OUR SCIENCE ROADMAP TO 2032

Guiding our science direction and organisational investment towards a cleaner, safer and more prosperous future for the people of Aotearoa New Zealand

GNS SCIENCE
TE PŪ AO

Mai i te rangi ki te nuku o te whenua, ka puta te ira tangata i te po, i te whaiao i te ao, mārama – Tihei Mauriora! – 'From the sky and the land came people, from the night, to the old world, to the world of light'

ROADMAP RESEARCH CHALLENGE

OUR FUTURE ENVIRONMENT AND CLIMATE

Understanding the drivers of climate and environmental changes and their impact on ice sheets, groundwater, and ecosystems to mitigate warming and adapt to unavoidable sea level rise.

ROADMAP RESEARCH CHALLENGE

NATURAL HAZARDS AND RISKS

Growing our understanding of natural hazards, building resilience to natural hazard events, and improving our ability to manage risk associated with different natural hazards.

Cover image: Sunset at Aoraki/Mt Cook, partly masked by low cloud on the horizon, as seen from the Hooker Valley. Credit: Dougal Townsend

ROADMAP RESEARCH CHALLENGE

THE FUTURE ENERGY NEED FOR NEW ZEALAND

Helping transition our national energy ecosystem to a low-carbon, resilient cost effective alternative through improved energy generation approaches, storage methods and utilisation models.

ROADMAP RESEARCH CHALLENGE

LAND AND MARINE GEOSCIENCE

Building the fundamental understanding and revealing the processes that continue to shape Te Riu-a-Māui / Zealandia and impact our wider society and economy.

Introduction from the Chief Scientist

Uia mai koe ki ahau, “He aha te mea nui o te ao?” Māku e kī atu, “He tangata, he tangata, he tangata.” If you were to ask me, “What is the most important thing in the world?” My reply will be, “It is people, it is people, it is people.”

Over the next decade, Aotearoa New Zealand will face unprecedented challenges from rapidly changing Earth systems. Society's expectation of how we interact with natural processes and how we resource our long-term future requirements is also changing.

As the Crown Research Institute for Earth and Material sciences, GNS Science is already helping our country navigate these issues. We already know future needs will be greater and meeting them more challenging. These needs and expectations set our research direction.

In this document, we look forward a decade from now and outline these future needs and expectations, and identify the research areas we need to focus on to address them. We identify the organisational response needed to ensure GNS Science is fit-for-purpose to undertake the required research. We have also identified the projected impacts we will see from our research effort.

People and society are central to the approach we will take to better understand Earth systems, Earth surface processes, and our impact on these processes. People are also central to how we better resource our growing and changing energy needs and manage the risk from natural hazards (earthquakes, tsunami, volcanic eruptions, landslides and climate induced hazards). It is also people who will determine how best to manage this incredible land and its natural resources, above and beneath the sea, for future generations while supporting the commitments made under Te Tiriti o Waitangi.

GNS Science, and its predecessors under the New Zealand Department of Scientific and Industrial Research (the New Zealand Geological Survey, Geophysics Division and the Institute of Nuclear Sciences), has invested more than 100 years in understanding the origin of Te Riu-a-Māui / Zealandia. Looking forward, we intend to build on this legacy, draw on our international partnerships and play a critical role in a vibrant and integrated science system in Aotearoa New Zealand.

Our Roadmap will be delivered through our Science Theme plans supported by upgrades to research infrastructure and our organisational support strategies. Our approach is one of collaboration across the sector with GNS Science leading where placed to do so and also collaborating with others where appropriate. We expect to revisit the Roadmap every two years to adjust our direction as required in response to changing natural systems, changing societal need, and informed by the progress we have made in knowledge and understanding through our research.

While the Roadmap's primary role is to aid GNS Science in developing its future research direction, we expect it will also be useful for our shareholder and stakeholders to see the shared societal challenges we are focusing on as we invite them to collaborate with us in developing innovative solutions.

Prof Gary Wilson
Chief Scientist

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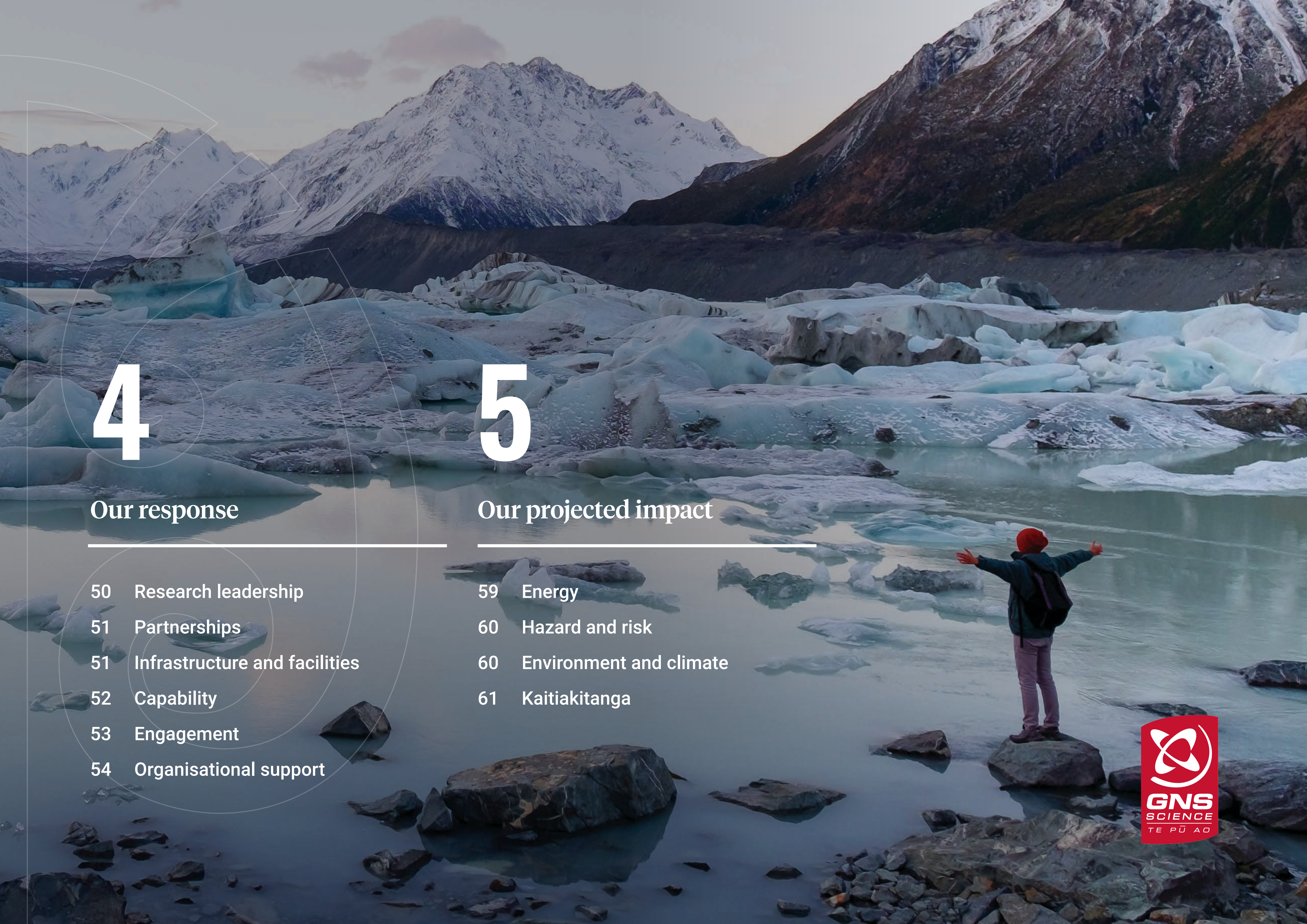

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Toitū te kupu, toitū te mana, toitū te whenua.

We anchor our planning and thinking as we look to the future wellbeing for Aotearoa New Zealand.

1

Our current context

The role and scope of the GNS Science Roadmap

GNS Science is contributing to a 30-year vision for Aotearoa New Zealand through Treasury's Living Standards Framework and UN Sustainable Development Goals.

Our contribution will help Aotearoa New Zealand:

- achieve its long-term energy needs
- meet climate action goals (carbon net zero 2050)
- have sustainable and resilient environments, ecosystems and societies
- secure its freshwater
- enable industry, innovation, infrastructure and economic growth

With these 2050 goals and aspirations in mind, GNS Science has developed a 10-year Roadmap to identify where GNS Science can best deliver benefit through our research for future stakeholders and New Zealanders and realise our vision.

Through our research contribution, by 2032 we expect to have reduced our dependency on fossil fuels, increased the resilience of our energy supply, reduced our energy emissions profile and saved the nation more than $5 billion a year in energy associated costs.

We also expect to have progressed our resilience to natural hazards (earthquakes, tsunami, landslides, volcanic eruptions) to futureproof against hundreds of billions of dollars in potential economic shock, damage and loss of hundreds of thousands of homes, and the potential loss of hundreds to thousands of lives. And, we will have developed our understanding of the climate and carbon cycles to enable Aotearoa New Zealand to meet its net zero 2050 aspiration, secure long-term groundwater availability, and resolved the changing pressures on the coastal environment.

GNS Science has developed a 10-year Science Roadmap to identify where we can deliver future focused benefit for all New Zealanders.

The Roadmap outlines the scientific research that GNS Science will have put in place for this projected research and impact to be delivered.

Along with the Science Strategy, the Roadmap provides the information required for GNS Science's Property, Financial, People and Culture, Stakeholder Engagement and other strategies to be developed. Importantly, GNS Science's Māori Strategy has been developed in parallel and will provide guidance to support Māori and iwi goals and aspirations in Earth Science, Hazard, Climate Change, Energy and Materials research.

Our Impact by 2032

GNS Science will contribute to the following:

Energy	**A science-led transition to locally produced low-carbon energy** which is expected to bring more than $5 billion back into the New Zealand economy by 2032 and reduce our annual energy emissions by up to 30 million tonnes.
Hazard and Risk	**Greater resilience to a significant geohazard event through a range of planning, regulatory, and education measures, improved response, and improved forecasting of scale and breadth of impact.** Combined, these efforts could save hundreds to tens of thousands of lives and reduce economic shock by billions of dollars.
Environment and Climate	**The connectivity of environmental systems is understood and a plan in place to protect our groundwater.** We will be able to forecast and minimise the impact of our activities on the environment and adapt effectively to unavoidable change. We will contribute scientific knowledge and implement actions to reduce anthropogenic atmospheric CO_2 which could have an ETS value of $2 billion by 2032.
Kaitiakitanga	Not only will the potential resources, energy, environments, hazards and origin of Te Riu a Māui / Zealandia be valued, understood, respected, protected and restored, we will work with communities / iwi to develop **a comprehensive plan to monitor our changing environment so current and future generations can live sustainably and resiliently in Aotearoa New Zealand.**

Implementing our vision

The Roadmap reaches beyond all current funding instruments and beyond current government systems and approaches.

