Aggregate supply and demand in New Zealand

August 2022

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Waka Kotahi NZ Transport Agency research report 693

Contracted research organisation – University of Auckland in collaboration with WSP

WAKA KOTAHI NZ TRANSPORT AGENCY

New Zealand Government

ISBN 978-1-99-004473-1 (electronic)
ISSN 2815-8377 (electronic)

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Wilson, D., Sharp, B., Sheng, M. S., Sreenivasan, A., Kieu, M., & Ivory, V. (2022). *Aggregate supply and demand in New Zealand* (Waka Kotahi NZ Transport Agency research report 693).

University of Auckland, in collaboration with WSP, was contracted by Waka Kotahi NZ Transport Agency in 2020 to carry out this research.

Keywords: aggregates, demand, econometric model, land transport infrastructure, roads, resource use, supply, sustainability

An important note for the reader

Acknowledgements

The project team would like to acknowledge the Project Steering Group (Christine Moore, Sharon Atkins, Tim Journeaux, Adam Leslie, Wayne Scott, Cathy Bebelman) and the help of various other staff members of Waka Kotahi (Lonnie Dalziel, Rob Napier), the Horizons Regional Council (Ramon Strong and Michaela Rose), Stantec (Jamie Povall and Ken Clapworthy), Auckland Transport (Peter Scott and Murray Burt), EROAD (Gareth Robins) and the Aggregate & Quarry Association of New Zealand (AQA – Mike Chilton). Appreciation is also given to the internal peer reviewers (Stacy Goldsworthy – Civil Contractors New Zealand – and Stephen Selwood) for their helpful review and suggestions on the report.

Abbreviations and acronyms

ADF	Augmented Dicky-Fuller
AQA	Aggregate & Quarry Association of New Zealand
CAPEX	Capital expenditure
CCANZ	Cement & Concrete Association of New Zealand
DMC	Domestic Material Consumption
DMI	Direct Material Inputs
EMC	Environmentally weighted Material Consumption
ESA	Equivalent Standard Axles
EU	European Union
GDP	Gross Domestic Product
GIS	Geographic Information Systems
InfraCom NZ	New Zealand Infrastructure Commission Te Waihanga
ISCA	Infrastructure Sustainability Council of Australia
LINZ	Land Information New Zealand
LM	Lagrange Multiplier
M/4	Premium basecourse specification
MBIE	Ministry of Business, Innovation and Employment
MfE	Ministry for the Environment
NIMBY	Not in My Back Yard
NZP&M	New Zealand Petroleum & Minerals
OPEX	Operating expenses
RAMM	Road Asset Assessment and Maintenance Management
RCA	Road Controlling Authority
RCC	Recycled Crushed Concrete
RMA	Resource Management Act
SE	Sand Equivalent
TNA	Training Needs Assessment
VEC	Vector Error Correction

Contents

Executive summary

The aggregates market plays a pivotal role in the economic development and well-being of New Zealand by matching the supply of construction materials with the demand for both maintaining existing infrastructure and facilitating the growth of the built environment. While the transport sector is only one user of aggregate material in New Zealand (aggregate is also a key raw material for building and housing), the transport sector accounts for up to 50% of demand.

Key issues that affect improving the sustainability of the aggregates sector's planning, sourcing and management of land use/environmental effects include:

- a lack of understanding, data and knowledge of the factors influencing aggregate supply, demand, quality and performance, both nationally and within regions
- expediency of decision making regarding using virgin aggregate material products and methods, alongside risk averseness in organisations regarding using alternatives to premium materials and trialling new treatments, and a reluctance to share risk
- perceptions that recycled materials are inferior products
- a lack of long-term planning and forecasting of demand requirements
- community and cultural sensitivities regarding quarrying, extraction practices and land use, especially within Māori communities, and a lack of understanding of the need to partner with Māori.

Failure to understand the temporal and spatial patterns of supply and demand can result in uncompensated externalities associated with long-haul transport, increased fuel use, CO_2 emissions, accelerated damage to transport infrastructure and in some cases, increased traffic congestion. Understanding and addressing these factors, as well as reducing the risks associated with supply, would contribute to policy aimed at improving the performance of the aggregates market.

When aggregates are viewed as natural capital, absolute scarcity does not appear to be a major concern in New Zealand. However, at a more granular level, scarcity becomes relevant due to unequal spatial distribution and quality, population density and growth pressures. Recovery of aggregates affects other dimensions of natural capital, including waterways and ambient air quality. Community and cultural sensitivities, especially for iwi and hapū, are contributing to a decline in the stock of potential aggregate resources in some areas, especially in the larger urban regional areas and regions where unsustainable or poor historical practices have created increased sensitivity.

There are also significant barriers to the increased use of alternative materials (both recycled and local non-premium virgin-quarried materials), blocking the more sustainable use of aggregate materials. Recycled aggregate materials include 'on-site recycling', where maintenance interventions can re-use existing materials by including the addition of stabilisers to improve the in-situ performance of the asset, and/or extend its life, rather than using a transported material of higher quality.

A unique feature of the aggregates market is that both supply and demand are site specific and issues are therefore region specific. This results in regions that have significant constraints in being able to sustainably source quality (premium) aggregates to meet their increasing aggregate demand. The cost of transportation is a major factor in determining supply price, creating an incentive to locate quarries relatively close to demand. The demand related to large public infrastructure projects can outstrip previous demand levels within a region, constraining supply.

This research highlights the multi-sector aspects and complexity of the issues surrounding the sustainable planning, extraction and use of aggregates as non-renewable mineral resources. The effect of aggregate extraction on associated resources is not well understood and there are many examples where historical uses have not been adequately monitored or regulated, resulting in poor environmental, community and cultural outcomes.

Data on the demand quantity for aggregate from infrastructure construction and maintenance projects throughout the infrastructure life cycle are difficult to obtain, due to the multiple agencies and industries involved and the lack of integration of asset systems. There are no simple fixes to these issues, as there are significant difficulties related to obtaining the appropriate data to manage aggregate resources at both the national and regional level.

This research project had five key objectives:

Objective 1: To understand the current and predicted future national picture for aggregate supply and demand in the transport and broader construction industry to inform the development of a national sustainable aggregate-sourcing strategy.

Objective 2: To understand how aggregate supply and demand forecasting data is currently collated/reported, to inform decision making.

Objective 3: To establish a baseline of the current use of different aggregate materials, including recycled and re-used materials.

Objective 4: To inform the development of methodologies/tools to enable robust collection/forecasting/reporting and geospatial representation of national supply and demand.

Objective 5: To develop recommendations for improving access to, and supply of, sustainable aggregate resources.

The key research findings for Objectives 1 to 4 were as follows:

- While New Zealand has an abundant endowment of aggregate (a non-renewable mineral resource), aggregate supply and demand is not evenly distributed geospatially. Some regions have significant supply constraints; others have an abundance that can drive overuse of premium resources.
- There is a genuine desire across the industry to use locally sourced aggregate products more sustainably, but this needs to be carefully planned and managed to enable the development and maintenance of infrastructure that is fit for purpose.
- The quality of, and demand for, aggregate products differs across New Zealand, and the geography and geology of Aotearoa can mean long haul distances from source to site.
- The demand for aggregate, whether national, regional or by type of transport infrastructure, is largely not well understood because little quality data is being collected, stored, shared and analysed to support better decision making. This makes forecasting and planning for aggregate on a regional basis very difficult.
- Aggregate supply and demand is significantly influenced by the economy and the government’s fiscal response to economic events.
- As city boundaries expand and land development intensification increases the nation’s carbon footprint, growing environmental and cultural sensitivities have made it more difficult to operate quarrying businesses close to demand. This has led to the planning and consenting of future aggregate sources taking much longer than before. Regional land use planning and zoning requires secure areas for future aggregate resources.
- Agencies that procure public infrastructure need to use both ‘carrot’ and ‘stick’ approaches to encourage aggregate use that is more sustainable.

- Improved supply and demand data by region is required, especially for regions outside the main centres, where critical mass is more difficult, many small operators exist, and alternative materials from premium specifications (eg recycled materials) are less available or economic.
- Data systems across the transport system need to be more integrated, to allow a better understanding of demand by type of infrastructure for forecasting of aggregate demand regionally and nationally.
- Econometric models are helpful for identifying national demand and supply scenarios, but the lack of data availability means that they are not currently very useful at a regional level.
- Telematics data can be used to gain greater understanding of the movement of trucks and aggregates.
- A long-term partnership approach is required in the aggregates sector, requiring leadership from the transport and broader construction industry to develop enduring and sustainable Māori partnerships with iwi and hapū.

The key recommendations from this research to improve access to, and supply of, sustainable aggregate resources (Objective 5) are as follows:

- Develop an aggregate data integration framework to standardise, collate and improve aggregate data information at both the national and regional levels where possible.
- National agencies and regional and local authorities should plan with a long-term horizon of at least 50 years specifically for aggregate resources.
- Develop an aggregate minerals supply and sustainability strategy as part of the government's minerals resource strategy and in partnership with the Infrastructure Commission's 30-year New Zealand Infrastructure Plan.
- Introduce mandatory reporting on national and regional usage of aggregate resources for public infrastructure, by product quality and purpose.
- Identify and target regions/areas where there are opportunities for increased use of recycled materials in transport infrastructure.
- Road Controlling Authorities and contracted consultants should demonstrate leadership by encouraging a more sustainable use of aggregate.
- Regional and local councils, in conjunction with Central Government (eg Ministry for the Environment (MfE) and MBIE NZP&M) and iwi/hapū, should develop best-practice aggregate consent application templates/guidelines for the extraction, processing and management of hard-rock quarries and alluvial-sourced operations.
- Waka Kotahi should establish an integrated national database for infrastructure resource quantity, product quality and pricing, by region and by transport infrastructure type and activity, to enable better forecasting of aggregate demand by product. This could potentially be integrated into the Infrastructure Commission's forward works programme.
- Road controlling authorities should actively encourage leadership in the use of sustainability-rating schemes that can differentiate operations and activities by aggregate use, to prioritise low-carbon-emission options.
- Waka Kotahi should commission a Training Needs Assessment regarding the levels of training required across the key land transport infrastructure delivery activities to build the capacity and skills to use aggregate resources more sustainably.
- Establish a working group to encourage collaboration and constructive cooperation among the relevant key public and industry organisations.

- Commission research into investigative measures and sensing (data analytics) that could be used to tag, identify and track aggregate (or other raw resources) from the supply site to the place of use, as well as its condition and movement over time.

Abstract

Aggregates are an important non-renewable resource and the primary raw material for land transport and maintaining the built infrastructure. New Zealand has an abundant endowment of rock minerals suitable for built infrastructure; however, aggregate supply and demand is not evenly spread geospatially by product quality. Further, there is an increasing demand for aggregates in many regions of New Zealand.

Additionally, there are increasing sensitivities to the extraction of aggregates, as communities and iwi/hapū have experienced the effects of poor industry practices. Currently, little data is available either nationally or within regions to sustainably plan, manage, use, re-use and recycle aggregates for built infrastructure, making it difficult to forecast future aggregate demand. The data that is available is very difficult and resource intensive to obtain and it is not in a form that can be readily integrated with other data systems.

This project reviewed the literature and aggregate and land use consent data, undertook an industry survey, evaluated truck-haul distances, developed a framework aggregate-forecasting model and facilitated a workshop and case study of aggregate supply and demand in the Horizons region. Recommendations are made on how to better manage aggregate supply and demand for land transport infrastructure in New Zealand.

1 Introduction

1.1 Research purpose and objectives

The purpose of this research is to better understand the transport sector's requirements in relation to aggregates (in terms of access, supply, demand and use) to enable the sustainable sourcing of materials. This will help in the development of a national coordinated strategy and action plan to optimise material use within the transport and wider infrastructure sector. The implementation of a strategic approach presents a very real opportunity to take a long-term, holistic and sustainable approach, achieve cost savings and environmental improvements, and reduce the effects on communities. The objectives of the research are to:

- understand the current and predicted future national picture regarding aggregate supply and demand in the transport and broader construction industry to inform the development of a national sustainable aggregate-sourcing strategy
- understand how aggregate supply and demand forecasting data is currently collated/reported, to inform decision making
- establish a baseline of the current use of different aggregate materials, including recycled and re-used materials
- inform the development of methodologies/tools to enable robust collection/forecasting/reporting and geospatial representation of national supply and demand
- develop recommendations for improving access to, and supply of, sustainable aggregate resources.

1.2 Background

Aggregate is any coarse- to medium-grained particulate material (eg sand, gravel, crushed stone) that is used for construction purposes. Aggregates provide the necessary compressive strength while taking up a bulk of space. They may be used alone for unbound railway ballast and road pavement layers, or they may be mixed with cement or bituminous material to form a bound concrete/asphalt mix or mortar for construction (Christie et al., 2001). Aggregates are the most mined and most used material in the world, second only to water (Menegaki & Kaliampakos, 2010). Aggregates are either produced from quarrying sites by breaking up rocks or quarried from river (alluvial) gravels. Although they are present in abundance in most countries, including New Zealand, they are considered a non-renewable mineral resource.

Some of the characteristics of aggregate extraction include the following:

- Aggregates are bulk, low-unit-cost materials that derive market value by being located close to market.
- The engineering performance of aggregates depends upon the quality of the aggregate source, the production processes (eg crushing, washing and mixing of materials) at the quarry to produce a product, construction quality and the design life traffic loadings expected.
- Aggregate resources and quality vary geospatially with geological source properties.
- Although the claim that demand is price inelastic is plausible, it has very little supporting evidence.
- Increasingly, the large mineral aggregate producers are vertically integrated through either concrete product business or land transport/roading business.
- Much of the cost associated with the use of aggregates is for transportation, due to its weight and the quantity requirements.
- Aggregates are capable of being recycled (unlike conventional fuel minerals).

Current practices related to the planning and extraction of virgin materials are not considered sustainable because of their environmental effects, as well as cultural values. In New Zealand, there is no concern about depleting aggregate resources, which eliminates the problem of future supply. The challenge here is ensuring access to appropriate materials geospatially by connecting supply and demand; failing to do this generates environmental externalities from the increased transport of aggregate products, which then increases emissions and congestion, as well as accelerating the deterioration of road infrastructure (Langer & Tucker, 2003). From an environmental and social perspective, some of the problems with aggregate material extraction are noise, pollution, disturbance of waterbeds and ecology and water resource use, and poor visual effects. This gives rise to a ‘Not in My Back Yard’ (NIMBY) attitude towards most extractive and heavy industries. Some of the economic consequences of the current aggregate production methods include supply–demand mismatch, increasing price and deterioration of infrastructure, loss of land value in nearby areas and insufficient incentives to use recycled materials.

Further, historical injustices in land confiscation for ‘infrastructure purposes’ (eg the Public Works Act) by successive governments since the signing of the Treaty of Waitangi has led to Māori communities distrusting infrastructure agency providers. As various Treaty of Waitangi claims have been settled, Māori have been given back land that in some cases has included quarries, and there is a reluctance by some iwi groups to continue their operation due to various interpretations of Mātauranga Māori guardianship principles. There is a wide spectrum of perspectives from Māori communities; some are completely against aggregate extraction, and others have actively purchased quarries or have continued to operate quarries that have been given back to them as part of land settlements. It is important that Mātauranga Māori perspectives and economic opportunities are both enabled and facilitated in the future planning for aggregate supply and demand.

The aggregates market plays a huge role in the economic development of a nation. Increased demand can be considered a consequence of economic development while also creating significant employment opportunities. For example, a study by Brown et al. (2011) showed that in 2005, the aggregates industry in the UK contributed £810 million as gross value added and created more than 8,300 employment opportunities. Even when a monetary value was attached to the negative impacts the aggregates industry posed on the environment (£386.8 million–£444.7 million), the benefits outstripped the negative effects.

The objective of this report is to shed light on some of the practices that are currently employed in New Zealand (successfully or unsuccessfully) to manage aggregate supply and demand and to enable the improved planning, use and re-use of the resource in a more sustainable manner. First, the report reviews some of the key national and international literature to:

- review the economic and econometric models used to forecast the demand for aggregates and practices to ensure the supply of the resource
- evaluate the national and international policies and regulations that are in place to sustainably manage aggregate use worldwide
- discuss the aggregates market in New Zealand with emphasis on supply and demand and the materials used in aggregates.

Second, the report reviews and discusses some of the key challenges and issues to be addressed to implement some of the successful practices for sustainably managing aggregate supply and demand in New Zealand. Third, the research reports on a national industry survey, additional interviews and a facilitated workshop to identify the key aggregate-related issues that exist in New Zealand, both nationally and regionally, and how these issues may be addressed. Fourth, the research develops and tests an econometric model to forecast the future demand for aggregates based upon national and regional economic factors.

2 Review of international literature

2.1 Supply and demand

The long-term production and use of aggregates per capita is positively associated with population growth, GDP and additions to the built environment. For example, the annual demand for aggregates in the UK increased from 1/16 tonne per capita in 1900 to 5 tonnes per capita in the early 1990s (Kellett, 1995). In the US, short-term fluctuations in aggregate production have reflected the economic cycle, ranging from 4 to 12 tonnes per capita over the period 1990 to 2000 (Robinson & Brown, 2002). Aggregate use is a leading indicator for the business cycle.

Demand derives from the value that society attaches to the services associated with the built environment, transport infrastructure, commercial and residential buildings, and enhancements to the natural environment. Demand for a particular aggregate is a function of its price; the price of substitutes (including recycled material); preferences and standards related to its use; and the ability of organisations, units of government and individuals to pay. A study by Bee-Hua (2000) identified seven factors contributing to residential construction demand in Singapore: (1) building tender price index; (2) bank lending for housing; (3) population size; (4) additions to housing stock; (5) national savings; (6) gross fixed capital formation for residential buildings; and (7) unemployment rate. Although the study was specific to residential construction, these factors can be considered drivers for aggregate demand. Material inputs into the economy are significant. In 2002, the aggregates industry was the most resource-intensive sector in Europe, accounting for 40% of the direct material inputs (DMI) into the European economy; mineral fuels represented another 25% (Bleischwitz & Bahn-Walkowiak, 2006).

To illustrate, construction activities that maintain existing road infrastructure dominate aggregate use in the Mid-Atlantic region of the US (Robinson & Brown, 2002). New road construction funded by governments in the Mid-Atlantic region usually lags population growth by large margins, because of delays in land acquisition and financing. Aggregates for roads account for 32% of national demand in the UK (Kellett, 1995). Investment in road improvements often arises over public concern about accidents. Statistics from the National Highway Traffic Safety Administration show that in 1998 in the US, large trucks (which largely transport the aggregate used in land transport infrastructure) accounted for 3% of all registered vehicles, 7% of total vehicle miles travelled and 12% of traffic fatalities (Robinson & Brown, 2002). Road pavement surfacings require the highest quality aggregates for safety reasons.

Aggregate supply is a function of an economy’s endowment of resources, availability of land, the technology used in recovery and beneficiation, transportation costs, recyclable material, and other factors of production, such as labour and capital. Aggregates have a high place value and quarrying commonly takes place close to consumption sites (Bates, 1960). Kaliampakos and Benardos (1999) in Greece estimated that delivering as far as 15 km from the quarry led to a 30% price increase. A delivery distance of more than 40 km is therefore unusual, at least in the European Union (EU), although it is very country-context specific. Most studies report that the cost of transporting aggregate is a major consideration in quarry site selection. In the late 1990s, truck transport costs were reported as US$0.18 to $0.25 per metric ton[1] per road mile transported in the Mid-Atlantic region of the US, and this could equal the production (mining and processing) costs of crushed stone aggregate at truck-haul distances of 48 to 80 km. In the same region, rail transport costs were approximately one-third of truck transport costs (Robinson & Brown, 2002). The price of aggregate is also affected by related sectors such as electricity and carbon prices.

[1] 1 metric ton = 1 tonne.

Although transport costs favour quarry locations that are relatively close to demand, increased population density and concerns about environmental protection have resulted in the aggregates industry moving further away from growth centres (Kellett, 1995). A qualitative study by Poulin and Sinding (1996) suggested that increasing urban sprawl, which limits the sources of aggregate, would escalate transport costs and translate into unnecessary social costs. Shortages stemming from delays in bringing new sources into production can produce price spikes. The use of recycled aggregates can be hampered by the permitting process, lack of experience with the technology and the variability in, and supply of, the material.

Technological advances have resulted in a long-term decline in the price of crushed rock in the Mid-Atlantic region of the US, where the industry structure is changing, with large ‘super-quarries’, located in regions that are less densely populated, feeding into dispersed local distribution sites. This has reduced both the cost of supply (lower land cost, economies of scale and lower transportation cost) and the level of community opposition. Twenty-five percent of the sites now provide nearly 60% of the production (Robinson & Brown, 2002). However in New Zealand, due to the low population and land use density, this model of super-quarries is unlikely to be feasible, other than potentially for the two main urban centres of Auckland and Wellington.

Land management data in the US indicate that available aggregate resources decrease with population density. Regulatory and zoning changes have caused a decline in the resource base for aggregate production (Robinson & Brown, 2002).

2.2 Empirical evidence

A limited number of papers have approached empirical estimates of aggregate supply and demand informed by economic theory and the use of sound econometric methods. In general, aggregate demand, supply and price are estimated by mathematical modelling, and the distribution of supply to centres of consumption is optimised by linear programming. The objective function used in the process minimises overall transport costs. The aggregates considered are of two types, namely coarse aggregates and aggregates for concrete – overall demand of an entire study area is forecasted by econometric procedures based on general economic factors. The technique uses a function based on gross state product and population level, with the effect of interest rates added. Total supply is tied to total demand. Through a systematic study of supply, demand, price and transport characteristics of aggregates, relevant modelling parameters suitable to the level of available information can be identified. This important aspect of model construction should never be overlooked.

Poulin and Bilodeau (1993) developed a quantitative model that incorporated the analysis of aggregate supply, demand and price based on geographic information collected in 1987 (with projections to 1992). The aim was to examine the overall aggregates market in the US Eastern Seaboard and more specifically, to investigate the effect of low-cost allochthonous sources of aggregate on the stability of the aggregates market by considering the sensitivity of the market to increases in transport costs. Econometric estimates of demand were based on gross domestic product (GDP), population level and interest rates. Strictly speaking, their supply model was not an economic model in the full sense of the term but rather, a production-level model based on labour input. An optimisation model was structured around minimising transportation costs subject to supply and demand. Their results showed the optimal distribution of aggregates within the region. They indicated that first, the developments/expansions of both existing and anticipated quarries in established areas tended to be restricted by regulations more than by resource availability and technology. Second, the dependency on alternative sources of aggregates by the Eastern Seaboard would increase in the future. Overseas coastal mega-quarries, located in Canada and Mexico, could be considered to partially fulfil these shortages.

Van der Voet et al. (2005) applied a materials balance model to EU time-series data over the period 1990 to 2000. Two indicators, Domestic Material Consumption (DMC) and Environmentally weighted Material Consumption (EMC), provided estimates of the linkages with economic growth and resource use. Their econometric models provided estimates of the relationship between GDP/capita, economic structure (eg share of construction sector), innovation and technical progress, waste treatment (eg the percentage of recycled material) and location. Overall, a 1% economic growth resulted in an increase in the EMC of almost 0.6% and an increase in the DMC of 0.4%. As this was smaller than 1%, there was some relative decoupling over the period. A 1% increase in the share of construction in GDP resulted in a 3.6% increase in per capita DMC and a slightly lower per capita EMC. The DMC adequately measured dematerialisation. If the material composition of an economy had remained unaltered, DMC would have been a good proxy for reduction of environmental pressure due to the use of materials. However, EMC would have been a better indicator if environmental gains had been an objective of policy.

According to Menegaki and Kaliampakos (2009), who conducted a case study to analyse the relationship between the production of aggregates and population and GDP respectively in the wider area of Athens (the Attica basin), aggregates represented 40% of the DMI into the European economy in the mid-2000s. They addressed the issues around the extraction of aggregates in the vicinity of urban developments, such as environmental implications and conflicts with other land uses. A two-stage time-series regression analysis, based on consumption per capita and the percentage of aggregates used, produced forecasts extending out to 30 years. Three scenarios based on increase/decrease in population growth were analysed. These empirical results showed an estimation of the demand for aggregates to a maximum of 1,122 million tons (1,017.9 million tonnes) in the case of the Attica basin. This volume of aggregates could be fully exploited by the already-established quarrying zones, solving a long-standing problem in Athens. However, the lack of a performance evaluation or validation in their study, and their use of simplistic forecasting methods, may have limited the accuracy of the proposed models in practice.

Menegaki and Kaliampakos (2010) provided quantitative estimates of the main drivers of aggregate production in 26 European economies. Their analysis was based on data for the 10 years 1997 to 2006. Recognising that the sources of demand were driven by macroeconomic and demographic factors like population growth and economic growth (Coriolis Consulting Corp., 1996), production was estimated as a function of population, GDP, construction sector's share of GDP and unemployment rate. The latter variable appeared to have been included to capture the state of the economy. Each explanatory variable was statistically significant. Aggregate production in each country was found to be strongly affected by the share of the residential building sector within the total construction sector. This reinforced a general observation made earlier. Residential production in the Central and Eastern European economies accounted only for 26%, by value, of the total construction sector. In contrast, in the Western European economies, the residential sector accounted for more than 49% of the total construction sector.

Material flows can be reduced by innovative technology. Smith (2017) reported that 28% of the aggregate used in Great Britain in 2015 came from recycled aggregate and industrial by-products. Thus, constant per capita forecasts of long-run demand for aggregates can be misleading. The distinction between stocks and flows is relevant. Population level is a stock, whereas population growth is a flow. Per capita consumption of the demand for construction aggregate muddles the distinction between population level and population growth. Simple regression analysis, with aggregate demand as the dependent variable, shows that using change in population as an explanatory variable provides superior statistical results compared with using population level. Smith's analysis did not include other covariates, such as construction sector's share of GDP. Smith (2017) concluded that a more promising approach was to predict demand from the bottom up, using variables such as the housing and infrastructure that would be built in a given area. However, predicting future construction activity using this bottom-up approach is not practical at the economy level.

Furthermore, useful insights can be gained from the use of scenarios, based on robust econometric models of supply and demand.

Several studies have applied methods from environmental science and engineering to highlight other dimensions of aggregate use. Ioannidou et al. (2017) assessed the local criticality of quarried aggregates of quarried construction aggregates (gravel and sand). Two new concepts, strong locality versus weak locality, were introduced to examine different substitution scenarios given a local supply constraint. The assessment involved three dimensions: (1) supply risk, including geological, technological, economic, social, regulatory and geopolitical aspects; (2) environmental implications based on a life-cycle inventory; and (3) vulnerability to supply restriction. Measures of criticality identified the regions within France and Switzerland that faced the highest risk of supply constraints.

A more recent study by Blachowski and Buczyńska (2020) developed a multicriteria Analytical Hierarchy Process technique to identify the views of a Lower Silesia community in Poland on raw material mining. The method relied on spatial statistical measures (including density and directional distribution) in Geographic Information Systems (GIS) to aid the descriptive statistics usually used for such purposes. Their proposed methodology could be used universally for other raw rock-material source regions, especially for aggregates, which could help to develop a knowledge database for governmental agencies in any country under consideration.

2.3 Policy and sustainability

Policy responses to the adverse impacts on communities and the environment associated with aggregate production, transport and use are a common theme in the literature. Kellett (1995) examined revisions to the UK’s policy on aggregates from the perspective of sustainability. Population growth and concerns about environmental protection in the South East has resulted in the industry moving further from growth centres, increasing the cost of supply. However, the solutions of industry relocation or developing super-quarries would not address the issue of sustainability; they would simply shift the environmental and social impacts. In addition, as super-quarries cannot supply all required aggregate products, there would always be a need for specific products to be as local as is possible. Environmental impacts, rather than resource depletion, were considered key issues.

The connections among changes to planning regulations, the market and environmental impacts need to be carefully considered. For example, a suggestion to reduce the duration of land banks in the UK could have the effect of increasing prices and enhancing the competitiveness of super-quarries. Increasing urban sprawl, which limits the sources of aggregates, could escalate transport costs and result in social costs (Poulin & Sinding, 1996).

Integrating aggregate production within land management planning in order to better manage the natural resource stock of aggregates has been advocated in numerous studies (eg Bloodworth et al. 2009; Poulin & Sinding, 1996). Kellett (1995) suggested that demand management was the key to a sustainable policy. While localisation of supply and demand generally makes sense from a sustainability point of view because the economic and environmental issues are more obvious to local populations, there are limits to this logic because interregional trade and the opportunities for recycling in other regions necessitate interregional transport. Problems associated with the use of recycled aggregates include the permitting process, lack of familiarity with the technology, variable attributes of source material, lack of knowledge of the capabilities of recycled material, and sourcing a reliable flow of quality material. At the time of this literature review, the local UK authorities had not taken on board the sustainability theme. Bloodworth et al. (2009) suggested that planning for the future use of land for mining and quarrying in the UK would need to address carbon sequestration and low-carbon production, consider the broader spatial aspects of planning policy, and better understand public perceptions.

Baker and Hendy (2005) discussed the aggregate policy in place at that time for all states in Australia. Given the challenges faced by the industry, they recommended developing a sustainable planning framework for aggregate extraction considering the following four main aspects: (1) establishing a database of inventories for aggregate resources available, including location, quality and quantity data; (2) suitable environmental protection not just for resource depletion but also for the irreversible damage done to the environment; (3) reclamation of abandoned pits as an integral part of the approval and development process; and (4) comparing the use of recycled materials against virgin products. A study by Thomas et al. (2009), in a large redevelopment project in the centre of Birmingham, UK, showed that significant CO_2 reduction could be achieved where site-derived demolition waste was reprocessed for use on site as recycled aggregate. However, as discussed earlier, the use of recycled aggregates remains a challenge. Baker and Hendy (2005, p. 12) claimed, ‘As long as supply of resources continues to be more than the recycle cost, it will not be economically viable’. This mandates the need for an inventory to track the flow of materials from cradle to grave.

