Aggregate Opportunity Modelling for the Wellington Region of New Zealand

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ABSTRACT

Efficient utilisation of aggregate resources is important to supporting infrastructure development and reducing operational and transport costs related to extraction of raw materials. In order to understand the spatial distribution of future resources, aggregate opportunity in the Wellington region has been mapped. Modelling of geological, land-use, infrastructure and cultural digital data has been used to map where future resources are located, facilitating prioritisation over less-critical land uses to support our growing economy. Aggregate opportunity areas are places that have overlapping spatial data classes favourable for extractive activities. These indicate where there is a good possibility that an aggregate resource could be developed; however, follow-up investigation of unmapped geotechnical data; non-spatial factors, such as community and iwi values; and local council plans and policies need to be considered.

A spatial modelling approach has been used to identify places with opportunity for future hard rock, gravel and sand extraction in the Wellington region. The modelling process involves three levels: classification of source data into mappable criteria layers, combination of criteria layers into predictive components and development of aggregate opportunity models. Geographic information system (GIS) software has been used to build 21 maps of the essential components of aggregate opportunity: source rocks, land use, feasibility and cultural sensitivity to extractive activities. The maps are then combined using fuzzy logic expert-weighted spatial modelling to qualitatively rank aggregate resource opportunities in the region, identifying high-value areas for aggregate exploration. The resulting maps and their accompanying GIS datasets of sand, gravel and hard rock aggregate opportunity can be used to manage aggregate resources; generate targets for exploration activities; and provide insight into future resources, ensuring that they are not unavailable in the future due to other land use.

The project identifies constraints such as regulatory and cultural considerations, emphasising the importance of comprehensive data integration and stakeholder engagement in resource management. Despite challenges such as incomplete data and regulatory complexities, the modelling approach provides valuable insights into aggregate resource distribution and potential extraction sites. Results for the Wellington region show large areas of opportunity for sandstone hard rock resources near most major cities, areas suitable for gravel extraction away from active river channels in the Wairarapa and potential for sand material in the Kāpiti Coast and southern Wairarapa. This project’s findings facilitate informed decision-making for sustainable resource utilisation and infrastructure development in Wellington Region.

KEYWORDS

Aggregate, aggregate opportunity concept, spatial modelling, fuzzy logic, hard rock, gravel, sand, resource planning, Wellington Region

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1.0 INTRODUCTION

The development of infrastructure requires large quantities of hard rock, gravel and sand aggregate material for roading, concrete and construction. New Zealand is fortunate to have large areas of accessible rock and gravel deposits throughout the country that can be utilised for aggregate. Much of this material is only slightly weathered at or near the surface. Aggregate in New Zealand can be largely grouped into three classes: (1) hard rock, including greywacke, sandstone, volcanic rocks and limestone; (2) gravel, particularly from river channels and alluvial terraces; and (3) sand from inactive and active dunes and river channels. This project uses a desktop approach to model opportunities for potential aggregate locations in the Wellington region using geological, land-use and other topographic and cultural considerations.

Aggregate materials are ideally extracted near to their site of end use to minimise the cost of transportation and emissions. Knowing where there are suitable resources and understanding the land-use and transport-distance factors, as well as people's sensitivity to extractive activities, is important to planning our future aggregate extraction locations, a process collectively referred to as 'opportunity modelling' (Hill 2021). Future opportunities for aggregate resources can be determined using spatial analysis to combine geological map data, land-use, infrastructure and cultural information to rank areas for future extraction potential. New Zealand's domestic production of aggregate is approximately 45 million tonnes (Mt) per year (AQA c2022), with more than 75% occurring in the North Island (Christie et al. 2001). Production is forecast to increase, and new aggregate resources are important for continued development of New Zealand's infrastructure.

Aggregate is extracted based on the source rock physical properties (strength, durability, cohesiveness, size), chemical properties and beneficial or lack of deleterious minerals, and quarries require homogeneity of material and volume at a site. As well as these geological criteria, social and cultural aspects (proximity to urban areas, landscape values, areas of cultural significance), environmental (water, air and noise pollution) and resource economics (quality and distance to market) play a key role in the economic success of a quarry. Ideally, aggregate resources are extracted close to their end-use location; the cost of aggregate doubles after approximately 30 km due to transportation costs (NZIC 2021), so local sources are required to minimise the cost of new infrastructure projects. Future explorers and resource planners should carefully consider all of these parameters when developing new aggregate sources.

This project has mapped areas of ***aggregate opportunity*** using spatial modelling tools available in geographic information system (GIS) software. Higher-ranked aggregate opportunity areas are where data indicate the existence of suitable aggregate material close to transportation infrastructure and aggregate end uses with comparatively minor cultural, social and environmental disruption. Not all aspects related to aggregate extraction suitability can be spatially modelled. There are non-spatial considerations, such as community values and legal frameworks, as well as ecological and human health factors. Although some of these can be approximated through proximity analysis (the closer they are to aggregate operations, the greater the sensitivity), they are difficult to include in country and regional-scale models. Nevertheless, aggregate materials are well suited to spatial modelling techniques, as much of the data are readily available in digital databases and have continuous coverage across the project area. Digital datasets that contribute to determining aggregate opportunity have been acquired from Toitū Te Whenua Land Information New Zealand (LINZ), the Department of Conservation, Manaaki Whenua Landcare Research, GNS Science, the Ministry for the Environment and Statistics New Zealand (Stats NZ). The GIS is used to analyse the digital data and create classified maps that include geology, land use, critical infrastructure and factors that are culturally sensitive.

