avalon site was officially opened in May. Our ability to deliver in this space is world leading, and our outstanding accuracy and precision well known. The GNS Science experts providing these services for our own programmes and clients in Aotearoa New Zealand and around the world needed a fit-for-purpose lab and technology to ensure they can continue doing an excellent job into the future. We are also developing an electrocatalytic testing facility that will be open soon for researchers and industries to test materials for hydrogen production.

GNS Science is also investing in its information and communications technology (ICT) 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. Significant progress has been made this year in our joint venture with ESR with the implementation of the Workday enterprise system to replace our Financial, Human Resources and Project Management systems, with Phase 1 live now live. The new enterprise system will provide significant efficiency gains and enable the delivery of timely information and transparency for managers and decision-makers. We hope that the successful implementation of this shared system with ESR will provide a platform that other CRIs will be able to join in the future.

Our ICT upgrades for high-performance computing, associated data science opportunities and plans for an Enterprise Content Management System have progressed over the last year, with further work still to come over the next year to ensure our systems run as efficiently as possible. We are developing a detailed multi-year security roadmap to protect our systems from the cyber-attacks that have become more frequent in recent years and educating our staff in what to look out for in a possible attack.

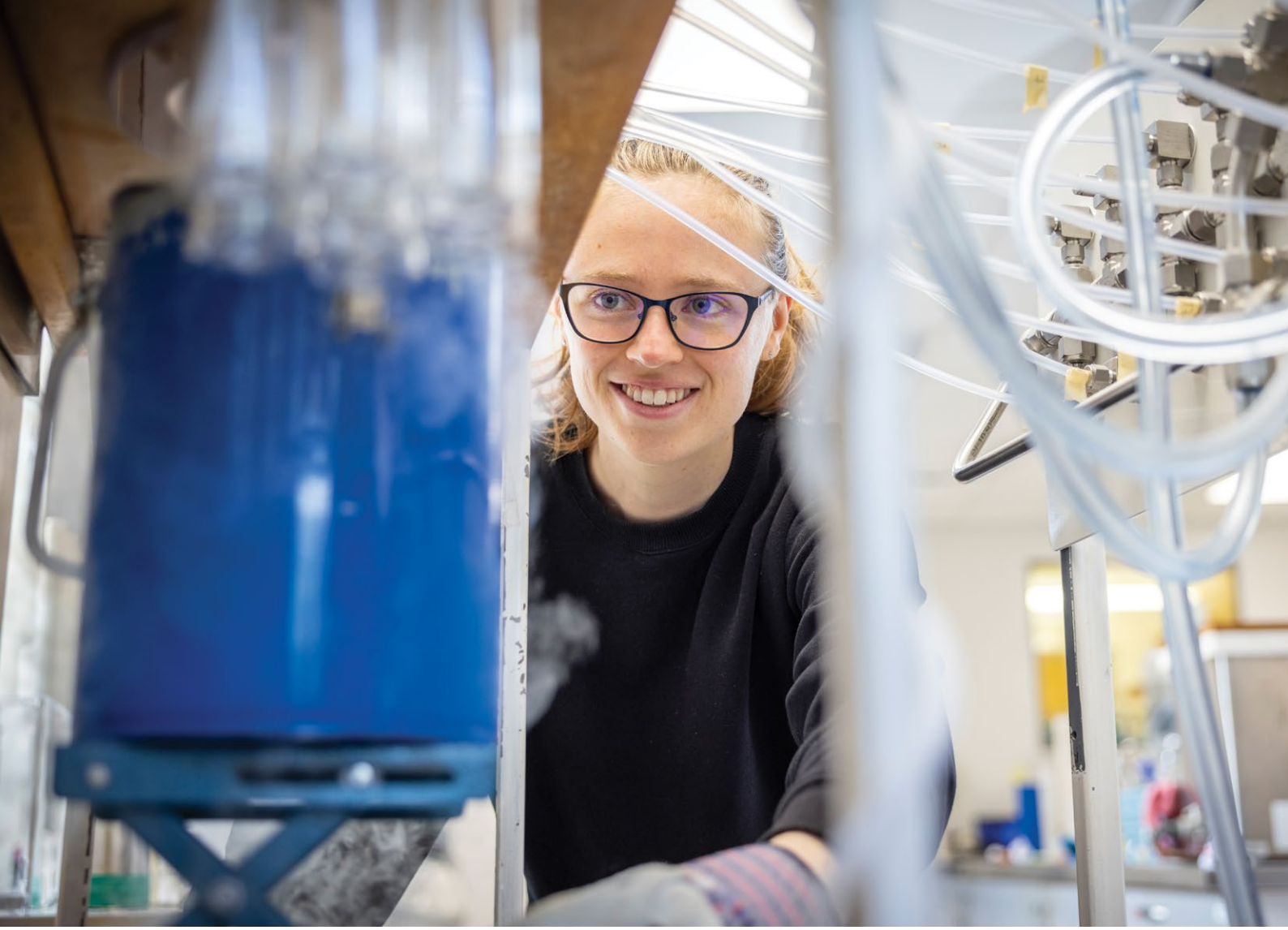
A new GNS Science website has been developed over the last year and was launched just prior to the publication of this report. The new website will enhance our public facing profile and reflect the organisation that we are becoming.