Zuo et al. (2013) used a GIS-based platform to model the CO_2 emissions associated with road transportation from quarries to construction sites in England and Wales from a UK Aggregates Mineral Survey in 2005. Four possible policy scenarios were discussed: (1) the development of new quarries closer to places of high demand; (2) enabling more aggregates to be transported by rail rather than by road; (3) modernising the fleet of lorries used to transport aggregates; and (4) increasing the use of marine sources of aggregates. Linear models were used to estimate the amount of CO_2 emissions associated with the existing set of flows, with a set of estimated costs for recycled aggregates introduced as a benchmark for scenario evaluation. Their results revealed that switching to rail transport was the least feasible option due to the cost of new track, while aggregate recycling was the most effective option.

Blachowski (2014) conducted a case study of Lower Silesia in Poland, a region that was experiencing increased demand for aggregates, which were being used for road, railway and building construction purposes in the years 2006 to 2010. The aim of the study was to examine the importance of resources and mining management in the context of regional spatial planning. GIS was used to explore changes in the identification, exploitation and transport of aggregates in the region. The results showed that quarries in the region occurred in roughly longitudinal bands and that a small, gradual shift of the zones of intensive production towards the east, where demand was located, was of interest in the development of large quarries and the substitution of railway infrastructure for road transport.

Aggregate taxes (including sand, gravel and/or crushed rock) have been implemented in several European economies (Bleischwitz & Bahn-Walkowiak, 2006), with two approaches: an ad valorem tax based on the value of the aggregate and a unit tax applied to a physical quantity of the aggregate. It was not clear whether the European quarries in this research were owned by the state or by private entities. In addition to providing revenue to the government, the royalties generated information that was useful for monitoring aggregate use and data for policy analysis.

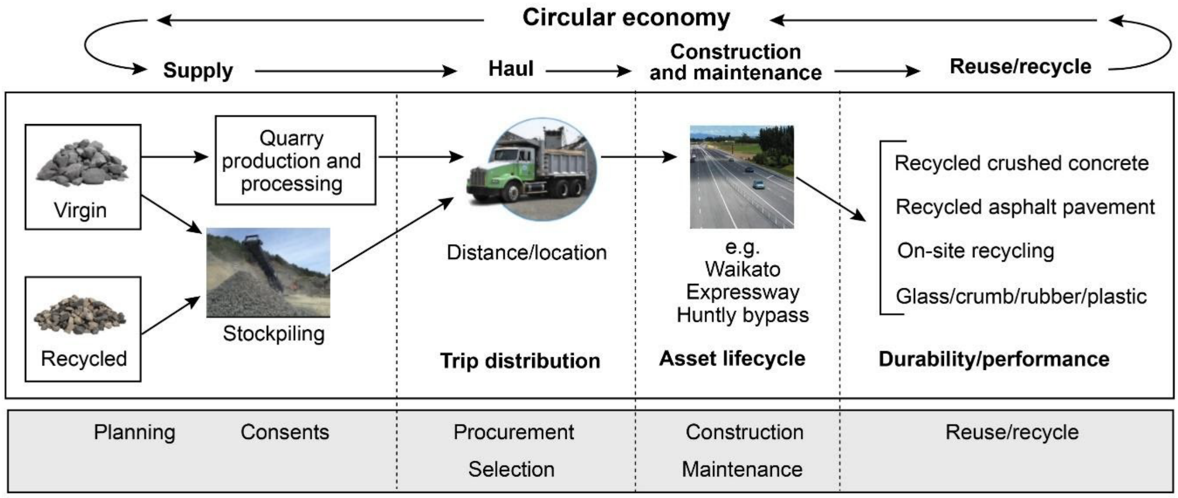
In New Zealand, information supplied to the Ministry of Business, Innovation and Employment (MBIE) and New Zealand Petroleum & Minerals (NZP&M) currently relies largely on voluntary participation in annual surveys for privately owned quarries. Unless data on the value of recovered aggregates are available, it is not possible to estimate a supply equation. At best, we can assume that supply equals demand and follow the above approaches that estimate use (demand) as a function of socio-economic variables.

3 Review of aggregates in New Zealand

3.1 Aggregate resources and infrastructure demand

This research project sought to better understand the aggregate supply issues in relation to the demand for aggregates through the transport infrastructure life cycle decision-making process (see Figure 3.1).

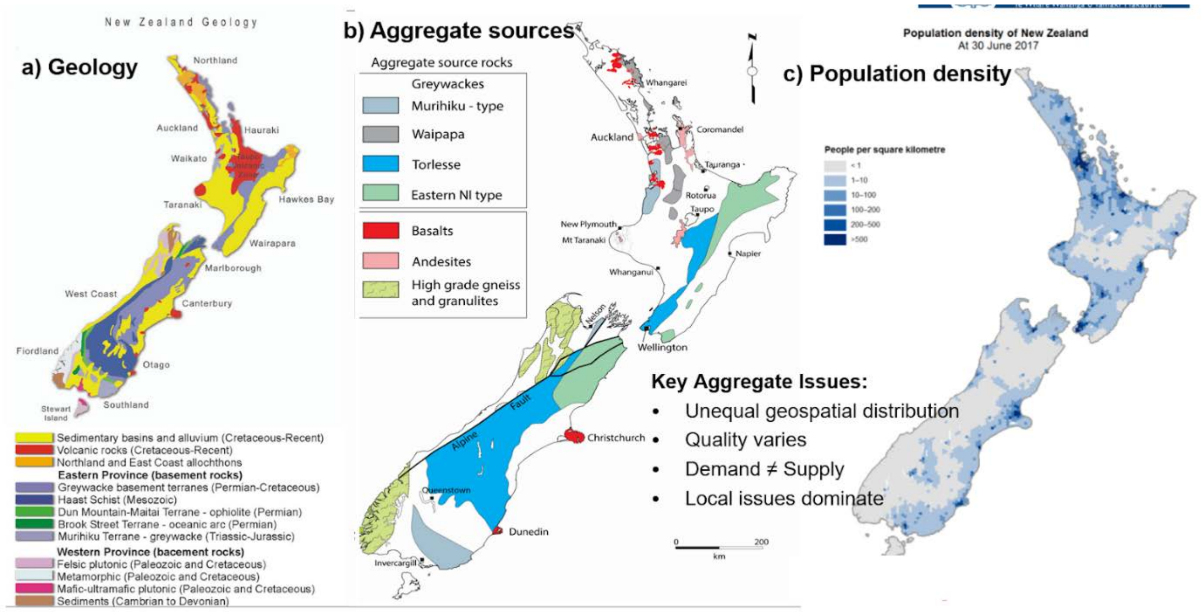
Figure 3.1 Aggregates life cycle decision-making process



New Zealand has a large supply of quality aggregates (endowment) but it is unevenly distributed both geospatially and in quality (see Figure 3.2), and it is not necessarily close to the demand for built infrastructure. In addition, as urban centres have grown, and environmental and cultural sensitivities have increased, aggregate resources have progressively become more difficult to access. According to Black (2009), there are four main sources of aggregates in New Zealand, with the first two being virgin hard-rock quarry sources:

- Greywacke – Makes up to 25% of the exposed rocks in New Zealand and supplies source rock for 75% of aggregates produced in the country. It is prominently found in the South Island, although there are also significant resources in the North Island.
- Igneous rocks or volcanic rocks – A source rock for 25% of aggregates produced in the country. These are predominantly found in the North Island, especially in the Northland, Bay of Plenty and Taranaki regions.
- Gravels and conglomerates – Sediments composed of pebble- to boulder-sized rock fragments, sourced mainly from river or beach beds.
- Artificial aggregates – Slags produced mainly from iron and steel manufacturing (eg melter slag and calcined bauxite).

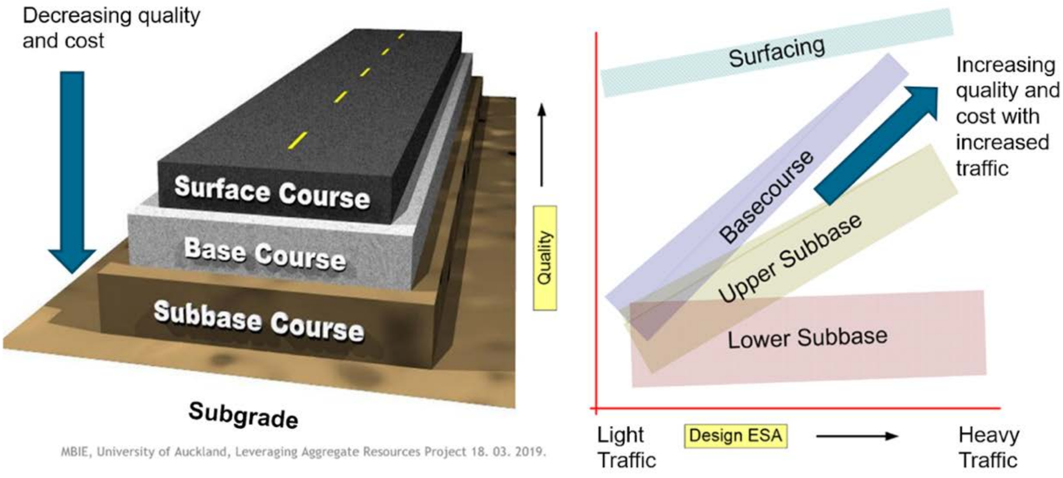
Figure 3.2 a) New Zealand geology (information supplied by Institute of Geological and Nuclear Sciences); b) Aggregate sources (reprinted from Wilson, Black & Webster, 2019, slide 35); Population density (reprinted from Stats NZ, 2017)



More recently, the use of recycled materials for aggregate use has been encouraged, to minimise reliance on virgin products. Some of the commonly used recycled materials are Recycled Crushed Concrete (RCC), Recycled Asphalt Pavements, crushed glass, crumb rubber and recycled brick (O'Donnell et al., 2018). An advantage of the use of recycled aggregates is the variety of roles they can perform (eg RCC can be used both as a substitute for virgin products and as a filler). Some of the recycled materials used as aggregates are of superior quality to virgin products and outperform them. According to Ellis et al. (2014), the demand for premium RCC exceeds the supply in the US because of its premium quality, if processed appropriately, and if it is available near to demand sites in built up environments. In New Zealand, the Cement & Concrete Association of New Zealand (CCANZ), in partnership with the Building Research Association of New Zealand and supported by the Aggregate & Quarry Association of New Zealand (AQA), published a guideline report for the use of recycled materials as aggregates in New Zealand (CCANZ, 2013). Ardalan (2017) estimated that in 2015, around 11% of total road aggregate demand in Waikato could have been supplied by recycled concrete and glass from that region. The challenge with the use of recycled products is the need for quality sorting, production processing, quality assurance and auditing, which all require the use of the latest technology and management systems to supply the final quality product.

In comparison to countries with denser populations, due to our relatively low traffic volumes, New Zealand road pavements are largely designed and constructed as flexible pavements and consist mostly of multiple layers of unbound granular construction. They typically consist of three layers above the subgrade (see Figure 3.3); the subgrade is defined as the top 1.0 m of underlying foundation material, which could be an imported material or the in-situ material on which the road is constructed.

Figure 3.3 Road pavement cross-sectional layers and relationship to aggregate quality and traffic loads (modified from MBIE, 2019, slide 4)



The quality of the pavement layers generally decreases with increasing depth and reduced stress and strain from induced and repetitive vehicle traffic loading. The quality of the aggregate material can vary by Road Controlling Authority (RCA) specifications but the benchmark specifications that are used for state highways, and to which most other road authorities refer, are the Waka Kotahi NZ Transport Agency material specifications and notes, which largely determine the material quality requirements for roads and highways in New Zealand. Some regional authorities have region-specific specifications. The quality and design depth of the pavement material layers are a function of the heavy vehicle traffic loading over the life cycle of the asset and the strength of the materials in the underlying subgrade layer (the road foundation). The three aggregate-intensive layers of unbound granular road pavements for state highways in New Zealand and their Waka Kotahi specifications are as follows (see Figure 3.3):

- Surface course (M/6) – Requires premium-quality aggregate for chip seals rolled into a sprayed bituminous layer or a thin layer of Asphalt Mix (M/10) or Stone Mastic Asphalt (M/27). Requirements are more than strength and durability, as road safety requirements require materials that are resistant to microtextural polishing.
- Base course layer (M/4) – This is the uppermost granular layer adjacent to the surfacing and is the reference or standard specification for primary basecourse (premium quality) for heavy-duty use in flexible pavements with thin surfacings. Requires premium-quality aggregate that must generally pass a series of binary pass/fail aggregate material test criteria and is specified by most RCAs for the top layer of any road construction.
- Subbase course layer (Transit NZ [TNZ] M/3 notes) – The lower pavement layer(s) between the basecourse and subgrade layer. Requires material of lesser quality, as the zone of intense wheel-load-induced stresses and strains are reduced. Industry often uses the terms ‘marginal’ or ‘alternative’ materials in referring to the material that does not meet M/4 ‘premium’ quality. However, this does not mean that it cannot be used as a fit-for-purpose material in the right application, as is commonly undertaken in the subbase layer.

In New Zealand, premium-quality aggregates are assessed according to the guidelines and specifications provided by Waka Kotahi and previous entities – eg TNZ M/4 specifications – and refer to New Zealand Standard 4407 (2015) for the testing of road aggregates.

MBIE classifies five end-use products from aggregates (Lane, 2017). The main three are:

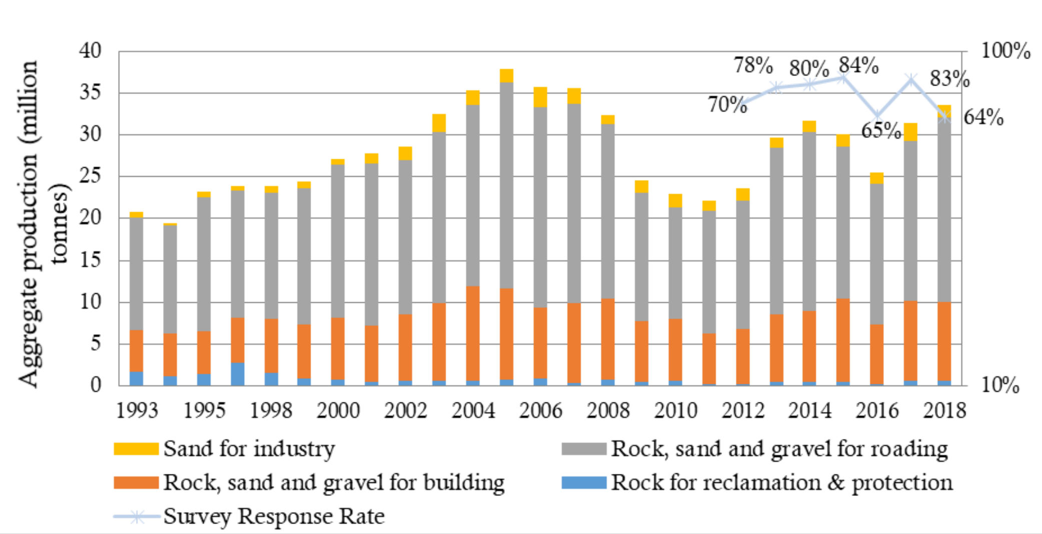
- rock for reclamation and protection

- rock, sand and gravel for building
- rock, sand and gravel for roading.

According to AQA (n.d.), the current corrected domestic production of aggregate in New Zealand is approximately 50 million tonnes per year, 10 tonnes for every person in New Zealand.

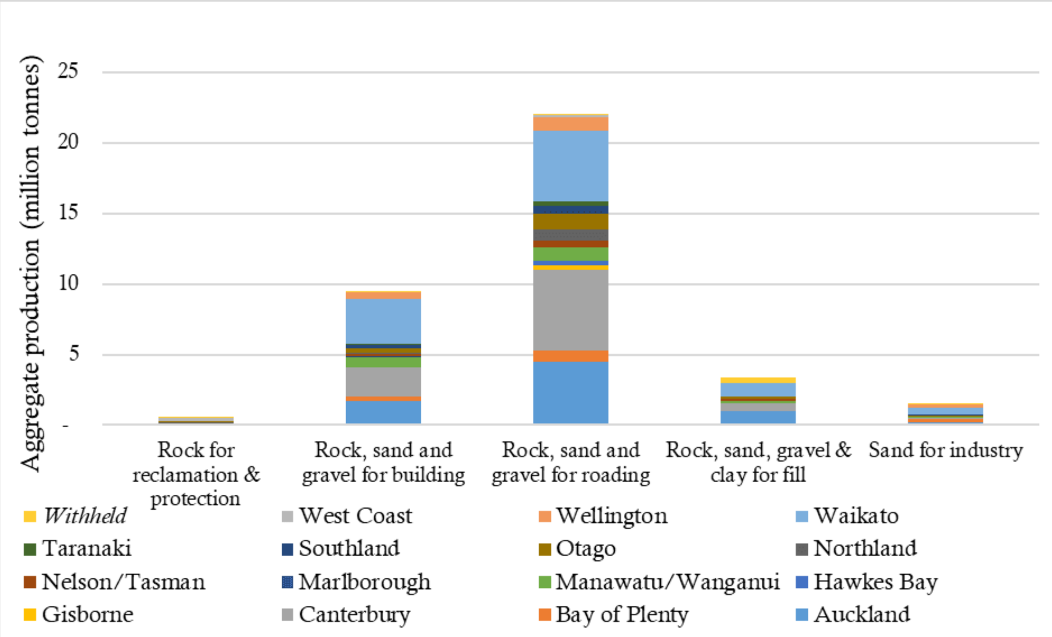
Figure 3.4 shows historical aggregate production in New Zealand for quarries that completed the annual production survey and Figure 3.5 provides an example of the individual splits of the 2018 production data, by region of New Zealand.

Figure 3.4 Aggregate production 1993–2018 (information supplied by NZP&M)[a]



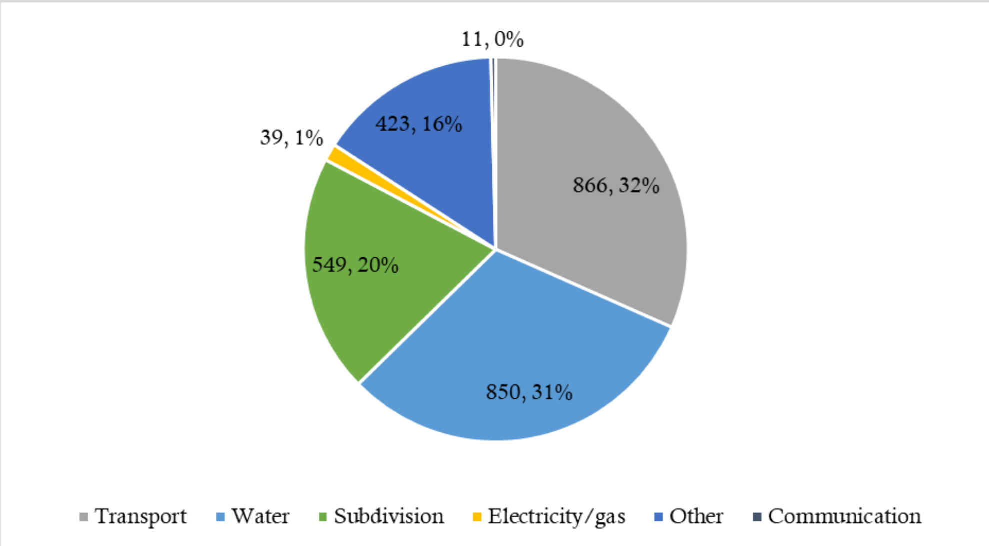
(a) The survey is not a statutory requirement for non-Crown consents and responses are voluntary.

Figure 3.5 Aggregate production 2018 (information supplied by NZP&M)



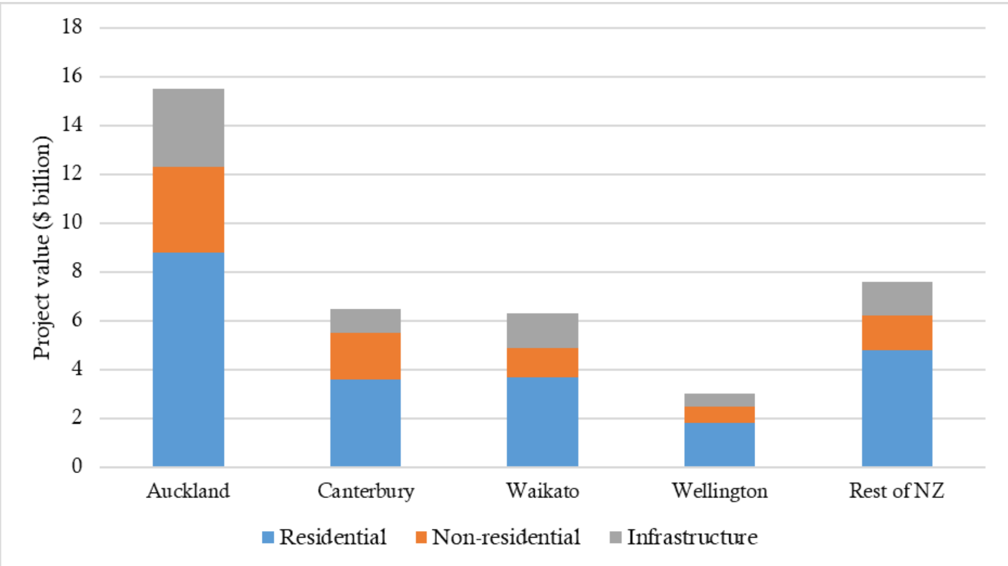
The figures show that from a strictly demand perspective, road development dominates the use of aggregates, followed by building construction purposes. Figure 3.6 and Figure 3.7 show that in terms of planned infrastructure development, 32% of new projects anticipated to start in 2019 would be for improving transportation infrastructure, followed by water-related projects. This places a heavy emphasis on supplying aggregate resources for roadway infrastructure, mainly in the Auckland region.

Figure 3.6 Number of infrastructure projects expected to start in 2019 (based on data in MBIE, 2019)



Building construction projects (largely using aggregate for concrete) tend to have the highest cost value and most of that development is taking place in Auckland, mainly because of the city's increasing population. Some rural regions of New Zealand have supply-related concerns because of large transportation infrastructure projects that significantly increase demand (eg Waikato Expressway projects, Transmission Gully and the planned replacement highways – Ōtaki to north of Levin [Ō2NL] and Manawatū Gorge) and can overpower normal historical aggregate demand for the region.

Figure 3.7 Project values by region 2018 (based on data from MBIE, 2019)



According to Welvaert (2018), aggregates are mostly supplied from nearby sources because of the geographic dispersion of quarry locations.[2] Aggregates are almost entirely transported by road. Ministry of Transport data (2017, p. 57) show that in 2012/13, aggregate transport accounted for only 11% of freight transport and there was rarely any aggregate freight transport between regions, with the exception of Auckland. The demand in Auckland cannot be supplied within the region and additional supply was sourced by aggregates from the Northland and Waikato regions, making the product expensive and difficult to access.

With the recent boom in the construction of public and private infrastructure, constraints on the availability of construction resources in New Zealand have led to several considerations. The latest New Zealand Government Policy Statement on Land Transport (Ministry of Transport, 2020) outlined record levels of investment ($48 billion) planned over the next decade on transport-related infrastructure development throughout the country, requiring aggregates of various specifications. Auckland was expected to continue dominating the demand for aggregates in the future, based on residential growth driving demand for houses, roads and infrastructure to support the expanding economy. In 2018, 40% of the total construction-sector value and 39% of new dwelling consents in New Zealand was attributed to Auckland (MBIE, 2019). This report generated four forecast trends for regional and nationwide construction activities in New Zealand. The private sector was expected to initiate non-residential projects, while residential and large-scale infrastructure development were expected to be initiated by local government (see Table 3.1).

Table 3.1 Future development projects in different regions (based on data from MBIE, 2019)

	Projects likely to start before March 2020	
	Non-residential building	Public infrastructure projects
Auckland	10	9
Waikato	3	3
Canterbury	2	NA[a]
Wellington	1	NA
Rest of New Zealand	NA	3

Note: Considers only projects valued at over $100 million.
[a] Not Available.

Overall, some of the key issues that the literature identified regarding the sustainable use of aggregates in New Zealand were:

- a mismatch between the supply location and the demand location (mainly Auckland and Wellington)
- difficulties with accessing quality aggregates
- lack of specification and industry technical knowledge for the use of alternative aggregates in rural projects where premium-quality aggregates were not required, leading to overuse of premium aggregates
- the use of aggregate from quarries that were available close by and cheap, even if it was of high quality, for sub-standard requirements, leading to inefficient use.

As mentioned earlier, in comparison with other mineral extraction, aggregates are relatively inexpensive as a low-value mineral resource, in the range of $30/tonne for high-quality aggregates, $60/tonne for surfacing

[2] Freeman (2020) provides a list of quarry locations in New Zealand.

aggregates (premium) and $20/tonne for marginal-quality aggregates (Lane, 2017). Pennington (2019), at Radio New Zealand, noted it was 'crunch time' for New Zealand quarries due to excessive demand for aggregates. This increase in demand led to the reopening of the Old Willowbank Quarry in the North Island.

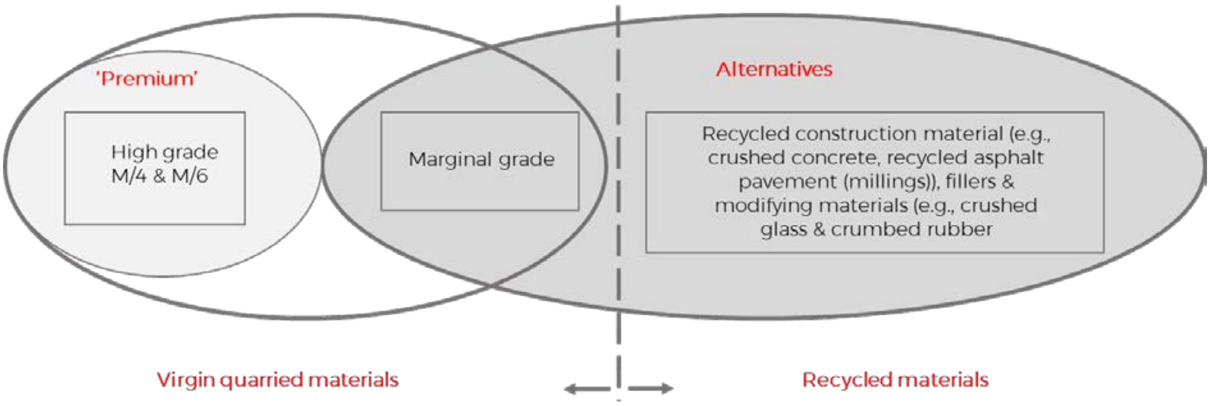
Although shipping aggregates from other countries is a possible option, the logistics involved, including increased truck movements from ports, port capacity, increased costs, resource inefficiency and increased carbon emissions footprint, currently means that it is not viable.

3.2 Use of recycled materials for aggregates in New Zealand

This section discusses some of the barriers to the use of recycled materials as aggregates in New Zealand. Figure 3.8 shows the multiple sources and grades of materials for pavement aggregates[3] (Mora et al., 2019). Some research has investigated the multiple barriers to greater efficiency in the use of aggregates through increased uptake of alternative materials in pavement construction (Mora et al., 2019; O'Donnell et al., 2018).

Barriers and corresponding opportunities have been identified throughout the pavement life cycle. Improving information about the supply and demand for all types of aggregates has been identified as a critical component in aiding better decisions by individual practitioners and organisations at all stages (Mora et al., 2019). For example, findings from stakeholder interviews showed there was likely to be risk aversion to the use of recycled aggregates if the supply chain was perceived as being inconsistent. Opportunities identified included investing in a steadier and therefore better economic supply chain through improved economies of scale (eg from strategic stockpiling) and coordination (Mora et al., 2019).

Figure 3.8 Aggregate types (reprinted from Mora et al., 2019, p. 1)



Knowledge gaps about the impending shortages in premium quarried materials have also been identified as a barrier to practices that are more sustainable (Mora et al., 2019; O'Donnell et al., 2018). Understanding of shortages was not universal across the country, meaning there could be little incentive to change practices. A common theme to reducing barriers to uptake was to make it easier and less risky for decision makers to specify and use alternative materials, with ready access to information on reliable sources of alternatives to high-grade virgin aggregates. Specific recommendations based on their findings are noted in Table 3.2.

[3] For clarity, this report uses the term 'premium' materials to refer to high-grade (M/4 and M6) virgin-quarried materials for road pavement construction. The term 'alternative materials' is used to cover recycled materials (eg crushed concrete) and marginal-grade virgin-quarried materials. 'Recycled materials' are not distinguished by grade and therefore, this term includes all grades.

Table 3.2 Supply- and demand-related initiatives to increase resource efficiency (adapted from data in Mora et al., 2019)

Owner	Initiative
Waka Kotahi	Database: An accessible database for all aggregate products could assist the coordination of supply and demand. The database could include: • spatial information • cost factors such as transfer costs • time-sensitive information on availability • link with suitability of materials for different uses. A database could start with existing quarry and recycling plants and their 'business as usual' products and then add in 'live' data of temporary stocks (eg from demolition).
Waka Kotahi	Supply timeline: Develop and show a timeline of the known supply of virgin aggregates across the country to show the supply challenge. The timeline could incorporate the regional and national costs of developing new quarries.
Industry	Collaboration initiatives: Share information on supply and demand for alternative materials, such as CivilShare (http://civilshare.co.nz/). This could be based on the New Zealand Geotech Database initiative that arose from the need for greater efficiency in knowledge sharing of geotechnical assessments in post-earthquake Christchurch, which has since become a national initiative.