This modelling project is developed around the ***aggregate opportunity concept*** (Hill 2021), which not only identifies several critical or highly important features that must be present together for a resource to be economic and for a quarry to succeed but also, and importantly, identifies contra-indicators that affect the viability of a quarry or restrictions to its development. Maps of source material, land use, quarry feasibility and sensitivity to extractive activities are used to represent all components of the aggregate opportunity concept. Data in these maps are classified into subjective ranges and weighted relative to the aggregate opportunity concept by considering advice from industry experts and modelled ranges using spatial statistics.

This project is focused on the aggregate opportunity for the Wellington region and encompasses the Wellington, Porirua, Upper Hutt and Lower Hutt cities and the Kāpiti Coast, Masterton, Carterton and South Wairarapa districts (Figure 1.1). The region has approximately 75 operating quarries that extract greywacke and other sandstone, limestone, basalt, gravel and sand material to primarily support the local market. Sandstone and limestone hard rock resources are extracted from ridges and slope faces of exposed or near-surface rock. Gravel material is extracted from deposits of alluvial gravels in active or abandoned river channels. Sand is also extracted from alluvial gravel deposits as well as active and inactive dune deposits.

The geology of the Wellington region is comprised mainly of Mesozoic-age indurated sandstone and mudstone rocks of the Torlesse Supergroup (Begg and Johnston 2000; Lee and Begg 2002). Minor basalt is locally present, and semi-schistose rocks occur in the far west of the area. The rocks of the Torlesse Supergroup are commonly collectively referred to as 'greywacke', although the term is more specifically applied to the dominant sandstone component in this report. Unconsolidated Quaternary gravel and sand deposits occur in river valleys and coastal plains in the region. The area also includes Paleogene and Neogene sandstone and limestone in the Wairarapa area. For more detail on the geology of the Wellington region, refer to Begg and Johnston (2000) and Lee and Begg (2002). Based on an interpretation of GNS Science's regional (1:250,000 scale) geological map dataset (Heron 2023), the rocks in the Wellington area can be divided into eight ***aggregate type classes*** (Figure 1.1). The outputs of this project highlight where the best aggregate opportunities for each of those classes are located.

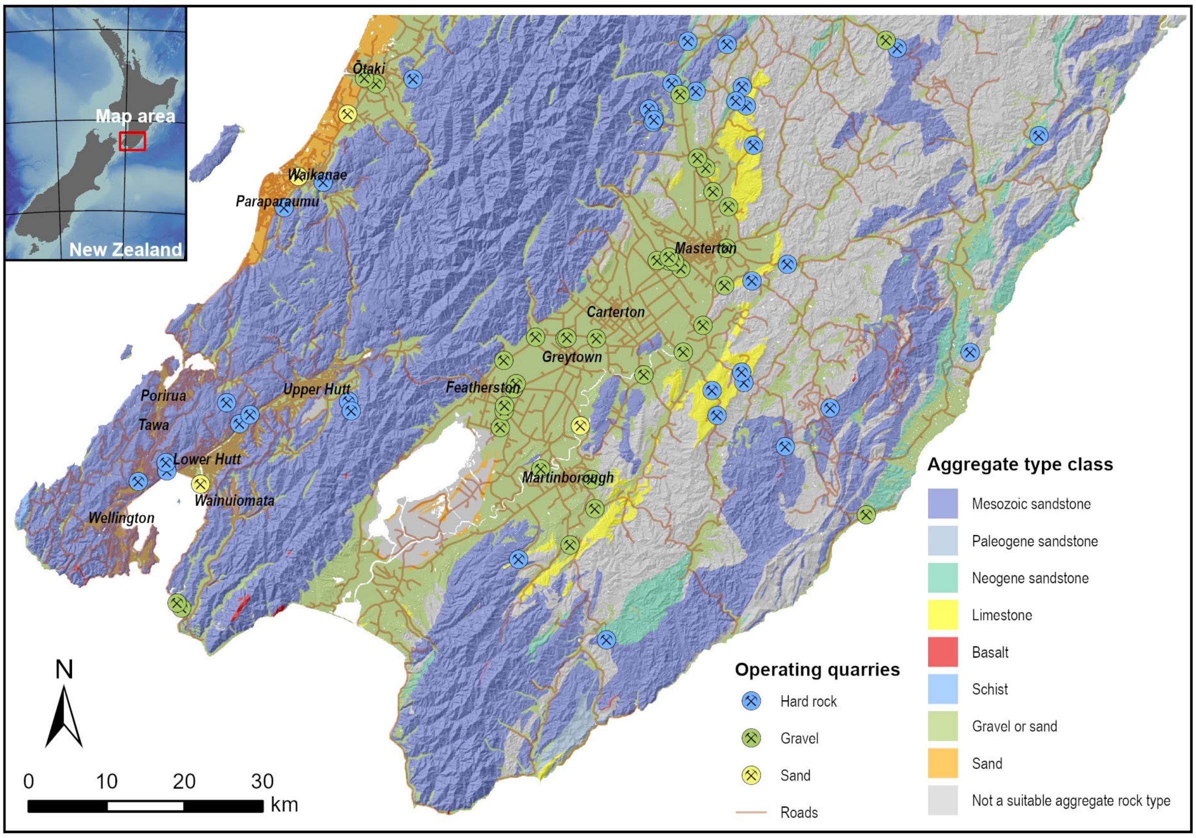

Figure 1.1 Map of aggregate type classes and the extent of the modelled area in Wellington Region. Aggregate type class is based on interpretation of regional geological mapping (unit map name, description, main and sub-rock types, and age [Heron 2023]).