The completion of a GNS Science Communications Strategy over the last year is guiding how we talk about ourselves, our research, and our impact. It emphasises that people are at the heart of our research – that our research matters because of the people who live on the Earth's surface, and that our scientists and researchers are our storytellers.

The benefits these projects will bring to GNS Science over time will be significant.

Connectivity and innovation

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 Programme (ICDP).



The GNS Science Innovation Hub is an internal mechanism to incentivise and support higher-risk innovation with co-creation 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. Our innovation initiatives provide our people with new ways to identify research opportunities that are valued by our stakeholders and generate impact for Aotearoa New Zealand, with more targeted collaborative initiatives in order to build deeper partnerships with stakeholders. While the innovation is currently mostly virtual, we have been working towards developing innovation spaces to support ideation and the development of an innovation community of practice across GNS Science.

In-person stakeholder engagement opportunities, especially large-scale events, remained a challenge throughout the year due to the ongoing COVID-19 pandemic. Reluctance to engage in person has meant digital engagement continues to be dominant. The effort to maintain GNS Science relationships remains high level, and this engagement is leading to positive connections for larger events in the first half of the next financial year. As self-isolation restrictions ease and stakeholders both nationally and internationally become more comfortable engaging again, we will target events for stakeholders to engage with our scientists.

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. An increasing number of face-to-face engagements have also taken place, for example, the first targeted GNS 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.

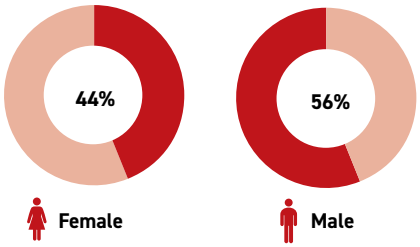
A new GNS Science website has been developed over the last year and was launched just prior to the publication of this report. The new website will enhance our public facing profile and reflect the organisation that we are becoming.

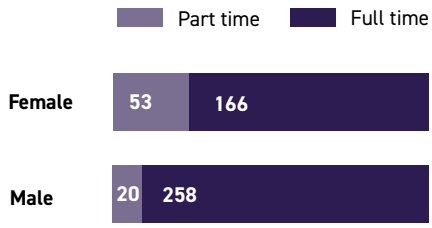
Left: Field Technician, Lauren Coup.
Right: Our Tritium and Water Dating Laboratory at Avalon.