According to the literature, a ready supply of virgin aggregates close to centres of demand has kept prices low and disincentivised capital investment into recycled-aggregate supply chains, which has, in turn, affected cost, volume and quality (Alabaster, 2005; Bailey et al., 2001; Lane, 2017; O'Donnell et al., 2018). The pattern observed in New Zealand is mirrored internationally (Hassan et al., 2004), although in overseas jurisdictions, demand driven by post-war reconstruction created high demand coupled with a ready supply of recycled aggregate material, which fostered the development of recycling technology, facilities and knowledge base. In New Zealand, fluctuations in demand have been closely linked with economic prosperity (Lane, 2017). Findings from stakeholder surveys and case studies have suggested that demand fluctuations further disincentivise (Alabaster, 2005; Pidwerbesky, 2015) long-term capital investments into recycled-aggregate supply chains (O'Donnell et al., 2018). In New Zealand, government consumption accounts for a substantial portion (56% in 2012) of aggregate production (Lane, 2017), making the government a key lever in the market. Respondents to a national survey by O'Donnell et al. (2018) observed a limited mandate by clients for the use of recycled materials, including Waka Kotahi. During in-depth interviews by Mora et al. (2019), Waka Kotahi and Auckland Transport were identified as key leaders in encouraging the greater use of recycled materials.

Although aggregate supply is technically large across the nation, sources close to centres of demand are becoming depleted or operationally limited, due to urban encroachment. Production is also uneven, with premium-grade aggregates accounting for approximately 10% of all output and the highest grades sourced from a minority of quarries (Lane, 2017). In turn, survey and case study findings have suggested that inadequate or unreliable supplies of recycled aggregates (because of distance, available volumes or quality) are impediments to specifying recycled aggregates in contemporary projects (O'Donnell et al., 2018). The respondents reported that while demand was far outstripping supply, the cost of scaling production might not be viable in an economy of New Zealand's size. The researchers found that despite the growing cost of virgin aggregates because of dwindling supply, consumers consistently 'over-specified' virgin aggregates when there were viable alternatives from technical, policy and economic standpoints (Mora et al., 2019; O'Donnell et al., 2018), which Lane (2017) described as creating 'unnecessary demand'.

Researchers have found that over-specification of virgin supplies and depressed demand for recycled aggregates could be partly the result of knowledge gaps. Their participants identified gaps in information about the location, quality and reliability of recycled aggregate sources, along with technical knowledge about standards and specifications for alternative materials. Their survey findings indicated that risk aversion was incentivising the use of virgin aggregates over recycled alternatives, and that having general experience in using recycled aggregates was relatively rare (O'Donnell et al., 2018).

Respondents to the national survey conducted by O'Donnell et al. (2018) reported that the externalities they were aware of (eg noise, dust) were only minor barriers to increased use of recycled materials. However, the evidence from the wider literature suggests that market failure has meant that a failure to account for environmental and social costs of aggregate production and supply, as well as benefits in the current aggregates market, has substantially shifted the cost–benefit balance in favour of using recycled aggregates in recent projects (Hannaby et al., 2015; Lane, 2017; Paling et al., 2010; Slaughter, 2005; Wu et al., 2015). Transport costs, for example, were identified as critical factors that could go unmeasured on a per-vehicle, per-load basis (Baas, 2012). Local and international literature has cited the need for a life-cycle perspective that factors in both such externalities, in addition to the capital investment and lead times required to develop reliable supplies of recycled aggregates (O'Donnell et al., 2018).

Overarching barriers to the use of alternative materials have been further explored through in-depth interviews (O'Donnell et al., 2018). They found that in terms of supply and demand, the key barriers were (1) perceived risk from supply chain issues as well as performance costs and working outside of standard practices, and (2) the use of alternative materials requiring additional effort in managing supplies and signoff or work to demonstrate the benefits.

Waka Kotahi, national agencies and some transport controlling authorities are increasingly encouraging the use of sustainability-rating schemes (eg the Infrastructure Sustainability Council of Australia – ISCA) to prioritise lower carbon emission options. The Green Building Council has points for the recycling of aggregates, promoting the use of them in vertical builds. In a future de-carbonised economy, low- or no-carbon options will be preferred. Having mechanisms in place to promote their use will be important, alongside the implementation of procurement practices that consider social, cultural and environmental objectives rather than primarily lowest cost, which has been the traditional model to date.

3.3 Aggregate demand data sources from land transport infrastructure

There is currently very little literature or knowledge about the demand for aggregates for land transport infrastructure per section length of infrastructure type, both in New Zealand and internationally. Some countries (eg Canada) have undertaken studies to determine the ranges of commodities (raw materials) per building type and some ranges for infrastructure for utilities (Coriolis Consulting Corp., 1996). However, the nature of building construction and horizontal infrastructure is very different in New Zealand, compared with US practices, and their findings cannot be directly related here.

Our research reviewed a range of existing data sources in New Zealand to try to determine generic aggregate quantities in relation to various types of transport infrastructure and maintenance treatments. The following data sources were investigated:

- Road Asset Assessment and Maintenance Management (RAMM) database
- proprietary RCA maintenance databases – eg Auckland Transport
- Infrastructure Commission Forward Works Programme (recently developed and expanded from the Christchurch Rebuild Forward Works Programme)
- NZP&M data held at MBIE
- specific project as-built construction drawings and quantity estimates from schedules of quantities.

3.4 Geospatial modelling of mineral resources

Hagemann et al. (2016) referred to mineral system modelling as a type of theoretical and holistic model that could be used to theorise the formation of ore across various geological and geospatial scales.

Hill (2018) used a mineral potential modelling approach to identify the possible locations of quarries in the future. Maps were created using GIS software to represent explorations of aggregate sources, using the environmental, geological, statistical and geographical data that was available. Out of the 30-plus predictive maps, Hill chose 19 suitable maps to finalise the modelling process and combined them using fuzzy logic spatial modelling, taking into account the sources of rocks, the demand for aggregates, environmental restrictions, infrastructural supports and cultural sensitivity.

To create the predictive map, Hill (2018) used various spatial techniques, such as:

- classification of area
- analysing the distance
- using zonal statistics
- fuzzification formula
- spatial statistics from New Zealand quarries.

The various geographic layers of maps that formed the aggregate resource opportunity map created by Hill (2018) is shown in Figure 3.9. The 19 predictive maps representing the mapping criteria were combined into component maps, which were then combined into a final aggregate mineral potential map and shown for the lower North Island (see Figure 3.10). However, it is noted that the aggregate mineral potential model did not specifically account for land areas for which the ownership was either by iwi/hapū or still unresolved due to Treaty of Waitangi claims. Māori interests in land and waterways (Te Mana o te Wai and especially in relation to alluvial extraction) must be incorporated into future considerations.

Figure 3.9 Geographic information used to create an aggregate resource opportunity map (Hill, 2018, p. 160)

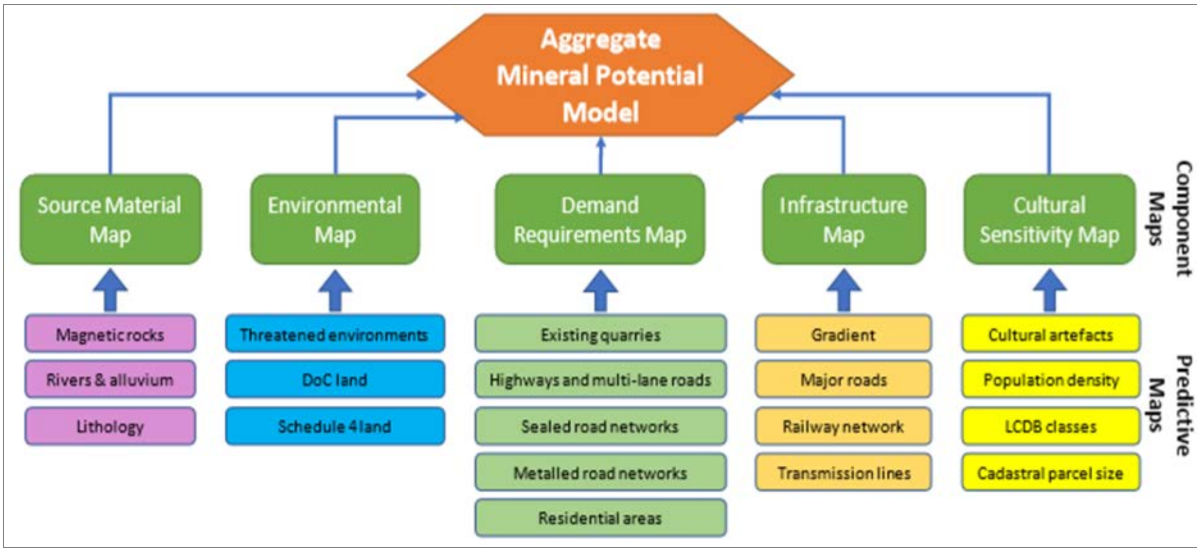
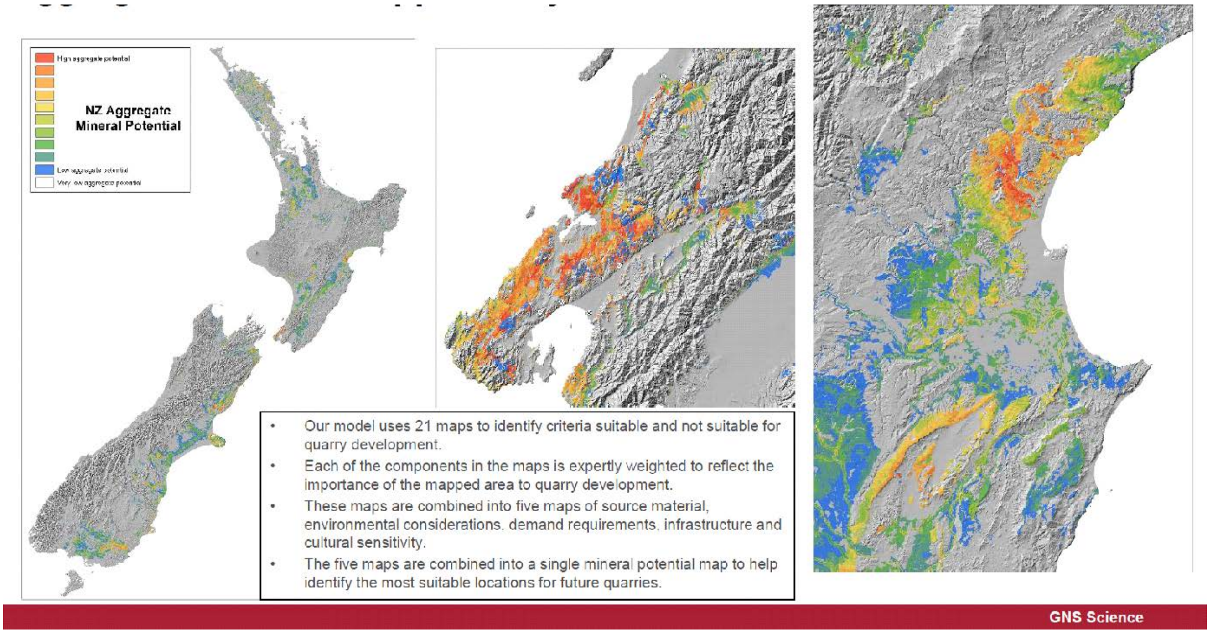


Figure 3.10 Aggregate resource opportunity map model (Hill, 2018, p.161)



Hill's (2018) models accounted for the proximity of current quarries that met the local market demand and showed that these areas were largely near the major urban centres.

Durance et al. (2018) also used a spatial modelling approach to combine the mappable criteria, using GIS software to create a nickel and cobalt mineral model for New Zealand (important minerals in relation to batteries required for the increased electrification of the transport fleet). The model depicted potential regions with the highest nickel and cobalt mineralisation. The regions included in this study were Nelson, Tasman and Marlborough, located in the north of the South Island.

3.5 Summary of existing data sources

In summary, there are several existing sources of data, from geospatial data to databases that relate to aggregate supply and demand for public land transport infrastructure projects, including both new capital expenditure (CAPEX) investment and maintenance treatments, held within various central, regional or local government agencies. None of the data sources are currently in a form that can be easily data mined or aggregated to gain cross-sector inferences regarding the national aggregate supply and demand in relation to future infrastructure demand. Table 3.3 identifies the various sources of data, their types and their known advantages/disadvantages with respect to being able to use the data set to improve resource efficiency and industry sector understanding, or to enable practices that are more sustainable.

Table 3.3 Summary of existing data sources

Data sources	Data types	Advantages	Disadvantages/issues
NZP&M National Data (MBIE)	Annual national survey	• National data • Annual data • Best available data • Is a requirement of quarry consent when consent is with the Crown • Most large quarry owners do provide data • Participation is encouraged by AQA	• Currently voluntary for non-Crown-consented quarry owners, not full participation • Rates have decreased in 2018 (64%) • Not disaggregated enough to consider quality of product • Does not include recycled materials • Accuracy of quantity estimates is unknown
• Quarry consents (regional councils) • Resource Management Act (RMA)	• Land use planning consents • Environmental monitoring	• Regional focus • Can consider demand and effects on environment and local communities, including iwi/hapū • Significant variation by operator and region • Business/employment opportunities	• No real link to operation of quarry once consent approved • Little monitoring of wider effects, other than if complaints are made • Not separated by quality of product or volume of extraction • Resource reserves by region not monitored in relation to demand • Significant variation in quality of information across New Zealand/regions • Significant issues with adjacent communities, buffer zones, long-term use and historical injustices to Māori • Urban growth/expansion pressures • NIMBYism often prevents appropriate resource planning and management • RMA under revision, not currently meeting expected outcomes
RCAs	RAMM Database	• All New Zealand RCAs have used RAMM since 1990s • Has good inventory and condition data for existing assets • Has historic road asset data	• Difficult to mine globally • Quantities of aggregate not an asset item and source mostly not recorded • In places, aggregate volumes not readily available
Waka Kotahi	Asset achievement data	All projects that receive Waka Kotahi funding are required to provide achievement data	General sector access to data not currently available, as purpose of data is for auditing

Data sources	Data types	Advantages	Disadvantages/issues
Aggregate Performance Method (Stantec on behalf of Waka Kotahi)	Aggregate surface performance database by quarry source for road safety performance	Relates aggregate source properties, by quarry, for resistance to polishing in New Zealand to high-speed data skid-resistance performance measured by the Sideway Coefficient Routine Investigatory Machine (SCRIM)	Is only related to the performance of surfacing aggregate on one performance variable (resistance to microtextural polishing) but provides a good example of what can be achieved Does not consider other aggregate qualities
GIS mapping of aggregate opportunities	GNS Science	Have recently digitised previous NZMS series maps with various map layers eg geology, quarry sites (see Hill, 2018), which has allowed the development of an aggregate opportunities map	Access to data – it is unclear whether the opportunities maps and the various layers are open source and available for industry to use alongside other data sets that are important to consider While mapping of aggregate opportunities (showing not only the endowment of mineralogical resources but also areas of environmental and cultural sensitivities) is important, this is only part of the required aggregate framework – regional demand, quantity and quality aspects must also be a consideration
Infrastructure Commission Pipeline https://www.tewaihanga.govt.nz/projects/pipeline/	Forward Works Programme – built on the success of the Christchurch Forward Works Programme post the 2011 Christchurch earthquakes	• GIS-based programme • Information can be relatively easily updated • Is regionally based • Could be expanded to include raw materials	• New project information must be uploaded by Infrastructure Commission staff • Currently little ability to ensure the quality of the data is good • Currently is a list of projects (the project pipeline) across all sectors, their assessed construction costs and planned timeframe to construction market release – it does not consider any raw materials, including aggregate volume estimates

4 Existing data sources, gaps and needs

4.1 Geology and aggregates (natural endowments)

The roading industry is a significant consumer of aggregate and places around 24 million tonnes[4] per year of high-quality material on New Zealand's public and private road networks and on industrial pavements as base and surfacing material. New Zealand road pavements are predominantly of flexible unbound pavement construction due to relatively low traffic volumes; therefore, they require more regular maintenance intervention. Approximately 40 to 50% of the National and Regional Land Transport Programmes (~$4.5 B per year from the National Land Transport Fund and an additional $1.0 B per year from local government rate payers) is related to the maintenance and operation of the existing road network. The remaining 50 to 60% of funding is allocated to new transport infrastructure or services (eg public transport, cycling, walking and travel demand management). The concrete industry also consumes a significant proportion of New Zealand's aggregate production.

In New Zealand, while most aggregates for transport pavements are sourced from greywacke and volcanic rocks, a range of different rock types can be recognised within these two large groupings. Each rock type produces aggregate with a matrix of properties that are determined by the nature of its mineral and other constituents, as well as how these are arranged and held within the rock.

Although a quarry may exploit a single geological rock type, the engineering properties of the material may change markedly at various locations and even within a quarry itself. These changes may simply be the result of a greater level of weathering near the top of the quarry face, grain size or compositional variations within the rock itself, local crushing caused by shear and fault zones cutting the rock, or varying degrees of thermo-chemical (hydro-thermal) alteration. This is one reason for the engineering infrastructure industry being required to regularly sample and test the properties of aggregate being used for infrastructure.

As discussed earlier, in comparison to many countries, New Zealand is well endowed with vast geological rock formations across the country, especially the areas around the central alpine fault lines of both the North and South Islands (see Figure 4.1). This rock, if extracted, can be manufactured in many cases to produce good-quality aggregates for public and private infrastructure purposes. However, New Zealand is geologically very young and active, which means the variation in performance of aggregates even within the same geologic material is significant. Additionally, the rock formations are not evenly spread across the country and therefore, some areas/regions have significantly greater access opportunities to rock formations than others, especially when areas that are environmentally and culturally sensitive are also removed from potential use.

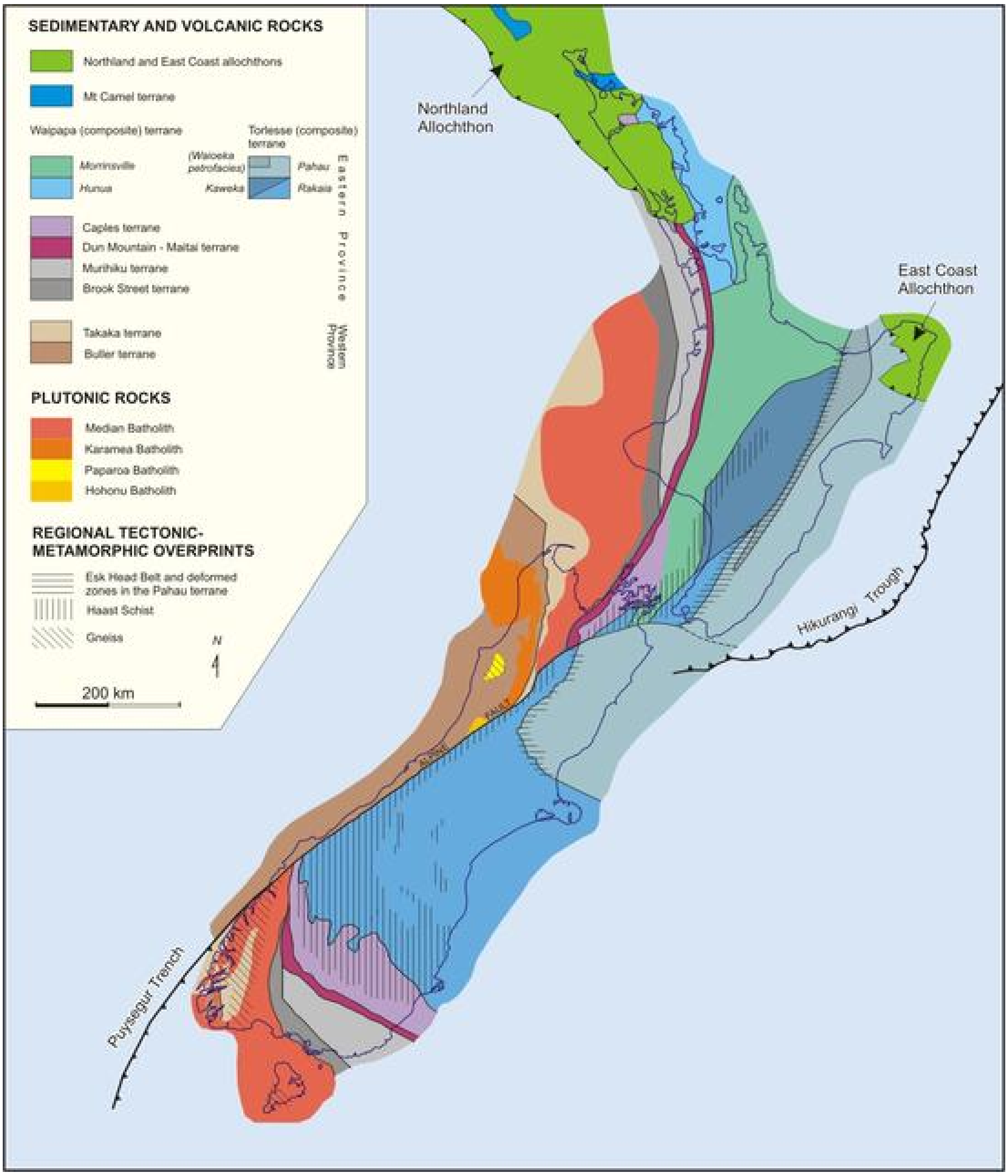
As shown in Figure 4.2, greywacke aggregates are the predominant source rock that forms approximately 75% of the aggregates used in land transport. However, greywackes have very variable properties; five different types can be recognised, each with a distinctive matrix of engineering properties (Black, 2009). Two of the greywacke types (Waipapa and Torlesse) have very high crushing resistance values. The low contents of fines produced can mean that sometimes these aggregates do not achieve target particle size distributions within the M/4 prescribed 'premium'-quality envelope without further production processing; in some instances they can be categorised as 'marginal'.

Gravels derived from the Torlesse-type greywackes forming the axial ranges of the North Island are the major aggregate resource for the Hawke's Bay, Manawatū, Wairarapa, Whanganui and Wellington districts. Since greywackes, even of a single type, have variations in properties, and large areas of greywacke are

[4] 2018 data.

being eroded to shed material into the river systems, the individual pebbles/boulders show a range of grain sizes and colours, although all appear to be Torlesse-type. Very small amounts of chocolate or reddish-coloured chert and igneous pebbles (both found in Torlesse–terrane greywacke sequences) can appear in some gravels.

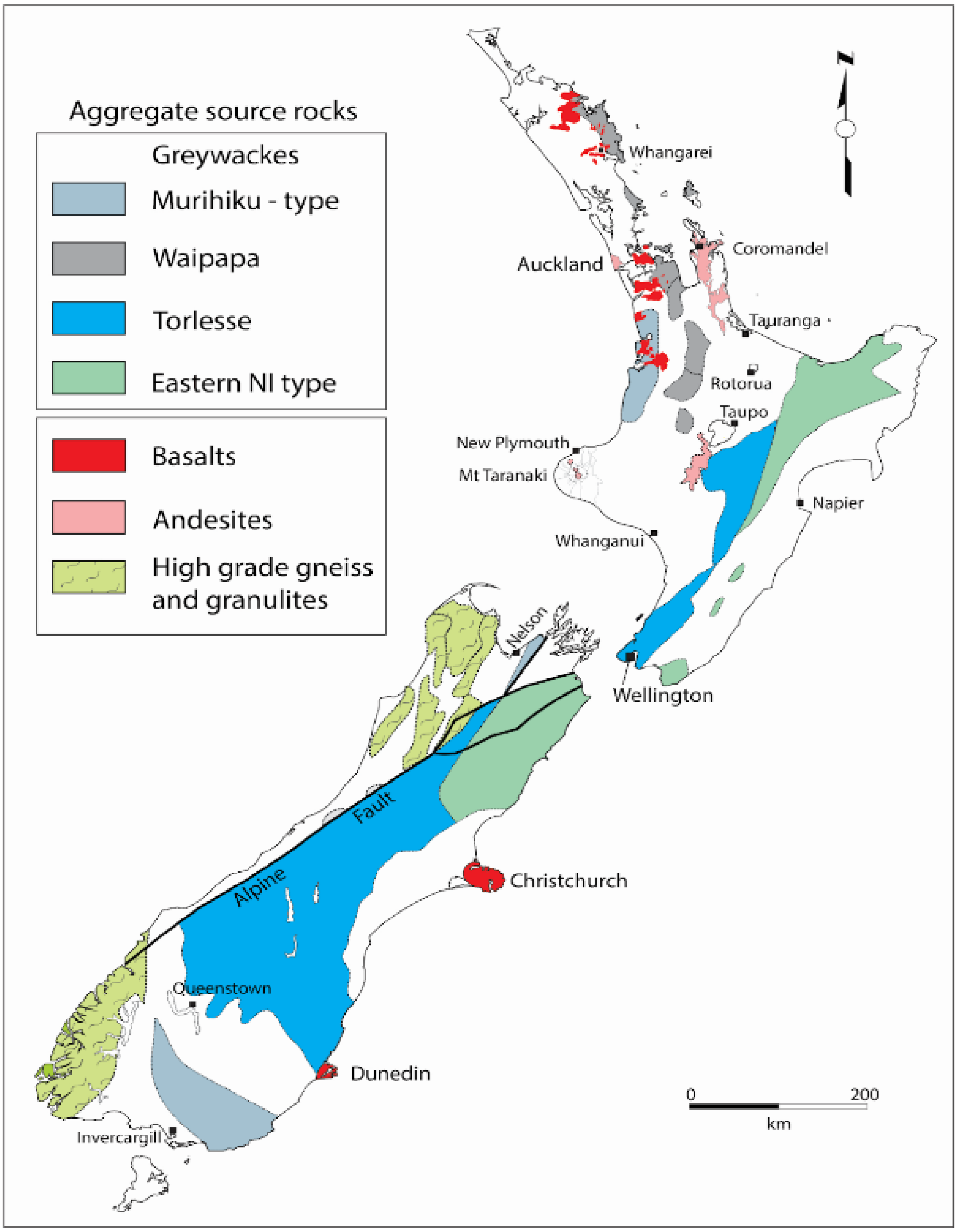
Figure 4.1 Geological map of New Zealand (reprinted from GNS Science website[5])



Natural sorting and abrasion during river transport have largely eliminated all the weaker rocks and generally provide a very clean resource that produces aggregate with properties in the high end of Torlesse-type greywackes.

[5] https://www.gns.cri.nz/Home/Our-Science/Land-and-Marine-Geoscience/Regional-Geology/Geological-Origins/Basement-terranes-of-New-Zealand

Figure 4.2 Aggregate geological source characteristics in New Zealand (Wilson et al., 2019, slide 35)



Volcanic rocks that form approximately 25% of the aggregates used in roading are a major resource for aggregate production in the North Island. The quality and nature of the aggregate resource is a function of the rock type (its chemistry and mineral content), as well as the environment into which it was erupted.

Three different types of basaltic aggregate sources are recognised: young intraplate basalts extending from the Bay of Islands to South Auckland and west Waikato; ophiolite basalts (Northland and East Cape); and arc-related basalts (includes basaltic andesites) in Northland, Coromandel Peninsula and the Rotorua–Taupō volcanic zone.

Other volcanic rocks used in road aggregates are andesites, which are commonly quarried in Northland and the Taupō region and are the major aggregate resource for the Coromandel–Bay of Plenty region. Some dacites and rhyolites in the Taupō region, which erupted as part of the arc-related volcanism along the eastern side of Northland and in the Taupō area, are also used.

Aggregates derived from volcanic rocks all have moderate crushing resistance (10% fines produced at < 300 kN), high cleanness and Sand Equivalent (SE) values. Other properties of volcanic rocks depend on the source rock type and to a considerable extent, on whether they have been erupted in a terrestrial or marine environment.

Provided they have not been hydrothermally altered, basalts and andesites that have erupted on land have negligible clay and plasticity indices (a positive property for road infrastructure pavements), although weathering of volcanic rocks can produce some smectite and ultimately, kaolin clay (swelling clays) that are susceptible to moisture changes in road pavements.

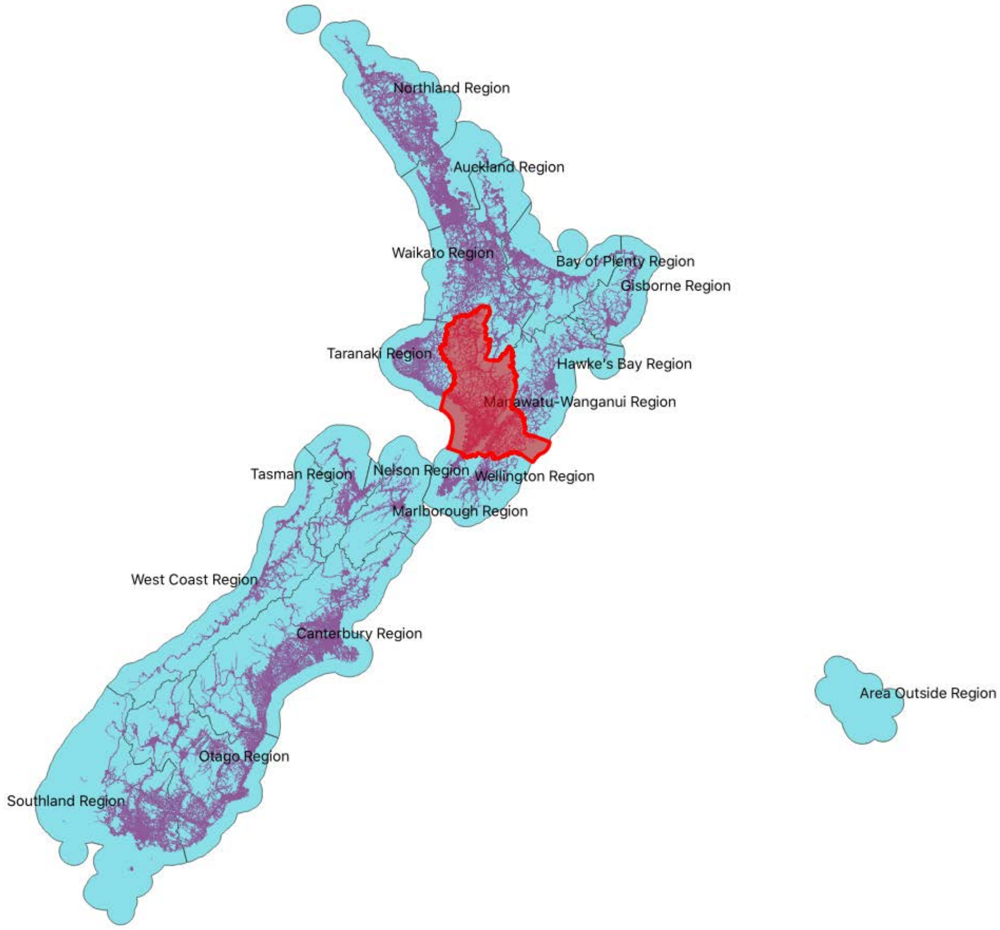
Eruption of basalts in a marine environment causes reactions between heated sea water and volcanic glass, forming smectite and zeolite, which are likely to be moisture sensitive and problematic for unbound granular road pavements.