2.0 DATA AND SPATIAL ANALYSIS

Determining aggregate opportunities is well suited to spatial modelling techniques, as much of the data required is readily available in digital databases and continuous across the entire region. Data from authoritative sources (for example, geological data from GNS Science, land areas from the Department of Conservation and population density from Stats NZ) are analysed and classified using dataset-specific and well-established spatial techniques (see Appendix 1 and examples such as Robinson et al. [2004], Blachowski [2014], Blachowski and Buczyńska [2020] and Hill [2021]). Classifications of these datasets are regarded as ***mappable criteria*** in the model (Figure 2.1). This 'first level' of the modelling created 21 mappable criteria maps for Wellington Region. The maps are 32 x 32 m cell-size integer grids built with the GIS software and were chosen to best represent the predictive components of the aggregate opportunity concept and minimise co-dependence (multiple-counting of input data). Variably weighted groups of the mappable criteria were combined to form four second level ***predictive model component maps*** (Source material, Land use, Feasibility and Cultural sensitivity). These component maps are weighted and combined using spatial modelling to form the final aggregate opportunity models (see Section 3).

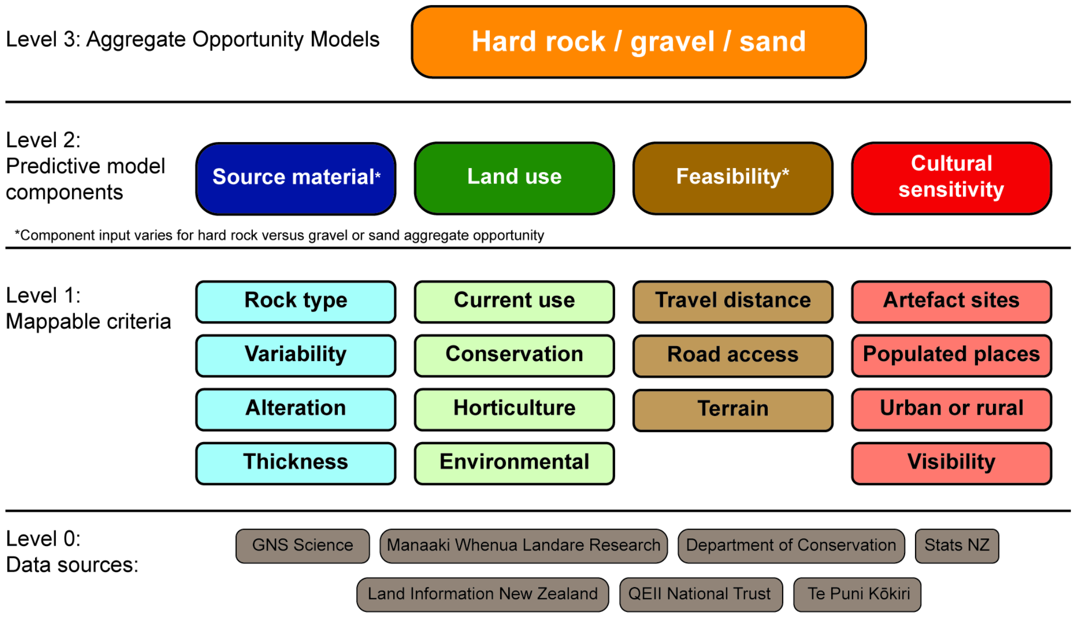

Figure 2.1 The aggregate opportunity concept involves classification and ranking of source data into mappable criteria layers that are variably weighted to support the predictive model components of Source material, Land use, Feasibility and Cultural sensitivity. The components are then weighted and combined into the Hard rock, Gravel and Sand aggregate opportunity models (modified after Hill [2021]).

For each of the mappable criteria, classifications (for example, different rock types, distances from infrastructure or ranges of population density) are assigned a ***class weight*** between 0 and 100 (see Appendix 2). These values represent an expert-opinion-derived (and, in some cases, spatially weighted) numeric value – the values can be perceived as an assessment of the relative suitability of a feature or a map area classification to a possible quarry site. These class weights are then converted to ***fuzzy membership values*** for spatial modelling by dividing them by 100 to give values between 0 and 1. In this project, most class weights fall between 10, which is a contra-indicator for quarry opportunity (for example, a high-value conservation land use), and 90, which is a strongly positive indicator (for example, an area of highly desirable rock type). A value of 50 has been used where there is neutral value in terms of quarry opportunity (for example, the distance from a road that is neither desirable nor uneconomic). These mappable criteria for each of the model concept components are discussed further in the sections below and are also illustrated in maps within Appendix 3.

2.1 Source Material

The location of source material is a fundamental component of the aggregate opportunity concept. Distribution of rock type and composition in the Wellington region is generally well-known from existing geological maps (Begg and Mazengarb 1996; Begg and Johnston 2000; Lee and Begg 2002; and references therein to prior mapping). These regional-scale maps do not convey fine-scale variation in rock properties, such as proportions of interbedded sandstone and mudstone within individual geological units. Information on measured rock property data (for example, rock density and degree of weathering) would benefit this modelling, but this information is rarely available and, where present, is typically insufficient for consistently adding more detail within geological map units.