OUR PEOPLE AT A GLANCE

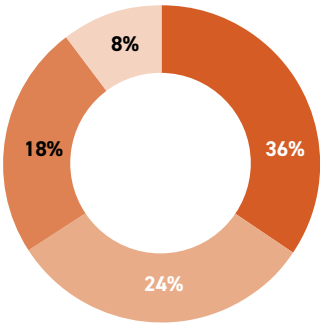
497

Staff





Qualifications

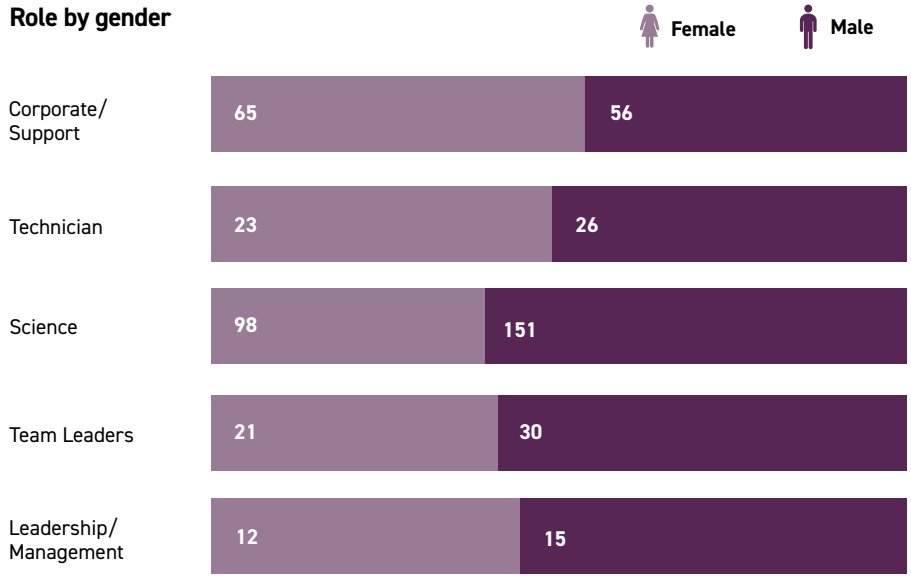


- Doctoral degree
- Master's degree
- Bachelor's or Honours degree
- Other

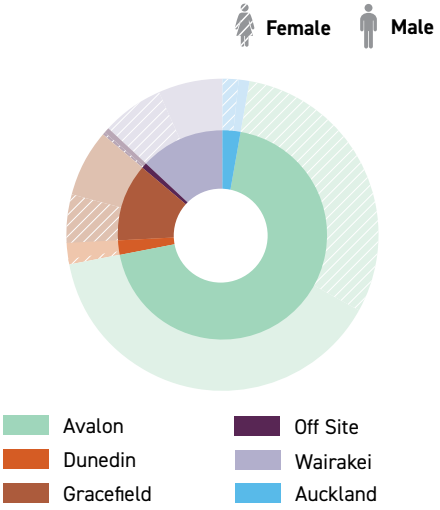
Age

70+	60–69	50–59	40–49	30–39	20–29
2%	15%	24%	26%	24%	10%

Role by gender

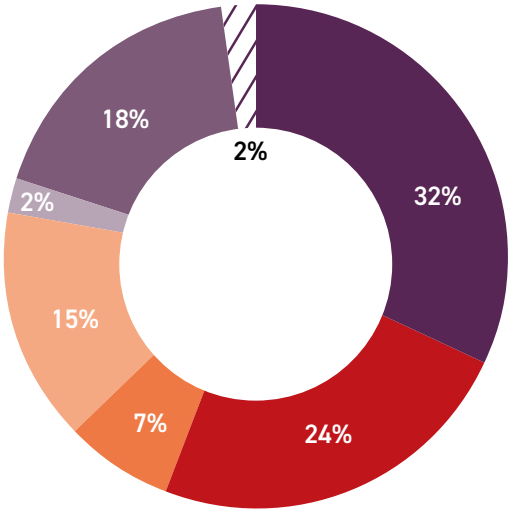


Split of staff by headcount



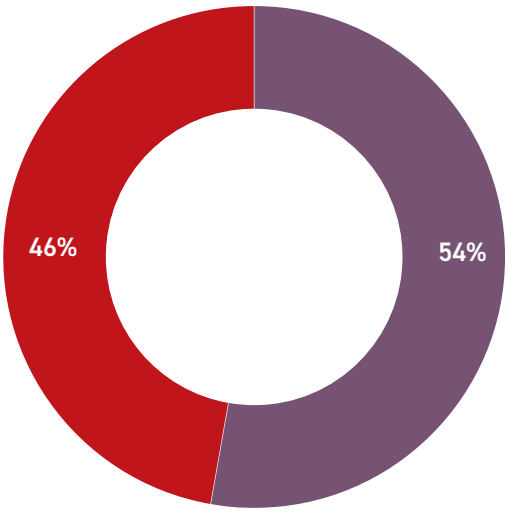
OUR NUMBERS AT A GLANCE

Revenue



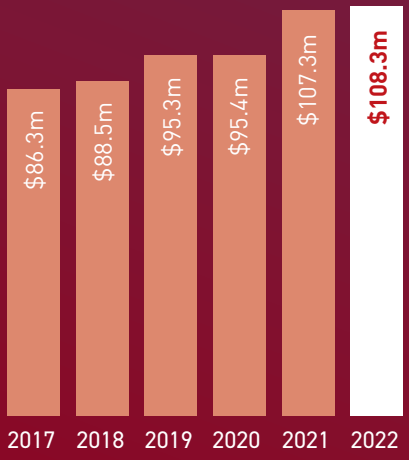
- Strategic Science Investment Fund contracts
- Other income