The Roadmap identifies how GNS Science will be best placed to support Aotearoa New Zealand in the challenges and opportunities associated with Earth system science, Earth surface and subsurface processes, energy and materials.

GNS Science is interested in all processes that shape the surface and subsurface of the Earth in the Aotearoa New Zealand sector of the Southwest Pacific, as well as the wellbeing, future needs and resilience of the people of Aotearoa New Zealand. Our landmass sits astride a major plate boundary and is part of the Pacific ring of fire, requiring comprehensive monitoring, forecasting and effective event response.

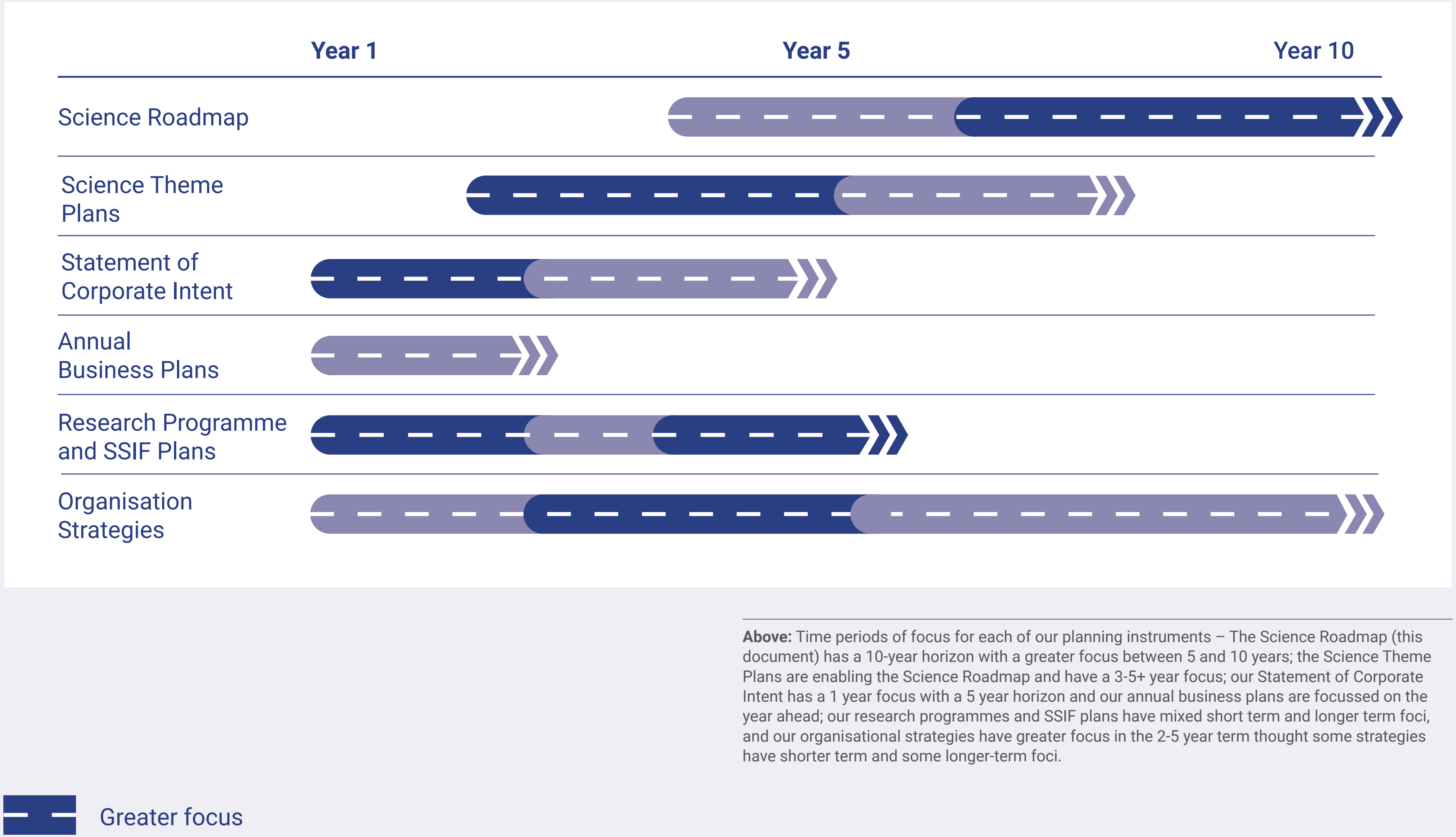
While Aotearoa New Zealand is the core focus of the Roadmap, we also recognise ongoing strategic interests in nearby regions such as Antarctica and the South Pacific and beyond, where we can learn from shared settings and challenges and where distant Earth events, such as tsunami and ashfall, can impact Aotearoa New Zealand and where Aotearoa New Zealand is part of global system, such as ocean and climate circulation change.

Taking guidance from the expectations and views of our shareholder and stakeholders, respectively, as well as wider government guidance, GNS Science has developed a set of challenges and science questions. These are the matters, research areas and questions that GNS Science expects to be able to address through our future research effort.

This Roadmap is a living document. It will evolve as research findings are gathered, shareholder expectations change, and iwi/Māori and stakeholder needs evolve. Accordingly, we will review the Roadmap on a biennial basis.

The Roadmap sets out GNS Science's future research direction based on our vision. Research Theme Plans (being developed) detail how we will implement the Roadmap. The theme plans focus specifically on what research we will do within each of GNS Science's Science Themes: Natural Hazards and Risks; Environment and Climate; Energy Futures; and Land and Marine Geoscience.

Our planning horizons



Above: Time periods of focus for each of our planning instruments – The Science Roadmap (this document) has a 10-year horizon with a greater focus between 5 and 10 years; the Science Theme Plans are enabling the Science Roadmap and have a 3-5+ year focus; our Statement of Corporate Intent has a 1 year focus with a 5 year horizon and our annual business plans are focussed on the year ahead; our research programmes and SSIF plans have mixed short term and longer term foci, and our organisational strategies have greater focus in the 2-5 year term thought some strategies have shorter term and some longer-term foci.

Our shareholder

GNS Science's Statement of Core Purpose (2010) identified GNS Science's purpose to undertake research that drives economic growth in Aotearoa New Zealand's geologically-based energy and minerals industries, develop industrial and environmental applications of nuclear science, and increase resilience to natural hazards through enhanced understanding of geological and Earth system processes.

Since the Statement of Core Purpose was drafted, Aotearoa New Zealand has suffered multiple destructive earthquakes with loss of life and significant damage to national infrastructure and a volcanic eruption on Whakaari/White Island also with loss of life.

Government direction has changed from encouraging fossil fuel exploration to addressing the changing climate resulting from fossil fuel use. Emphasis is now on greater wellbeing of Aotearoa New Zealand society, a more sustainable and inclusive economy, and closer relationships with Māori. There is growing evidence that economic practices benefit when te ao Māori is included and the interconnected importance of land, ecosystems, heritage, environment, cultural authenticity and community in building resilience and sustainable practices and approaches is recognised.

The Ministry of Business, Innovation and Employment (MBIE) commissioned a review of Aotearoa New Zealand's Crown Research Institutes (Te Pae Kahurangi) in 2010, which identified the need for greater collaboration across the Science system and with Māori in order to tackle some of Aotearoa New Zealand's most pressing issues when it comes to building a more resilient society, including issues of climate change, water availability, land use, alternative energy and natural hazards and risk. Central government is addressing some of these matters through legislative reform.

Societal expectations have also increased with respect to improving resilience, insulation from economic impact and decreasing loss of life from geohazard events and changing Earth system processes, like coastal erosion.

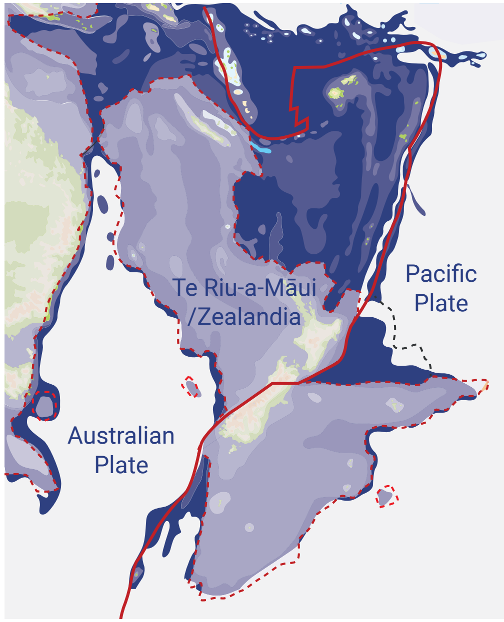
Society expects greater resilience to geohazard events and changing Earth system processes.

Key stakeholders that GNS Science works with:

Māori and iwi, Ministry of Business, Innovation and Employment, National Emergency Management Agency, Earthquake Commission, Ministry of Foreign Affairs and Trade	**Regional Councils, National Institute of Water and Atmospheric Research, Department of Conservation, Ministry for the Environment, energy companies, Antarctica New Zealand**

And more...

Toitū Te Whenua Land Information New Zealand, New Zealand Lifelines Council, New Zealand Infrastructure Commission, Envirolink, Department of Internal Affairs, New Zealand Defence Force, MetService, Treasury, Parliamentary Commissioner for the Environment, He Pou a Rangi Climate Change Commission, Ministry for Primary Industries, Tourism NZ, Firstgas, Ara Ake, the industrial heat and petroleum sectors, Energy Efficiency and Conservation Authority, Transpower, research partnerships



Iwi / Māori relationships

Relationships with Māori and iwi are central to the way we work. We know we can better prioritise and engage with Māori and iwi. We have developed a Māori Strategy, which sets out how our resources and efforts will underpin our developing partnerships with Māori and iwi. We know we can better prioritise and engage with Māori and iwi. We have developed a Māori Strategy, which sets out how our resources and efforts will underpin our developing partnerships with Māori and iwi.

GNS Science will leverage opportunities in Earth system science and Earth surface processes to build strong relationships with Māori and iwi as we work together to develop broad societal understanding and diverse approaches to the challenges of a more sustainable future. Improved Māori relationships and capability will also enable GNS Science to better understand the science needs and expectations of iwi/Māori and deliver on their aspirations. By partnering with iwi/Māori and communities in our work, GNS Science will ensure our research is relevant and societies trust our science. This in turn will mean higher uptake of our research findings.

Implementing principles of Te Tiriti o Waitangi

GNS Science is committed to upholding the principles of Te Tiriti o Waitangi. GNS Science's Māori Strategy will guide how we will incorporate Treaty principles of partnership, active protection and participation with our aspirations, strategy and working practices to inform and guide the delivery of the Roadmap. This Roadmap sets out our scientific direction of travel to allow our Treaty partners to consider, influence and work with us to on shared goals and aspirations.