For most use cases, hard rock resources should be well indurated (hard), have a consistent mineralogy and be free from significant jointing, fractures and weathering. Gravel resources generally should be comprised of clasts with a consistent rock type that is strong, unaltered and unweathered, resistant to weathering, free of reactive minerals and organic material and not coated with clay or other fine grain-sized particles. Sand can be the product of erosion of many different rock types. In New Zealand, sand typically contains quartz, feldspar and, locally, iron oxides and other heavy minerals. Sand resources can be sourced from rivers, dunes, beaches, offshore marine deposits, amongst gravel deposits and from volcanic sand deposited by airfall or a river. Sand can also be manufactured from crushing of coarser gravel-sized material. Like gravel deposits, sand should also be free of finer-grained material, be inert and not contain organic material or salts.

At a regional scale, geological units can be qualitatively generalised in terms of their aggregate resource quality based on their documented lithology and rock type composition. This project has used the digital geological maps from Begg and Mazengarb (1996) and the QMAP 1:250,000-scale geological map of New Zealand (Heron 2023) to create maps of the source rocks for hard rock, gravel and sand source rocks. Over 100 unique classes of lithology (based on unit map name, description, lithology and age fields) are classified into 32 mappable criteria classes (Appendix 3 – Map 1) and given class weights based on their composition relative to a suitable source rock. The source rocks in Wellington are divided into eight aggregate type classes: Mesozoic-age sandstone (often referred to as greywacke); Paleogene- and Neogene-age sandstone (younger sandstone rocks); limestone; basalt; schist, gravel or sand (dominantly gravel deposits but can also contain sand); and sand deposits (see Figure 1.1).

The geological map units are also reviewed in terms of subordinate rock material variability – rock units with less variability (monolithic) are more favourable than those with a lot of different material types. An assessment based on the unit description and lithology types of how variable the different materials are in each map unit, using a subjectively ranked scale from monolithic to highly variable, is used to map that variability (Appendix 3 – Map 2).

In the Wellington region, relatively unweathered basement rocks commonly occur on the upthrown side of major faults, with weathering intensity typically increasing away from these faults. Locations where the less weathered material is closer to the surface are favourable for hard rock quarrying. Areas within and immediately adjacent to major fault zones are not favourable quarry sites because of closely-spaced fracturing and/or alteration. Mappable criteria classes are created based on the proximity to major faults and distance from the fault on the upthrown side (Appendix 3 – Map 3).

A notable spatial correlation between mapped soil permeability classifications (LRIS 2010b) and gravel or sand resources helps distinguish between well-draining gravel or sand areas and areas of peat or finer-grained clay-dominated sediments (Appendix 3 – Map 4). The source material for gravel and sand resources is usually in close proximity to the ground surface (<10 m). A borehole database for ~9000 sites in the Wellington region has enabled a map of sediment thickness within 10 m of the ground surface (GWRC 2018), and this identifies where thicker deposits of gravel or sand material occur (Appendix 3 – Maps 5 and 6).

2.2 Land Use

Land use is one of several non-geological model components used for determining sites that are suitable for quarrying activities and areas of restricted land where mining activities are prohibited or where access restrictions may apply. Five mappable criteria outputs were created to classify these land-use conditions:

1. LINZ cadastral databases are used to identify areas of water conservation, environmental protection, parks, cultural sites (for example, hospitals, schools, cemeteries, etc.) and roads from a keyword search in the statutory records (Appendix 3 – Map 7).
2. Public conservation land areas managed by the Department of Conservation are divided into 21 section classifications. Areas such as national parks are not suitable for quarrying activities; however, in some parts of stewardship areas, quarrying may be appropriate, so class weights are applied to Department of Conservation land relative to conservation value (Appendix 3 – Map 8).
3. The Land Cover Database (LCDB) (LRIS Portal 2019) classifies different areas of vegetation and land uses based on satellite data. It is particularly useful for identifying areas of ecologically significant indigenous native vegetation, high-value cropland or areas more suitable for quarrying activities such as exposed rock or harvested forest. Each of the 34 different LCDB classifications is given a class weight based on the current land use's suitability for extractive activities (Appendix 3 – Map 9).
4. The Land Use Capability (LUC) (LRIS Portal 2010a) database categorises land into eight classes based on its long-term productivity using physical qualities of the land, soil and environment, then four sub-classes based on erosion, wetness, physical or chemical properties, and climatic limitations. The National Policy Statement for Highly Productive Land (Ministry for the Environment and Ministry for Primary Industries 2022) promotes restrictions applied to LUC classes 1, 2 and 3, so these are given lower class weights in the model (Appendix 3 – Map 10).
5. QEII National Trust land areas are located throughout New Zealand and are inappropriate for quarrying activity, so are therefore assigned low class weights in the model (Appendix 3 – Map 11).

2.3 Feasibility

Ideally, quarry developments should be close to supporting infrastructure, such as the road network, and end-users of the extracted material and should also be located within suitable terrain for the style of extraction activity and deposit type. This model component has used datasets to represent quarry feasibility that includes the distance from roads classified by size and use, as well as the driving distance along the roading network to potential aggregate end users. The assessment of suitable terrain for the style of extraction activity and deposit type is also included as part of the feasibility analysis.

The elevation and steepness of terrain are included as part of the feasibility component, as terrain affects the style of extraction at a given site. In general, hard rock quarries favour steeper sites to access less-weathered material and to minimise the removal (stripping) of the overburden. Gravel and sand quarries typically occur in low-lying terrain where materials have been deposited by river or dune systems. Using these characteristics, this project has used geomorphon modelling (Jasiewicz and Stepinski 2013) to map 10 geomorphic terrain types and assign class weights based on where the terrain is most suitable for quarrying. Two separate mappable criteria outputs are created, one for hard rock and the other for gravel or sand quarrying (Appendix 3 – Map 12).