- Contestable funding contracts
- Research subcontracts
- Commercial – New Zealand
- Commercial – overseas
- GeoNet services

How we spent our money

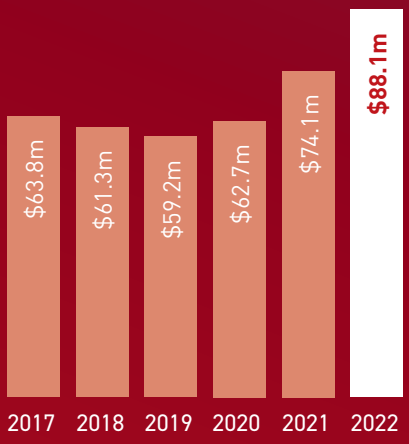


- Employee related expenses
- Other operating expenses

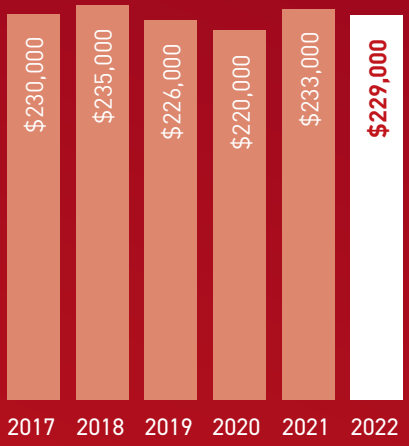
Revenue ($m)



Total assets ($m)



Revenue per FTE ($)



OUR BOARD OF DIRECTORS

Dr Nicola Crauford

Chair

BSc (Hons), PhD, DistFEngNZ, FAICD, CFInstD

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.

Dr John Sharpe

BSc, MSc (Tech), PhD, CMInstD

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.