4.2 Geographical mapping and geological characteristics

In this project, we used the data from Land Information New Zealand (LINZ) and Geoscience Society of New Zealand to explore the geospatial and geological characteristics of New Zealand. The data were incorporated into Q-GIS, which is a popular open-source software, to visualise and process the data.

Figure 4.3 shows a map of all regional councils in New Zealand. In this project, we specifically focused, as a case study, on the red-highlighted area, which is the Manawatū–Whanganui region or Horizons region (more details of this case study can be found in Chapter 6 of this report). The road network in New Zealand is also illustrated in purple in Figure 4.3.

Figure 4.3 Map of regional councils and road networks in New Zealand (based on data from the LINZ database)



4.3 Aggregate extraction and consenting requirements

In February 2019, an official request was made for information, under the Local Government Official Information and Meetings Act 1987, regarding quarrying consents (both new consents and extensions of existing consents) in the period 2016 to 2018 from the regional councils and territorial authorities in New Zealand. This information was requested to enable an evaluation of consent information to determine what data the applicants provided and what consenting authorities required in relation to aggregate supply and demand factors. The aim was to determine whether any useful data on quarry consents could be obtained on a regional basis, and then aggregated together with respect to supply and demand volumes, quality aspects, and the effects on adjacent communities, the environment and specifically, iwi/hapū. The information requested involved the:

- data held by each territorial authority for the period 2016 to 2018
- number of quarrying consents received and approved or declined
- details of each consent (restricted discretionary or other status), period of consent, geological type of aggregate (if known), volumes of aggregate and number of allowable truck movements
- special consent conditions (especially environmental protection/mitigation measures, buffer zones, etc).

Data obtained from regional, district and city councils provided the necessary information for this project. Some regional councils provided documents containing a summary of the consents. Most provided the consent request forms from the clients (with confidential information removed), which contained all the information requested.

Information relating to aggregate extraction or associated activities for 509 resource consents was received from 34 territorial authorities. Analysis of the consents revealed a lack of consistency in the information provided. This presented a significant challenge in collating the information into a specific format for analysis and building a national picture of aggregates in New Zealand.

Between 2016 and 2018, the Hawke's Bay Regional Council received the greatest number of consent applications (see Figure 4.4), comprising up to 43% of the 509 consents received. This was followed by Waikato Regional Council, which received 94 consent applications and as expected, most of the applications were for discharge permits, followed by permits related to land use, water and coastal activity. Most of the applications received by all regional councils were for land use consents (81%), followed by discharge and water use permits. However, more than half of the permits (68%) did not mention the type of activity (discretionary, restricted discretionary, etc) that was going to be carried out (see Figure 4.5), but 23% were for carrying out discretionary activities for which the approving authorities could grant or decline the consent, with or without conditions.

Figure 4.4 Number of consents seeking aggregate use between 2016 and 2018 (from information obtained from local and regional authorities in New Zealand)

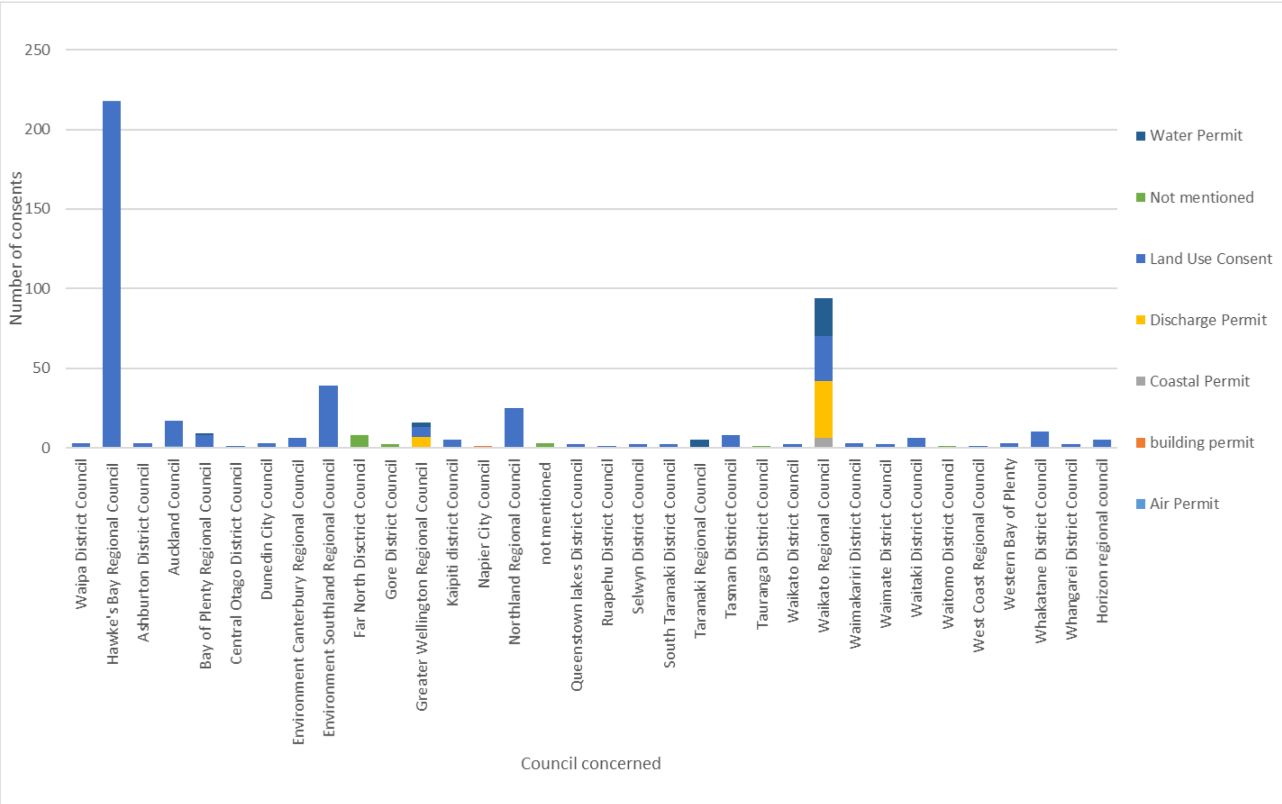
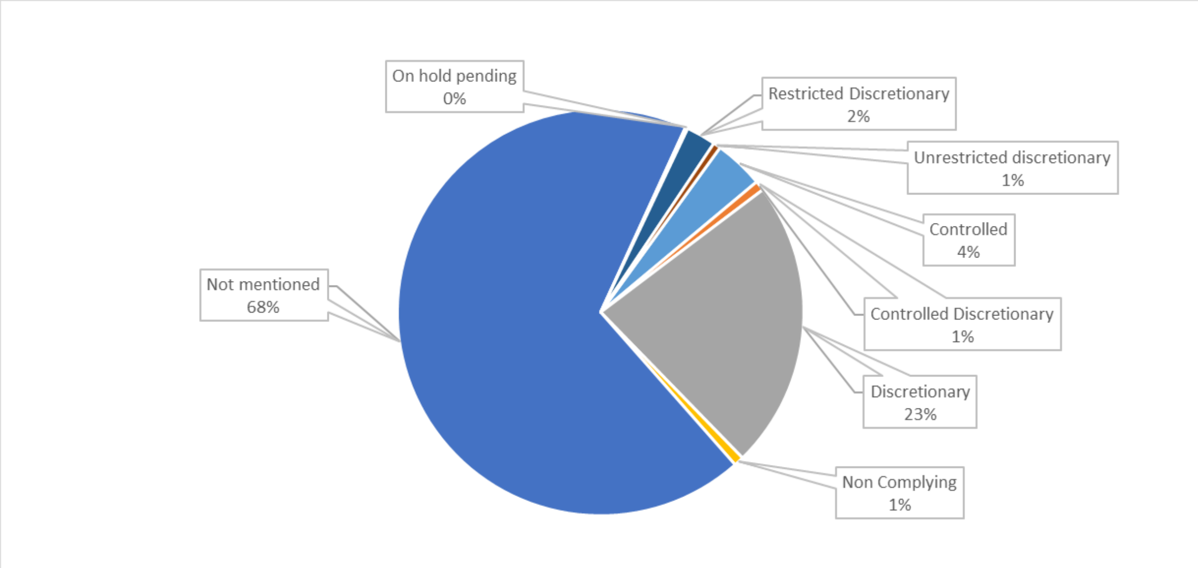


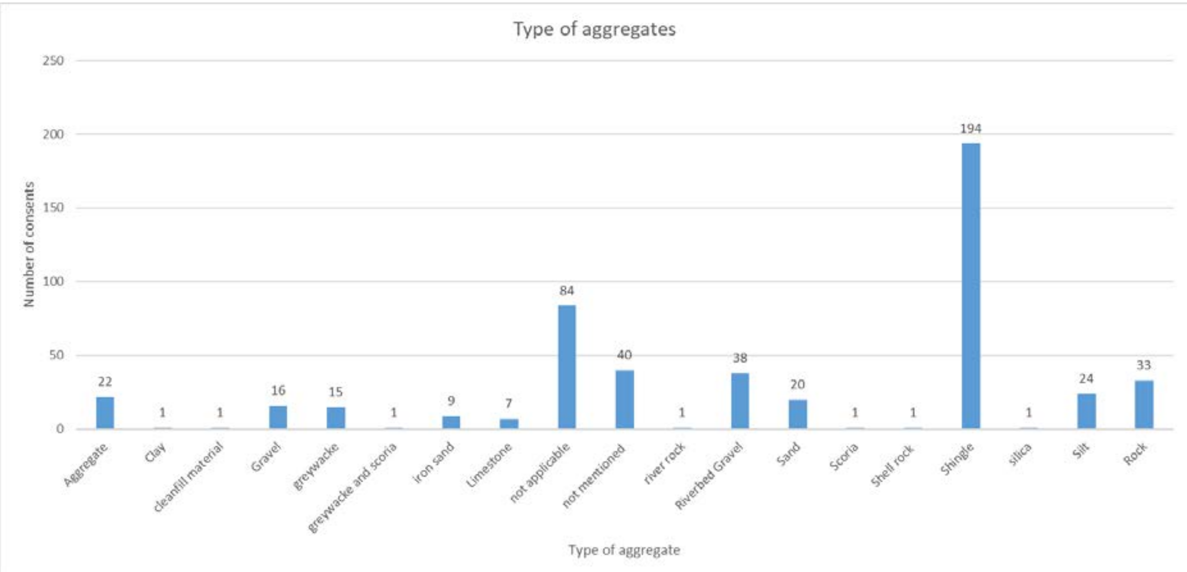
Figure 4.5 Type of activity



Of the resource consents that did not require information on rock type (other than discharge, air, water and building permits), the vast majority did not mention the geological classification of rocks. Of the remainder, 11 resource consents required extraction of basalt, which was the most mined rock type.

Overall, 17 different types of bulk aggregate-based mineral resource were extracted during this period (see Figure 4.6), with shingle the most extracted aggregate resource identified (194 resource consents). This was followed by riverbed gravel and aggregate extracted by quarrying rocks. Some of the non-quarrying-related applications were categorised under the 'not mentioned' and 'not applicable' categories.

Figure 4.6 Bulk aggregate mineral resource identified in the resource consent



Unfortunately, the review of data obtained from this Official Information Act request demonstrated that very little useful data could be obtained from both quarry consent applications and the responses from the consenting authorities. In general, there was a very large variation in the quality of the quarry consent applications, with a significant proportion not even identifying the geological aggregate formation that they were seeking consent to extract. This meant that aggregate quantities, quality and demand (regarding truck movements), and the effects on local communities, environment, other resources (eg water) and iwi/hapū, were mostly not appropriately evaluated. However, there were some good examples that could be used to help create a template for applicants to use in the future.

4.4 Transportation infrastructure planning and design construction data

In general in New Zealand, the only data sources in which actual quantities in relation to specific aggregate product demand can be related to various infrastructure typologies are project infrastructure files, as-built drawings, typical cross sections and tendering schedules of quantities held within RCAs or their consultant offices. To gain this information and relate it to variables such as subgrade strength and design traffic volumes is a very time- and resource-intensive manual process and in many cases, RCAs can be reluctant to give access to project files. However, these material quantities are placed in project schedules of quantity estimates for tendering purposes and held by RCAs, as well as in tendered prices for item values. In the past, it was standard practice for the Ministry of Works to hold internal quantity-surveying databases, by region, for estimation purposes. It seems that this is no longer the case but it would be very useful if this information could be collated within regions and aggregated nationally.

For this research project, the decision was made to identify typical ranges of demand for aggregate quantities (basecourse and subbase) per km, given various design scenarios (eg low or high underlying subgrade strength and low, medium or high traffic volume loadings) from various road cross-sectional standards from recent and planned infrastructure projects. The estimates in demand did not include the typical bulk earthwork volumes required to bring the road formation up (or down) to the subgrade formation level upon which the pavement layers would be placed. The quantities also did not consider aggregate demand for concrete (eg bridges, kerbs, channels, footpaths, cycleways, stormwater and other utilities, retaining walls, and specific aggregate drainage/bedding materials); these comprised a subset of total infrastructure aggregate demand. Table 4.1 summarises the unbound pavement material layer aggregate demand data that was calculated from various sources.

Table 4.1 Aggregate demand in road pavement layers, by various road typologies

Road type descriptor /quantities	Urban local road	Urban collector road	Urban principal arterial	Rural 2-lane 2-way state highway	Rural 4-lane divided state highway expressway
No. of traffic lanes & lane width	2 × 3 m	2 × 3.5 m	8 × 3 m	2 × 3.5 m	4 × 3.5 m
Shoulder width	2.2 m	2.2 m	1.8 m	2 m	2.5 m
Central median width	NA	NA	2.5 m	NA	9 m
Total sealed surface width	10.4 m	15 m	27.6 m	11 m	19 m
Estimated equivalent standard axles (ESAs) low to high	3.6 × 105 ESAs	1.1 × 106 ESAs	2 × 107 ESAs	1 × 106 ESAs	2 x 107 ESAs
Aggregate basecourse quantities (low to high range) tonnes per km	32,451–37,452	5,400	13,005	38,851–41,802	11,000

Road type descriptor /quantities	Urban local road	Urban collector road	Urban principal arterial	Rural 2-lane 2-way state highway	Rural 4-lane divided state highway expressway
Aggregate subbase quantities (low to high range) tonnes per km	37,453–82,402	61,203–144,002	122,853–361,202	68,653–151,202	114,903–391,402
Sealed surface area (m^2)	10,400	15,000	27,600	11,000	19,000

Note: Low range is for high subgrade strength (CBR = 10). High range is for low subgrade strength (CBR = 3).

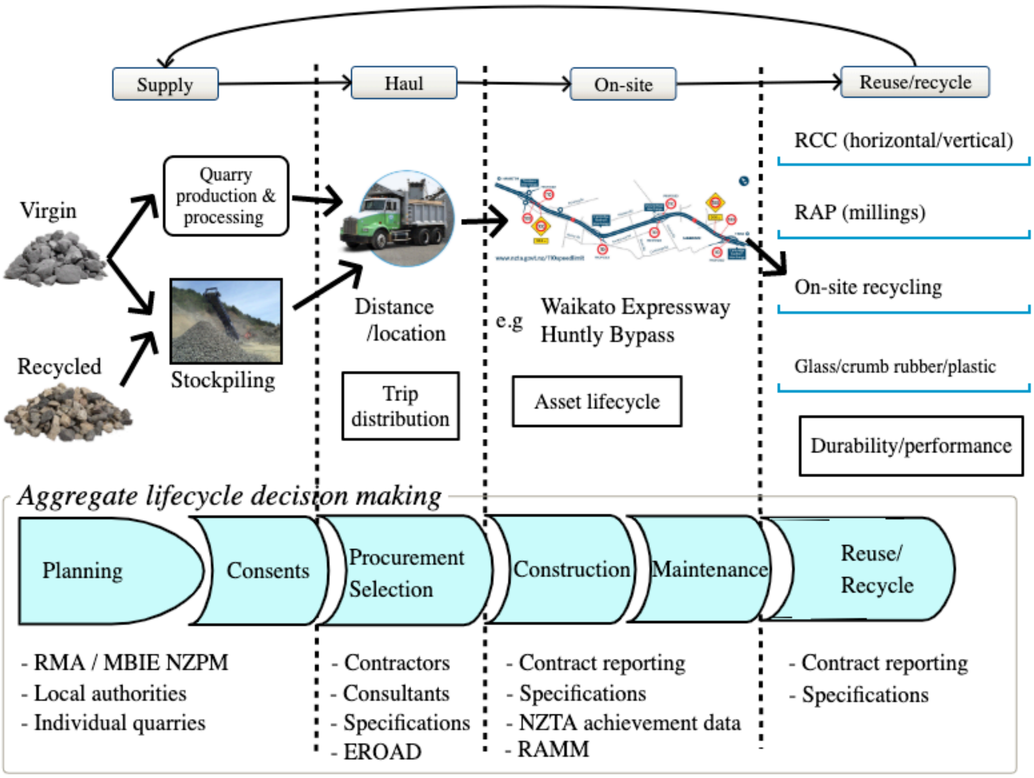
The analysis and data shown in Table 4.1 indicates that the demand for aggregates for transport infrastructure can vary significantly as a function of traffic volumes and underlying foundation strength. Premium basecourse quantities per km can vary from 3,250 tonnes for a local urban road to 13,000 tonnes per km for an urban principal arterial and 11,000 tonnes per km for a rural 4-lane divided expressway. Additionally, subbase aggregate quantities for the same road typologies can range from 3,750 to 36,100 tonnes per km for urban roads and 39,100 tonnes per km for a rural 4-lane divided expressway. Generally, the lower the strength of the foundation material and the greater the traffic volumes, the greater the depth of pavement layer and volume of aggregate required to reduce traffic-induced stress and strain in the underlying road foundations.

Alternative pavement design strategies can be deployed to reduce the depth of pavement layers and quantities of aggregates on low-strength foundations by using subgrade or aggregate improvement techniques (eg in-situ lime or cement stabilisation). Although these methods can both reduce aggregate dependency and optimise pavement costs per square metre or lineal pavement length, in many existing cases this resource use optimisation has not been adequately considered through the investigation and design stage of infrastructure projects. Resource usage that is more sustainable can be encouraged by incorporating design and selection strategies that aim to minimise the carbon footprint of transport infrastructure construction and maintenance practices. Currently, there is not enough data available to enable undertaking this kind of design strategy analysis.

4.5 Distances aggregates are transported

To analyse truck journeys, this research used telematics data from EROAD, one of New Zealand's leading providers of fully integrated technology, tolling and services. The term 'telematics data' refers to a combination of data in 'telecommunications' and 'informatics'. EROAD provides the telecommunications system to send, receive and store the location and timestamps of a large proportion of the commercial truck fleets in New Zealand. Figure 4.7 demonstrates the data analytics workflow in this project to analyse the telematics data from EROAD.

Figure 4.7 The telematic data analytics workflow, using EROAD data



The hauling of aggregates from suppliers of virgin and recycled materials was analysed to on-sites and to recycle yards. The aim of this exercise was to examine the current distances of aggregate transport journeys and obtain insights on how they could potentially be reduced to shorter, ideal distances to minimise the costs and negative impacts of transporting aggregates.

The study initially noted the locations of suppliers (ie aggregate quarries) on a geographical map, using LINZ GIS data. Since there were more than 1,000 quarries in the LINZ data, the focus was on a smaller, selected list of 15 quarries across New Zealand, to demonstrate the benefits of truck data analytics (see Figure 4.8).

Figure 4.8 Location of selected quarries across New Zealand

The EROAD data were collected with the following considerations:

- The data covered from 1 January 2019 to 31 December 2019.
- Only heavy vehicles were included.
- Quarries and worksites (eg the Huntly Bypass) had a ~300 m buffer to include locations that were not perfectly inside the provided geometry.
- To capture trips that did not 'ignition off' at the worksite, trips were derived from the data on either 'ignition' or 'vehicle moving' to either 'ignition off' or 'vehicle stopped'.
- Trips were combined into chains by grouping trips that had less than five minutes between the end of one trip and the start of another. Smaller trip-chaining thresholds resulted in longer trips.
- Trip chains had to start or stop in one of the supplied but geospatially different geometries.
- Trip chains that started and stopped in the same geometry were excluded.

Apart from the quarries, one significantly large Waka Kotahi construction site (the Huntly Bypass) was used as an example to determine how aggregates were being hauled to the Waikato Expressway site, as illustrated in Figure 4.9. The Huntly Bypass was a 15.2 km worksite that was under construction during 2019 at the time EROAD data was analysed, prior to the site being opened to general traffic. It was assumed that all trucks that visited this worksite from a quarry would be carrying some aggregate product.

Figure 4.9 Huntly Bypass case study (green section), as part of the Waikato Expressway

Table 4.2 shows some examples of EROAD data samples. Each line shows an individual trip chain from a 'start' quarry/worksite to an 'end' location, as well as the 'start' and 'end' timestamps, and the distance of this journey (in kms). The 'start' and 'end' columns name the start and end points of an individual trip.

Table 4.2 Examples of EROAD data

Start	End	Start timestamp	End timestamp	Distance (km)
Te Kowhai	Horotiu1	31/01/19 0:06	31/01/19 3:48	119.204
Otaka2	Waikanae1	26/09/19 3:43	26/09/19 4:23	27.891
Otaka2	Waikanae1	11/11/19 1:57	11/11/19 2:29	27.459
HUNTLY EXPRESS	Te Kowhai	30/09/19 22:29	30/09/19 23:16	18.987
Horotiu1	Horotiu2	20/02/19 19:40	20/02/19 19:54	3.562

The data was used to create Chord diagrams to visually represent the truck movements between the specified locations (see Figure 4.10), especially the movements between the Huntly Expressway worksite and the studied quarries (see Figure 4.11). A Chord diagram represents flows or connections between nodes. In this case, the nodes were aggregate quarries or work sites, represented by a fragment on the outer part of the circular layout, and the size of the fragment represented the popularity of the quarry in the data. The arcs between each node in Figures 4.10 and 4.11 are proportional to the number of journeys between that pair of locations.

Figure 4.10 A Chord diagram of truck movements between the selected locations

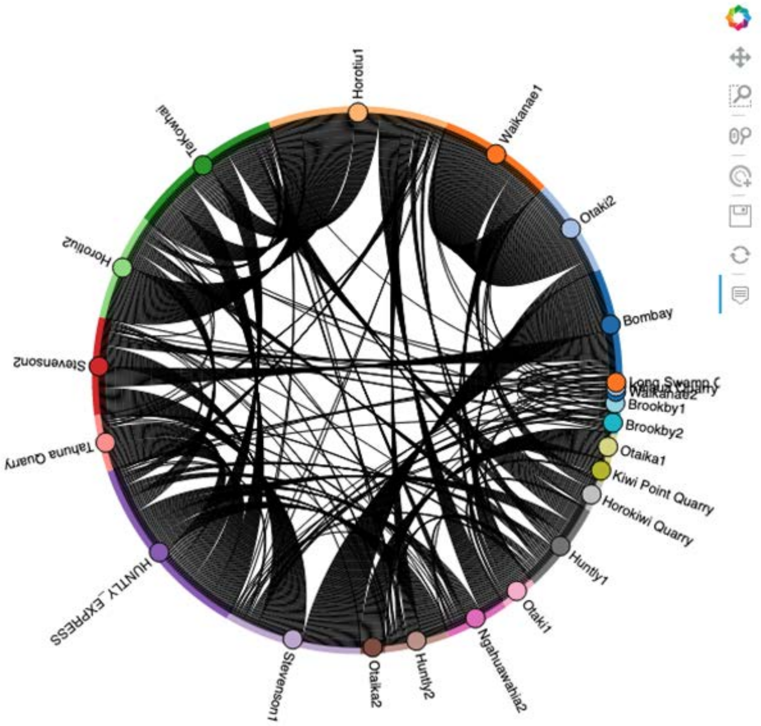


Figure 4.10 shows several large quarries with many truck movements (eg the Te Kowhai, Horotiu, Waikanae and Stevenson Quarries), which was expected as these quarries are among the largest in New Zealand. The figure also shows the Huntly Bypass worksite, which also attracted a significant number of truck trips. Figure 4.11 illustrates these truck journeys between the Huntly Bypass worksite and the studied quarries in more detail, leading to the following two distinct insights:

- From the map in Figure 4.8 and the Chord diagram in Figure 4.11, it can be seen that most of the journeys to and from the Huntly Bypass were from quarries close to Huntly, such as the Te Kowhai, Horotiu and Tahuna Quarries.
- Eleven different quarries had trucks moving to or from the Huntly Bypass worksite and many of these were some distance away, suggesting a potential inefficiency in the hauling distance of aggregate. However, the purposes of the trips between these locations are unknown and they could have been related to other required activities and not aggregate haulage.

Figure 4.12 illustrates the distribution of journey start times through a particular day, showing that most truck journeys started within the peak traffic periods between 5:30 am and 3:30 pm. These time constraints could have been due to required quarry or construction site working conditions, such as to reduce noise in communities or on specific urban roads. Some of these constraints may be addressed in the near to medium-term future, with the availability of electric (therefore quieter) and autonomous fleets (for driver-free transport of aggregates). Advances in optimising truck routes for carrying aggregates and truck start times may be able to find time windows and routes that satisfy certain requirements regarding noise and travel time. While these routes may potentially be longer, travelling during off-peak periods may mean shorter travel times and better overall efficiency. These specific optimisations were out of scope for this project but they could be explored in future research.

Figure 4.11 Truck movements between the Huntly Bypass worksite and the studied quarries

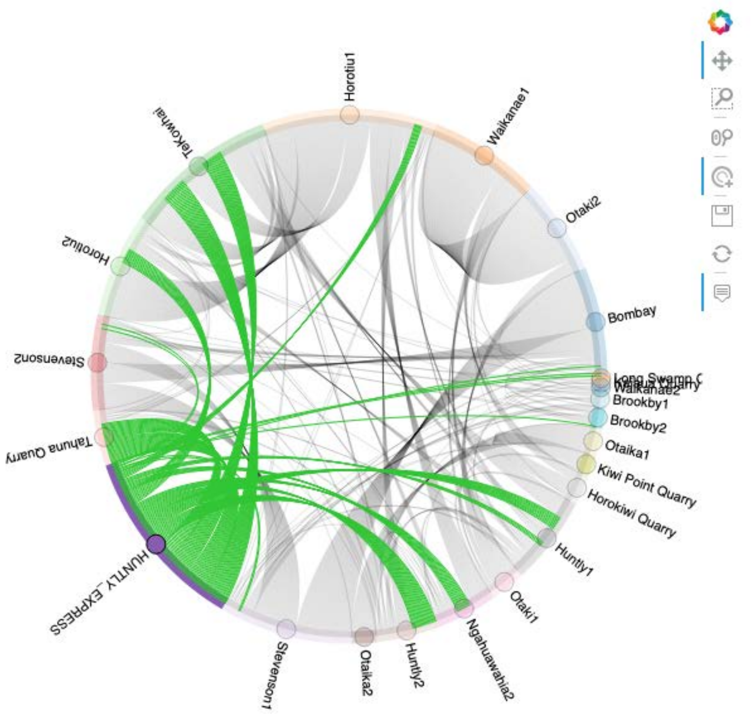
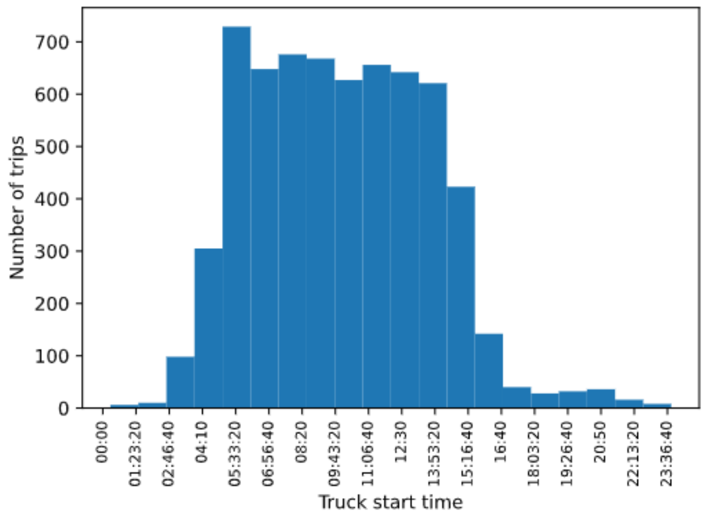
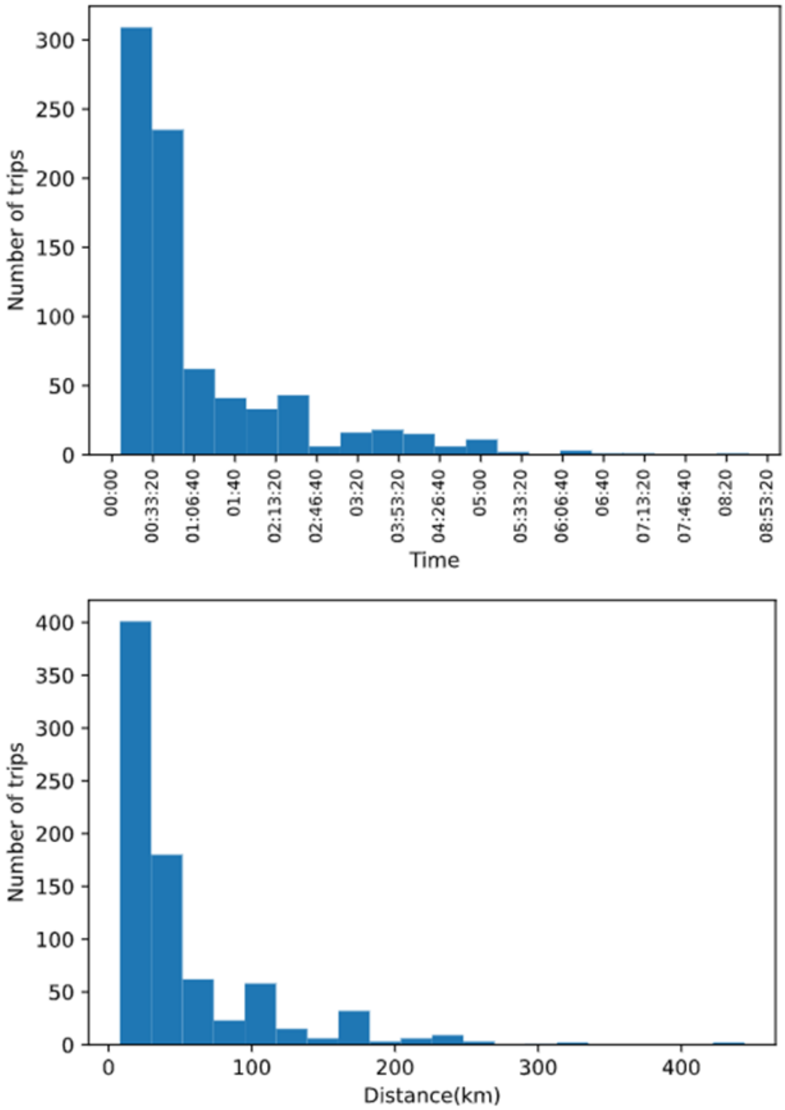


Figure 4.12 Distribution of truck start times within a day



The distributions of travel time and travel distance to the Huntly Bypass worksite were also examined, as illustrated in Figure 4.13. The figure shows that for both travel time and travel distance, the distributions were highly skewed to the left, showing that most of the journeys were short. Occasionally, aggregates could be transported from more than 300 km away, taking more than seven hours to haul in, although further analysis could have found that these were multiple truck trip chains for possibly transporting goods other than aggregates.