Proximity to high-demand aggregate markets and roading projects is important to understanding the future demand. A service area analysis has been used to determine the truck-driving distance along sealed roads or two-lane metalled roads to cities, towns and urban areas. A cost factor was then applied for the direct distance away from those road sites to represent off-road travel or road development needed away from established infrastructure and class weights determined from a small fuzzification function (Hill 2021). Three service area analyses were modelled, one for each of the major, large and minor populated places; these were then combined for the final mappable criteria output (Appendix 3 – Map 13).

Future quarry sites need to have access to the road network to transport aggregate. Suitable roads are mapped from the LINZ Topo 50 road data and a function is used to calculate the distance from highways, sealed roads and gravel roads. To create class weights, a small fuzzification function has been used to calculate a fuzzy membership value dependent on the distance from the roads (weights based on the analysis in Hill [2021]; Appendix 3 – Map 14).

2.4 Cultural Sensitivity

For all extractive activities, cultural sensitivity and social licence to operate are important considerations. Ideally, quarries should be located close to their markets, but the sensitivity of residents to quarrying can place significant constraints on operators. This project has created four mappable criteria layers that represent sensitivity considerations in relation to extractive activities:

1. Cultural artefacts such as archaeological sites, airports, cemeteries, hospitals, schools, historic sites, marae, pā, and sport and recreation sites are mapped, and a distance buffer around each of these sites is given a low class weight (unsuitable for quarry development). The distance from the site is determined from a spatial analysis of those sites and current operating quarries around New Zealand (Appendix 3 – Map 15).
2. To map the effect of extractive activities on areas where people are living, a mappable criteria output is created as a function of the usual population and distance from buildings with a footprint greater than 100 m^2. This identifies a decreasing influence on people away from places of residence, and it is classified using spatial analysis of that function and current operating quarries around New Zealand (Appendix 3 – Map 16).
3. Quarry operation and consenting associated with extractive activities is more favourable in rural land compared with residential or urban areas. The land areas are mapped and class weights are assigned to the mappable criteria based on their suitability for extractive activities (Appendix 3 – Map 17).
4. Cultural sensitivity is also manifest in the visibility of quarry operations. A visibility analysis has been undertaken that results in a mappable criteria layer that shows how much of the land area can be seen within 5 km of a place where people are likely to reside or regularly travel (for example, residential areas, schools, while driving on sealed

roads and in populated buildings). Numerical class weights for these data reflect the number of those locations that can be seen from any grid cell in the digital elevation model used for the analysis. The classes with lower point counts are more favourable to quarry activity, as they are less likely to be seen and have visual impact on communities (Appendix 3 – Map 18).

2.5 Data Gaps

Although there is a wealth of data that can be used to understand geology, land use, economics and community sensitivity in relation to extract activities, there is still a lot of information that is either not possible to map (non-spatial), not available or not evenly distributed over the project area (incomplete or patchy data). These can be broadly classified into three groups: geotechnical, regulatory and cultural.

- Geotechnical data, including detailed datasets that convey fine-scale variation of lithology or rock properties (density, impurity, weathering, fractures, etc.). These data are not widely collected across New Zealand, so cannot be used in regional modelling studies.
- Regulatory data gaps include nationally consistent local and regional council zoning. Although data such as district plan zones, heritage areas and protected environments are mapped by all councils, the lack of standardisation in the terms and interpretations used, mapping techniques and data formats makes combining these data difficult and, in some cases, inappropriate.
- Cultural data gaps include less-tangible values of local communities and Māori custodians of land areas, as well as high scenic and tourism values.

These geotechnical, regulatory and cultural influences are important factors that should always be investigated early on as part of aggregate exploration or quarry development activity. They cannot be incorporated into this modelling project due to their non-spatial nature or limited availability but need to be carefully considered alongside the data-driven opportunity model results.

3.0 AGGREGATE OPPORTUNITY MODELLING

This project has created three aggregate opportunity models, one for each of the hard rock, gravel and sand aggregate resource classes. Although all three resource classes share the same criteria for land use and sensitivity, they differ in source material and feasibility, so different models were run to incorporate these variations. The models were created by combining spatial datasets with mapped areas classified by suitability for quarrying resources or extractive activity. After the data were combined, high-value results represent areas where all parts of the aggregate opportunity concept are favourable and overlap and therefore where there is the best opportunity for aggregate resources to be extracted.

The project uses the knowledge-driven ***fuzzy logic*** spatial modelling technique to combine maps into the aggregate opportunity models (Bonham-Carter 1994; An et al. 1991; Zimmermann 2001). It uses expert and statistically derived ***fuzzy membership values*** and ***fuzzy operators*** to combine the maps that make up the model. Fuzzy logic is a widely used and conceptually simple method for combining spatial data. This approach is guided by recent aggregate modelling in New Zealand (see Hill [2021]) and has worked well in this project, as the model is able to include more detailed maps and spatial analyses created at a regional scale.

The class weights assigned to the mappable criteria in this project have been determined from spatial analysis of map areas, locations of existing quarries and expert knowledge. A statistical approach using weights of evidence analysis (see Hill [2021]) provided insight into correlations between classes in the mappable criteria and operating quarries that allowed class weights to be assigned based on those results. As well as the statistical analysis, class-weight evaluations provided by industry experts and local or regional council representatives were important to ensure that weights realistically represented the aggregate opportunity concept, especially in datasets where spatial statistical analysis was not suitable.