Left: Aotearoa New Zealand straddles the boundary between the Pacific and Australian plates. Te-Riu-a-Māui (the hills valleys and plains of Maui) is the submerged continent that includes the exposed islands of Aotearoa New Zealand

Our stakeholders

A high proportion of GNS Science's customers and stakeholders lie within the public sector and have a strong focus on societal wellbeing and resilience and better delivery of that through stronger partnerships.

Our stakeholders tend to work within, and seek answers with respect to, single components of the Earth science system and/or Earth surface.

Hence, a significant challenge facing GNS Science is developing an understanding of the high degree of connectedness and consequent feedbacks in the Earth system. With a changing demographic and changing land use, the impact of other natural hazards and phenomena become more intense and less predictable, and the demands for energy and natural resources grow exponentially. Collaboration across the science and government sectors and with iwi will be vital to making progress in this complex setting.

GNS Science has also developed several products that better engage wider society, industry and the public sector in building a cleaner, safer, more prosperous Aotearoa New Zealand.

For example, GeoNet's communications and geohazards data networks support data collection for research, monitoring and response. Other examples include RiskScape™ which is our integrated risk assessment tool, as well the National Seismic Hazard Model, which uses geological, geophysical, and statistical science to estimate and understand potential seismic hazards.

Disaster risk reduction

Multiple government agencies are engaged in disaster risk reduction under the Sendai Framework, in response to the UN Sustainable Development Goals, and in support of community wellbeing. Their goal is to reduce mortality, reduce the number of affected people, reduce direct economic loss, and reduce damage to infrastructure through developing best international practice in hazard understanding and management, and increase in early warning and risk information.

Collaboration across the science and government sectors and with iwi will be vital to making progress in this complex setting.

Left: Sharing environmental insights with iwi partners Te Rarawa Kaiwhare as part of a collaborative study of ecosystem changes in Hokianga Harbour. Credit: Kyle Bland, GNS Science

A wider group of agencies is focussed on understanding risk scenarios, probabilistic frameworks and associated economic impacts, building risk awareness and use of new techniques, data and technologies to manage risk. All of these require an underpinning research capability generally supported by MBIE, EQC and our international partnerships with the Global Earthquake Model, IODP and ICDP.

The same agencies are also engaged with emergency response and recovery through information and intelligence systems for decision support, developing capability and capacity for response, and the ongoing safety and wellbeing of communities. Behind all of this is a drive to develop greater community resilience through empowerment, collective response, better critical infrastructure design and strong regulatory frameworks.

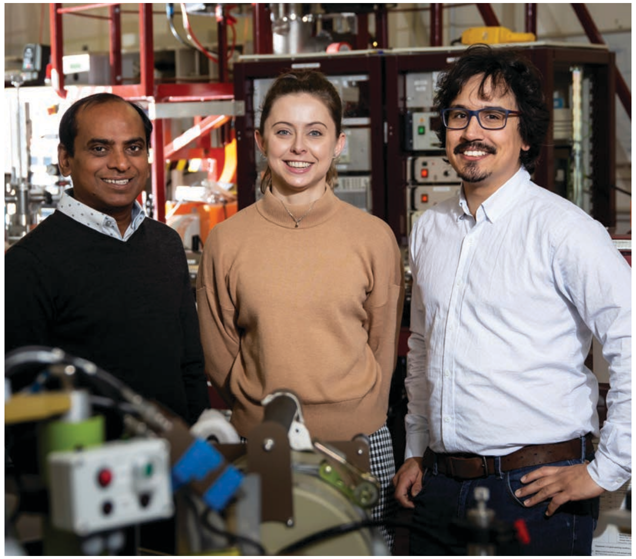
Climate change response

A growing focus for government agencies is supporting New Zealanders to prepare for and adapt to the effects of climate change, reduce our CO_2 emissions to net zero by 2050, and contribute to the global effort under the Paris Agreement to limit the global average temperature increase to 1.5°C above pre-industrial levels.

While changing patterns of rainfall and evapotranspiration across Aotearoa New Zealand are of significant concern for our agriculture-based economy, inundation and changing coastal erosion from rising sea levels is equally challenging for a country with a long coastline, significant submerged continental landmass and coastal settlement and infrastructure.

Aotearoa New Zealand plays a significant role in the understanding of changing sea levels from changing mass in the Antarctic Ice Sheet and thus has the potential, with global partnerships, to help understand the pattern of rising sea level and climate change across the South Pacific and Southern Ocean.

Closer to home, impacts of rising sea level and changing atmospheric and ocean circulation are of direct concern to regional councils, iwi and coastal and marine industries. These impacts include changing coastal sedimentation, coastal erosion, and rising groundwater and salinization. With changing land use in the coastal environment, the natural cycle of carbon burial is also impacted, countering efforts to sequester carbon through increased forestry.



Conservation and environmental science

Sustainability is at the heart of Treasury's economic development plan. Managing our environment and natural capital in a sustainable manner requires a high degree of understanding of natural systems and processes and their resilience to human impacts and changing global temperatures and conditions. Degradation of our natural resources (mineral wealth, soils and carbon, water, and the conservation estate) through changing use, over-use and impacts of changing climate is of direct concern to regional councils, Department of Conservation and Iwi.

The government's Three Waters reform is focussing on the future sustainability of water supply. An estimated 80% of surface water stems from groundwater and 40% of our potable water is sourced from groundwater.[1] The impacts of changing land use and changing climate on groundwater reservoirs and systems have yet to be understood.

Understanding the importance of our natural ecosystem, biodiversity and ocean response to changing natural and anthropogenic environmental conditions is vital to the industries and sectors that rely on healthy and productive ecosystems, including the blue ocean economy and tourism. It is also vital for protecting our environmental and ecosystem taonga which are integral to our identity.

The energy challenge

While the energy sector is deregulated, it is based on a traditional model of focussed energy and heat production with distribution via a national grid and transport network. Transition from petroleum for transport, and gas and coal for heat and energy generation, presents a challenge for both baseload and peak generation of electricity and supply of energy for the transport sector.

As Aotearoa New Zealand transitions from traditional sources and approaches (to address the climate challenge), energy security becomes challenging with reliance on international availability and supply and changing supply avenues and networks. Alternative transport fuels are available through hydrogen and electricity, but the cost of production and infrastructure for supply and use is not yet available or cost-effective. Electricity generation from geothermal fields has yet to realise the production potential required while reducing CO_2 emissions.

Society has yet to fully embrace different technologies and changes needed to switch to non-coal and petroleum-based industries.

80%
of surface water stems from groundwater

40%
of our potable water is sourced from groundwater

Top: Paleoecologist Marcus Vandergoes and General Manager Māori and Stakeholder Relations Tania Gerrard collect a sediment core from Hokianga Harbour, to be used to study recent environmental change. Credit: Kyle Bland, GNS Science
Bottom: GNS Science experts (from left) John Kennedy, Michelle Cook and Jérôme Leveneur are working to make green hydrogen a viable future energy source for New Zealand. Credit: Jeff Brass, GNS Science

1 New Zealand Groundwater alliance. https://www.esr.cri.nz/our-research/research-projects/new-zealand-groundwater-science-and-research-platform/

International connectivity, opportunities and responsibilities

Aotearoa New Zealand through its claim to the Ross Dependency and as a signatory member of the Antarctic Treaty maintains a comprehensive programme of scientific research in the Ross Sea sector of Antarctica. Not only does Aotearoa New Zealand share geological heritage with Antarctica, but it is inextricably linked by Earth surface processes that have driven and continue to drive changes in Aotearoa New Zealand's ocean and climate but also changing sea levels through changing ice mass in Antarctica. Antarctica offers a unique and important opportunity for global geophysical observatories and Aotearoa New Zealand's operation in Antarctica is also subject to impact from geological hazards.

Through the Pacific Reset, the New Zealand Government intends to better support its Pacific neighbours and dependencies through an emphasis on engagement, partnerships and collaboration. Thus, the reach of the Earth sciences, changing Earth surface processes, impacts from natural hazards and the impacts of climate change across the Pacific sector are an important additional focus for research programmes. Working with Pacific Island nations adds an important dimension to quantifying and managing risk from geohazards and Earth surface processes.

Aotearoa New Zealand research has been at the forefront of understanding fundamental Earth system processes. Not only is Te Riu-a-Māui/Zealandia one of the most geological active parts of the Earth (tectonics, global circulation, erosion, and response to human impact) but our researchers are valued for leading global understanding of those processes and the link to policy and management approaches. Within the wider Asia Pacific context, we also have an opportunity to assist our neighbours with sustainable energy development.

The natural Earth system

GNS Science, through its extensive geological, geophysical and environmental databases and monitoring networks, has the means to develop a greater understanding of the fundamental geological processes and properties that support a broader understanding of geological and Earth system materials and resources. From this fundamental understanding, Aotearoa New Zealand is well placed to realise its resource potential, understand the human impact on the natural Earth system, develop robust approaches to building resilience and ensure enduring kaitiakitanga (stewardship) of our natural environment.

Bottom: Ice Sheet and Climate Modeller Dan Lowry in Antarctica. Credit: Laurine Van Haastrecht, Victoria University of Wellington

He ao te rangi ka uhia, mā te huruhuru ka rere te manu.
Just as the clouds adorn the sky, so do birds need feathers to fly.

2

Our Organisation

Our strategic science direction

As the National Institute for Geological and Nuclear Sciences, we are focussed on delivering benefits for the people of Aotearoa New Zealand from natural processes occurring in the Earth's crust and Earth surface processes that directly affect our infrastructure, industry and environment.

GNS Science's purpose is to undertake research that increases Aotearoa New Zealand's resilience to natural hazards, enhances our understanding of geological and Earth system processes and drives innovation and sustainable economic growth in Aotearoa New Zealand's energy sector and develops new materials, products and approaches to assist other agencies with sustainable management of risk, environment, and natural Earth and groundwater resources.

GNS Science has responsibility for managing the GeoNet system which delivers geohazard data used for research, monitoring and response. This includes sensor networks and data processing which support detection of earthquakes and tsunami, monitoring of land movement and volcanic activity. Using GeoNet, GNS Science provides assessments of these hazards to the National Emergency Management Agency (NEMA) to support their decision making in their role as the agency that issues national warnings and advisories about geological hazards.

More broadly, we provide scientific advice to government agencies to support response and recovery in terms of a geohazard event including earthquake, tsunami, volcano and landslide, as well as reduction of risk through research. We also contribute to public information and education on geological hazards.