Paul White

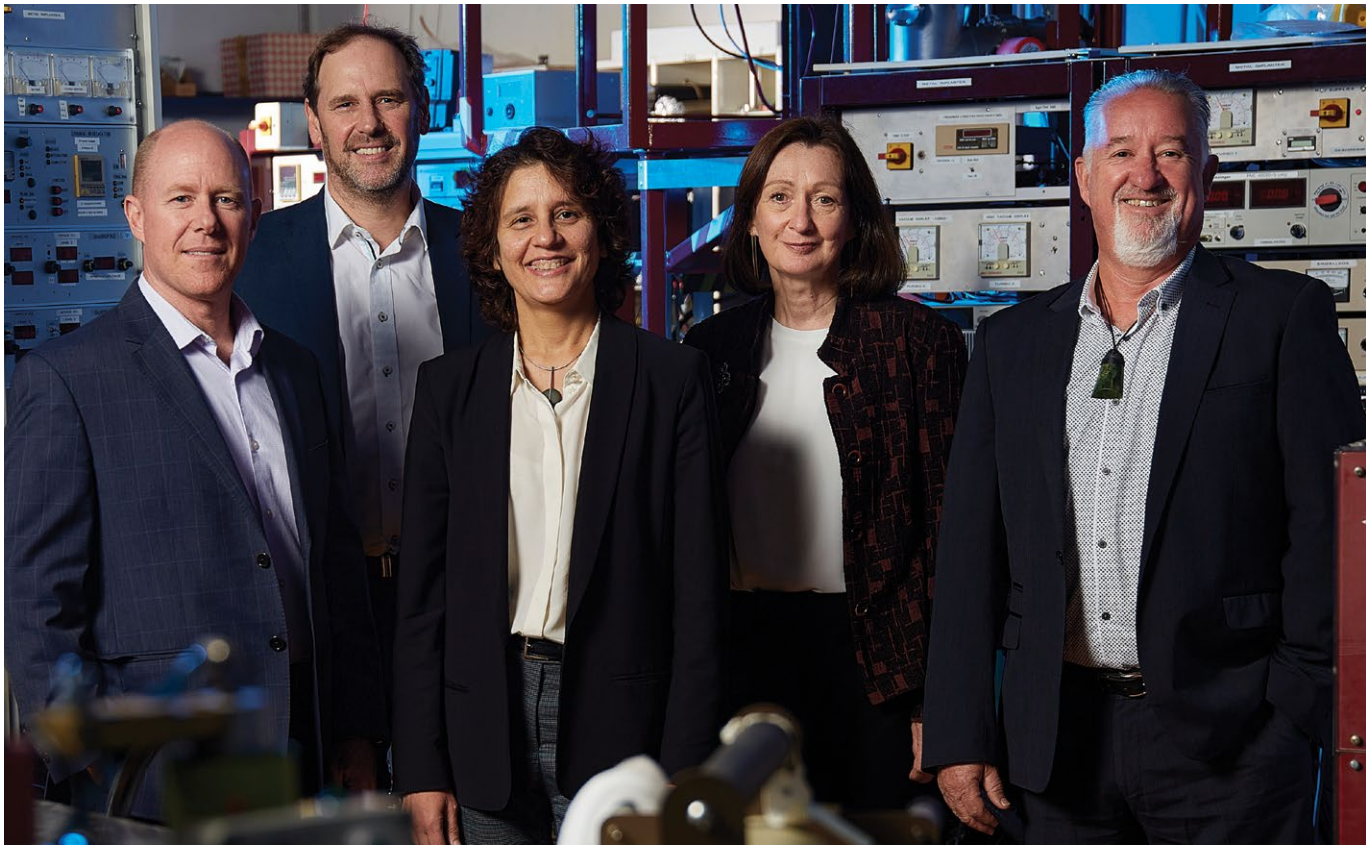
B Arch, MBS

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, Forest Industry Training and Education Council, 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 New Zealand'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.

Felicity Evans

Graduate of the Australian Institute of Company Directors (GAICD)

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.



Wendy Venter

FCA, MInstD

Wendy is a board director and independent consultant with expertise in governance, risk management, organisational change and assurance. She is a former partner at EY, deputy chief executive at the Ministry of Social Development and assistant auditor general.

Wendy is a director of Plant and Food Research and a trustee of Wellington's Nikau Foundation. She is an independent member of the Treasury's Audit Committee for the Government Financial Statements, and she chairs the risk and assurance committees of Stats NZ and the Parliamentary Counsel Office.

Wendy is a Fellow of Chartered Accountants Australia and New Zealand.

Andrew Cordner

LL.B (Hons); LL.M; B.Com

Andrew is Director of Legal at Fonterra. In this role, Andrew serves as Fonterra's General Counsel and leads the highly experienced Fonterra Global Legal Team, with lawyers based in New Zealand, Australia, China, Chile, the Netherlands, the United States, and Brazil.