3.1 Combining the Spatial Data

Maps for the modelling were created at three levels:

- **Level 1:** Initially, the Level 0 input data was classified into ***mappable criteria*** layers that represent aggregate potential features or contra-indicators (see Section 2). Class-weight values in the Level 1 maps are expert/knowledge-driven weights relative to the aggregate opportunity concept.
- **Level 2:** Seven intermediate maps were then created representing the four ***predictive components*** of the aggregate opportunity concept. These were created by combining the mappable criteria maps (Level 1 above) using the fuzzy GAMMA, AND and OR operators and class weights. The resulting maps have data values ranging from 0 to 1 that are the fuzzy membership values utilised in the next level of modelling.
- **Level 3:** Lastly, the aggregate ***spatial model result maps*** were created by combining the predictive component maps (Level 2 above) with the fuzzy GAMMA function for each of the hard rock, gravel and sand maps. The maps have data values ranging from 0 to 1 that represent low to high opportunity, respectively.

Figure 3.1 illustrates some of the map data used in the modelling and the three-level modelling process, as well as the difference between the maps used for the hard rock, gravel and sand models. Maps of spatial data for the Level 1 mappable criteria, Level 2 predictive components and Level 3 spatial model results can be found in Appendices 3, 4 and 5, respectively.

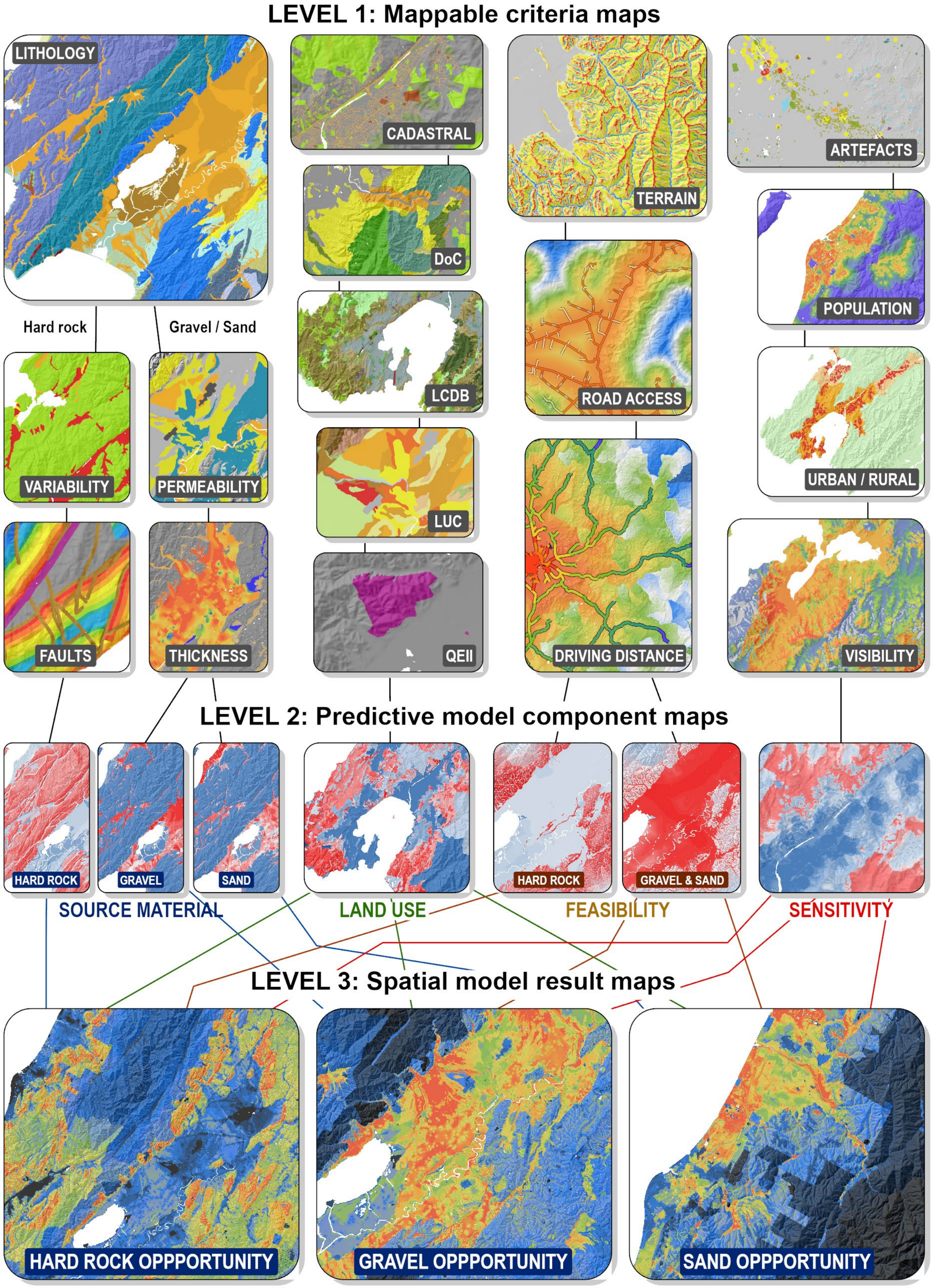

Figure 3.1 Overview of the spatial modelling process for aggregate opportunity modelling and examples of datasets used in this project. Mappable criteria outputs were combined to represent the predictive model components which were then combined to create the final spatial model result maps. Data combination varies for hard rock, gravel and sand models, where the source rocks and terrain maps vary for the different models. Representations of data for the whole project area for each panel in this figure are available in Appendices 3, 4 and 5 of this report.