Our expertise contributes to a cleaner, safer and more prosperous Aotearoa New Zealand by:

- Understanding freshwater, energy and mineral resources to enable wise custodianship, sustainability and building of intergenerational wealth and wellbeing.
- Reducing the impacts on society (physical and economic) from geological hazards, including through forecasting, improving hazard awareness and preparedness, and developing more resilient communities and buildings.
- Understanding past climates in order to improve global models that are used to forecast the future impacts of a changing climate, including critical tipping points.
- Developing and applying novel technologies such as nano-scale devices and isotope measurements to create new value for industry.
- Ensuring Earth science data and physical collections have enduring value to our Earth science research and through wider utilisation of data streams and collections.

In response to our shareholder expectations, stakeholder views and our engagement with iwi/Māori, our work is focussed on four Science Themes associated with the natural settings and geological challenges facing Aotearoa New Zealand and its people.

Natural Hazards and Risks

Natural hazards are part of our country's DNA and climate change is increasing both the risks and the impacts of hazard events. Managing our increasing exposure to natural hazards is critical to our future wellbeing and prosperity. GNS Science's extensive knowledge of Earth sciences combined with social science research in resilience and preparedness, helps us span the full value chain to support response and grow resilience.

Energy Futures

As the 'Energy CRI', we play a major role in enabling Aotearoa New Zealand's transition to a low-carbon future through the development of alternative energy and heat sources (geothermal, hydrogen, solar), Earth system energy storage, new materials for energy systems and storage, and cross sector support needed for enhanced energy security and resilience.

Environment and Climate

Our work in Environment and Climate focusses on sustainable management of the environment, and effective adaptation to climate change. Our work on natural Earth systems underpins our global response such as the carbon cycle, sea level change, and groundwater. From our work on geological records we will reveal the fundamental drivers and interactions of our global ocean and climate system.

Land and Marine Geoscience

We generate knowledge about our continent and oceans recognising kaitiakitanga to improve forecasting capability for hazards and disasters, understand global-scale environmental change, variability and impacts, identify new sustainable natural resources, and be custodians of our databases and collections.

Our four science themes are connected by inter- and cross-disciplinary research in social science, data science and Vision Mātauranga.

Social science

To maintain social, environmental, economic and cultural wellbeing in Aotearoa New Zealand's geological landscapes we must understand the interplay between geological resources and processes and the people who live on and with them. Through a better application of how society functions including governance and policy frameworks, we expect there will be a greater uptake of the physical and environmental science that GNS Science undertakes, to ensure that our research findings are useful, usable and used.

Data science

GNS Science's research is data intensive, covering the length and breadth of Aotearoa New Zealand, working at global scales, and developing predictive forecasting capacity through advanced algorithms, computer and statistical models. Leading-edge techniques and expertise in data science (including Deep Learning, Decision Support Models, Data Lens, and trust in Artificial Intelligence) is being applied across our science themes and to all GNS Science databases, satellite and GeoNet data.

Vision Mātauranga

Vision Mātauranga is at the core of GNS Science's strategic framework. Through our ongoing engagement with Māori interests, our focus is on building strong, meaningful relationships so that GNS Science can better understand Māori science needs and expectations.

Core capabilities

GNS Science maintains broad capability in Earth structure, processes and materials (including geophysics, geodynamics, seismology, earthquake physics, petrology and geochemistry, and volcanology), Earth systems and Earth surface processes (including geothermal processes, thermodynamics, geomorphology, geophysics, geochemistry, sedimentology, stratigraphy, paleontology, groundwater and hydrogeology). GNS Science also maintains a strong capability in science communication and engagement to ensure the societal elements of environment, risk, Earth system modelling are included so that our research is incorporated into management, planning and policy development.

Core facilities

GNS Science runs the 24/7 National Geohazards Monitoring Centre at the Avalon site which is enabled through the GeoNet network of monitoring instruments located across Aotearoa New Zealand. The National Isotope Centre (Gracefield site) is home to the Rafter Radiocarbon Laboratory and ion beam, accelerator mass spectrometer and standard mass spectrometer facilities. GNS Science hosts the National Ice Core facility at Gracefield. The World's most accurate tritium water dating laboratory is housed at the Avalon site to avoid contamination from stray particles. At our Wairakei Site, GNS Science runs the New Zealand Geothermal Analytical Laboratory. Across its sites, including Dunedin and Auckland, GNS Science is also host to Nationally Significant and important databases associated with the Earth sciences, Earth material and resources, and geohazards.

Left: On board the RV *Joides Resolution* drill ship examining drill cores recovered from the deep ocean offshore Aotearoa New Zealand: Credit John Callan, GNS Science
Middle: GNS Science Geodesy Specialist Neville Palmer works with Calum Chamberlain from Victoria University of Wellington to install temporary GPS equipment to monitor slow slip earthquakes on the Hikurangi Subduction Zone. Credit: Jeff Brass, GNS Science
Right: GNS Science's National Geohazards Monitoring Centre. Credit: Margaret Low, GNS Science

Left: Geodetic Scientists Neville Palmer and Laura Wallace deploying geophysical instruments from NIWA's Research Vessel *Tangaroa*. Credit: Emily Warren-Smith, GNS Science

Partnerships

GNS Science delivers significantly greater outcomes and outputs than the value of its contracts with the New Zealand Government through cofunding and access to international research infrastructure. Internationally, we have strong ties and ongoing collaboration agreements with national geological survey and Earth science research organisations[2]. We hold memberships in several international research initiatives and partnerships[3] which allows access to international resources normally beyond the capacity of New Zealand agencies. And, we have numerous collaborations with universities across Europe, the Americas, Asia and Africa that are research-project specific.

Within Aotearoa New Zealand, GNS Science's strong relationships enable us to deliver on our science themes. We work hard to ensure such collaborations are part of our culture – seeking to collaborate with CRIs and other partners whenever possible for mutual benefit and to improve the outcomes for Aotearoa New Zealand.

Some examples of collaboration include NIWA (through RiskScape™ National Environmental Data Science, climate and ice sheet modelling and marine geoscience), Te Herenga Waka Victoria University of Wellington (through the Joint Antarctic Research Institute and MacDiarmid Institute), University of Otago (in environmental geophysics, geodesy), Cawthron Insitute (in lake and environmental health), University of Canterbury (in disaster, risk and response), Waikato and Auckland universities (in coastal science) and through the New Zealand Groundwater Science and Research Alliance (including ESR, Aqualink, Lincoln Agritech and Māori).

> We work hard to ensure collaboration is part of our culture.

2 Including United States Geological Survey (USGS), Geoscience Australia, Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO), German Research Centre for Geosciences (GFZ), Italian National Institute of Geophysics and Volcanology (INGV), International Research Institute of Disaster Science (IRIDeS)

3 Such as International Ocean Discovery Program (IODP), International Continental Scientific Drilling Program (ICDP), Global Earthquake Model (GEM), Geothermal Energy Research and Development Company (GERD), Groundwater Modelling Decision Support Initiative (GMDSI), Global Alliance of Disaster Risk Institutes (GADRI), World Community of Geological Surveys (WCOGS)

Our ambition

By 2032, GNS Science aspires 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.

We aspire to be:

- An established advisor to Government, iwi and communities on the requirements to build resilience and develop sustainable approaches to Earth surface processes and systems. GNS Science will be the go-to CRI for understanding the geohazards that face New Zealanders, developing energy security, understanding the global capacity for change in Earth surface processes, groundwater and understanding the continent of Te Riu-a-Māui / Zealandia and the processes that shape and form it at depth, beneath our surrounding ocean and the landscape we live on. We expect to have lifted our influence through the development of strong relationships across the education, government and commercial sectors.
- A pre-eminent international partner – valued for our understanding of the capacity for global scale challenges where Aotearoa New Zealand can lead the global conversation.
- The employer of choice in the geological and nuclear sciences, recognised for our bicultural understanding and approaches under Te Tiriti. We will be proactive in supporting the growing needs of the sector and the value our research can contribute to growth including through the development of fit-for-purpose partnerships.
- Global leaders in understanding the natural Earth system and how to live with it. We will be valued for maintaining a long-term view in the development of geological and nuclear science research. Our approach will include all Aotearoa New Zealand and New Zealanders by upholding our responsibilities under Te Tiriti and we will be proactive in building resilience through the dissemination of knowledge to all parts of society.
- The public face of science and evidence for understanding, adapting to, mitigating, and building resilience to the challenges of the Natural World. We also expect to help empower people and communities to make sound and sustainable decisions concerning the environment and landscape. We will lead by example where change or action is in the best interest of Aotearoa New Zealand.

In order to achieve our ambition, GNS Science will need to:

ensure we have access to world class fit-for-purpose facilities for research (either through our own facilities or through resilient partnerships) and to develop a strong and fit-for-purpose pipeline of future employees. Financial sustainability is a prerequisite for a successful research organisation, as are modern infrastructure (building, computing and information) and a modern approach to workforce structure and support. We will need a clear picture of the value our organisation represents, develop partnerships for education knowledge sharing and communication to help tell our story and share our value.

In 2032, GNS Science will be successful if it achieves the following aspirations:

Externally facing
Widened respect for the knowledge and value that we generate in our research
Increased the degree to which society is empowered to live sustainably and resiliently
Developed a broader constituency in resilience – not just natural hazards, but also energy and environment
Ensured that the true and complete value of land and marine geoscience is understood and valued
Supported Aotearoa New Zealand to meet its commitments to international climate and hazard and risk agreements
Built robust and additive joint ventures with partners – (CRIs, universities, and commercial entitites)
Maintained the voice of our science in an alternative fact world
Developed research leadership across the sector
Translated and communicated our research findings to ensure they are useful, usable and used

Internally facing
Built modern facilities that are resilient, fit-for-purpose and world leading
Grown and expanded our science and research in our cross-theme areas – mātauranga Māori, social science and data science
Developed our talent pipeline and strengthened our leadership capabilities
Strengthened our industry sector partnerships to support needs across the low-carbon energy sector
Developed financial sustainability – tracking better financially to enable our vision and aspirations
Developed nimbleness, flexibility and agility in our workforce as priorities change and evolve
Replaced our aging buildings and infrastructure including computing infrastructure (either inhouse or through national supercomputers)
Continued to build enduring relationships with iwi /Māori and gain a better understanding of iwi aspirations and perspectives.
Embraced the opportunities afforded by big data and state-of-the-art analytical approaches

Ko te manu ka kai i te miro, nōna te ngahere.
Ko te manu ka kai i te mātauranga, nōna te ao.

The bird that partakes of the miro berry, reigns in the forest. The bird that partakes of knowledge, accesses the world.