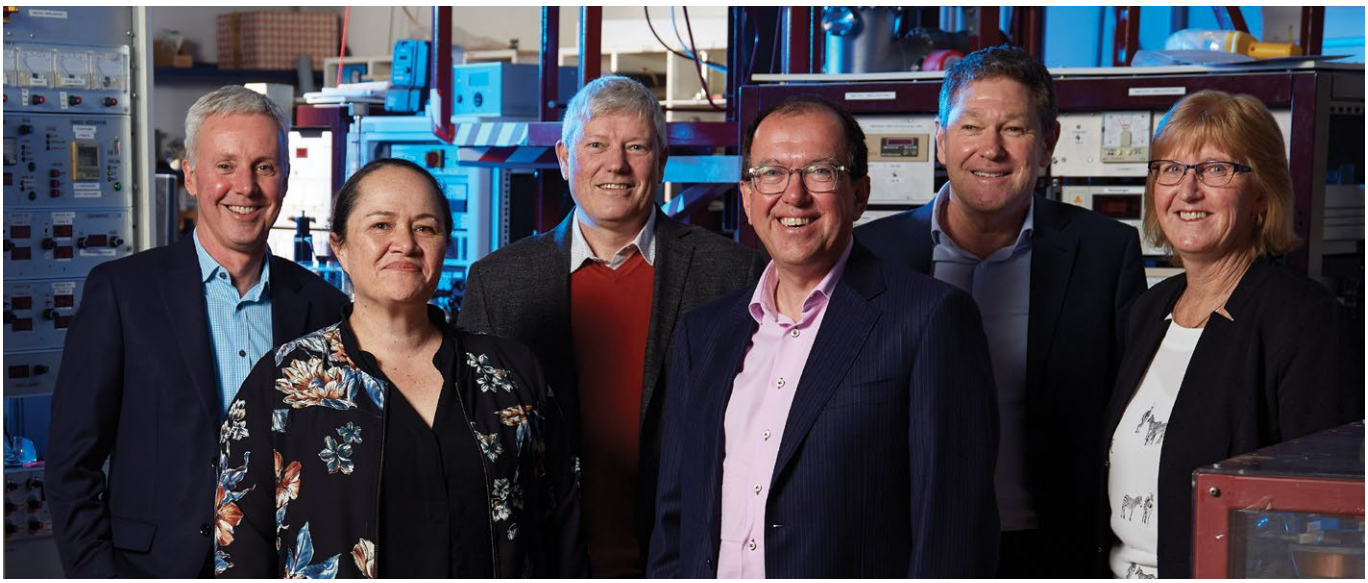
Andrew also serves as Company Secretary to the NZX-listed Fonterra Shareholders' Fund (NZX:FSF).

Prior to joining Fonterra in 2007, Andrew was a partner at Foley Hoag LLP, a leading US corporate law firm, specialising in corporate and commercial advisory work, venture capital, bankruptcy, intellectual property, mergers and acquisitions, securities law, and international transactions.

He has a LL.B (Hons) and B.Com from Canterbury University and an LL.M from Duke University School of Law. Andrew is currently a member of the NZ Law Society's National Standards Committee, which investigates and considers complaints that are sufficiently major, complex or of public interest or importance to the NZ legal profession. He is also a member of the Board of Trustees of St Andrew's Village, a large, aged care charitable trust.

Left to Right: John Sharpe, Andrew Cordner, Wendy Venter, Nicola Crauford, and Paul White (missing from photo Felicity Evans).

OUR EXECUTIVE TEAM



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

Ian Simpson

Chief Executive Officer

BSc (Mathematics) (University of Manchester), MBA (INSEAD, France)

Ian joined GNS Science in January 2017. Prior to his appointment he spent seven years as the head of the Toka Tū Ake 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.

Rose Macfarlane

General Manager, People and Culture

Post Graduate Diploma in Management Studies, Waikato University

Rose joined GNS Science as General Manager, People and Culture, in August 2018. She is responsible for leading and managing the Human Resources, Communications, Health and Safety and Administration functions of the organisation.

Prior to taking this role, she was GM Human Resources at DairyNZ. Rose's background spans a range of people-focused roles across education, social services, health, local government and science. She has held senior management roles in health, Hamilton City Council and DairyNZ. Rose is experienced in managing change, understanding the challenges of differing business environments and dealing with a broad range of organisational culture and people matters.

Peter Benfell

General Manager, Science

BE (Hons) (University of Auckland), DipBusAdmin (Victoria University of Wellington)

Peter joined GNS Science in October 2018 as General Manager, Science. He is responsible for the leadership and management of our research teams, as well as the quality and performance of our research projects and geohazard monitoring activities. Peter has had more than 30 years' experience in research, science and technology and its successful application, as well as in establishing several major Research and Development partnerships. He previously worked at GNS Science as Group Manager, Environment and Natural Resources Group between 1998 and 2001.

Prior to re-joining GNS Science, Peter was Chief Executive at the Infrastructure Industry Training Organisation, Connexis. Peter has held senior management roles at the Foundation for Research, Science and Technology, AgResearch and Opus International.