Figure 4.13 The distribution of travel distances and travel times between studied quarries and the Huntly Bypass



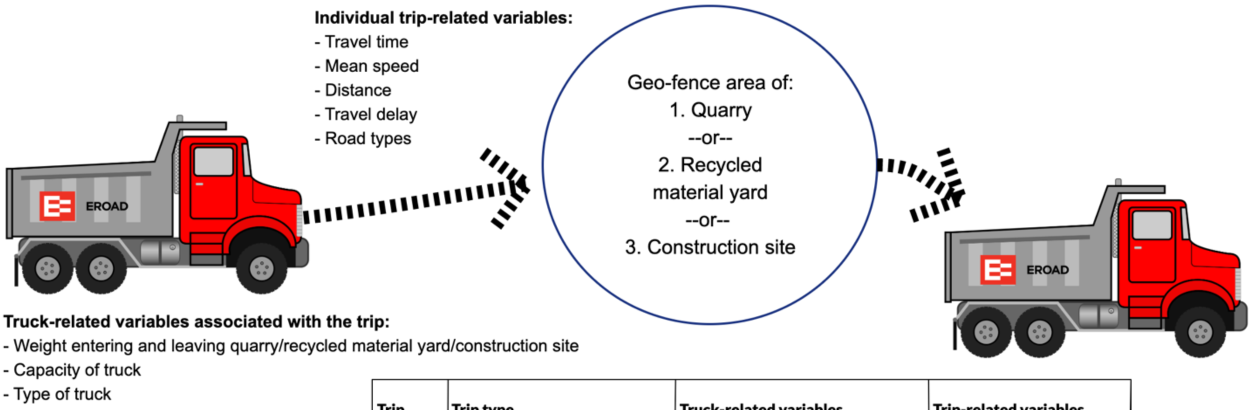
4.6 Data gaps and needs

In the previous section, an example of EROAD's telematics data was leveraged to allow insights regarding the movements of truck fleets between quarries and the Huntly Bypass worksite, as part of the construction of the Waikato Expressway. However, when comparing this information against the overall construction process that was illustrated in Figure 4.7, the following gaps in the dataset became apparent:

- In the Supply step, information on the type of aggregate (eg virgin vs recycled) being transported was missing.
- In the Haul step, although distance, location and trip distribution (spatially and temporally) were available, it could only be assumed, not confirmed, that the trucks were transporting aggregates.
- As noted in the previous section, the trip-chaining procedures also used some assumptions (eg the trucks' 'ignition' and a 300 m buffer zone around the quarries or worksites) because 'trip purpose' information was missing.
- Information on the re-use/recycle step was missing.

While the EROAD data was not originally collected for the purposes used in this research, it demonstrated how telematics data could be used to gain greater understanding of the movement of trucks and aggregates. A potential future telematics system that collected dynamic data of materials logistics (if they could be tagged, identified and tracked from place of origin to destination and potentially, on various road typologies) could become part of a very useful traffic operations and raw resource-use system, allowing further insights into the aggregate transportation process (see Figure 4.14).

Figure 4.14 Ideal dataset to provide insights into the aggregate transportation process



Trip	Trip type	Truck-related variables	Trip-related variables
1	To quarries or from construction site	Weight_enter, Weight_leave, Capacity, Type	Travel time, Speed, Distance, Delay, Road_types

The ideal dataset should include detailed data on the individual journeys of the truck fleet carrying aggregates from quarries to construction sites and recycled material yards. The included variables could be classified into trip-related and truck-related categories, as follows:

- trip-related variables – specific information about the truck journey, such as travel time, mean speed, distance, travel delay and the types of roads on which the truck travelled
- truck-related variables – information on the truck used for the above journey, such as the type of aggregates being transported, the weight/volume of aggregates, and the total capacity and type of truck.

These data would enable greater insights into the transportation of aggregates process, as well as offering an opportunity to optimise the travel distances and start times of such journeys. For instance, a shorter distance could be achieved if the sources of aggregates for construction sites or recycled material yards were optimised; the trucks could travel during off-peak periods to minimise both travel costs and negative impacts on the environment.

4.7 Aggregate supply and selection summary

In summary, the issues regarding aggregate supply and selection for transport pavements are complex and multi-layered, for the following key reasons:

- Aggregate endowment in New Zealand is abundant but increasingly, access to aggregate sources in various locations and regions is becoming more difficult.
- Aggregate sources are unequally distributed geospatially in relation to location and quality, and in some areas, premium-quality aggregate resources are under significant pressure.
- Transport infrastructure requires multiple aggregate products, rather than just one material (eg basecourse, subbase, drainage material, concrete, etc). This often means multiple sources are required.

- Locally sourced materials are always preferred, to reduce transport and product-to-site costs; however, specification requirements can mean locally sourced materials are not the most appropriate ones.
- In areas where premium resources are located near the site of use and easy to produce, there is little incentive to protect their sustainability on behalf of neighbouring regions that are more challenged in being able to produce premium resources.
- Increased transport haul distances of aggregates from source to site of use not only increases costs but also increases pavement deterioration, thereby reducing remaining pavement life.
- In some areas, especially where hard-rock quarries are not locally available, historic extraction practices have depended on alluvial extraction from existing or old riverbeds and demand may have outstripped replenishment (aggradation) rates, especially where hydro schemes have altered upper-catchment river flows.
- Demand for aggregate for public and private land transport infrastructure, nationally or within regions, is largely unknown and therefore, cannot be managed.
- Data on aggregate supply and the demand for various types of transport infrastructure are scarce or very difficult to obtain, which prevents the development of aggregated learnings. Advanced telematics data (such as EROAD) have the potential to provide richer insights regarding the carried aggregate, the types of trucks and the specific truck movements.
- There is a growing realisation, from the perspectives of both resource planning and resource use efficiency/sustainability, that as non-renewable resources, aggregate resources need to be managed more sustainably. With the availability of advanced data, future studies could explore the possibility of optimising truck start times and routes to improve efficiency and reduce travel times and negative impacts on our communities.
- A long-term partnership approach with iwi and hapū within regions would enable a te ao Māori approach, which acknowledges the interconnectedness and interrelationship of all living and non-living things, of Papatūānuku, whenua and mauri, to be applied to the aggregates industry to improve current and future practices. This approach would enable and encourage resource sharing and economic opportunities for Māori and rangatahi within regions (should iwi/hapū decide to participate), leading to the improved well-being of Māori and rural communities.

5 Industry survey and interviews

This engagement with the wider aggregates industry sought to gain better understanding of the information and forecasting needs that were required to support the sustainable use of aggregates. It used a mix of an online survey and interviews so that a national picture of the current situation could be developed, as well as drilling down into more detail on the emerging challenges.

The online Aggregates Supply and Demand Survey 2020 was completed by 89 participants between October 1 and October 15, 2020. Recruitment was through targeted emails to individuals and key champions within leading organisations. These people were invited to ‘snowball’ recruitment through their networks and organisations, to gain coverage that was as broad as possible.

The survey covered perceptions of supply shortages, nationally and regionally, and the challenges of managing supply. It also asked participants to consider how information was used to forecast supply and demand, as well as the challenges they faced obtaining and using the right information.

5.1 Participant characteristics

The larger regions were relatively well represented, with 15% of the participants coming from Auckland, 10% from Waikato, 8% from Wellington and 7% from Canterbury (see Table 5.1). However, no responses were received from Tasman or Nelson, and limited responses were received from Gisborne, Northland, Marlborough, Taranaki and the West Coast. Approximately a quarter of the survey participants (24%) stated they worked in multiple regions. Regions comprising > 5% of survey results are highlighted in green in Table 5.1.

The participants were asked to identify a region that they were aware had issues around aggregate supply and demand. Wellington was the region that was selected the most.

Table 5.1 Where the survey participants were from

Region	
Northland	1%
Auckland	15%
Waikato	10%
Bay of Plenty	7%
Gisborne	2%
Hawke's Bay	6%
Taranaki	1%
Manawatū-Whanganui	6%
Wellington	8%
Tasman	0%
Nelson	0%
Marlborough	1%
West Coast	1%
Canterbury	7%
Otago	8%
Southland	4%
Multiple regions	23%

Type of organisation	
Central government	15%
Local or regional government	9%
Engineering consultancy	18%
Construction company	19%
Virgin-materials supplier	30%
Recycled-materials supplier	1%
Transport infrastructure designer	0%
Industry or advocacy bodies	3%
Other	5%

When asked about the best term to describe their organisation, most participants selected 'virgin-materials supplier'. 'Engineering consultancy', 'construction company', 'central government' and 'local or regional government' were also well represented. No participants selected the 'transport infrastructure designer' option.

The survey sample represented a highly experienced workforce, with 67% having 16 years or more of experience (see Table 5.2). Only 9% of participants had less than five years of experience. Most of the participants said their main background was either in the supply of aggregates or engineering, and a significant number said their main background was in asset management. No participants selected the 'policy' or 'planning' options. Six percent described themselves as having a multi-disciplinary background. Forty-three percent of participants selected 'aggregates/materials supplier' as their typical role on pavement projects. The remainder were spread out relatively evenly across the other role types.

Table 5.2 Participant characteristics

Relevant experience	
Less than 2 years	3%
2–5 years	6%
6–10 years	8%
11–15 years	16%
16 years or more	67%
Main background	
Engineering	33%
Asset management	13%
Materials/laboratories	6%
Policy	0%
Planning	0%
Env. management, sustainability	2%
Supply of aggregates	38%
Other, including multi-disciplinary	8%
Role in pavement projects	
Project manager	14%
Procurement	4%
Design	7%
Construction	4%
Aggregates/materials supplier	43%
Testing/quality control	3%
Governance, policy & general management	6%
Technical specialist/engineering	10%
Asset manager/investment assurance	6%
Other, including multiple roles	3%

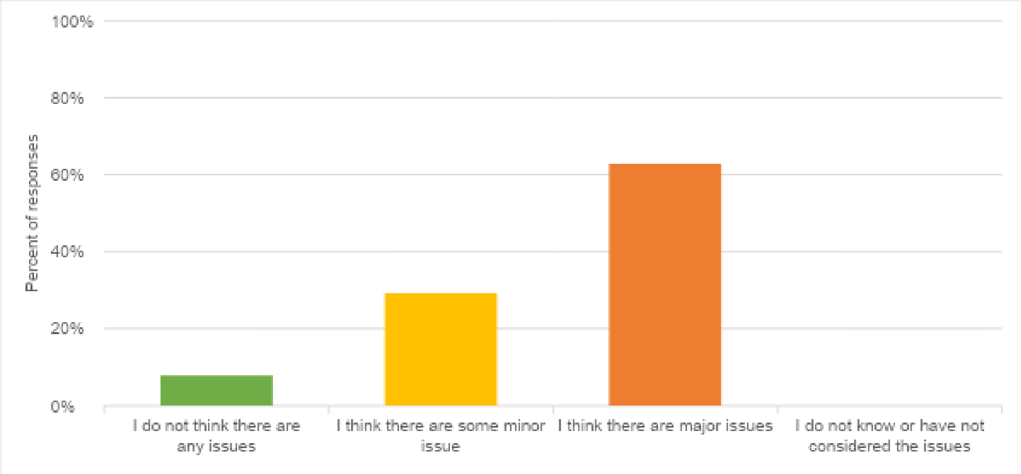
Experience with materials	
High-quality virgin aggregate	92%
Marginal-quality virgin aggregate	83%
Recycled concrete	42%
Recycled asphalt	44%
Recycled glass	27%
Recycled rubber tyres	9%
Stabilised aggregate materials	69%
In-situ pavement recycling	28%
Other	6%

Almost all the participants had had experience with high-quality and marginal-quality virgin aggregates. Experience with recycled materials, such as glass and in-situ pavement recycling, was also represented fairly well.

5.2 Perception of aggregate supply and demand issues

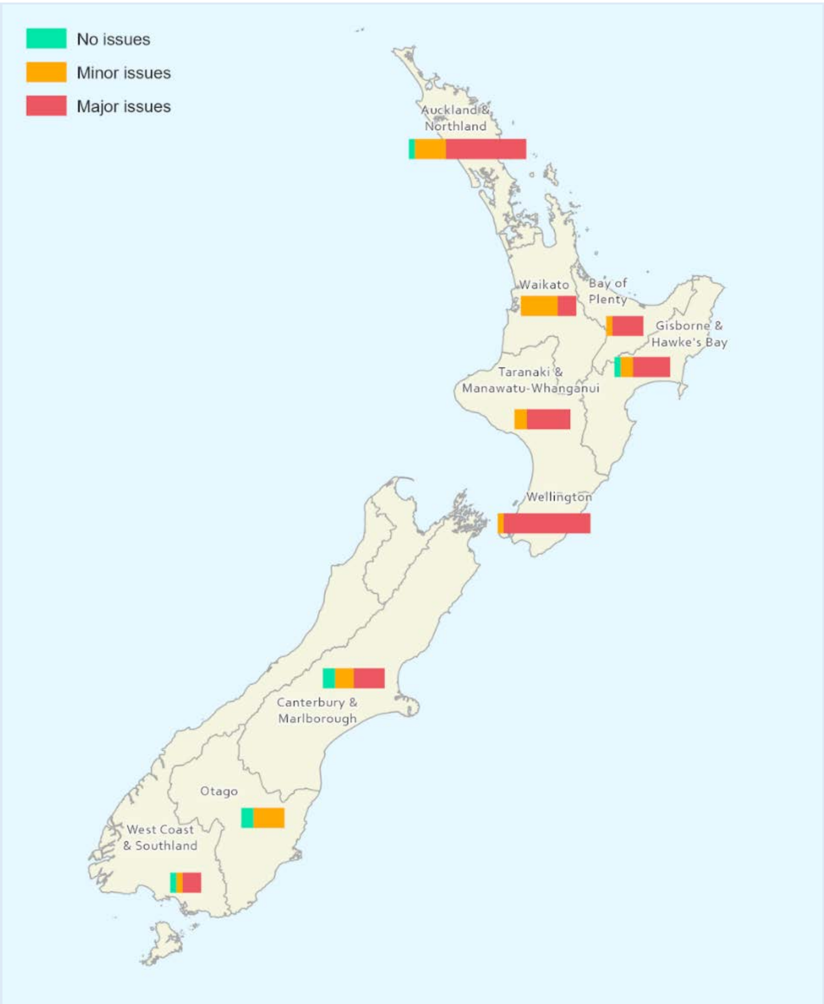
Most participants (63%) felt there were major issues with the supply of high-quality (premium-grade) virgin aggregates in their region (see Figure 5.1), with an even higher percentage (75%) when the whole country was considered. This indicated that while some participants had no (or only minor) issues in their own region, they were aware of problems nationally.

Figure 5.1 Perception of issues with supply of high-quality aggregates in the participant's region



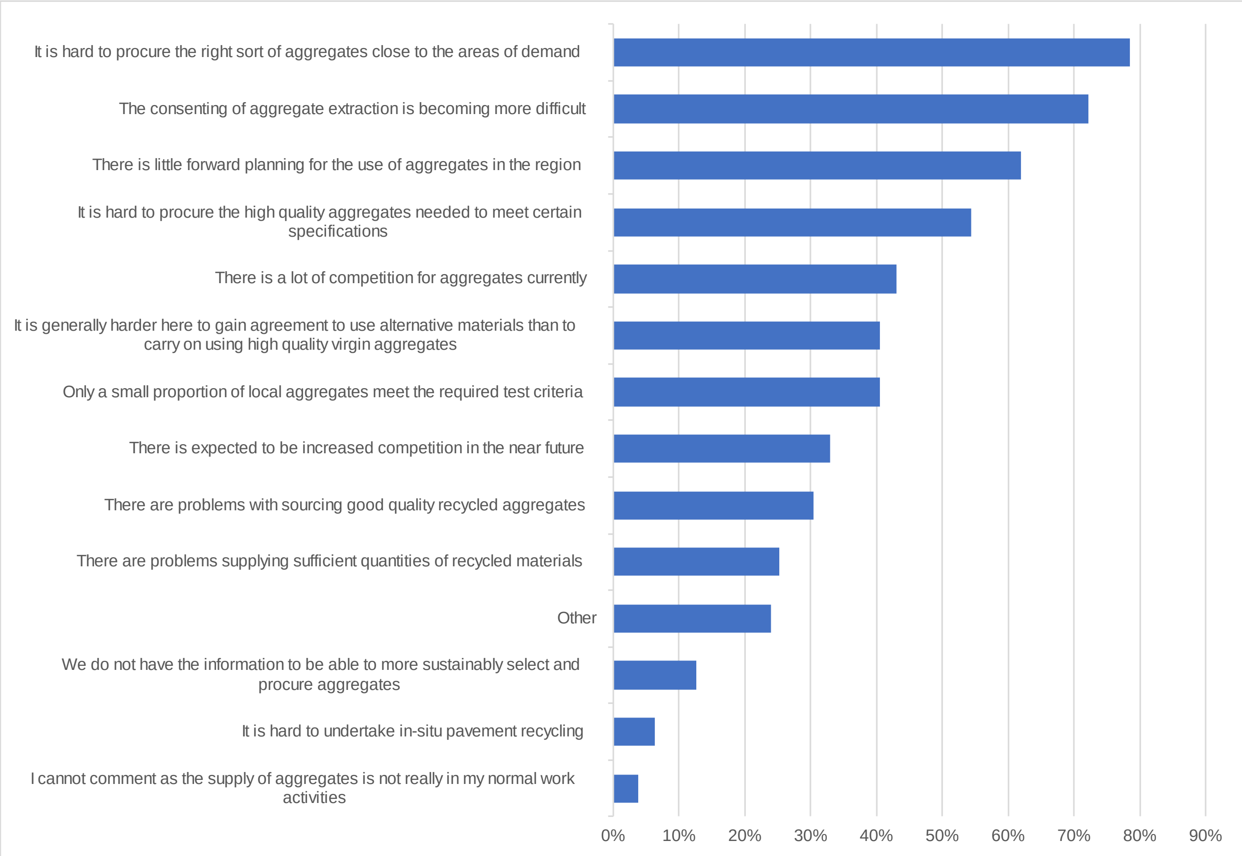
To gain a better idea of the issues by region, the responses to the question on perception of issues within the participant's region were broken down into their specific regions (see Figure 5.2). Regions without many responses were grouped together. While all regions had issues, North Island regions (particularly Wellington) appeared to be more affected than South Island regions.

Figure 5.2 Issues by region (number of responses indicated by bar length)



Participants were then asked to identify the key issues they experienced in the supply of aggregates. These were ranked by frequency (see Figure 5.3).

Figure 5.3 Perception of key issues experienced in the supply of aggregates (multi-choice)



Most participants identified problems with securing aggregate supplies of the appropriate quality and from sources close to the demand area. Competition for supplies and forward planning were often perceived to be issues. In terms of recycled materials, participants reported several issues around their use, with concerns over quality and familiarity. Very few reported that in-situ recycling was a problem. The ‘other’ category included 19 comments. A selection of key comments, summarising the general issues covered, is included below.

Participant comments — perception of other key issues in the supply of aggregates

‘The desired performance of the aggregate is not matched to the actual need of it.’

‘Large projects have a detrimental effect on supply for the local economy.’

‘There is no financial incentive to use recycled aggregates, for the supplier or the constructor.’

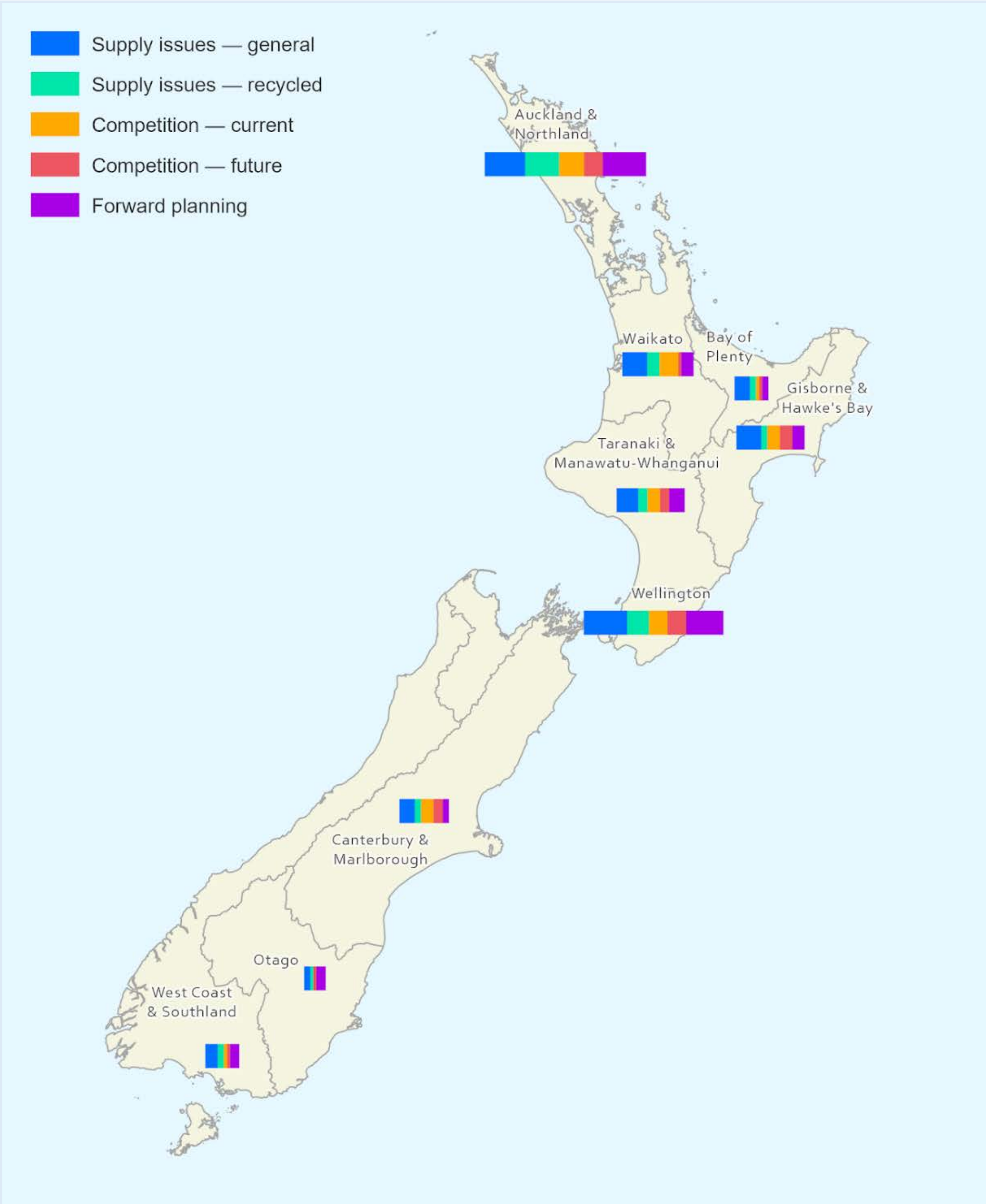
‘Quantity and cleanness of recycled material is a problem and the desire for it to be used is an issue.’

‘Limited areas designated (zoned) to quarrying and therefore obtaining resource consent is a long and costly process.’

‘There is little drive to investigate alternative aggregates. There is a high demand for high PSV sealing chip — generally outstripping availability.’

To better understand the types of issues experienced in the supply of aggregates by region, a selection of the key issues shown in Figure 5.3 were chosen and grouped into five categories, as shown in Figure 5.4.

Figure 5.4 Perception of key issues (generalised) experienced in the supply of aggregates, by region (number of responses indicated by bar length)



Participants were then asked open-ended questions relating to the supply of aggregates in their region. The responses from these have been summarised below.

Question: 'In your experience, to what extent are iwi/hapū perspectives on aggregate extraction/use considered in your region?'

Sixty-six participants answered this question. Some expressed clear, positive advocacy for iwi being key stakeholders, emphasising the importance of having a strong relationship. Some expressed a wish for greater engagement with iwi regarding the extraction of aggregates. Others described iwi being involved in a neutral way, advocating their inclusion in consenting as a matter of process. Some reported mixed experiences with iwi involvement, with varying levels of support and perspectives, and some described consideration of iwi perspectives as being ‘limited’ or ‘minor’. Several responses indicated that too much consideration was given to iwi perspectives, and/or that consideration of iwi perspectives ‘comes at a cost’. Approximately one-third mentioned being unaware of, or uncertain about, any consideration, suggesting limited knowledge about the end-to-end process for the supply of virgin aggregates.

Participant comments — consideration of iwi/hapū perspectives

‘Iwi in our area are very supportive and are a key part of our consultation and long term planning.’

‘Iwi are always involved with consenting processes, with the scope to protect the taonga for future generations.’

‘Consulted through RMA process for extraction consent.’

‘In most cases we have strong long-term relationships between our quarries and the local iwi representatives. There is always going to be factions that have an alternative view, but generally they are the exception to the rule.

‘There is minor engagement with iwi at present, I'd imagine that this has grown and will continue to grow.’

‘I don't think there is enough consultation with the local iwi when procuring aggregates in my region.’

Question: ‘If not already covered, we would like to hear examples of other challenges you face managing the supply of, and demand for, aggregates in the regions.’

Sixty-nine participants provided an answer to this question. Many of the responses expanded on the issues identified in the survey questions and provided useful insights into why, for example, consenting was becoming more difficult. While a thematic analysis was not undertaken, the following issues stood out in the comments:

- ***Proximity of sources to demand:*** Insufficient local supplies were seen as increasing the transport-related costs, competition for projects, and difficulty getting the right products for local conditions.
    - ‘*Transport costs for gravel from designated river areas inflates the cost of materials*.’
    - ‘*Multiple projects being allocated to a particular region at once puts large strain on quarries*.’
- ***Consenting and supply:*** A third of all responses raised issues around obtaining resource consent for quarry operations. Gaining consent for extraction was seen as being a challenge. Consenting was regarded as adding to costs and subject to conflicting interests (eg from neighbouring parties and other agencies such as the Department of Conservation and regional councils). Environmental concerns were often seen as being in opposition to the need to ensure the supply of aggregates. Some responses pointed out that the environmental impacts of restricting consents did not consider the implications of transporting aggregates over longer distances. Consents for extraction were reported as being increasingly difficult to obtain, with the effect of reducing supply in some regions.
    - ‘*Allocations from councils who issue extraction licences have halved, resulting [in] higher costs and transportation to keep business going*.’

- ***Forward planning:*** Many comments identified the need for better planning at several levels, such as planning for sourcing materials early in a project's life; planning for supply across multiple projects within a region; and long-term planning for national supply.
- ***Competition:*** Large capital projects placed demands on constrained supplies and competed with operational needs.

A selection of other key comments is included below to capture the general issues discussed above.

Participant comments — other challenges managing the supply and demand for aggregates

'Having a simple consenting process to expand existing operations.'

'Large projects affecting supply.'

'Significant consenting impediments that are both time consuming and expensive. Any major consents for a large quarry can take 3–4 years and a seven figure cost.'

'Without question the most challenging part of operating a quarry is finding a market for the marginal rock that lies above the high grade rock.'

'Supply of premium materials is becoming increasingly expensive.'

'It is harder to get good quality M/4 type products across New Zealand.'