3

Our challenges

Research challenges in the Earth science, Earth system and energy sectors

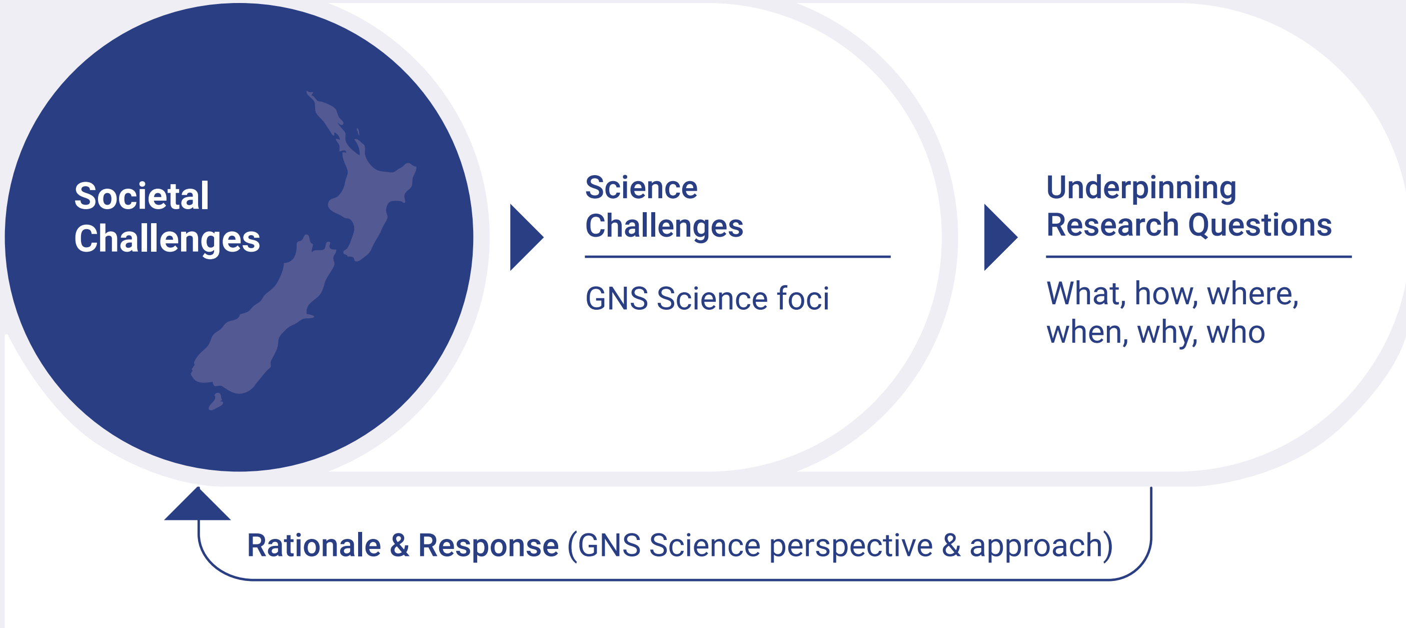
GNS Science is contributing to a 30-year vision for Aotearoa New Zealand aligned with Treasury's Living Standards Framework and UN Sustainable Development Goals.

Our contribution is to help Aotearoa New Zealand achieve:

- its long-term energy needs
- climate action (carbon net zero 2050)
- sustainable and resilient environments, ecosystems and societies
- security and protection of its freshwater
- economic growth in industries through innovation and the development of high-tech infrastructure

GNS Science's direction is defined by the required geological and nuclear science research to enable a cleaner, safer and more prosperous Aotearoa New Zealand. That is, a country more resilient to natural processes, a more sustainable environment and a better quality of life for all who live here. When mapped to the UN Sustainable Development Goals (SDGs), our science direction should contribute to SDGs 6, 7, 8, 9, 11, 13, 14 and 15.

Hierarchy of challenges and research questions in this roadmap



On the next few pages, we identify the high-level 10-year research challenges that will help define organisation direction, based on our four science themes, and underpinned by the respective theme plans.

Roadmap research challenges

Natural Hazards and Risks

SDG 8, 9, 11

Developing a better understanding of the complex physical processes that generate natural hazards

By 2032, we will have integrated physical and statistical models of how geological hazards work, through:

- better understanding of which physical variables control the timing, location and severity of natural hazard events, and learning to monitor and forecast those
- understanding the complexities of how natural hazards interact
- developing and sustaining GeoNet to deliver timely and accurate data, including onshore and offshore, citizen science, new and emerging technologies, and thinking beyond geological hazards

Developing and applying sustainable national hazard and risk models

By 2032, we will have fully integrated hazard and risk models for all geological hazards, through:

- improving our understanding and communication of uncertainty in long- and short-term forecasting for earthquakes, tsunami, volcanic eruptions and landslides
- understanding how the exposure and vulnerability of people, assets and the environment is changing
- recognising the impact of natural hazards on the communities of Aotearoa New Zealand in the face of environmental and demographic change
- integrating quantitative baseline and dynamic risk assessment across all hazards, including geological hazards, sea level rise, space weather and emerging threats
- identifying how future early warning systems for natural hazards could build on existing capability

Applying a people-centred, co-ordinated systems approach to national and regional resilience

By 2032, we will have communities at the centre of our research and all people in Aotearoa New Zealand will understand the risks they face and how to respond to them, through:

- working with communities to develop place-based resilience practices
- understanding how resilience supports wellbeing in the Living Standards Framework
- identifying the underlying systemic drivers of disproportionate risk

Top: Regular maintenance of the GeoNet monitoring network.
Credit: Marie Helliwell, GNS Science

Roadmap research challenges

Our Future Environment and Climate

SDG 6, 8, 13, 14, 15

Understanding the changing balance of ice and water on the planet

By 2032, we will have grown the resilience of Aotearoa New Zealand and the Southwest Pacific to rising sea levels, through:

- understanding ice sheet response to global warming
- predicting the rate, magnitude and impact of rising sea levels
- extending our reach to support our Pacific neighbours
- identifying shifts in coastal hazards and risks as they evolve with rising seas to inform a national coastal adaptation plan

Understanding the changing carbon cycle

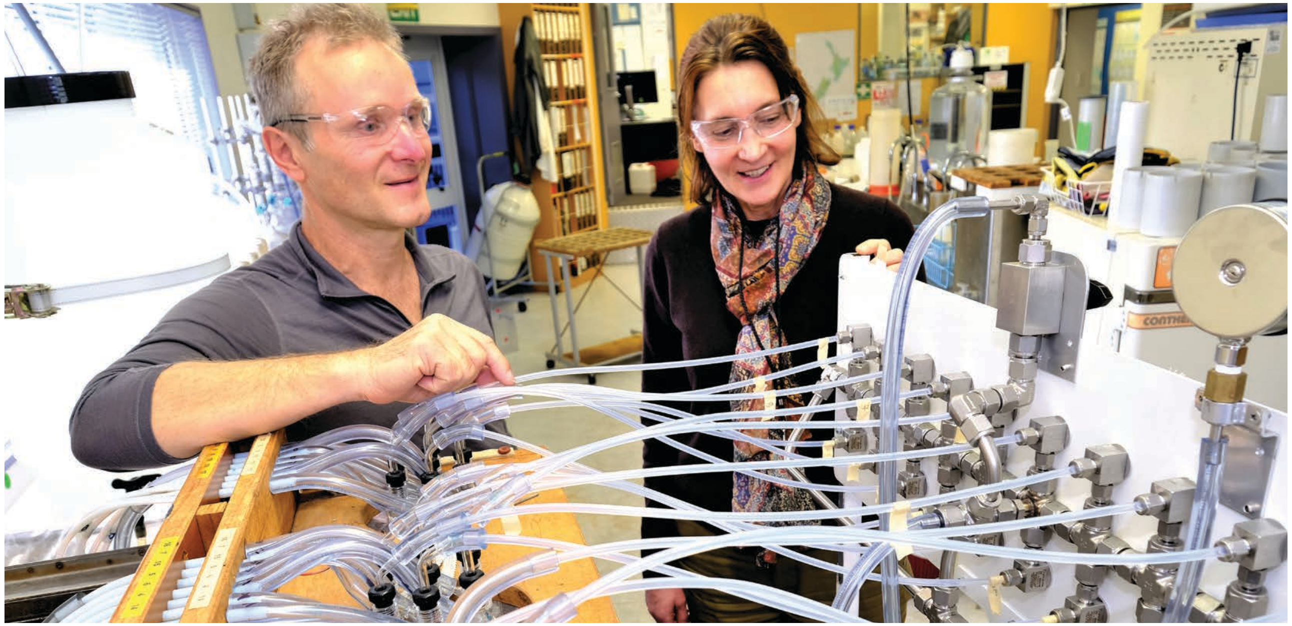
By 2032, we will have improved Aotearoa New Zealand's response to climate change, through:

- building a comprehensive understanding of the carbon uptake profile for the country
- modelling the response of the Earth system to changing atmospheric carbon concentrations
- monitoring and modelling our changing physical processes to reveal drivers of change

Supporting increasing need for clean groundwater

By 2032, we will have helped secure clean drinking water for all New Zealanders, through:

- building comprehensive groundwater maps and models for Aotearoa New Zealand
- developing our understanding of the current and future impacts of land-use change on drinking water quality and availability
- predicting system response to increasing use
- modelling the future impact of changing climate on groundwater



Left: Groundwater scientists Catherine Moore and Uwe Morgenstern in the Water Dating Lab, discussing isotope techniques for groundwater flow calibration. Credit: GNS Science

Roadmap research challenges

The Future Energy Need for New Zealand

SDG 7, 8, 9, 11, 13

Left: Geothermal Geologist Isabelle Chambefort examines pumice samples before placing them in a flow reactor to simulate geothermal reservoir conditions. Credit GNS Science

Building a low-carbon energy ecosystem for Aotearoa New Zealand

By 2032, we will have supported Aotearoa New Zealand's transition to low-carbon energy sources, through supporting commercial partners to:

- double the generation of green electricity production with significant contributions from geothermal and hydrogen energy
- increase the availability of direct geothermal to replace coal, gas and electricity use
- increase the energy storage potential through large scale environmental storage and materials development
- reduce the carbon cost of traditional energy sources through the transition

Developing scientific leadership in Energy Futures (in partnership with the sector)

By 2032, we will have supported the wider energy sector to secure our country's future energy needs through:

- supporting the government to build an energy strategy (including electricity, heat and transport)
- supporting the sector to transform energy production, supply sources and models
- developing a world observatory for energy resources distribution and storage potential
- building collaborative linkages across the Earth sciences, materials, engineering, production, transmission and conservation sectors

Roadmap research challenges

Land and Marine Geoscience

SDG 6, 7, 11, 13, 14

Better defining the processes that shape Te Riu-a-Māui / Zealandia and impact New Zealanders

BY 2032, we will have supported Aotearoa New Zealand's development of long-term resilience to natural hazards and prosperity from natural resources through:

- refining our knowledge of the underlying processes associated with plate boundary hazards to improve resilience to earthquakes, tsunami, volcanic eruptions and landslides
- developing models that show how heat and magma are generated to improve understanding of how renewable geothermal energy can be utilised
- quantifying how critical elements and materials are distributed in the subsurface through building new workflows for resource assessment.
- refining our understanding of surface processes in coastal and urban environments through integrated geological, geochemical, and geophysical investigations to inform modelling of sedimentation and erosion.
- refining the geological timescale and age control of past climate events to improve understanding of the rates and scale of change and climate impacts
- increasing the knowledge about our continent, Te Riu-a-Māui / Zealandia
- valuing mātauranga Māori, embodied in part through our databases, samples and collections, alongside understanding of the geological processes that shape Te Riu-a-Māui / Zealandia [as well as enriching Māori and Pasifika narratives of exploration and discovery]
- partnering with stakeholder, iwi, national and international organisations, especially IODP and ICDP to enhance understanding of global-scale environmental change, variability and impacts and improve forecasting capability for hazards and disasters

Left: The scientific drilling Research Vessel *JOIDES Resolution* is used by GNS Science through participation in the International Ocean Discovery Program (IODP). Credit: Carlos Alvarez Zarikian, IODP

Key underpinning research questions

These are sector-wide research questions that are important for GNS Science research to address. Many will include collaborative links to other research organisations across the science system.