Tania Gerrard

General Manager Māori and Stakeholder Relations
Te Whanau a Tāpuhi, Ngāti Porou
BA (University of Otago)

Tania is our General Manager, Māori and Stakeholder Relations and joined GNS Science in November 2018. She is responsible for the development and management of our external relationships and partnerships, including with government, iwi/Māori and industry.

Prior to joining GNS Science, Tania was Acting Director of Water at the Ministry for the Environment. There she also held roles specialising in iwi rights and interests, and water rights and interests. She has also held senior roles at the Waitangi Tribunal, the Office of Treaty Settlements, and Ministry for Primary Industries/Fisheries.

Tania is currently the Chair of Te Ara Pūtaiao, the pan-Crown Research Institute Māori Leadership Group, and she is an Associate of the New Zealand Institute of Directors.

Andrew Simpson

General Manager, Business Services
BCom (Otago), CA

Andrew joined GNS Science in July 2019, bringing with him a wealth of experience in corporate and financial leadership and management. He has held executive roles in the global tertiary education sector, including as Vice President for Finance and Operations at the University of British Columbia, Chief Operating Officer at Victoria University of Wellington and Vice Principal of Operations and Finance at Queen's University.

Andrew has specialist skills in risk management, internal audits, and business transformation projects. He works alongside GNS Science teams and business units to ensure the seamless delivery of corporate and business services.

Gary Wilson

Chief Scientist and General Manager, Research Strategy and Partnerships
BSc (HONS), BMus, PhD
(Victoria University of Wellington)

As General Manager, Research Strategy and Partnerships, Gary's role is to guide the organisation's long-term science research direction. Gary is also our Chief Scientist, which means he is actively engaged in research.

Prior to joining GNS Science, Gary held a range of academic positions around the world, including at the University of Oxford, Ohio State University, Stanford University and the University of Otago, where he remains an Honorary Professor in Geology and Marine Science. He has published more than 120 scientific papers in scholarly Journals and led a number of international research programmes. He has served as editor of a number of international journals and he is currently Editor of the *Journal of Marine Science and Engineering.*

Gary is 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. He received a Blake Leadership award in 2006 and the Royal Society Thomson Medal for Leadership in 2021.

STRATEGIC SCIENTIFIC AND USER ADVISORY PANEL

It is important that our work is regularly and independently scrutinised to ensure it continues to focus on excellence and is tuned into emerging priorities, trends and opportunities. Our Strategic Scientific and User Advisory Panel (SSUAP) consists of international and Aotearoa New Zealand experts, whose role is to review our performance, future research directions and capability needs. The SSUAP meets annually and reports directly to the Board.

Dr Chris Pigram
AM FTSE

Chris is a geologist with over 40 years' experience. A former CEO Geoscience Australia, Chris was made a Member of the Order of Australia in 2019 and was elected a Fellow of the Academy of Technological Sciences and Engineering in 2016.

Chris chairs the Independent Expert Scientific Committee, advising government on water issues related to large coal mines and coal seam gas developments; the MinEX CRC and CSIRO Minerals Resources Advisory Committee. He is chair of AuScope Limited, a company that manages research infrastructure funds for the geoscience research community on behalf the Australian Government. He is a member of the Advisory Panel for CSIRO's Deep Earth Imaging Future Science Platform and was appointed to the Australian Space Agency Advisory Group in 2019.

Dr 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 centres on the interface of statistics and geosciences and she has developed statistical models for geophysical hazards such as earthquakes and volcanic eruptions. Ting has participated in national and international collaborative multidisciplinary research projects, including projects funded by Toka Tū Ake 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.

Sarah Stuart-Black
QSO

Sarah is the New Zealand Red Cross Secretary General. Previous 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. Sarah was appointed the Executive Director of the Ministry of Civil Defence and Emergency Management in December 2014. Sarah was a member of the United Nations Disaster Assessment and Coordination Team for nine years and has represented New Zealand at a variety of international forums, bilateral, regional and global meetings, exercises and forums.

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 extra-terrestrial 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.

Trevor is the past President of The Meteoritical Society and is a Fellow of the American Geophysical Union and the Geochemical Society.