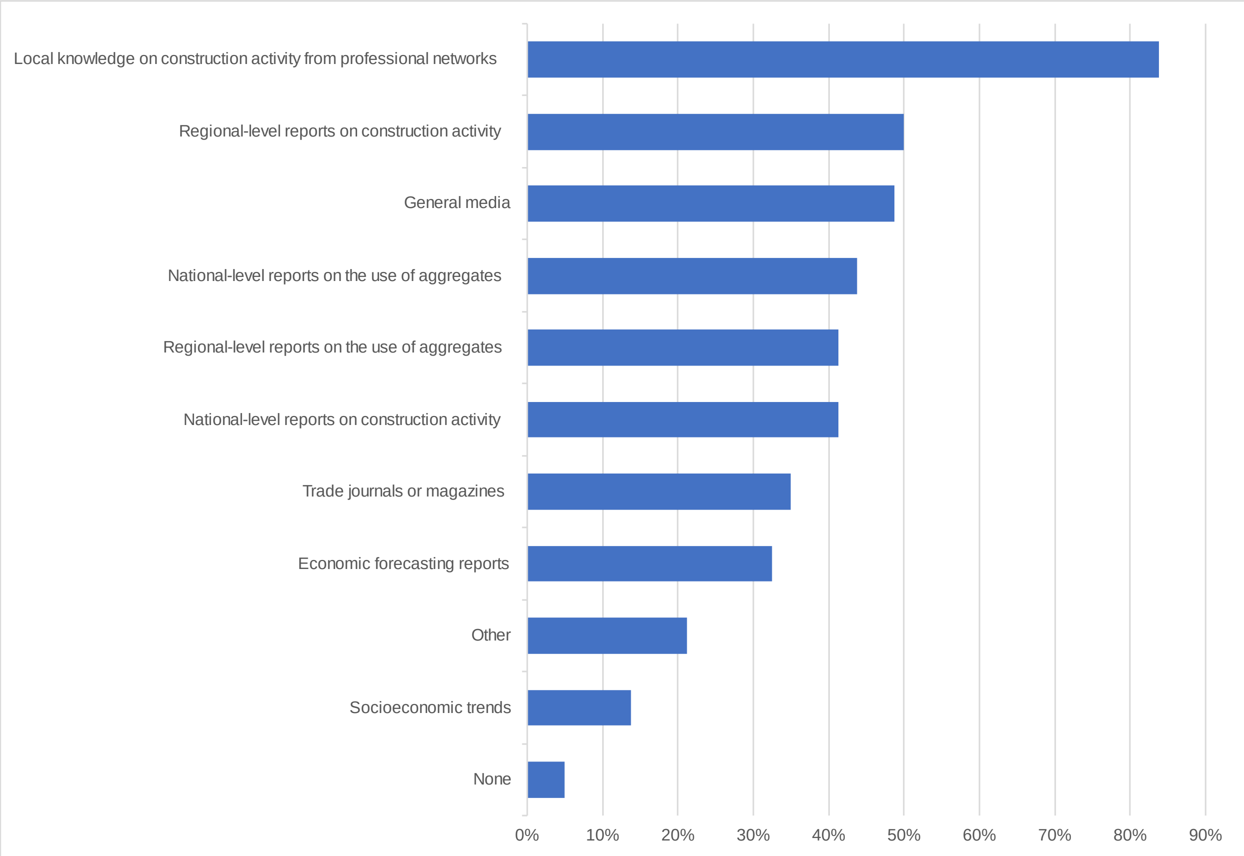
'The lack of true long term planning for aggregate resources remain at the core. We consistently see aggregate resources constrained or eliminated through poor planning at regional and government levels.'

'Lack of drivers to use recycled materials.'

5.3 Assessing information

The next section of the survey investigated ways in which the participants accessed information about aggregate supply and demand. They reported using a wide variety of information types and sources. Informal, network-based knowledge was reported most frequently, along with a mix of regional and national reports (see Figure 5.5).

Figure 5.5 Information types used to understand the supply and demand situation in the participant's region (multi-choice)



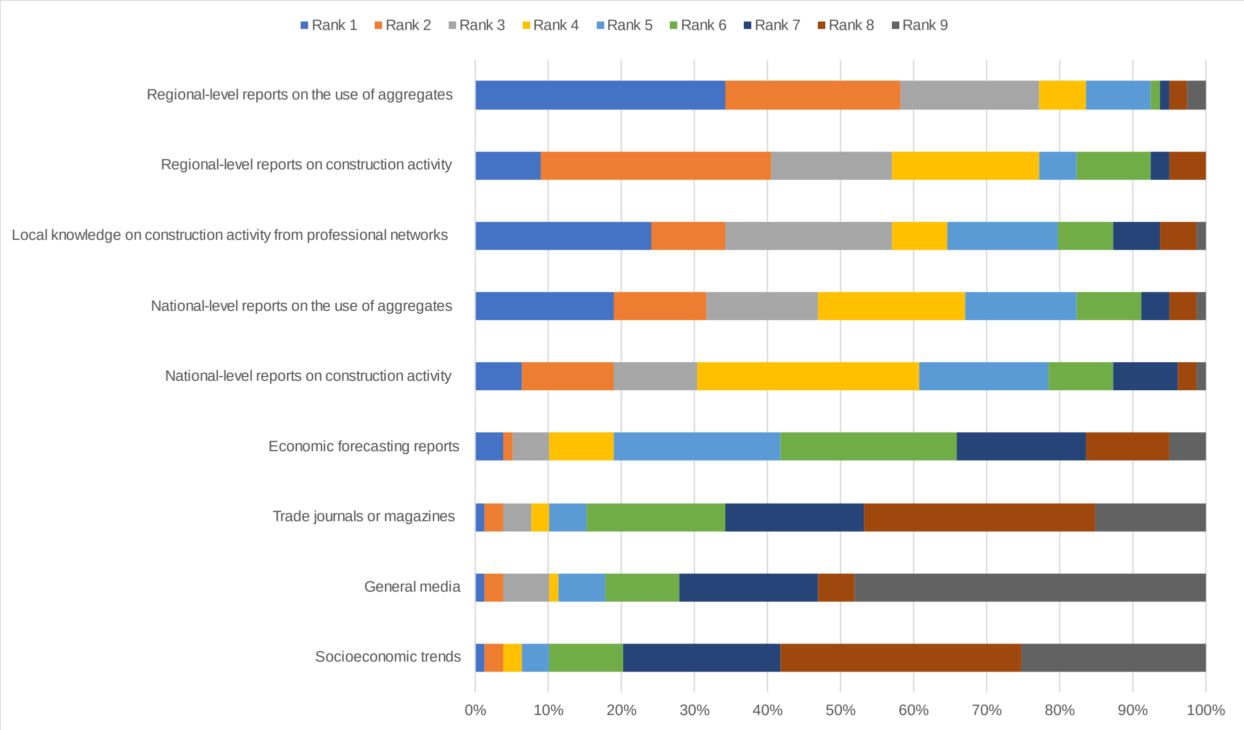
Nine participants selected the 'other' option and listed their sources of information, including:

- information from industry groups
- internal contacts
- the Government Electronic Tender Service
- the Inside Resources website.

The next question asked participants to rank information types by preference, on a scale of 1 to 9, where 1 was the highest-ranked source and 9 was the lowest. Figure 5.6 shows these in order of their overall preference ranking.

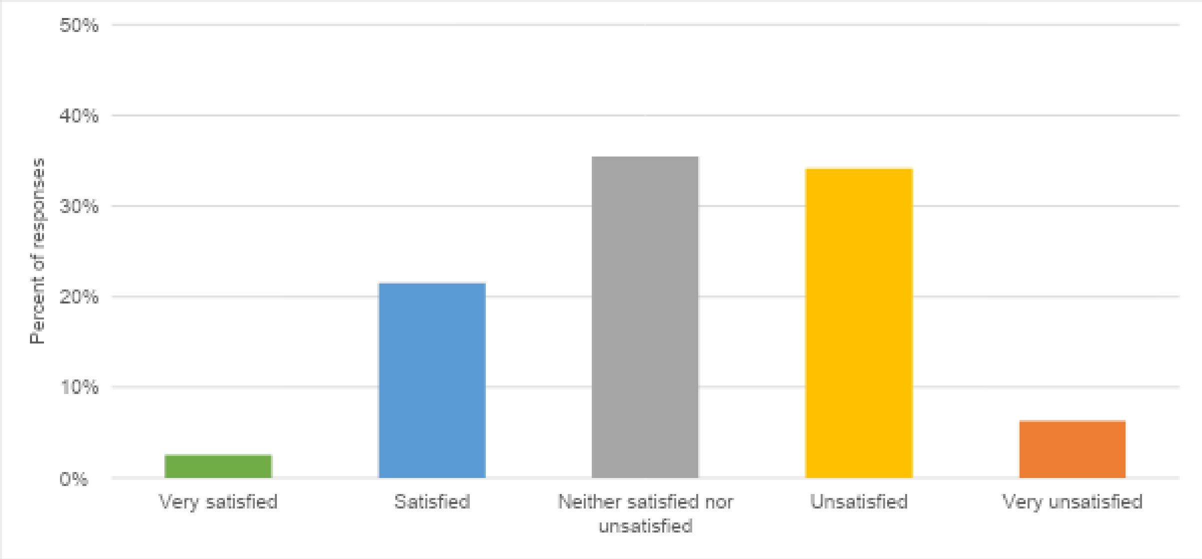
Although regional-level reports were ranked as the most preferred type of information, Figure 5.6 shows that many participants did not have access to them. This likely led some to use information types that were less reliable, such as the general media.

Figure 5.6 Ranking of different information types by preference



Participants generally reported that they were 'unsatisfied' or 'neither satisfied nor unsatisfied' with the information available to them regarding the supply and demand situation for aggregates (see Figure 5.7). This could have reflected the fact that many did not have access to their preferred information types.

Figure 5.7 Participants' satisfaction with information available regarding aggregate supply and demand



5.4 Providing information

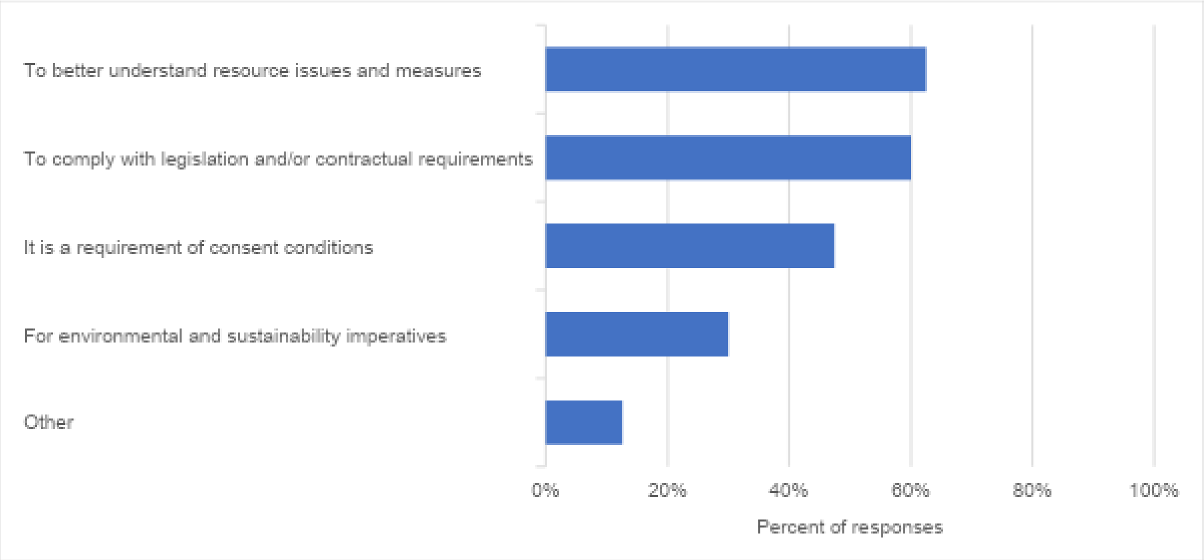
Participants were asked if they (or their organisation) provided information on the production and/or use of aggregates. Of these responses:

- 49% said they or others in their organisation provided information that could be used externally by others outside their organisation
- 35% said they or others in their organisation provided information that would be used only internally within their organisation
- 30% said neither they nor their organisation provided information to others regarding aggregates.

Those that said they or their organisation provided information were asked for their reasons for doing this. The main reason provided by both external and internal sharers was to better understand resource issues and measures; 60% of external providers also answered that they did so to comply with legislation and/or contractual requirements (eg resource consent conditions).

Figure 5.8 shows the reasons for supplying information for those who provided information externally.

Figure 5.8 For those whose organisations provided information externally, why they did so (multi-choice)



Five participants selected the ‘other’ option and listed their reasons for supplying information externally. These reasons included meeting design requirements, for operational planning and for the Waka Kotahi Annual Achievement Report.

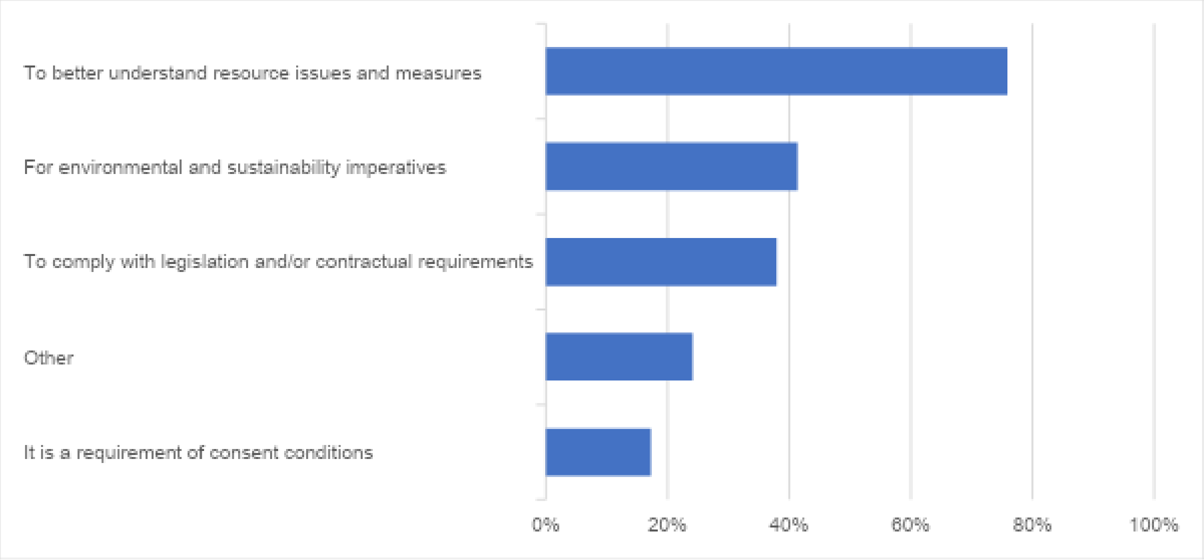
When asked ‘Which organisations, departments, groups, or specialists do you supply information externally to in relation to aggregates?’, participants identified the following:

- regional councils
- local councils
- Waka Kotahi
- Ministry of Business, Innovation and Employment
- Ministry for the Environment
- New Zealand Petroleum & Minerals
- Marine Protection Solutions New Zealand

- AQA
- consultants and contractors
- construction industry partners
- maintenance suppliers.

Figure 5.9 shows the reasons for supplying information for those who provided information internally.

Figure 5.9 For those whose organisations provided information internally, why they did so (multi-choice)



Seven participants selected the 'other' option and listed the reasons for supplying information internally. These reasons included for operational planning, to demonstrate shortages, for market comparison and for internal reporting.

When asked 'Which organisations, departments, groups, or specialists do you supply information internally to in relation to aggregates?', participants identified the following:

- company management team
- company board
- construction teams
- engineers
- planners
- financial team
- sales team
- other relevant staff.

Both external and internal information sharers were also asked what *types* of information they provided, as well as their perception of its quality. Figure 5.10 shows the responses from external providers and Figure 5.11 shows the responses from internal providers.

Most of the information provided both externally and internally was spreadsheet based. Generally, this information was perceived as being either 'very good quality' or 'adequate quality', with few participants perceiving it as being 'poor quality' and none perceiving it as being 'very poor quality'.

Figure 5.10 The types of information about aggregates that was provided externally, and their perception of its quality (multi-choice)

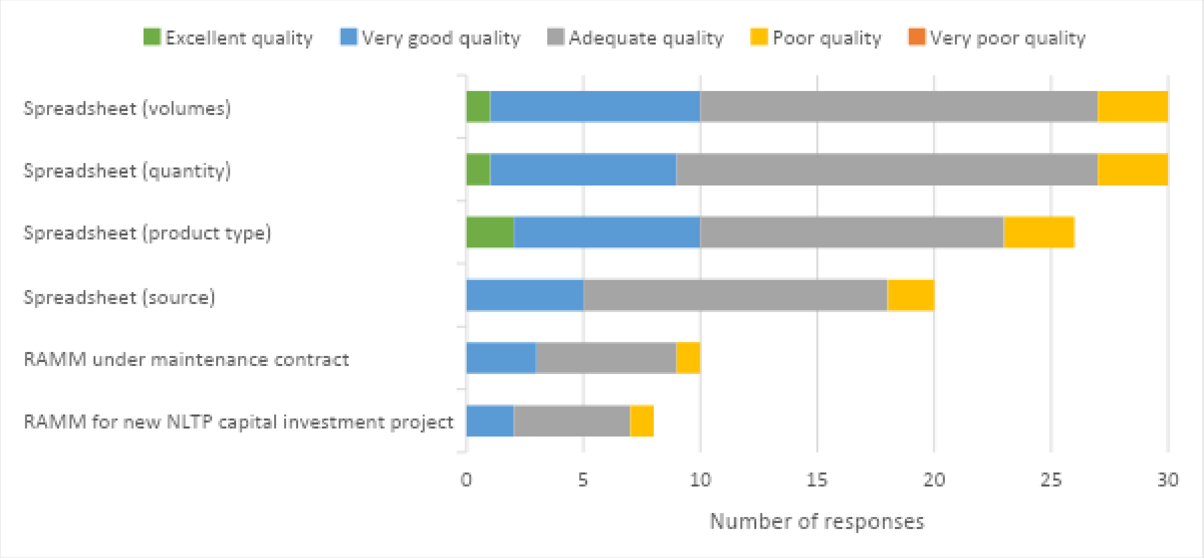
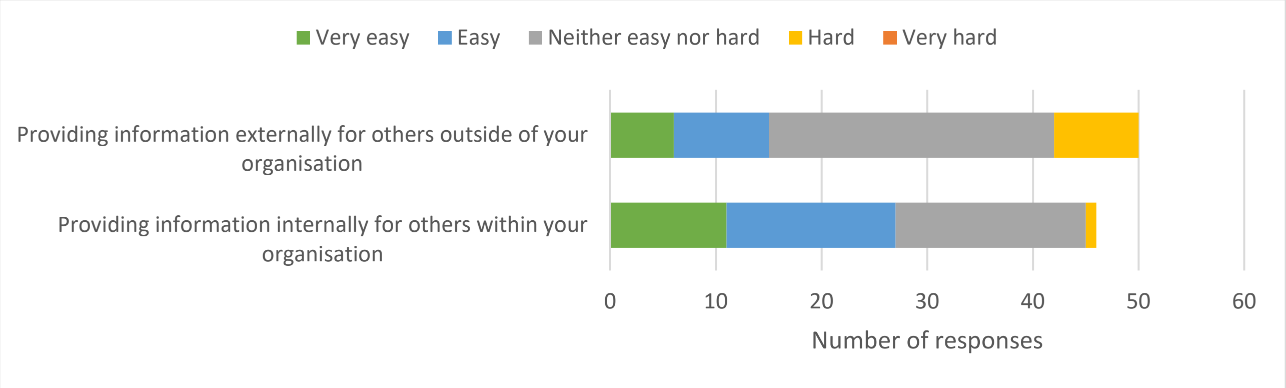


Figure 5.11 The types of information about aggregates that was provided internally, and their perception of its quality (multi-choice)

Most participants, from both the external and internal information sharers, perceived the process of providing information to be either 'easy' or 'neither easy nor hard' (see Figure 5.12). Few perceived it to be 'hard' and none perceived it to be 'very hard'.

Figure 5.12 Perception of the process of providing information



Both the external and internal sharers were asked to detail what made it easy to share information and what made it hard. Participants identified the following factors as making it easy to share information:

- established and user-friendly systems
- simple technology solutions
- strong relationships between information sharers and receivers
- available funding for data sharing
- reliable budgeting, projecting programming and planning
- 'one source' of data
- industry contacts.

Participants identified the following factors as making it hard to share information:

- poor coordination and cooperation between information sharers and receivers
- unreliable and incomplete data
- infrequent data collection
- time constraints
- confidentiality and commercial sensitivity
- time and effort required to compile information
- lack of information standardisation
- changes to standards and specifications
- lack of easy sharing solutions.

Finally, participants were asked the following open-ended question:

> *'What do you see as the key barriers to making information about aggregate supply and demand more available and useful for planning purposes?'*

Seventy-nine participants provided an answer. The key comments below summarise the general issues covered.

Participant comments — key barriers to making information more available and useful

'Inadequate strategic planning and procurement processes, understanding/consideration of supply chain constraints.'

'The market is not always predictable, therefore demand is not easy to predict.'

'Information is not held in a central location.'

'Lack of planning from a Central Government perspective. There does not seem to be any knowledge of how the industry works and level of importance that aggregate supply has in the maintaining and building of infrastructure projects.'

'Commercial sensitivity, limited collaboration at a regional and national level, consenting issues.'

'Obtaining accurate information from the operators concerning production and available remaining resource.'

'Diverse and disparate range of stakeholders involved.'

'There is no central control of aggregate supply. As such if you own a quarry the supply limitations or opportunities are your intellectual property and will not be shared, making a national overview impossible.'

'Many operators don't like disclosing annual volumes to competitors.'

'Lack of confidence around the accuracy of aggregate use and the future trends.'

5.5 Summary

As with a previous sector survey addressing sustainable use of aggregates (O'Donnell et al., 2018), there was wide participation from across the sector and the country, indicating a keen interest in the issue. Materials suppliers were more strongly represented here than in the previous survey, undoubtedly due to active recruitment through quarry industry champions and the topic of supply. Only a small number of participants identified having a policy, design or procurement role in projects, and none had policy or planning as their main background. Therefore, the insights and inferences made from the survey need to be tempered by the limited input from these groups, who play an important role in aggregate supply and demand.

The survey results presented here show there was a strong appreciation of supply issues for high-quality virgin aggregates across the sector and that supply issues varied across the country. There was also strong recognition of the challenges for better management of supply. Along with general supply issues, competition and lack of forward planning in the Wellington and Auckland–Northland regions were highlighted.

The inclusion of iwi perspectives regarding the extraction and use of aggregates appeared to be mixed. Some participants commented with enthusiasm on the positive role iwi should play; some referred to iwi being included as a matter of process on consenting decisions; and a few reported mixed experiences or concern at the need to include iwi in decisions. Insights from iwi, planners and local authority consenting officers would provide useful insights into how iwi perspectives could be better integrated into decision making, particularly relating to the supply of aggregates.

Participants reported many challenges in managing aggregate supply and demand in their work. In particular, restricted local supplies meant longer distances to demand sites and more competition across regions, especially where there were multiple capital projects. Almost one-third of participants frequently saw getting consent for extraction as a key additional challenge that limited local supply and added to costs. As noted above, insights from the planning community could delve further into these realities. There was a strong desire for better forward planning, both for identifying and securing sources early in the project cycle and for planning across multiple projects and regions (including operational needs).

The survey results indicated a big appetite for better access to better information. For many participants, the ability of the industry to forecast and plan for the sustainable use of aggregates was limited because of insufficient access to information. Relatively few were satisfied with the information currently available to them. There was a strong preference for regional-level reports on aggregate use and construction activity to support forecasting. Trade journals were less desirable as a source of information, despite being a common source of information. Equally important, most participants also wanted to be able to provide better-quality information more easily to others.

Information sharing was reported as being a common practice for most participants, either to others within their organisations or to external parties. Better understanding of resources issues was a primary motivation for sharing information, along with the need to comply with legislation, contracts and consent conditions. This suggested that a combined ‘carrot and stick’ approach would be useful. Most of the participants who gave comments reflected on the barriers to improved information sharing, suggesting it was something they felt strongly about. In particular, the effort required to provide good-quality data, the lack of centralised information, and confidence in the data were repeatedly raised by participants.

Developing nationally consistent standards and processes for data collection, use, management and sharing would provide decision makers with better ways of monitoring and managing aggregates within regions, sectors and across the country. Careful consideration would be needed to work across the sector to ensure robust data was being provided. For example, if the barriers of time constraints and commercial sensitivity were not addressed, poor-quality data could muddy the waters. Equally important, the tools used to manage and access data would need to be easy if it they were going to be used by decision makers (Mora et al., 2019; O’Donnell et al., 2018). If additional effort was required to access high-quality information, people would be likely to rely instead on their existing familiar sources, even if they were unreliable.

5.6 Key additional interviews

Specific non-structured interviews (via phone calls, Zoom calls and email correspondence) were undertaken with various key individuals in the industry to understand the various supply and demand issues related to aggregates. A number of these interviews were targeted to the case studies undertaken in the Horizons region. The interviews are described below.

Peter Scott, Murray Burt** and **Cathy Bebleman (Auckland Transport) – Discussions were held with Auckland Transport staff (including Cathy Bebleman on the Steering Group) regarding data collected and/or held in various forms for both the supply of, and demand for, aggregates in Auckland Transport. The information we gathered was used to prepare information on the demand for aggregates in various land transport infrastructure configurations based upon varying forecast traffic loadings, cross-sectional standards and subgrade conditions.

Ramon Strong** and **Michaela Rose (Horizons Regional Council) – Discussions were held on several occasions to examine the availability of data, the source and quality of data, and how easily the data could be obtained. This included gaining access to the Council’s OnePlan GIS platform. Other staff within the Council were also contacted on several occasions to extract data on the Horizons region.

Lonnie Dalziel, Shane Avers, Callum Pittout** and **Adam Leslie (Waka Kotahi) – Discussions were held with various staff in Waka Kotahi, including the above, with a specific focus on Waka Kotahi land transport infrastructure projects in the Horizons region and what data was being collected and available for improving aggregate supply and demand understanding. The Manawatū Gorge replacement highway and the Ō2NL expressway projects were used to determine potential demand for aggregate in the Horizons region. The project quantities were used to determine average aggregate quantities (basecourse, subbase and sealing chip) per km of highway based upon the cross-sectional standards.

Jamie Povall *and* ***Ken Clapcott*** (Stantec***)*** provided valuable technical information for the Ō2NL expressway project.

Johannes Ferreira (Porirua City Council) was contacted to discuss the problems that Porirua City Council were having in obtaining aggregates for maintenance projects due to other large projects in the region taking precedence.

Mike Chilton (AQA Technical Manager) – Discussions were held specifically in relation to AQA member considerations and quarrying activities in the Horizons region.

Lewis Winiata *and* ***Jenny Mauger*** (Ngāti Hinemanu and Ngāti Paki) – Discussions with these representatives from the Rangītikei District of the Horizons region were held regarding aggregate supply and demand issues, especially for alluvial aggregate extraction. A Zoom discussion meeting (hui) was held to inform the project team of te ao Māori perspectives on aggregate extraction and especially in relation to their effects on communities and the awa (rivers) in relation to aggregate alluvial extraction practices. Both representatives also attended the Horizons region workshop to provide tangata whenua perspectives from the region.

Peter Murray, Owen Matthews*,* ***Brett Wood*** *and* ***David Berg*** (Infrastructure Commission) – An initial meeting was held with Peter Murray and Owen Matthews at the Infrastructure New Zealand conference in Auckland in late 2020. Further discussion with Owen Matthews then followed, regarding the Infrastructure Commission's GIS-based forward works database and plans to develop the 30-year New Zealand Infrastructure Plan in the coming months. This information was used in the preparation of workshop materials and it was presented in the workshop. An additional meeting was held in Wellington with Brett Wood, David Berg and ***Tim Journeaux*** (MBIE) to discuss key data issues/constraints and potential next steps in the development of an aggregate data framework.

6 Case study and workshop

A case study was developed so that detailed information could be gathered and the issues explored. The neighbouring areas Manawatū and Whanganui (the Horizons region) were identified as a useful case for several reasons. First, the region was known for having difficulty in sourcing aggregates. Second, there were multiple nationally significant public infrastructure projects underway in the region, requiring considerable quantities of aggregates well into the future. Third, obtaining aggregate supplies from either local or neighbouring sources was also limited because of large capital projects in those regions and constraints on consenting new quarries. Finally, the region's reliance on alluvial extraction from the Manawatū and Rangītikei Rivers (rather than from hard-rock quarries) has created specific cultural pressures/constraints on the supply and manufacturing of aggregates, due to historical industry practices and water-related resource use.

In preparation for the case study in the Horizons region and the subsequent workshop, the following data, people contacts and information were organised:

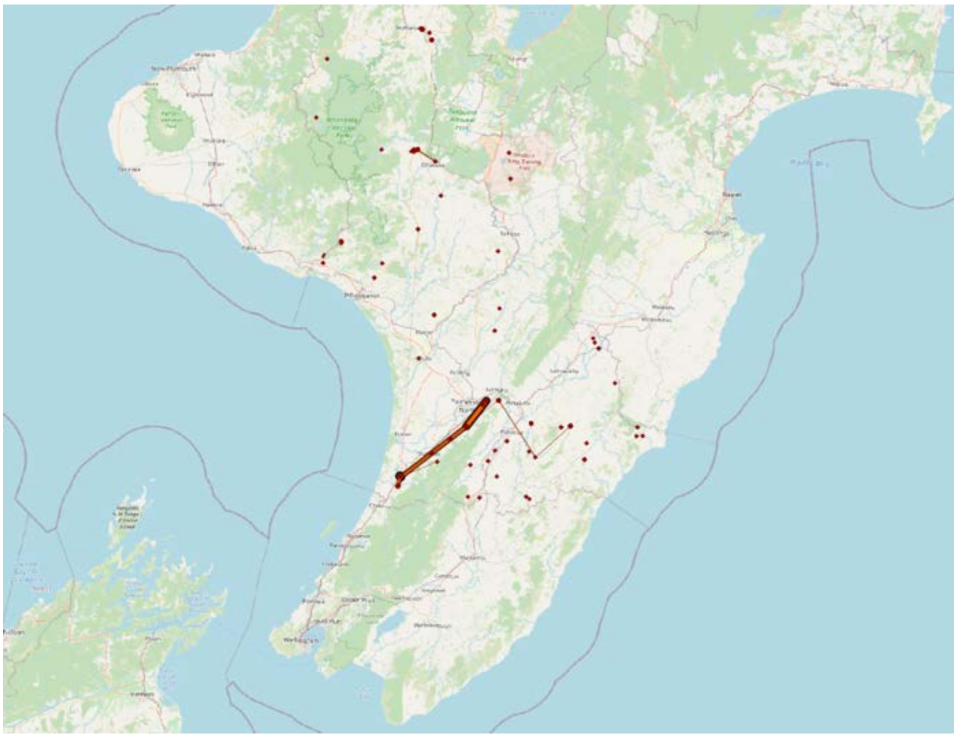
- planning, land use and public infrastructure network maps for the region (via Horizons Regional Council)
- geological maps of environmentally sensitive areas and features
- EROAD heavy commercial vehicle truck movements from quarry locations
- aggregate quarry data in the region (supply)
- demand for known infrastructure projects in the region (eg Ō2NL expressway, Manawatū Gorge replacement highway), project consultants (Stantec) and Waka Kotahi staff
- iwi/hapū groups specifically concerned about alluvial aggregate extraction practices in the region
- New Zealand Infrastructure Commission Te Waihanga (InfraCom NZ) Forward Works Programme for infrastructure demand in the region.