Managing our risk

Research question	Rationale and perspective
How can we better integrate physical and statistical models to understand Earth systems, processes and the likelihood of future geohazard events?	Different methods of understanding how the Earth works include building empirical, conceptual, statistical or theoretical models of processes occurring within the crust. If we can holistically combine the range of approaches, we will be able to more rigorously test and develop new hypotheses about those system processes, reduce uncertainty in hazard models and target research to fill gaps in our understanding.
How can we better assess and communicate uncertainty associated with subsurface processes to help us understand how the Earth works?	Traditionally, we have tended to estimate likelihood of occurrence of future events as a “single number”, without fully accounting for both epistemic (lack of knowledge or data relating to the process) and aleatory (randomness of process) uncertainty. This is particularly acute when we are observing data from surface sensors, which we then use to infer processes that are occurring in the subsurface – whether it is groundwater flow, magmatic degassing or stress build up before an earthquake. In some areas of science, we are increasingly able to incorporate uncertainty into model outputs, but this then presents challenges on how to communicate the range of outcomes and ultimately how these can be translated into science advice, practice and policy.

How do we develop model-informed monitoring and future-focussed data acquisition networks across all our hazards, environment and energy risks?	GeoNet is nationally critical infrastructure though not everyone recognises it as such yet. Expectations of levels of service and performance have risen as capabilities have increased and technology has advanced making continued support for GeoNet crucial. How can we extend the concept of national real-time baseline data collection to other environmental indicators such as how our landscapes change dynamically or how groundwater resources respond to climate change? How do we use our science to inform the development of new sensor networks, use of innovative technologies and real-time data analysis tools to inform decision-making?
How can we better detect and forecast tsunami generated from any source (earthquakes, submarine landslides, tsunami earthquakes or volcanic events) and provide timely, accurate advice regarding tsunami hazards to NEMA?	We have made strides over recent years to develop detection capability for tsunami generated by large offshore earthquakes; however, the network is still sparse and difficult to maintain. Our ability to detect submarine landslides which could generate tsunami at our coastlines with very limited warning times is non-existent. What is the potential for large, damaging tsunami from submarine landslides and volcanic edifice collapse and how can we harness new technologies and data analysis techniques to enable early detection of tsunami from all sources?
How do we read and interpret the dynamic signals associated with active volcanoes?	Volcanoes present us with some unique challenges in interpreting complex, chaotic geophysical systems. Our brief monitoring snapshot of their unrest history offers some glimpses of insight into how magma is generated, moves through the crust and interacts with geothermal systems on its way to the surface. As new monitoring technologies, models and data analysis techniques emerge, we need to constantly revise our hypotheses so we can increase our ability to forecast future eruptions.
How can we progress from monitoring natural hazards to forecasting their impacts, in both the long and short terms?	Natural hazard risk is dynamic. Currently, GeoNet enables us to constantly monitor for changes in baseline data so we can provide advice on likelihood of current and future hazards. However, stakeholders and end users really need an answer to the question "what does it mean to me"? This requires Aotearoa New Zealand to move towards forecasting the impacts of hazards events on people, infrastructure and the environment, both in the short term to inform response and recovery actions and in the long term to support targeted risk reduction measures such as land use planning.
How will climate change and societal changes affect natural hazard and risk profiles and influence the wellbeing of our communities and how do we adapt to or mitigate those risks?	Climate change is clearly influencing the frequency and severity of extreme weather events and associated geological hazards. Coupled with sea level rise, demographic changes and geopolitical changes, the exposure and vulnerability of communities, infrastructure and our economy to natural hazards shocks and stresses will evolve. Our challenge is to understand the interplay of these complex changes, develop dynamic risk models (with uncertainty) and propose innovative risk management solutions.
How can we contribute to the acceptable risk discussion for Aotearoa New Zealand and New Zealanders?	Increasingly the vernacular of "risk reduction" is being used across society and is being enshrined in legislation, such as resource management reform, emergency management and health and safety law. However, there is no shared understanding of how to assess risk and what can be considered acceptable or tolerable risk. Risk metrics are often ill-defined, and the governance of risk is ambiguous. Government has noted the need to have a national conversation about the risks we face and how best to mitigate them. Our science can help to guide that conversation and provide the evidence base for communities to make good risk management choices.

Our evolving environment and climate system

How can we project the impact of changing environmental systems on the future of urban environments, coastal zones and coastal systems?	Sea level is rising and will affect our coastal environments and communities. To enhance our resilience to unavoidable change we need to improve certainty in sea level projections, evaluate how sea level rise will affect our coastal environments and communities, and establish culturally appropriate mechanisms and plans to adapt.
How do we integrate understanding of the broader carbon cycle into Aotearoa New Zealand's approach and response to climate change?	There is a critical need to achieve net zero atmospheric carbon emissions by 2050 to avoid a dangerous increase in global mean surface temperature > 2°C above pre-industrial levels. Transition from fossil fuels as an energy source is key, but we must also avoid actions that turn our natural carbon sinks into a source. Furthermore, we need to identify parts of our carbon system that can be used to sequester and store carbon as we strive to remove excess CO_2 from the air.
How will the Antarctic Ice Sheet respond to changing climate and how will change in the deep south affect Aotearoa?	Antarctic ice sheet melt is accelerating but estimates of the rate and amount of future ice mass loss remain uncertain. Meltwater from Antarctica contributes to sea level rise and freshens the ocean surface. These Antarctic-driven ocean changes will affect our coastal systems, ocean productivity, and our climate. Therefore, reducing uncertainty in future Antarctic Ice Sheet response to climate change is needed to enhance our ability to forecast and adapt to global change.
How will changing land-use and climate affect our groundwater systems and impact freshwater security?	Freshwater security is key to our health and economy. Access to a reliable and safe supply of freshwater is fundamental to our survival. Aotearoa New Zealand relies on high-quality freshwater stored in our underground aquifers and climate change will impact this critical resource. Rising seas can cause coastal aquifers to become salty and changes in rainfall will affect recharge with potential impact across the system. While we work to better quantify and evaluate our underground water systems today, we must assess the potential impact of changing land-use and climate change on our critical groundwater resource.
What is the equilibrium response of our climate and ocean system at decadal to intergenerational timescales?	Aotearoa New Zealand is a maritime nation. Our ocean systems exert significant control over our regional climate, support our economy, and provide a key recreational resource. Our climate is also strongly influenced by shifts in the strength and position of the westerly winds. Future changes in ocean temperature will affect climate and ocean primary productivity species diversity. Longer-term changes in ocean and atmospheric circulation will affect our climate but large uncertainties exist. We must use information from the past and present to better project change as our climate evolves to a 'new' equilibrium under higher than pre-industrial atmospheric CO_2.

Powering Aotearoa New Zealand

How can we define the true environmental impact of energy generation?	Energy generation in Aotearoa New Zealand has a history of significant environmental impacts. As the country seeks to replace fossil fuels in the energy mix, new energy developments will be required. It is important that we understand the full consequences of these developments, including the full life-cycle of emissions, changes to land, biosystems, communities and natural systems such as the carbon cycle.
How can we identify, define the scale of, and define the producibility of new energy sources?	To reduce carbon emissions from the energy sector the country needs to replace fossil fuels which currently account for 60% of our energy use. Aotearoa New Zealand needs to identify the location and sustainable capacity of new energy sources that can supply more than 500 PJ each year.
How can we use natural Earth systems and new materials to store energy?	As the country moves to higher levels of renewable energy generation, issues with intermittency will increase. These are both short term (hourly timescale) and long term (yearly timescale). Large scale energy storage is the most practical solution. Current options are expensive and lack flexibility, so there is a need to look for new opportunities.
How can we define the resilience of new energy systems?	Energy powers the economy and underpins the wellbeing of communities. It is vital that the energy ecosystem is reliable, delivering energy as needed. In the future, climate change may alter the standards that a new energy system has to meet – demand requirements, engineering specifications etc. There is a need to develop methods for assessing the resilience of new energy developments.
How can we cost-effectively produce green hydrogen at scale?	If green hydrogen is to become a viable fuel to replace petroleum the production costs need to fall by 80% by 2050 (Japan's current target). This will require reductions in capital and operational costs. Scale will provide some of the this, but new technologies will also be needed to meet this target.
How do we encourage transition from an energy system designed around petroleum, gas and coal to a distributed green energy system?	Aotearoa New Zealand has set targets to reduce fossil fuel use since the early 1990s, but progress has fallen short of the goals. Understanding the barriers to moving to a post-petroleum world and formulating responses to overcome them will play a key role in the transition.

How can we modify surfaces at the molecular scale to deliver new clean energy technologies?	Recent international analyses suggest that the path to a zero-carbon energy future will require technologies that are not available today. Functional material made through modifications at the molecular level will be part of a new industrial revolution. Applying this to energy applications offers the opportunity for new disruptive clean energy technologies.
Is it possible to reverse the impact of long-term fossil fuel use on our future climate trajectory?	The International Energy Agency is engaging in carbon capture, utilisation and storage as an important emissions reduction technology that can be applied across the energy system. Direct applications here include capturing CO_2 directly from geothermal production. Negative emission actions are also being considered such as capture from bio-based processes and from the atmosphere (likely by restoring natural carbon sink processes) to address the current commitments already made from past fossil fuel burning, forest clearing and environment degradation.