3.2 Modelling Results

The model results show high-opportunity areas where the most suitable locations based on the mappable criteria overlap and therefore where there is the most opportunity for future aggregate extraction. Importantly, historic and current aggregate workings are independently identified within highly ranked locations, providing confidence that the results are reflecting aggregate opportunity. The models are presented as a coloured plot of values that represent the modelled aggregate opportunity for the entire project area. Level 3 result maps for the hard rock, gravel and sand models are illustrated in Figures 3.2, 3.3 and 3.4, respectively.

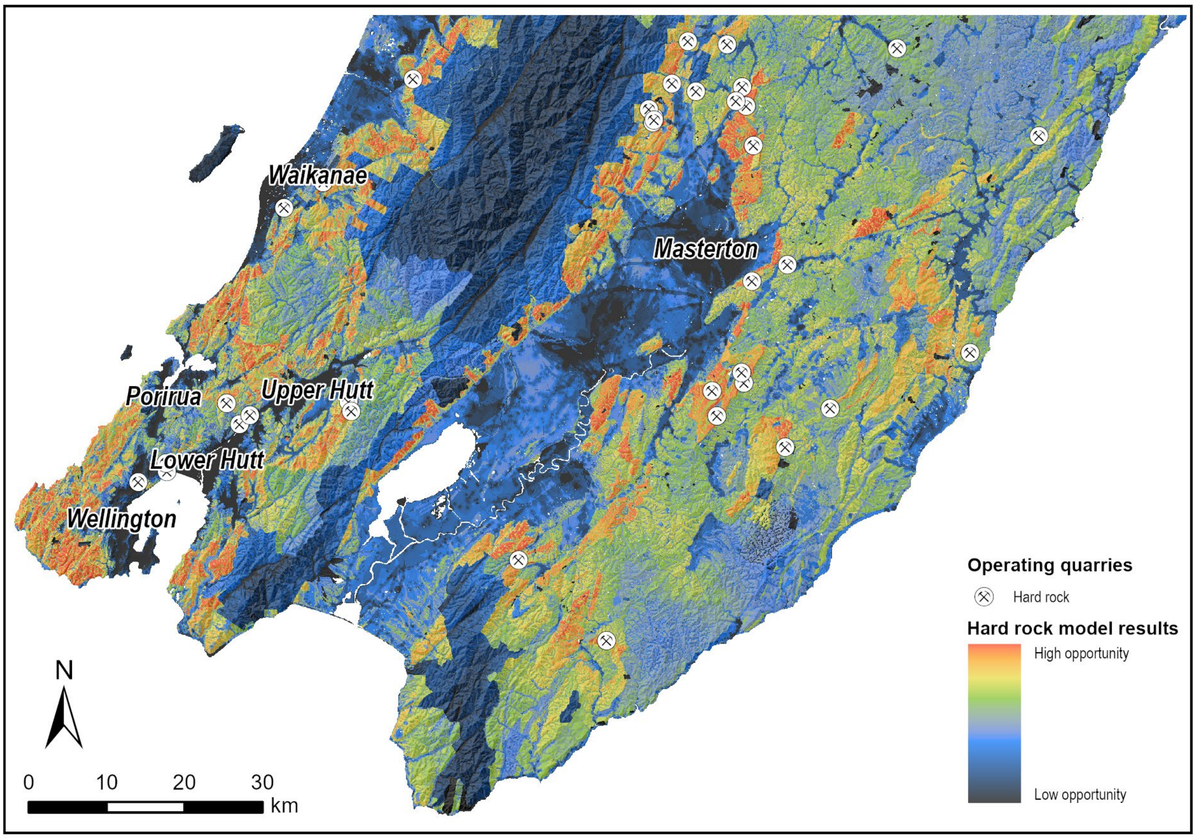

Figure 3.2 Spatial modelling results for hard rock material from the combined predictive component maps of source rocks, land use, feasibility and sensitivity data using fuzzy logic modelling. This represents Level 3 of the aggregate opportunity modelling process. Maps are scaled and coloured from the resulting fuzzy logic spatial model values that represent low aggregate opportunity (black) to high aggregate opportunity (red). This map is presented at a larger scale as part of Appendix 5.