The relevant data were evaluated, collated and analysed, and materials were prepared for the facilitated workshop that is discussed in the following section.

6.1 Horizons regional case study

Using the aggregate transport data described in Section 4.5, analysis was undertaken of the truck journeys from quarries and the routes travelled in the Horizons area. Figure 6.1 illustrates the location of the quarries (red dots) and the truck journeys to and from them (red lines), with the thickness of the lines representing the number of journeys on that link.

Figure 6.1 The location of quarries in the Horizons area and the truck journeys between them, based on EROAD data



The figure shows that despite the area having many quarries, the EROAD data showed truck journeys involving only a few of them. This may have been because at the time of this research, EROAD technologies were not yet popular in the region for the smaller quarry operators. Gathering more data on the quarries themselves, such as the type and quantity of aggregate in each, could have provided further insights on the transportation of aggregates in the region. Despite these limitations, the data showed a clear pattern of the most popular corridor of truck journeys between Levin and Palmerston North, which was also one of the main business and development corridors in the region.

6.2 Workshop

As part of the case study, a workshop was held to explore in greater depth the ways in which better information could have facilitated a more sustainable use of aggregates at that time. Participants were invited based on their involvement in the Horizons Regional Council case study and/or their role at a national level in the supply and demand for aggregates. A total of 18 people attended.

The three-hour workshop was held online, using the Zoom platform, with facilitated breakout rooms for more in-depth discussion in two exercises. The workshop was structured to demonstrate information possibilities and data needs within the case study and to explore the data issues and priorities. The workshop began by introducing the case study, describing the issues faced by Horizons Regional Council as well as iwi perspectives on whenua, kaitiaki and resource use in the region. The results of a) econometric modelling and forecasting of demand at national and regional levels; b) the Infrastructure Commission's forward works programme (Pipeline); and c) telematics data and visualisation/analysis of truck movements between quarries and work sites were then presented to demonstrate the data needs and possibilities.

6.2.1 Breakout rooms Exercise 1

This first exercise asked participants to identify the key information gaps, when making sustainable decisions, in terms of the significant issues and drivers for aggregate supply and demand, as well as the availability of information on those drivers.

Participants across the groups identified multiple factors related to the materials themselves (what they were, where they came from and where they were being used) and the varying levels of availability of information. They also identified several other contributing factors, as detailed in Table 6.1. They appeared to have little knowledge about potential sources of the required information. For example, while they could identify several types of resources needed to support aggregate extraction and production, such as water and human capital, they could not identify sources of information about these.

Table 6.1 Factors that feed into aggregate supply and demand issues

	Factor or issue	Information availability and source
Supply and demand of materials	Quality and quantity of aggregates	Information on quantity is available, but not much on quality; variable availability
	Location of other quarries and competition	Most councils have knowledge of location of quarries and consented sites but information on aggregate quality at these locations is limited
	The location of construction (use) Route choice, distance, travel time	Queried whether information on sourcing could be part of awarding a contract. Aggregate specification (quality and quantity) can change significantly over the course of a project due to various project construction methods
	The need for transparent permits and/or consent processes	Permit information is readily available; consenting information is variable but should be available
	Capacity to establish and run supply Lead-in time to establish new sources of aggregates Expertise and labour required to run quarry or alternative supply	
	Wai/awa Resources needed to support aggregate production – water	
Contributing factors	Ownership of minerals and land	Ownership information is not easily available – needs to be a GIS layer that includes public/private ownership of both land and minerals
	Priority levels of major projects at national and regional levels Includes the timing of how quickly aggregate is needed – eg whether something has been bumped up the list or is in response to an emergency Reflected in budgets	Uncertainty around political changes in priorities; regional vs national needs – data on decisions is often not available

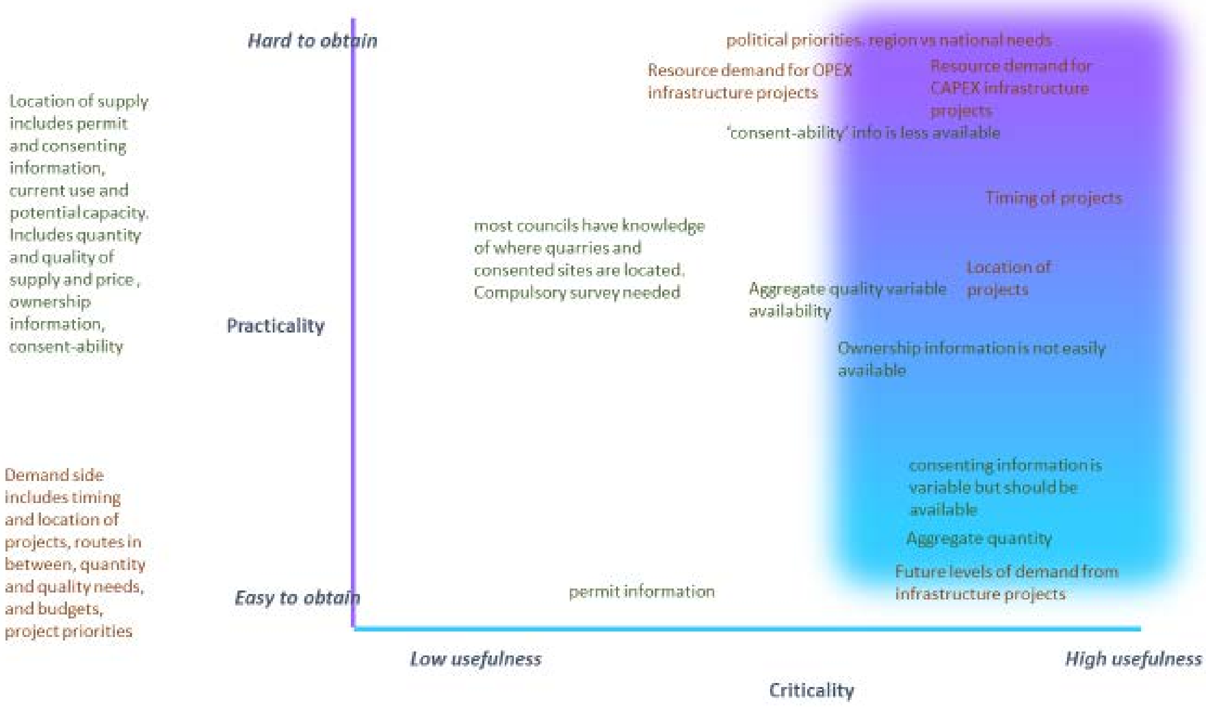
	Factor or issue	Information availability and source
	Proximity to communities and sensitivities (‘consent-ability’ for supply, consideration of routes) Combination of conditions likely to lead to consenting (RMA changes may introduce uncertainty)	‘Consent-ability’ information is not easily available
	Changing climate impacts on supply and demand	
	Economics – costed and un-costed	
	Treaty partnership	

6.2.2 Breakout rooms Exercise 2

The second exercise asked participants to prioritise information needs based on practicality and criticality criteria. Information items were colour coded into demand side and supply side and then ‘mapped’ onto a matrix (see Figure 6.2) so that information on items that were highly useful and easy to obtain could be highlighted (the ‘low-hanging fruit’) and compared with equally useful items for which information was hard to obtain. The exercise highlighted the lack of information that was critical to making informed and strategic decisions on the sustainable use of aggregates. For example, information on the resource demand for CAPEX of public land transport infrastructure projects and the timing of those projects was not seen as being easy to obtain. In addition, qualitative information on the factors that made a quarry ‘consent-able’ (eg community sensitivities, routing options and feasibility, iwi concerns, etc) were not easily available.

The participants said that several types of information were of variable quality and availability. Information on aggregate quantity was seen as both useful and available, whereas information on aggregate quality was harder to obtain. Information on consenting was considered variable, despite its importance. Information on ownership of both aggregates and land was also considered harder to obtain than it should be, despite it being regarded as a fundamental basis for identifying possible supply. Additional information needs also emerged through discussion, notably the need for better information on national and regional priorities and how they could be balanced over time. For example, while local road maintenance was a high priority at a regional level, a nationally significant road would take precedence for supply, which in turn would affect the cost and availability of aggregates for local projects.

Figure 6.2 Information priority based on practicality and criticality criteria



Throughout the workshop, information emerged about wider supply and demand considerations, which could guide future steps to improve the sustainable use of aggregates. They were not discussed in detail and so are not expanded below, but they demonstrate the richness of the discussion and the need to think more broadly about how to work with the aggregates sector. They included:

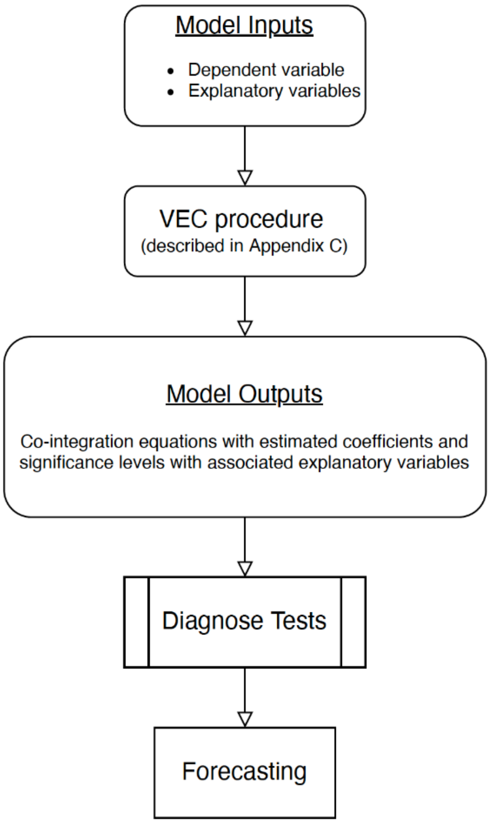
- identifying a way for 'soft' information to be incorporated into projects (eg compliance and monitoring)
- examining how well te ao Māori world view and partnering is incorporated into decision making and problem identification
- developing a framework for inputting and using robust data to improve monitoring and planning
- developing guidelines, specifications, education and capability building across the sector
- examining where aggregates fit into the re-use/recycle circular economy
- examining governance, planning and regulatory factors and who is responsible for working towards the sustainable use of aggregates.

7 Demand/supply forecasting model

Multivariate time-series econometric models were used to estimate the relationship between the demand for/supply of aggregates and the associated macroeconomic and investment characteristics. Figure 7.1 depicts the modelling flow chart of the aggregate demand/supply forecasting model. Most of the collected data were used to explain the demand/supply forecasting model (thus, they were called 'explanatory variables'). They contributed to an econometric model to help explain the 'dependent variable' of interest, which was the production of aggregates in the national model and the regional total production of aggregates in the regional models.

First, both the explanatory and dependent variables were determined based on economic theory, data availability and previous literature – the econometric model provides a set of equations with optimised parameters and significance levels, so the relationship between explanatory and dependent variables can be analysed. Second, using STATA 14.0, an integrated econometric software package, the Vector Error Correction (VEC) method was performed, using model inputs. Next, the model outputs, including information on co-integration equations, were derived from STATA 14.0. Then diagnostic tests were performed to ensure the model selection and estimations were statistically sound. Finally, forecasting was achieved based on the model outputs.

Figure 7.1 Demand/supply forecasting model flow chart



In this project, a range of both national and region-specific data was obtained from various sources. For instance, the annual aggregates data regarding specific use (ie Rock for reclamation and protection; Rock, sand and gravel for roading, etc) came from NZP&M. The annual total production of aggregates data were collected from AQA with corrected figures based on NZP&M data, which have yearly varying industry response rates.[6] Macroeconomic variables including GDP, construction sector's contribution to GDP and population were gathered from Statistics New Zealand. Finally, roading investment from both Waka Kotahi and other local authorities came from the Waka Kotahi website's Data and Tools section.

It is important to note that because of the lack of demand-side data for aggregates, for this study we assumed that an equilibrium existed between aggregate supply and demand at the national level. It was also assumed that inventory levels were insignificant and producers could adjust to market needs.

7.1 National model

For the national model, the dependent variable was the production of aggregates (in million tonnes) at time *t*, while the independent variables were GDP ($NZ in millions), roading investments ($NZ in millions) and population growth rate (%), all at time *t*. The timeframe was the period 2000 to 2018, for which the information on all the variables was available. The main variables that were used for the national model are displayed in the three graphs in Figure 7.2. These show the scatter plots between New Zealand GDP vs total aggregates production; roading investment vs total aggregates production; and population growth vs total aggregates production, respectively.

Figure 7.2 Graphical relationship between dependent and independent variables for the national model

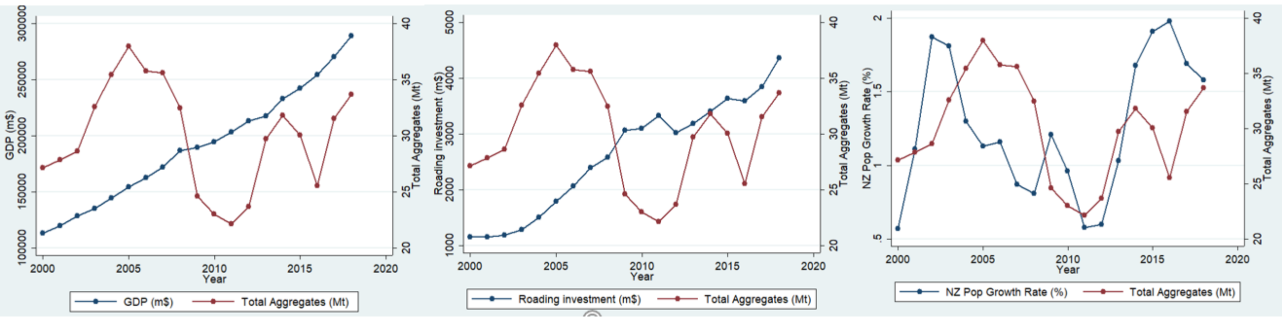


Figure 7.2 shows that GDP and roading investment from both Waka Kotahi and local authorities tended to increase at a relatively constant rate over time. However, both the total production of aggregates (which is the sum of Rock for reclamation and protection; Rock, sand and gravel for building; Rock, sand and gravel for roading; and Sand for industry) and the population growth rate fluctuated throughout the sample period and did not exhibit any patterns. The VEC method was used to estimate the relationships between aggregate production and the explanatory variables, considering any co-integration relations, or a possible correlation between time-series processes in the long term, that were built into the specified time-series. (Co-integration is a statistical property of a collection of time-series that restricts the long-run behaviour of the explanatory variables to converge to their co-integrating relationships while allowing for short-run adjustment dynamics.) The five steps used to estimate the VEC model are described in Appendix C.

All variables were transformed into natural logarithms. Hence, the aggregate demand/supply model was a log-log regression in which the target variable and the predictors were log-transformed. The Augmented Dicky-Fuller (ADF) tests showed that all variables were non-stationary and first-order integrated (ie they were I(1) variables), as all contained one unit root. Therefore, they could exhibit long-term causality. The optimal number of lags for the national model was 2. This implies that at the national level, the demand for/supply of

[6] Mike Chilton (AQA) said that according to WorkSafe's quarterly reports, in June 2021 there were 1,050 quarries operating (verified or notified WorkSafe by appointed manager). However, NZP&M is surveying fewer quarries each year.

aggregates for the previous two years had the most explanatory power regarding the outcome of the predicted year's demand for/supply of aggregates in New Zealand. At maximum rank 2, the trace statistic (12.71) did not exceed critical values (15.41). Therefore, we accepted the null hypothesis that there was co-integration of two equations. Thus, as per maximum rank 2, Total Aggregates, GDP, Roading Investment and NZ Pop. Growth Rates were co-integrated. This meant there was a stationary linear combination of these non-stationary random variables. Since there was co-integration of the three variables, a VEC model was considered the most appropriate model to use.

The log-transformed regression implied that the estimated coefficient was interpreted as the percent increase in the dependent variable for every 1% increase in the independent variable. Overall, two main outcomes were found, other things being equal:

1. A 10% increase in roading investments from Waka Kotahi and local authorities would boost the production of aggregates by 13%. This result implied that aggregate demand/supply at the national level was significantly influenced by the overall economy and the government's fiscal response. Moreover, aggregate demand/supply increased more than proportionally to the increase in roading investments.
2. An increase in roading investments and population growth would also increase New Zealand's GDP.

To determine whether the VEC model was correctly specified, a set of diagnostics tests, including serial correlation and normality tests, were performed. Results from the Lagrange Multiplier (LM) test, and the Jarque-Bera, Skewness and Kurtosis tests, showed that at lag 2, the constructed VEC model did not suffer from either of the aforementioned issues. Hence, we concluded that the model performed well.

Figure 7.3 Forecasting for the next decade (from 2018) for the national model

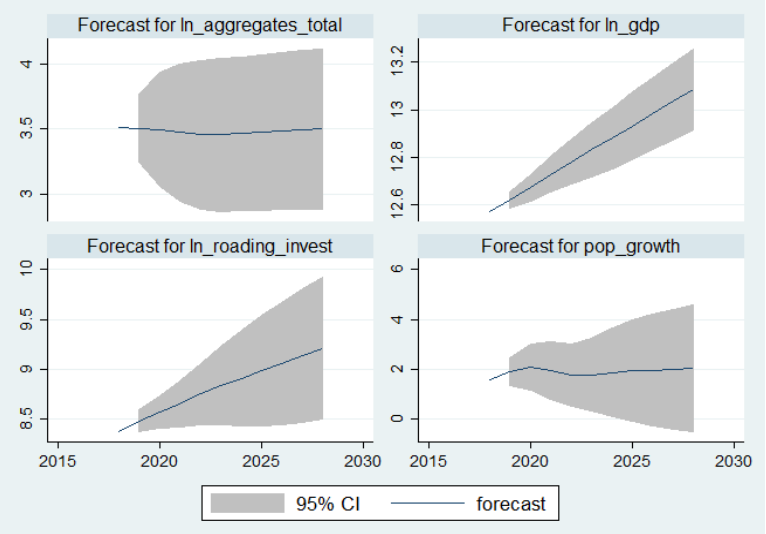


Figure 7.3 shows that in the national model, the confidence intervals grew with the forecast range. For the decade beginning 2018, the total production of aggregates in New Zealand and the country's population growth rate were expected to increase at a relatively constant rate of around 1.2% and 0.7%, respectively, while the national GDP and investment for roading sector would increase at a greater rate. This result signalled that projected aggregate supply was relatively satisfactory nationally, despite the projected increase in roading expenditure; however, this could not be said within all regions, especially when considering the range of aggregate products.

7.2 Regional model – Horizons

For the Horizons regional model, we constructed two sub-models: one with the regional total production of aggregates in million tonnes at time *t* as the dependent variable and the other with the regional production of aggregates for roading activities in million tonnes at time *t.* The independent variables were regional GDP from the construction sector ($NZ in millions), regional roading investments ($NZ in millions) and regional population growth rate (%), all at time *t*. The timeframe was the period between 2000 and 2018, for which information on all variables was available. The main variables that we used for the two sub-models are displayed in Figure 7.4 and Figure 7.5.[7] The graphs below show the scatter plots between regional GDP from construction vs total aggregates production/aggregates production for roading activities; roading investment vs total aggregates production/aggregates production for roading activities; and population growth vs total aggregates production/aggregates production for roading activities, respectively.

The GDP from the Horizons region increased at first from 2000 to 2009, and then started to decline until 2014 before rising again from 2015. Conversely, roading investment (from both Waka Kotahi and local authorities) and the regional population growth rate plateaued for about a decade and then increased from 2015. As with the national model, the total production of aggregates, as well as the production of aggregates for roading, did not seem to exhibit any patterns. We followed the same five-step procedure here as described for the national VEC model.

Figure 7.4 Graphical relationship between dependent and independent variables for regional model 1

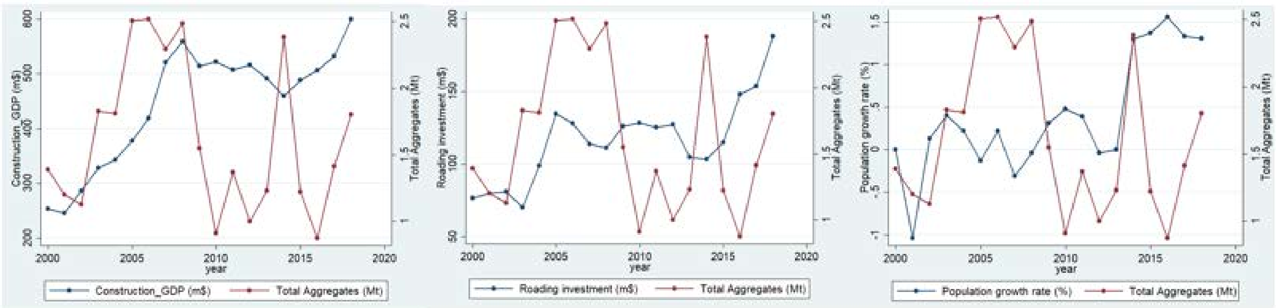
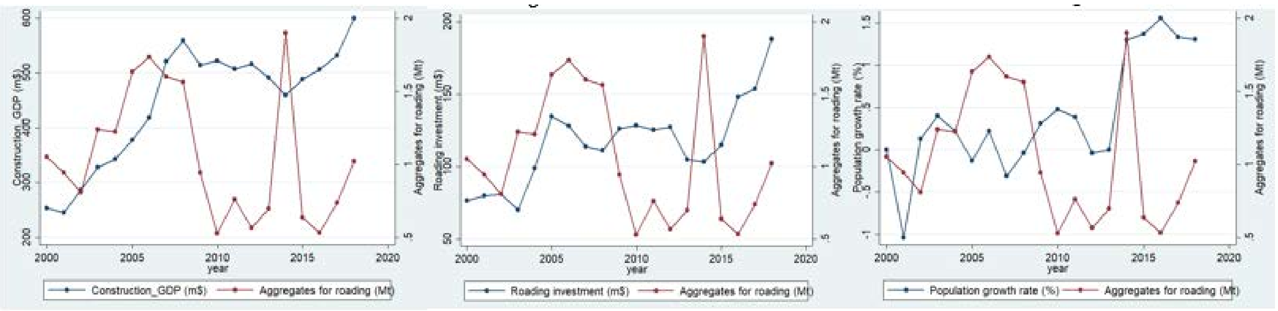


Figure 7.5 Graphical relationship between dependent and independent variables for regional model 2



All variables were transformed into natural logarithms. The ADF tests showed that all variables were non-stationary and were first-order integrated (ie they were I(1) variables). Therefore, they could have exhibited long-term causality. The optimal number of lags was 2 for both regional sub-models. This implied that at the

[7] Independent variables of GDP, Employment, Population and Population Density from the Horizons region, as well as Business Interest Rates in New Zealand, were trialled in the regional model. However, the combination of the three explanatory variables used in the regional sub-models gave the best results.

regional level, aggregate demand/supply for the previous two years had the most explanatory power regarding the outcome of the predicted year's demand/supply in the Horizons region. At a maximum rank of 2, for regional sub-model 1 the trace statistic (15.34) did not exceed critical values (15.41). Likewise, at a maximum rank of 2, for regional sub-model 2 the trace statistic (8.33) did not exceed critical values (15.41). Therefore, the null hypothesis that there was co-integration of two equations for both regional sub-models was accepted.

For regional sub-model 1, two overall key results were discovered (other things being equal):

- A 10% increase in roading investments from Waka Kotahi and local authorities would boost the total production of aggregates in the Horizons region by 19%, while a 10% increase in roading investments would increase the construction sector's contribution to GDP by 11%. The empirical result from regional sub-model 1 implied that the aggregate demand/supply at the regional level was significantly influenced by the regional economy, as well as the government's fiscal response. Moreover, aggregate demand/supply increased more than proportionally to the increase in roading investments. The increase in roading investments was more or less the same as the increase in the construction sector's contribution to GDP.
- Population growth rate had a negative impact on both production of aggregates and GDP from the construction sector.

For regional sub-model 2, two overall key results were discovered (other things being equal):

- A 10% increase in roading investments from Waka Kotahi and local authorities would boost the production of aggregates for roading activities in the Horizons region by 18%. A 10% increase in roading investments would increase the GDP from the construction sector by 11%. The empirical result from regional sub-model 2 confirmed that aggregate demand at the regional level was significantly influenced by the regional economy as well as the government's fiscal response. Moreover, aggregate demand increased more than proportionally to the increase in roading investments. The increase in roading investments was more or less the same as the increase in the construction sector's contribution to GDP.
- Population growth rate had a negative impact on the production of aggregates for roading activities and no effects on GDP from the construction sector.

Compared with the national model, the unexpected results from regional sub-models 1 and 2 regarding the negative relationship between the Horizons region's population growth rate and aggregate production and GDP from the construction sector was most likely due to the lack of data. Hence, the differences in the corrected national volumes and the regional non-corrected volumes demonstrated the significant benefits of using 'cleaned' data in the modelling process. In summary, econometric models were helpful in identifying national demand/supply scenarios, but the lack of available data meant they were not yet fully useful at a regional level.

For a robustness check, results from the LM test, and the Jarque-Bera, Skewness and Kurtosis tests, showed that at lag 2, the constructed VEC models did not suffer from either autocorrelation or normality issues. That is, the regional sub-models performed well.

Figure 7.6 Forecasting for the next decade (from 2018) for regional sub-model 1

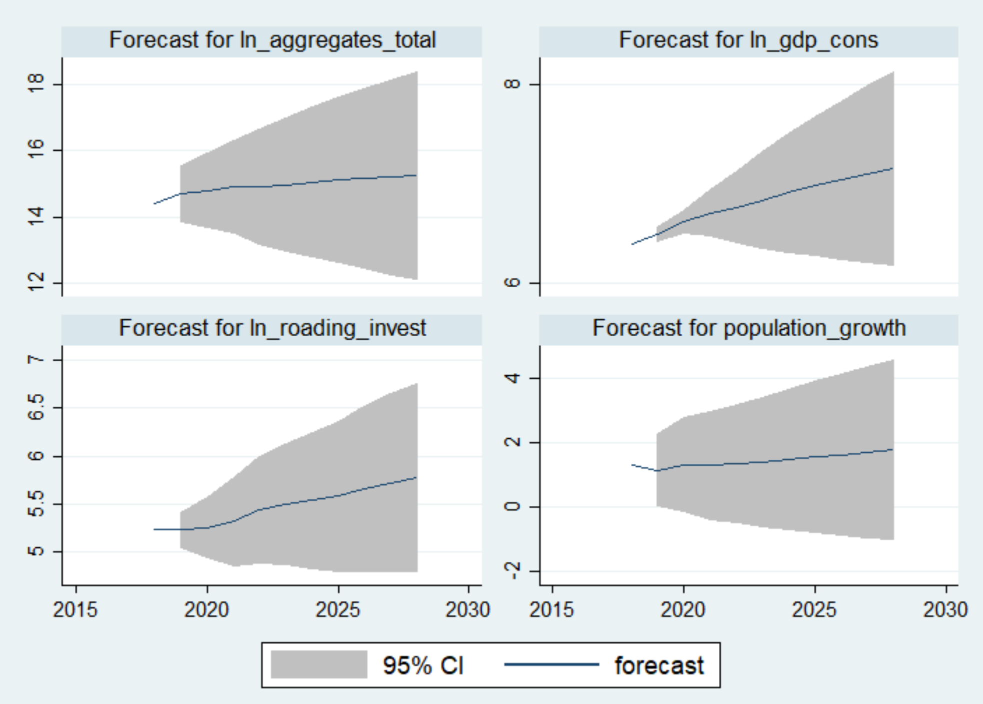


Figure 7.7 Forecasting for the next decade (from 2018) for regional sub-model 2

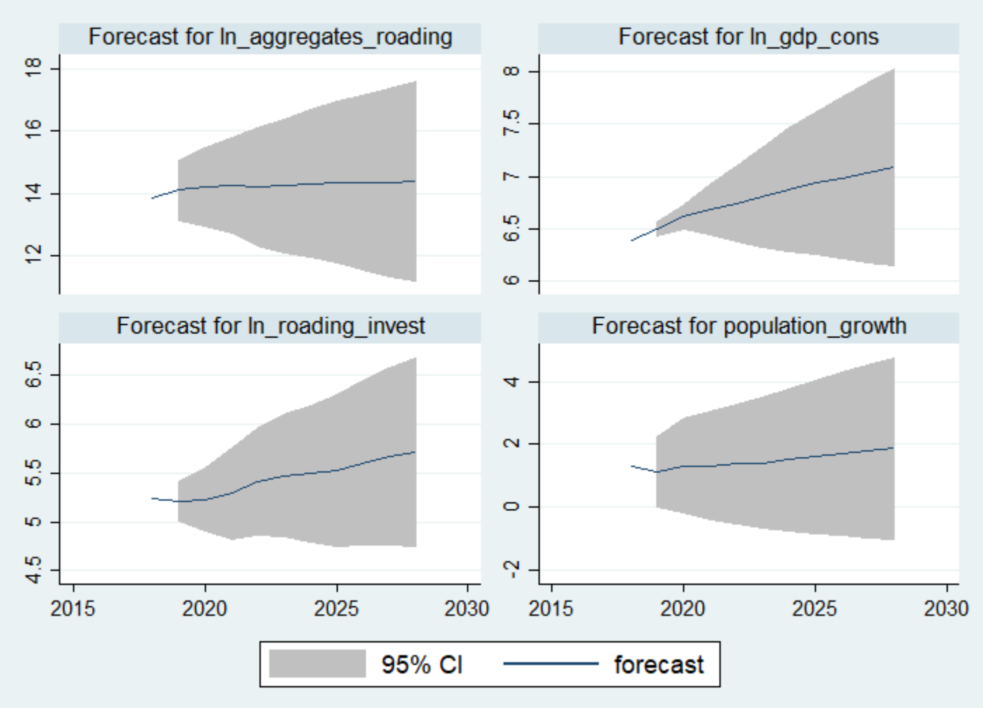


Figure 7.6 and Figure 7.7 show that as expected, the widths of the confidence intervals grew with the forecast horizon. For the decade from 2018 in the Horizons region, total production of aggregates, production of aggregates for roading activities and regional population growth rate were expected to increase at a relatively constant rate of around 2.7%, 2.6% and 0.6%, respectively; in contrast, GDP from the construction sector and investment for roading sector would increase at a faster rate.