Defining our geological setting and geological processes

What are the physical properties of the lithosphere and how do they evolve and affect seismicity and heat flow in Aotearoa New Zealand?	Rock measurements, geophysical imaging and modelling will improve constraints on fault geometry, seismogenic depth, earthquake location and source mechanism parameters for hazard and risk assessment. Better understanding of crustal structure, rheology, fluid pressure, and thermal processes will support new opportunities for use of moderate to low enthalpy geothermal energy and resource potential of critical elements.
What role do Earth surface and sea floor processes play in defining the changing dynamic of Aotearoa New Zealand's landmass?	Improving our ability to measure and model surface processes across land, coastal, and marine settings will provide essential insight into the changing environments. Our data and models lead to improve land and marine management, safer infrastructure and risk planning that enhance the effectiveness of Aotearoa New Zealand's response to hazards and climate change.
How can Aotearoa New Zealand sustainably access and use our critical elements and geological materials to secure essential resource supplies and reduce carbon emissions?	Increasing understanding and distribution of critical elements and geological material in Aotearoa New Zealand, including minerals and rock aggregates, is critical to addressing supply issues of low-carbon technologies, contributing to major infrastructural development and reducing associated carbon emissions.
How do volcanism and geothermal systems in Aotearoa New Zealand link to magma, heat production, and crustal fluid circulation?	Measuring and modelling connections among magma generation, storage, transport and fluid interaction are necessary to understand the controls of geothermal systems. Knowing the links between tectonism, volcanism and geothermal systems in Aotearoa New Zealand improves volcanic hazard assessment for risk models and enhances geothermal resource potential and management.

Why, when and where do large plate boundary earthquakes happen?	Anticipating the timing and location of major earthquakes requires a fundamental understanding of the physics controlling earthquake generation, slow slip, and fault creep, and their underlying connection to plate motion. Integrating a range of geophysical, geological, and geochemical observations enables more reliable forecasts and assessments of the risks to vulnerable populations and infrastructure posed by rupture on major faults and tsunamis leading to improved hazard preparedness and response.
How are stress and strain distributed across the New Zealand plate boundary?	Mapping the details of crustal deformation measured at the surface is important for determining which faults are most likely to produce earthquakes. Refining our knowledge of the underlying processes associated with fault slip behaviour will improve resilience to earthquakes, tsunami and volcanic eruptions.
What does our past reveal about Aotearoa New Zealand biodiversity and the dynamics of the climate system?	Research on the impacts of future climate changes is aided by understanding how the tectonic and climatic evolution of Te Riu-a-Māui / Zealandia has affected marine and terrestrial biological and physical systems in the past. Knowledge gained from examining past archives will inform society about the rates of change and irreversibility of some Earth system processes and inform assessment of mitigation and adaptation measures.
How does earthquake motion propagate along and across multi-segment and multi-fault structures?	The understanding of earthquake forecasting is built on rupture physics and simulated earthquake interaction informed by geological, geodetic and seismic observations of properties and frequency of multi-segment and multi-fault ruptures. Combining knowledge of earthquake phenomena through system-level, physics-based modelling and communicating understanding of seismic hazards will help reduce earthquake risk and promote community resilience.
How will the natural and built environments respond to strong shaking, from large earthquakes?	Modelling how the natural and built environments respond to strong earthquake shaking will be informed by analysing ground motion data and developing simulations and models that emulate observations. Refining ground-motion simulations will enhance probabilistic seismic hazard and risk analysis and lead to improved infrastructure performance and better-informed loss modelling to ensure Aotearoa New Zealand can recover more quickly from major events.

Engaging with society

How can we apply our developing research understanding to anticipating and defining the challenges faced by our Pacific partners from climate change?	Aotearoa New Zealand aspires to build deeper, more mature partnerships with our Pacific Island neighbours through ensuring that Government decision-making on domestic issues considers the implications for the Pacific Island region. Climate change, hazards, resilience, and energy security are also priorities for our Pacific partners, and they have lower levels of resilience than Aotearoa New Zealand requiring a consideration of Pacific-wide Earth system and Earth surface processes.
How does geological understanding inform mātauranga and kaitiakitanga of the Te Riu-a-Māui / Zealandia continent	Knowledge of our continent, Te Riu-a-Māui / Zealandia has enduring value. Mātauranga, embodied through our databases, collections and analysis of taonga, inform geological processes that shape Te Riu-a-Māui / Zealandia as well as enriching Māori and Pasifika narratives of exploration and discovery.
What is the natural state we are trying to manage to? (pre-human? Te Ao Māori world view? partially impacted?)	We are facing rapid changes in climate, ocean circulation, groundwater and Earth surface processes, but these are occurring on the backdrop of a natural climate cyclicity and with a complexity of thresholds of change. We need to engage with Māori and across society to determine whether we wish to restore our climate and environment to pre-industrial and pre-settlement levels or mitigate the worst impacts. If the latter, then we need to determine what are the worst impacts for our multicultural society and develop a clearer understanding of the future projections of those.
How do we incorporate Earth science into societal planning?	Decision-making is often undertaken in a linear fashion, yet Earth science is a complex set of interactions, processes and feedbacks that do not conform well to linear decision-making. The more we can incorporate system science into our decision-making, the more impactful our management decisions and approaches will be.
How do we ensure social licence for Earth science and Earth surface process research?	Improved social licence will ensure Earth systems will be incorporated earlier into decision-making and planning, which will enable us to build a more resilient society in the long-term. Social licence, however, varies across society and engaging with Māori, iwi, Government, and industry is a prerequisite.

What is society's tolerance for risk and how does this vary across society?	Often this is litigated after the fact rather than negotiated in advance of an event. Negotiating and understanding across society and with a more holistic understanding of Earth processes and systems will ensure a better prepared and more resilient society.
What is the role of science in emergency management?	Societal and government value of scientific data and understanding is growing, yet the pathways for incorporating data and science into decision-making are not clear, and roles and responsibilities are not well understood. Decision-makers need to be able to make critical calls that require a yes/no answer, yet science rarely provides this level of certainty, especially where the research is not mature or is not settled. Narrowing and clarifying the uncertainty, the ability to communicate uncertainty and an open dialogue between science and responding agencies will help with the incorporation of scientific findings into decision-making and planning.


He waka eke noa
We are all in this together

Our Response

4

Natural Hazards and Risks

Environment and Climate

Energy Futures

Land and Marine Geoscience

Our research effort is focussed into four science themes underpinned by research plans linking our current science and research with future direction and identifying specific research steps and requirements.

Delivering future focussed research outcomes for Aotearoa New Zealand will require considerable change across GNS Science. This includes the science team, research leadership, infrastructure (buildings, network, monitoring and computing), laboratory and analytical facilities, capability, workforce structure and alignment, financial sustainability, and communication and engagement ability.

Science team

GNS Science's future research will continue to be heavily reliant on improving our fundamental understanding of Te Riu-a-Māui / Zealandia. We expect to transform our capability in offshore geology and geophysics so we can continue to develop a comprehensive understanding of the entire continent of Te Riu-a-Māui / Zealandia. This, in turn, will foster a more holistic understanding of the natural Earth system processes that will shape Aotearoa New Zealand's future. Maintaining core capability in Earth system science will ensure our country is well placed to realise the opportunities for future energy production and storage as well as Earth material suitability and availability for infrastructure.

The demand for forecasting and response in geoscience will continue to grow, particularly our ability to decipher non-linear response in complex and diverse systems. Understanding of the time component of Earth systems is critical and we will need to build our modelling, analytical and data science capability across the organisation to help address this. Sustainable and maintainable data driven science will be heavily reliant on data infrastructure, data science and data management specialists. Collection of new observations and data sets will continue to be required in order to better define the Earth system processes we are attempting to explain and forecast.

Our technical expertise will also need to grow as we will also require greater ability to develop science specific software and analytical products.

Working with wider society to build the required understanding of the Earth system in order to build resilience, reduce impact and manage response will require increasing diversity and mobility in our workforce in order to broaden the knowledge base within the organisation.

Building our Māori science base will also be vital to ensuring we are able to uphold the principles of Te Tiriti. Increasing our Māori researcher capacity and capability is an important goal for the organisation.

We need to develop leadership in our science, research and technical staff as well as diversity in our workforce. We want our workforce to embody a culture that is innovative, agile and adaptive.

Infrastructure

GNS Science's current facilities in Wairakei and Wellington (Avalon and Gracefield) are old and no longer fit-for-purpose. Challenges include outdated and insufficient laboratory and analytical facilities that are at the end of their service life, compromised containment of hazardous materials at our Gracefield site and business continuity risks to the National Geohazards Monitoring Centre at Avalon.

GNS Science needs contemporary facilities to enable the delivery of great science outcomes, to minimise health and safety risks to our staff and support their wellness, to create connection both internally and externally, and to bring our people together under a one GNS Science vision. We need facilities that enable connection, collaboration and innovation. We are committed to working closely with others in the science system and Government to ensure the best Aotearoa New Zealand-wide outcome for the research we need to undertake to address the science challenges we face as a nation.

Our specialist laboratory facilities and technical expertise will be critical to our future success. Cutting edge experimental and technical methods and approaches are required to advance our research. It is what distinguishes us from commercial entities. Specific requirements will evolve over the next decade, but we will require newer and safer buildings, capex investment and technical experts to run experimental equipment. Our collections will also continue to be important for geological research, especially research involving the offshore environment. Greater analytical capability and access to high performance computing (HPC) will also assist us in helping develop greater resilience across Aotearoa New Zealand society.

Top: The National Core Store in Featherston houses tens-of-thousands of drill core samples and is managed by GNS Science on behalf of MBIE. Credit: Kyle Bland, GNS Science

We have identified the following strategic responses that will require focus over the next decade to ensure GNS Science is fit-for-purpose and able to deliver the projected research needs in 2032:

Research leadership

Outcomes	Out-takes
Ensure strong linkages across our research effort and alignment with our strategic direction	• Continue to build the research direction under the guidance and direction of our Science Themes • Strengthen our cross-theme science and research programmes to ensure our research is linked to societal demographic and need • Ensure our SSIF contract is agile and able to pivot and develop the capability our strategic direction requires • Grow our ability to commercialise and build value in our intellectual property • Clarify our role in science sector initiatives (lead-contribute-support-mentor)
Pilot engagement programmes that demonstrate how our research can have impact	• Grow our ability either directly or through collaboration to build protype solutions from our research • Model the responses that need to be adopted by the sector (e.g. carbon management, alternative energy, hazard and risk response) • Grow our engagement across the sector to help build cross-sector uptake of our research

Partnerships

Build and maintain strong research partnerships and collaborations along the full value chain	• International partnerships ensure research excellence of the highest standard and access to facilities and resources beyond GNS Science's and our country's means • Ensure our university partnerships support a strong pipeline of future employees • Industry partnerships ensure fit-for-Aotearoa New Zealand research aims, direction and results • CRI collaborations ensure a strong science system • All are built from shared research initiatives through joint funding and joint appointments
Build and maintain rewarding and productive relationships with iwi and Māori	• Te ao Māori provides a vital link between geological processes, natural environmental systems and societal engagement. Growing the inclusion of Māori and iwi in our research and building codesign and alignment of research effort will be fundamental to Aotearoa New Zealand's future society • Enduring partnerships ensure we can provide clear advice and support from our experience and expertise