Dean Kimpton

Dean runs an infrastructure strategy and advisory business, Tuhura and Partners. He was formerly Auckland Council's Chief Operating Officer, gaining significant insight into the unique challenges of growth, the built environment, infrastructure strategy, and delivery. Prior to this he was Managing Director for AECOM NZ.

Dean is an independent director on the New Zealand Upgrade Programme Advisory Board (Waka Kotahi), he chairs the Eastern Busway Alliance (Auckland Transport), the Bay of Plenty transport system investment initiative and is strategy advisor to the NZ Construction Sector Accord. 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.

Cameron Madgwick

Cameron is the Chief Executive of Gibson Sheat, a leading Wellington law firm. He is also a director of entities in both the commercial and not-for-profit sectors. His exposure to Earth science came at an early age, growing up in Taranaki where his father worked for Shell in the region's petrochemical industry. This led Cameron initially to study geology, before pursuing a career in the law and then executive leadership. He describes the science being progressed at GNS as incredible and the team undertaking it as awe-inspiring! Surrounded on the Panel by experts in their fields, who challenge GNS on that science, Cameron pushes the GNS team to advocate for the value of their science to Aotearoa New Zealand, and to ensure that they can clearly communicate the importance of it to all of us.

Dr Lucy Jones

Lucy is the founder of the Dr Lucy Jones Center for Science and Society, whose mission is to foster understanding and application of scientific information to support resilient communities.

Lucy is a Research Associate at the Seismological Laboratory of Caltech. Lucy spent 33 years with the US Geological Survey, where she created the first Great ShakeOut drill, now a worldwide event with over 60 million participants. Her pioneering science has been recognised with numerous international awards, including the Samuel J. Heyman Service to America Medal, the Ambassador Award from the American Geophysical Union, the William Rodgers Distinguished Alumni Award from Brown University, and the Frank Press Medal from the Seismological Society of America.

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 works with governments, the United Nations and NGOs to help develop and implement solutions to environmental and resource problems. 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 Te Kani Kingi

Te Kani is Executive Director of Research and Innovation at Te Whare Wānanga o Awanuiārangi.

Te Kani has previously been a member of the AKO Aotearoa Assessment Committee, the Board of the Joint Centre for Disaster Research, a Research Associate of the National Institute for Economic and Demographic Research, and currently Chair of the Te Rau Puawai mental health scholarship programme and a board member of Tane Ora. He was recently appointed to the Veterans' Health Committee, the Prime Minister's Science Awards Panel, the Royal Society of New Zealand's Council, the Independent Science Panel (Sustainable Seas National Science Challenge) and to the Australian Physiotherapy Council Accreditation Board.

Te Kani was born and raised in Poroporo (near Whakatāne) and educated at St Stephen's School (Sth Auckland). He has tribal affiliations to Ngāti Pūkeko, Ngāti Awa, and Ngāi Tai.

James Hutchinson

James is Chief Executive Officer of Kiwi Innovation Network (KiwiNet), a national organisation that funds and supports commercialisation of publicly-funded research for the benefit of Aotearoa New Zealand. He is passionate about the important role that science and the scientific community must play in growing our economy into new high-tech and knowledge-based sectors, informing public policy and changing our world for the better.

James has international experience in supporting research and innovation, with a particular focus on life sciences, global societal challenges and entrepreneurship.

Photograph acknowledgements

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Our office locations and staffing

Auckland
15 staff

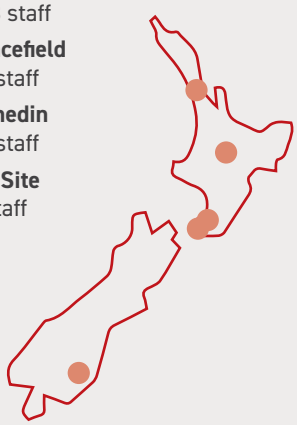
Wairakei
64 staff

Avalon
343 staff

Gracefield
60 staff

Dunedin
11 staff

Off Site
4 staff



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Wendy Venter

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Chief Executive

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General Manager,
Research Strategy and Partnerships
& Chief Scientist

Peter Benfell
General Manager,
Science

Andrew Simpson
General Manager,
Business Services

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People and Culture

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