8 Summary and discussion

This research has set out a methodology to fulfil the project objectives successfully in the following ways:

- It has described the current data, as well as methods for predicting the future national picture, for aggregate supply and demand in the transport and broader construction industry. This can inform the development of a national sustainable aggregate-sourcing strategy.
- It has reviewed the way aggregate supply and demand forecasting data is currently collated/reported, to inform decision making, and it has developed and tested a prototype econometric forecasting model.
- It has established a baseline of the data currently available and the issues involved in the use of different aggregate materials by various infrastructure typologies. An industry survey and workshop focused on a case study of the Horizons region. While this included the use of recycled and re-used materials, very little quantified data was available at the time.
- It has informed the development of methodologies/tools to enable robust collection/forecasting/reporting and geospatial representation of national supply and demand.
- It has provided recommendations for improving access to, and supply of, sustainable aggregate resources.

Using both existing and novel data sources, the research has revealed the following insights:

- Both the endowment and use of aggregates is very uneven across New Zealand, with demand also varying considerably over time.
- Aggregates are transported varying distances, but the quantities and qualities of the materials transported are unknown.
- While it was onerous to gather much of the data needed to establish supply and demand, we found some useful novel data sources.
- Better information is wanted by people in the sector, who recognise the problems of not being able to forecast supply and demand. However, the question remains – given the commercial nature of the market and uncertainties around demand, how much difference would better information make to decision making? For example, a roading authority may plan for the supply of aggregates for maintenance and then find themselves competing for aggregates with a delayed or newly announced capital project.

The process of developing a picture of supply and demand to facilitate forecasting and planning revealed considerable challenges to the sector for the sustainable use of aggregates. For some key factors, information is either not available or very difficult to obtain for a regional or national picture. For example, while data is collected on the quantity of virgin aggregates, no information is collated on their quality.

The uncertainty around the approval and timing of large capital projects particularly limits planning for the best use of constrained supplies. There does not appear to be a coordinating mechanism to manage competing demands.

There are sensitivities around information because of the commercial nature of the market, which affects identifying and establishing new sources and where products are being transported to.

Overlapping demand from multiple large capital projects has resulted in high levels of demand, prices and transportation of aggregates. The uncertainty of their timing has restricted the ability to plan reliably for the sourcing and costs of supply and to understand the implications of infrastructure decisions.

The lead-in time to establish new supply sites and the uncertainty of demand elevates the risk for suppliers. This is particularly relevant for alternative materials and the need to develop a confident market. In the survey, interviews and workshop, land use and consenting issues emerged as key difficulties in securing supplies of virgin materials. While it was beyond the scope of this project to explore in detail, better information about what extraction activity is being consented and the ongoing monitoring of consents could improve the understanding of supply and demand.

The ‘uneven playing field’ between operating expenses (OPEX) and CAPEX makes it very challenging to plan for the sustainable sourcing and costing of aggregates for maintenance, especially when local authorities are competing with national-scale infrastructure projects.

Suppliers are responding to a commercial model that does not fully account for transport and extraction costs over the life cycle of an asset, nor the social and environmental impacts of the supply. Improved information would allow for more transparency about the trade-offs associated with the supply and sourcing of materials

Determining sustainable future supply sources requires additional information on materials quality, transport links, and social, cultural and environmental factors; this information is not readily available, if it is available at all.

Summary points from the econometric models:

Aggregate demand/supply, at both the national and regional levels, is significantly influenced by the overall/regional economy and the government’s fiscal response.

At both the national and regional levels, aggregate demand/supply increases more than proportionally to the increase in roading investments.

The forecasting signals that aggregate supply is relatively satisfactory nationally, despite the projected increase in roading expenditure, are based on the critical assumptions that an equilibrium exists between aggregate supply and demand at the national level, and that the inventory levels are insignificant, with producers being able to adjust to market needs.

Econometric models are helpful in identifying national demand/supply scenarios; however, due to lack of available data, they are not very useful at a regional level.

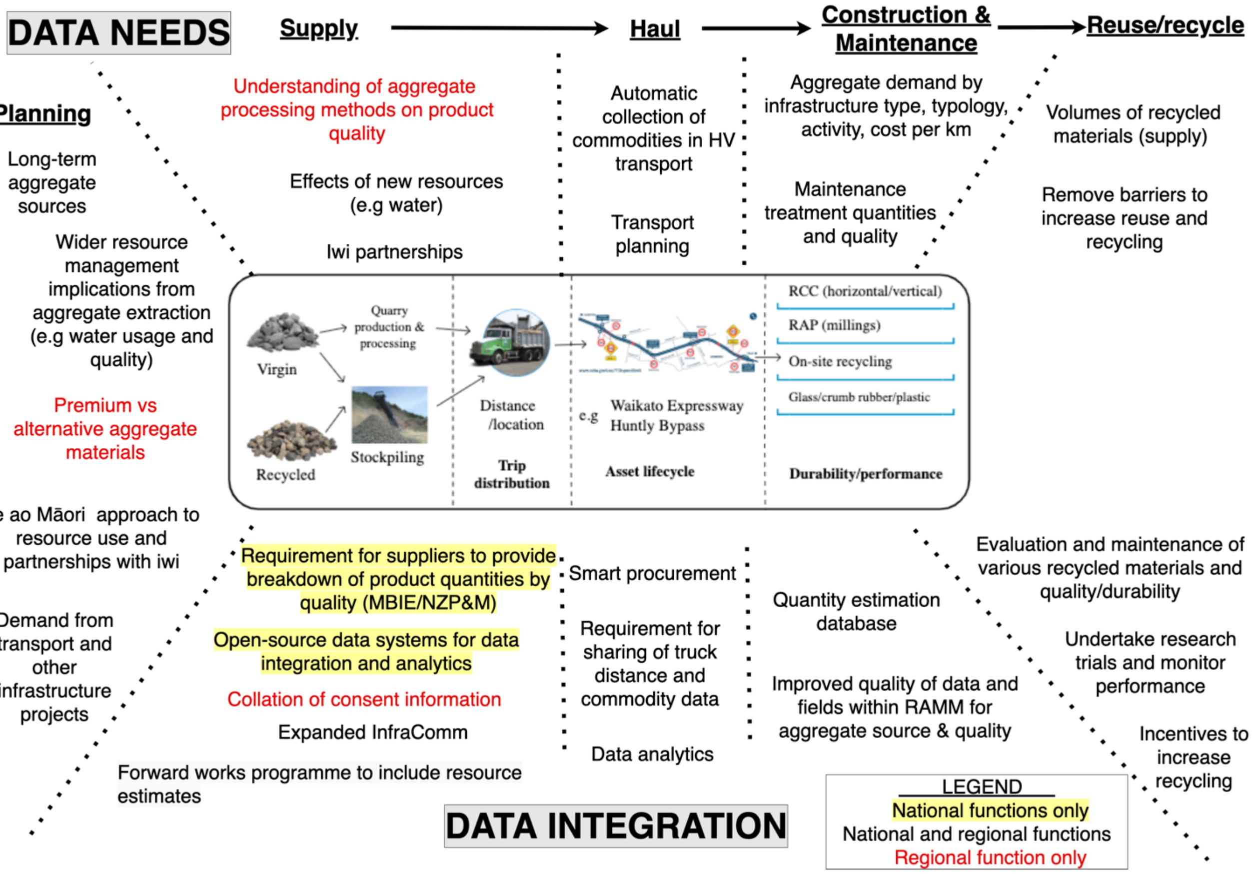
The ‘ownership’ of aggregates is complex. It is determined by both land ownership and mineral rights, which are held by a combination of public, private and iwi parties, in both temporary and permanent arrangements. Limited access to information on ownership makes it difficult to identify existing and future supply options, including how difficult it might be to establish new supply in key locations. It also means that the governance of the aggregate resource is unclear.

Although many of the participants in this research had had experience with recycled materials such as concrete and glass, non-virgin materials were rarely discussed in the survey, interviews and workshop. Unless participants were specifically prompted, alternative materials were largely invisible. This invisibility was likely because they were a relatively small part of the current and future market urgency that many participants were facing with securing large quantities of aggregates, sometimes competing with major capital projects for supply. In addition, it was also likely that alternative materials were perceived as being risky and requiring more effort. The implication of this invisibility is that opportunities to plan for and use recycled materials were being missed. Finding pathways for sharing better information on alternative materials could reduce the risk of using them and make them a higher priority.

Currently, understanding and having capability in the complex system of processes, and the importance of good early decision making with regard to aggregate supply and demand, to facilitate sustainable practices in New Zealand, are not well understood. Practices vary considerably across New Zealand and it is not clear whose responsibility it is to improve them. A whole-of-sector approach is required to improve practices by adopting a value approach. In addition, an education programme is required to ensure decision makers are aware of not only the complex issues involved but also their own organisational biases that can affect values and norms, reinforcing poor resource-use practices and outcomes. Figure 8.1 shows the complex and varied aggregate and associated resource data needs through the life cycle of land transport infrastructure.

Updated guidelines and specifications on the use of all aggregates is part of reducing risk and increasing comfort levels in the sector (Ivory & Bagshaw, 2020). Guidelines can provide varying levels of detail, from providing 'rules of thumb' for sector-wide guidance down to detailed guides and specifications for specialists. Relevant to the supply and demand issues discussed in this report, guidance can include how to determine whether materials are 'fit for purpose', reducing the risk for decision makers by providing performance measures. Guidance can also include safe stockpiling of different materials, including recycled materials, to increase confidence in supply lines. For guidelines to be effective in changing practice in the selection and use of materials, they need to be consistent, accessible and useable across the whole aggregates sector. Waka Kotahi is in a good position to provide leadership through the development and active dissemination of a complete 'use of aggregates' package.

Figure 8.1 Aggregate data needs through the life cycle of land transport infrastructure



The key project findings, listed by project Objectives 1–4, are shown in Table 8.1.

Table 8.1 Key findings

Obj.	Key project findings
1	Aggregate endowment in New Zealand is abundant but increasingly, access to aggregate sources in various locations and regions is becoming more difficult. Transport accounts for approximately 50% of aggregate use in New Zealand. Transport infrastructure requires multiple aggregate products, rather than just one material – therefore, various sources may be required (eg basecourse, subbase, drainage material, concrete, etc). This often means multiple sources are required for a specific infrastructure project. Locally sourced materials are always preferable, to reduce transport and product-to-site costs; however, due to specification requirements, locally sourced materials are not the most appropriate ones. Increased transport haul distances of aggregates from source to site of use not only increases cost but also increases pavement deterioration, thereby reducing remaining pavement life. Demand for aggregate for public and private land transport infrastructure, nationally or within regions, is largely unknown and therefore, cannot be managed currently. The uncertainty around the approval and timing of large capital projects, in particular, limits planning for the best use of constrained supplies. There does not appear to be a coordinating mechanism to manage competing demands. There are sensitivities around information because of the commercial nature of the market, which affects identifying and establishing new sources and where the products are transported to. Determining sustainable future supply sources requires additional information on materials quality, transport links, and social, cultural, and environmental factors; this information is not readily available, if it is available at all. The 'ownership' of aggregates is complex. It is determined by both land ownership and mineral rights, which are held by a combination of public, private and iwi parties, in both temporary and permanent arrangements. Limited access to information on ownership makes it difficult to identify existing and future supply options, including how difficult it might be to establish new supply in key locations. It also means that the governance of aggregate resource is unclear. Aggregate supply and demand at the national level is significantly influenced by the economy and the government's fiscal response, especially when attempting to stimulate economic activity in economic downturns. Aggregate sources are unequally distributed geospatially in relation to location and quality, and in some areas, premium-quality aggregate resources are under significant pressure. While all regions have issues, North Island regions (especially Auckland, Northland and Wellington, with spill-over effects to adjacent regions) are more affected than South Island regions, partly due to increased demand. In areas where premium resources are located near the site of use and easy to produce, there is little incentive to protect their sustainability on behalf of neighbouring regions that are more challenged in being able to produce premium resources. In some areas, especially where hard-rock quarries are not locally available, historic extraction practices have depended on alluvial extraction from existing or old riverbeds and demand may have outstripped replenishment (aggradation) rates, especially where hydro schemes have altered upper-catchment river flows. There is a growing realisation, from the perspectives of both resource planning and resource efficiency/sustainability, that as non-renewable resources, aggregate resources need to be managed more sustainably. As urban centres have grown, and environmental and cultural sensitivities have increased, aggregate resources have progressively become more difficult to access.

Obj.	Key project findings
	In land use planning documents, regional authorities need to include land zoning designated for quarrying purposes. This will allow the timeframes for consenting of quarries to be reduced when complying consents are received. A long-term partnership approach with iwi and hapū within regions would enable a te ao Māori approach, which acknowledges the interconnectedness and interrelationship of all living and non-living things, of Papatūānuku, whenua and mauri, to be applied to the aggregates industry to improve current and future practices. This approach would enable and encourage resource sharing and economic opportunities for Māori and rangatahi within regions (should iwi/hapū decide to participate), leading to the improved well-being of Māori and rural communities. Data on aggregate supply and the demand for various types of transport infrastructure are scarce or very difficult to obtain, which prevents the development of aggregated learnings. The project has been unable to answer the supply and demand question at a regional level because there is insufficient region-based demand and supply data available.
2	There are several existing sources of data, from geospatial data to databases that relate to the supply and demand for aggregates for infrastructure projects, including both new capital expenditure (CAPEX) investment and maintenance treatments, held within various central, regional or local government agencies. None of the data sources are currently in a form that can be easily data mined or aggregated to gain cross-sector inferences regarding the national aggregate supply and demand in relation to future infrastructure demand.
3	The project has not been able to establish a national or regional baseline of the current use of different aggregate materials, including recycled and re-used materials, because of the lack of available data. With regard to the use of recycled and re-used materials, the project found the following: • Problems associated with the use of recycled aggregates include the permitting process, lack of familiarity with the technology, variable attributes of source material, lack of knowledge of the capabilities of recycled material, and sourcing a reliable flow of quality material. • Some of the recycled materials used as aggregates are of superior quality to virgin products and outperform them. • The challenge with the use of recycled products is the need for 'quality processing', which requires the use of the latest technology to supply the final quality product. Establishing a framework to forecast supply and demand in the medium-term planning horizon would help to set the context and create a framework in which all opportunities to recycle, add, reconstitute and re-use materials could be better understood and taken advantage of.
4	Econometric models are helpful in identifying national demand and supply scenarios but the lack of data availability means that they are not very useful at a regional level. Telematics data could be used to gain greater understanding of the movement of trucks and aggregates. A potential future telematics system that collected dynamic data of materials logistics (if they could be tagged, identified and tracked from place of origin to destination and potentially, on various road typologies) could become part of a very useful transport operations and raw resource-use system, allowing further insights into the aggregate transportation process. International research has demonstrated the following: • The long-term production and use of aggregates per capita is positively associated with population growth, GDP and additions to the built environment. • Although transport costs favour quarry locations that are relatively close to demand, increased population density and concerns about environmental protection have resulted in the aggregates industry moving further away from growth centres. • Aggregate taxes (including sand, gravel and/or crushed rock) have been implemented in several European economies, with two approaches: an ad valorem tax based on the value of the aggregate and a unit tax applied to a physical quantity of aggregate. In addition to providing revenue to the

Obj.	Key project findings
	government, the royalties generated information that was useful for monitoring aggregate use and data for policy analysis. • A limited number of papers approached empirical estimates of supply and demand informed by economic theory and the use of sound econometric methods. In the case of New Zealand, national aggregate information (NZP&M data) relies on voluntary participation in annual surveys. Unless data on the value of recovered aggregates are available it is not possible to estimate a supply equation. At best, we could assume that supply equals demand and follow the above approaches that estimate use (demand) as a function of socio-economic variables.

9 Conclusions and recommendations

Aggregates are an important non-renewable resource for land transport and vertical building infrastructure. As a country, New Zealand has an abundant endowment of rock minerals suitable for aggregates for the construction, maintenance and recycling of public and private infrastructure. There is an increasing demand for aggregates in many regions of New Zealand, due to a deficit in infrastructure development over several decades, strong population growth in many areas and the approaching end of the useful and/or economic life of much of New Zealand's public infrastructure. Some regions of New Zealand have difficulties sourcing appropriate materials locally for infrastructure purposes and there are increasing sensitivities to the extraction of aggregates; many communities and iwi/hapū have experienced the effects of poor extraction and environmental practices in the industry, as well as the lack of regulation or monitoring of consent conditions. Currently, very little appropriate data is available, either nationally or within regions, to sustainably plan, manage, use and re-use/recycle aggregates for various public or private infrastructure and therefore, to be able to forecast future aggregate demand. The data that is available is very difficult and resource intensive to obtain and it is not in a form that can be readily integrated with other data systems.

Key recommendations from this research are as follows:

- **Develop an aggregate data integration framework** to standardise, collate and improve aggregate data information (both quantity and quality), at both the national and regional levels, for the extraction and processing of aggregates (supply). This will require integration of data on aggregates from various systems, regions and aggregate sectors, differentiating by aggregate product quality, to manage the value and effects of aggregate resource use more sustainably.
- **National agencies and regional and local authorities should plan with a long-term horizon** of at least 50 years for aggregate resources and designate land use areas/zones for quarrying/aggregate extraction purposes, taking into consideration the forecast demand in the region.
- **Develop an aggregate minerals strategic supply and sustainability strategy** as part of the government's minerals resource strategy and in partnership with the New Zealand Infrastructure Commission's (2022) *Rautaki Hanganga o Aotearoa: New Zealand Infrastructure Strategy 2022–2052.*
- **Introduce mandatory reporting on national and regional usage of resources for public infrastructure, by product quality and purpose,** including recycled materials and associated resources (eg water). This should be reported to NZP&M and/or regional/local authorities on a quarterly basis (currently, this is voluntary for non-Crown-owned lands) for all suppliers of aggregate, as part of the consenting requirements. Quarterly information will allow much better forecasting of demand, both within regions and nationally. It will be important to communicate the value of the reporting to all stakeholders, to provide context.
- **Identify and target regions/areas where there are opportunities for increased use of recycled materials** (eg where there is critical mass in urban areas – Auckland, Wellington and Christchurch), as well as where there are significant natural aggregate supply constraints (eg Northland, Hawke's Bay and the Horizons and Wellington regions).
- **RCAs and their contracted consultants should encourage an increase in the appropriate use of recycled/re-used materials** in their specifications, guidelines and contract tenders, as a priority over using virgin materials. Design and selection strategies should aim to minimise the carbon footprint by using appropriate local treatment strategies (eg in-situ stabilisation, which is already quite widely used).
- For all potential land use/quarrying consent applications, **develop best-practice aggregate consent application templates/guidelines,** along with a check list, via the establishment of a key stakeholder working group across central and local government in partnership with Māori. This working group should

identify how information/key data should be standardised to allow aggregation and collection nationally by territorial authorities (regional, district and local) and in conjunction with Waka Kotahi and NZP&M.

- **Waka Kotahi should establish a national infrastructure resource quantity and pricing database** for each Waka Kotahi region and integrate it into a national data base to allow an understanding of aggregate demand by infrastructure typology and maintenance activity. An example of the type of data that could be collected is shown in Table 4.1. This database could extend to all RCAs for projects (over a certain value threshold) that receive National Land Transport funding and this could be part of the required achievement data. The database should include as a separate module the projected land transport demand for aggregates, by region, to enable forward planning.
- **Expand the Infrastructure Commission's forward works programme** (Pipeline) to allow future planned public infrastructure to be broken down **to demand by region and to include primary raw materials** – this could be linked to the New Zealand Infrastructure Commission's (2022) *Rautaki Hanganga o Aotearoa: New Zealand Infrastructure Strategy 2022–2052* and the demand calculated by the Waka Kotahi resource quantity database for each region.
- **RCAs should actively encourage and provide leadership** in the use of sustainability-rating schemes that promote the use of recycled/re-used materials (eg ISCA) to prioritise low-carbon-emission options.
- Agencies that procure public infrastructure need to use both 'carrot' and 'stick' approaches to encourage aggregate use that is more sustainable.
- **Waka Kotahi should commission a Training Needs Assessment regarding the levels of training required** across land transport infrastructure delivery activities to build the capacity and skills to use aggregate resources more sustainably.
- **Establish a working group to encourage collaboration and constructive cooperation** among the key central infrastructure agencies (eg Waka Kotahi, Ministry of Transport, MBIE/NZP&M and InfraCom NZ Te Waihanga), to ensure an ongoing national conversation can be held across central and local government agencies, and industry and research organisations, to develop various aspects of the above recommendations.
- Undertake further research to investigate how aggregates (and potentially, other key raw resource materials) could be tagged, identified and electronically tracked from place of origin to destination.
- **Undertake further research on infrastructure sensing** that would allow remote data analytics and infrastructure condition monitoring to be developed throughout the stages of the infrastructure life cycle of aggregate materials, from source to place of use, to enable the sustainable use of aggregate minerals and associated resources.
- **Undertake research on aggregate quality** to complement the knowledge on quantity, to feed into building databases, costing analysis, planning and strategic policy development.

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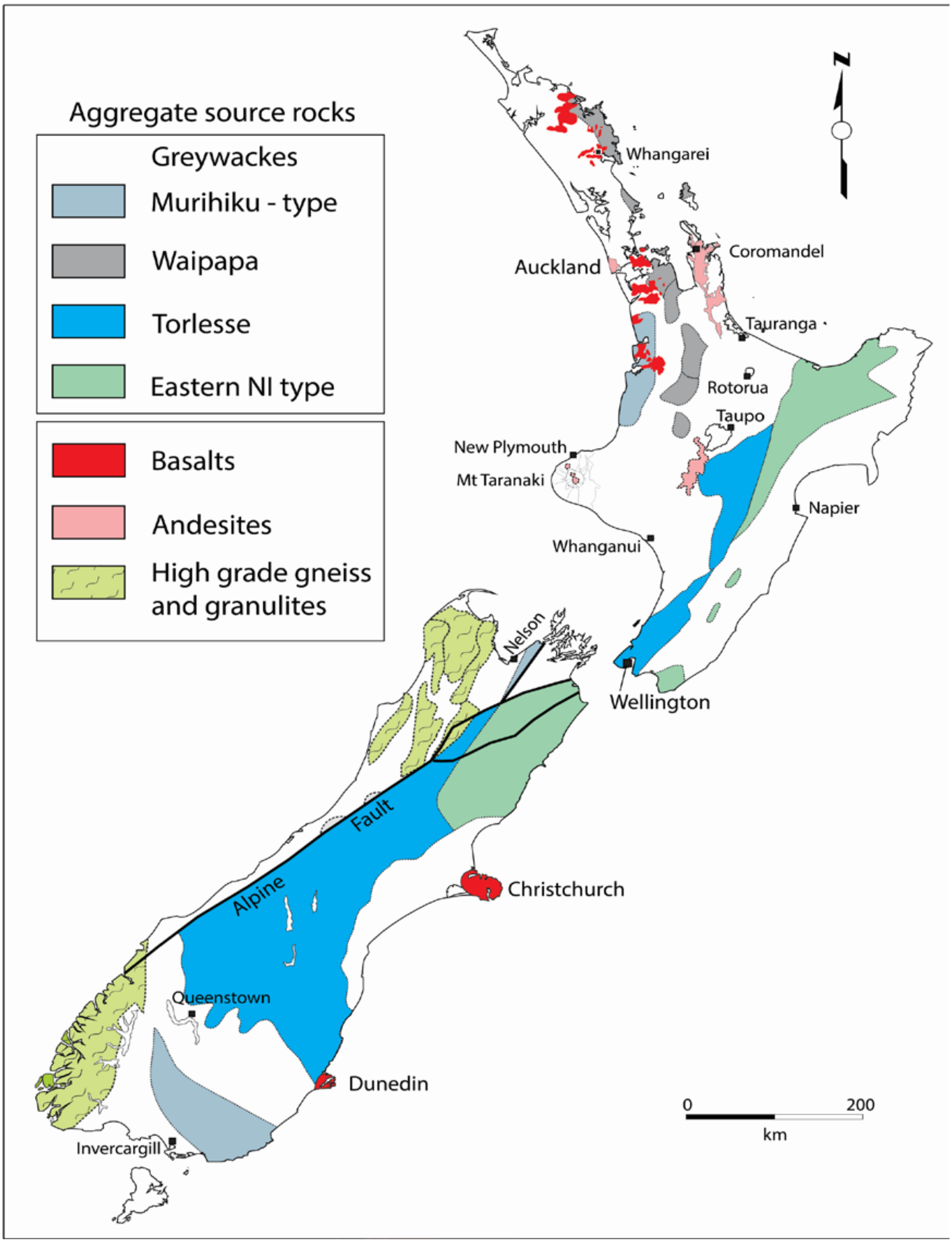
Appendix A: Aggregate geological maps of New Zealand

Figure A.1 Aggregate supply maps by geological source rock in New Zealand (Wilson et al., 2019, slide 35)



Appendix B: Quarry production survey

Figure B.1 Quarry production data (reprinted from https://www.nzpam.govt.nz/our-industry/nz-minerals/minerals-data/industry-statistics/)

ANNUAL RETURN OF INDUSTRIAL ROCKS AND MINERALS OUTPUT 2021
FOR PERIOD 1 JANUARY 2021 TO 31 DECEMBER 2021

Quarry Operator: *REF:*

Quarry Name:

Operational during 2021: ☐ or, Nil Output: ☐ or, Closed: ☐ *(please tick appropriate box)*
(please fill in table below)

Please clarify whether units are cubic metres or tonnes or truckloads

2021 Output	Quantity (Sold or Used) (Tonnes)	Value ($NZ) (Total sales value GST inclusive)
Amorphous Silica		
Bentonite		
Building and Dimension Stone		
Clay for bricks,tiles etc		
Clay for pottery and ceramics		
Decorative pebbles including scoria		
Diatomite		
Dolomite for agriculture		
Dolomite for industry		
Limestone for agriculture		
Limestone for industry		
Limestone and marl for cement		
Perlite		
Pumice		
Recycled Material*		
Rock for reclamation & protection		
Rock, sand, gravel & clay for fill		
Rock, sand & gravel for building		
Rock, sand & gravel for roading		
Sand for industry		
Serpentine		
Silica Sand		
Talc		
Zeolite		
Other *(please specify)*		

* Include any recycled materials, such as Slag, Concrete, Asphalt ETC.

Print Contact Name:.. Date: ....

Position:.. Phone Number: ....

Email address: ....

Postal address: ....

Confidentiality of Information:
The purpose of this survey it to help the Ministry of Business, Innovation, and Employment (the Ministry) improve its understanding of the New Zealand extractives operating environment. All information supplied to the Ministry will be held in confidence, with no information relating to an individual organisation being released to the public, unless disclosure is required by law. Only aggregated data will be published. The Ministry will restrict the publication of data in circumstances where the information is identifiable to the few number of operators in a particular region. This policy will apply where a region has three or fewer quarries. The information collected may be shared with other public service agencies and organisations to which Schedule 1 of the Ombudsmen Act 1975 applies and will only be used in accordance with this confidentiality statement.

Appendix C: Five steps of applying the VEC model

Table C.1 VEC model

1. Stationarity	The first step is to check stationarity in data. If the time-series data shows that the variable is non-stationary, then the first differencing should be used. Augmented Dickey-Fuller (ADF) tests are employed for this purpose, where H0: a unit root is present vs H1: the time-series is stationary.
2. Lag selection	It is unclear how many lags in the variables show interrelation. Therefore, the second step is to specify how many lags to include. Several selection criteria are applied to determine the optimal lag order value, including Final Prediction Error, Akaike Information Criterion, Hannan Quinn Information Parameters and Schwartz Information Parameters.
3. Test for co-integration	The implication of co-integration is that two or more variables have a long-run causality and in the long term, the variables might converge towards an equilibrium value. Equilibrium value is steady; therefore, they have equal means and variance, or in other words, they are 'stationary'. Co-integration indicates a long-term association between two or more non-stationary variables.
4. If co-integration is present, then we apply the VEC model	The VEC model allows for contemporaneous and lagged interconnection between the variables of interest to exist; therefore, it can provide estimates that are more qualitative. A likelihood ratio test, known as the Johansen's testing procedure, is applied to test the null hypothesis of no co-integration in the VEC model.
5. VEC model diagnostic tests	Review the assumptions of autocorrelation through a Lagrange Multiplier (LM) test and normality through the Jarque-Bera, Skewness and Kurtosis tests.