Infrastructure and facilities

Ensure our infrastructure is state-of-the-art, fit-for-purpose, resilient, as well as environmentally and financially sustainable	• Ensure our infrastructure is able to be responsive to changing needs and support interagency collaboration • Ensure our facilities exemplify our research purpose • Complete masterplans for our campuses and business cases for new buildings • Develop partnerships with other agencies to grow our national footprint and collaborative approach • Develop an asset management plan for GNS Science facilities and equipment
Ensure GNS Science can capitalise on its information and technologies to deliver improved research and commercial outcomes and provide new insights from our databases	• Develop and implement an enduring science data and collections strategy, which identifies the critical and high value data sets for GNS Science • Lift our data science and computational capacity and capabilities across GNS Science • Embrace new technology and develop data-intensive computing and software tools

Build and maintain state-of-the-art analytical laboratory, field and remote sensing facilities that generate time sensitive data to underpin our Earth system model development	• Aotearoa New Zealand often relies on international advancements in analytical and technological capability which means we must adhere to international priorities and timeframes • We need to lead technological advances in key areas for Aotearoa New Zealand Earth sciences • We also need to ramp up our ability to conduct more rapid and more frequent analyses
Instrument and develop data acquisition networks for the combined Aotearoa New Zealand terrestrial and marine Earth systems	• Aotearoa New Zealand and Te-Riu-a-Maui / Zealandia is our natural laboratory, but we need to transition our effort from mostly forensic to measuring, modelling and reporting change in real-time • The instrumentation network, supporting systems and infrastructure need to reflect the depth and breadth of the perils and hazards we are trying to understand • We need to increase our ability to measure and monitor offshore phenomena

Capability

Build a fully integrated social science (economic, psycho-sociology, planning) strand to all our work	• Recognising that people are central to our research is vital and will ensure impact from and uptake of our research findings • Integrate social science into each of our Science Theme and programme plans • Develop a social science awareness programme across GNS Science
Increase our ability to develop and scale Earth monitoring and energy products in order to move us to a more authoritative position as a partner to stakeholders	• Build data model integration into each of our research programmes • Increase the cross-disciplinary value of our research • Lift numerical capability across our programmes as well as geometric understanding
Increase our ability to work beyond the Aotearoa New Zealand coastline as many of the Earth system processes we work on lie offshore but impact onshore (e.g. earthquake, tsunami, coastal erosion)	• Much of the hazard and peril Aotearoa New Zealand faces originates offshore, through marine processes, marine geological processes, from Antarctica, through changing global climate, and rising sea levels • Increasing our ability to conduct marine geological expeditions • Increasing our access to marine geological and geophysical data sets

Increase our ability to leverage our data sets and engage in big data and data science	• Increase our data accessibility • Increase our access to High Performance Computing • Build a more direct link between our research programmes, monitoring processes and data analysis • Invest in programmes of research that generate value from our existing data sets • Ensure our data provisions parallel our research direction • Increase our use of high density satellite derived data sets
Increase our ability to image and map beyond the visible	• Our geophysical capability is very limited compared to most OECD countries. We have relied on oil industry partnerships to generate data sets of the subsurface • Our needs have changed to include more near subsurface and sea floor geology and hydrogeology, and we need to build such capability and capacity • Greater opportunity and coverage will be available from satellite derived data sets
Increase capacity and capability of Māori research and Māori researchers	• Develop a recruitment programme that is attractive to and reflective of the Aotearoa New Zealand demography • Incorporate Māori and iwi interests into our research programmes

Engagement

Develop a robust and integrated programme of engagement that increases our knowledge transfer ability (building on GeoNet and RiskScape™)	• Model our expected response to the findings of our research and share those stories widely • Increase the availability of real time information and data about our changing World, Earth surface change, geohazard events, climate indicators • Build a programme of stakeholder engagement that supports uptake and use of research data and findings to ensure our research is fit-for-purpose • Engage our key stakeholders in programmes of learning and sharing
Transform and grow our position as the national Energy CRI	• Provide examples of applications of new energies • Model low-carbon approaches to energy • Build industry partners to realise the full value chain for energy • Run appropriate think tanks to move the energy sector beyond petroleum

Organisational support

Ensure GNS Science has the financial capability to meet its strategic science aspirations	• Budget appropriate margin to support infrastructure, capital equipment and capability for future research pathways • Implement enterprise-wide system, processing and reporting to help develop our future capability need • Costing review and analysis to ensure we can invest appropriately in our research needs • Improve our ability to provide timely legal support for research contracting
Ensure our workforce understands and delivers to shareholder and stakeholder expectations	• Ensure our workforce demonstrates strong ownership of outcomes and a commitment to a shared vision. • Build our workforce to reflect the diversity of society • Deliberately recognise both breadth and depth as desirable attributes • Value a diversity of views and approaches in building our science and research teams • Increase our focus on developing good collaborations and attracting people who can work across industry, iwi and international partnerships
Develop high-functioning teams and teamwork	• Ensure our workforce is aligned to our strategy and we have the capability needed to fulfil future need • Ensure our leaders are capable and confident, trusted, connected, empowered, and adaptable • Develop and support a range of career pathways through the organisation • Recognise and reward high performance and the demonstration of GNS Science values

People are central to our research. Strong partnerships across the sector and with stakeholders will ensure impact from and uptake of our research findings.


Whāia e koe te iti kahurangi ki te tūohu koe, me he maunga teitei
Pursue excellence – should you stumble, let it be to a lofty mountain.

5

Our projected impact

By 2032, GNS Science expects to be part of a high performing research sector across the Crown Research Institutes, independent research organisations, government departments and universities delivering research that will have real impact in our core mission areas.

The primary aim will be to lead sector-wide, mission-directed approaches to prepare Aotearoa New Zealand for challenges from changing climate, significantly contribute to our changing energy profile to meet a low-carbon future, all while helping build resilience and reduce risk associated with geohazards.

Right: Seismologist Emily Warren-Smith deploys portable seismographs at remote locations across Aotearoa New Zealand to determine the sources and magnitude of earthquakes.
Credit GNS Science

Over the next 10 years, GNS Science will play a major role in helping Aotearoa New Zealand achieve the following:

Energy

Aotearoa New Zealand will be implementing a robust plan to transition from a predominantly imported fossil fuel reliant energy sector to a locally produced low-carbon emission energy sector. Currently, Aotearoa New Zealand imports $4.6 billion in oil, spends $700 million on Natural Gas, and burns more than 4 million tonnes of coal (Seventy percent of our energy needs are imported is imported at a cost of close to $1 billion[4]). The transition to locally produced low-carbon energy will bring more than $5 billion back into the Aotearoa New Zealand economy by 2032 and reduce our annual energy emissions by up to 30 million tonnes (40% of Aotearoa New Zealand's total emissions at an ETS value of more than $1 billion).[5]

To achieve this, and ensure resilience, our electricity sector will need to have installed an additional low emission base generation capacity of more than 1TW in addition to grid scale battery storage of 3 million MWh to manage seasonal variability in hydro generation and intermittency of wind generation.[6]

Top: Wairakei power station. Credit: Jeff Brass, GNS Science

4 Energy in New Zealand 2020, Ministry of Business, Innovation and Employment
5 Ināia tonu nei: a low emissions future for Aotearoa, Climate Change Commission
6 Te Mauri Hiko Energy Futures White Paper 2018, Transpower

Top: Damage to railway lines caused by the 2016 Kaikōura Earthquake. Credit: Steve Lawson, GNS Science

Hazard and risk

Aotearoa New Zealand will be more resilient to a significant geohazard event through a range of planning, regulatory, and education measures, improved response, and improved forecasting of scale and breadth of impact. Combined, these measures have the potential to save hundreds to tens of thousands of lives and reduce economic shock by one billion to hundreds of billions of dollars.

The 2010/11 Canterbury earthquakes (M7.1, M6.2) resulted in 185 deaths, 460,000 people directly affected, over 150,000 homes damaged (75% of homes in the region), including 30,000 seriously.[7] The direct cost of the rebuild is estimated at greater than $20 billion.[8] The almost contemporaneous and much larger Tohoku, Japan earthquake (M9.1) and tsunami affected about the same number of people, 400,000, but resulted in over 15,000 deaths, 300,000 buildings partially or totally destroyed, and 600,000 buildings damaged. The economic damage was estimated as being over US $200 billion.[7] The eruption at Whakaari/White Island in 2019 resulted in 22 deaths and 30 injured and significant indirect impact on the region's economy.[9] Aotearoa New Zealand has a number of active volcanoes closer to people and infrastructure, including our biggest city, Auckland.

Environment and climate

Aotearoa New Zealand will better understand the connectivity of environmental systems and be able to minimise the impact of our activities and actions and adapt effectively to our changing environment. Understanding the carbon cycle will ensure that our activities and actions result in reduced global levels of CO_2 in the atmosphere. Aotearoa New Zealand's CO_2 emissions are likely to have an ETS value of $2 billion by 2032[10] but this may be difficult to realise unless the carbon cycle and net change in emissions from all natural sources and sinks are accounted for.

The value of clean groundwater to the Aotearoa New Zealand economy was valued at $35 billion in 2018.[11] By 2032, we will better know the distribution of groundwater and the time lag from land use impacts. A significant proportion will be impacted by rising sea levels and saline incursion. A 0.5m rise in sea level could put roading, the three waters and buildings infrastructure (excluding individual homes) valued at $2.7 billion at risk.[12] Currently, more than a quarter of a million (5% of the population) New Zealanders live within 1-metre of sea level and will be displaced and suffer economic losses from rising sea level and associated impacts (e.g. increased inundation frequency). The risk associated with evolving coastal hazards is not linear and will increase exponentially with greater sea level rise. Direct climate impacts are likely to cost a further $1 billion annually and the average annual cost of climate change to our Pacific neighbours is likely to exceed $500 million.[13]

7 Reserve Bank of New Zealand Bulletin, vol. 75, 2012
8 Parliamentary Library Research Paper, Dec. 2011
9 Stuff, 22 Mar. 2
10 Ināia tonu nei: a low emissions future for Aotearoa, Climate Change Commission
11 NIWA Report for Horizons Regional Council, June 2018
12 Local Government New Zealand Annual Report 2019/20
13 Asian Development Bank Article November 2013

Kaitiakitanga

While it is difficult to place a monetary value on the land that sustains our nation under Te Tiriti, it is vital that the potential resources, energy, environments, hazards and origin of Te Riu a Māui / Zealandia are valued, understood, respected, protected and restored. Developing a deep knowledge and understanding of our environment together with iwi/Maori partners is essential. A comprehensive plan to monitor our changing environment, including its lakes, groundwater resources, urban and coastal environments, changing climate, terrestrial and marine biodiversity in the context of pre-settlement natural systems is vital to understanding how current and future generations can live sustainably and resiliently in Aotearoa New Zealand.

Top: Palaeontologist Joe Prebble works with tamariki to collect a sediment core during a Geo Noho wānanga in Northland.
Credit: Jess Hillman, GNS Science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