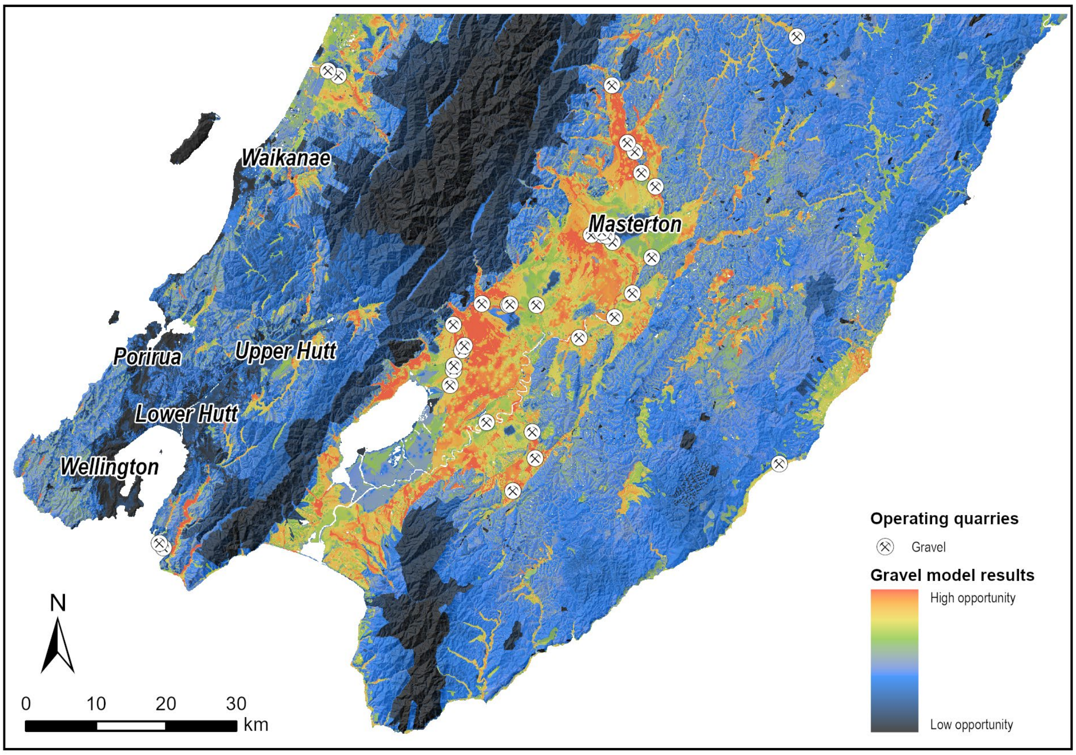

Figure 3.3 Spatial modelling results for gravel material from the combined predictive component maps of source rocks, land use, feasibility and sensitivity data using fuzzy logic modelling. This represents Level 3 of the aggregate opportunity modelling process. Maps are scaled and coloured from the resulting fuzzy logic spatial model values that represent low aggregate opportunity (black) to high aggregate opportunity (red). This map is presented at a larger scale as part of Appendix 5.

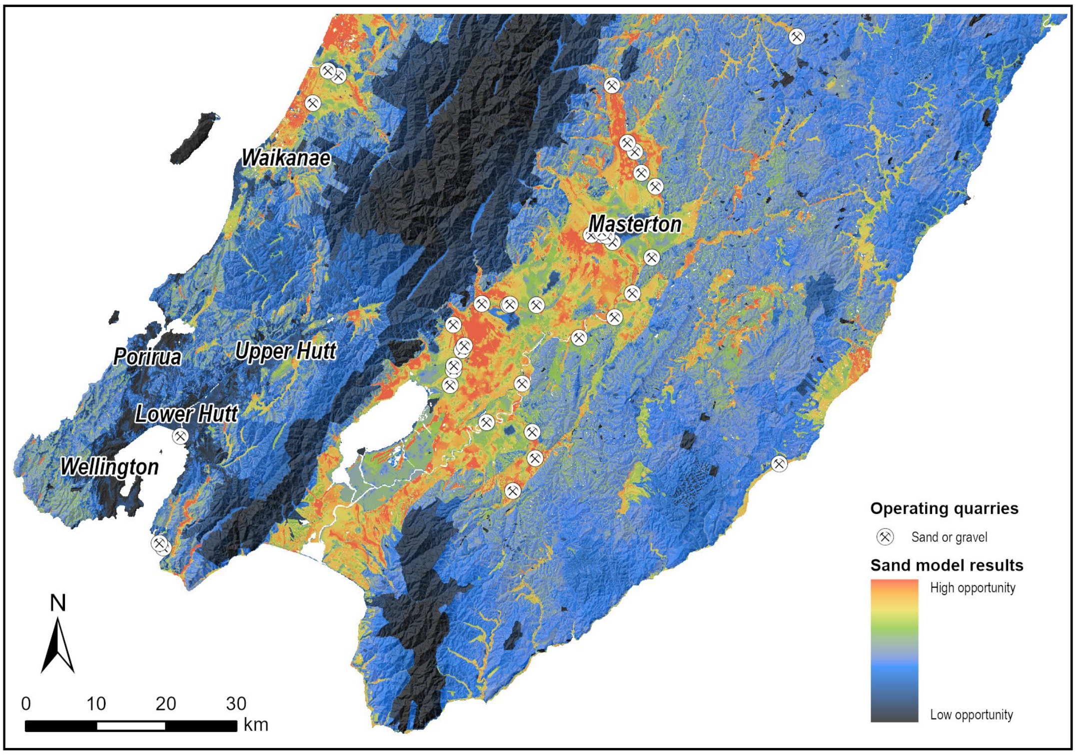

Figure 3.4 Spatial modelling results for sand material from the combined predictive component maps of source rocks, land use, feasibility and sensitivity data using fuzzy logic modelling. This represents Level 3 of the aggregate opportunity modelling process. Maps are scaled and coloured from the resulting fuzzy logic spatial model values that represent low aggregate opportunity (black) to high aggregate opportunity (red). This map is presented at a larger scale as part of Appendix 5.

The final ***aggregate opportunity model*** is developed from the spatial model result maps (Level 3) after the data are reduced to only values above a significance threshold (Figure 3.5). This threshold is determined from a spatial and statistical analysis of the model results against a dataset of existing quarries (training points) considered to represent ideal examples of future quarries and an expert review of map patterns. A model result value that a significant number of training points fall above is determined as the threshold for aggregate opportunity. Model areas above the threshold are separated into aggregate type classes of Mesozoic sandstone, Neogene sandstone, limestone, basalt, gravel and sand (see Figure 1.1). Maps of those classes represent where modelling indicates there to be better opportunities for aggregate resource. As many gravel deposits also include sand, the gravel spatial and opportunity models should be considered 'gravel and sand' opportunity sites. The sand opportunity model represents only those areas not already included in the gravel model where sand is more likely the dominant material type.

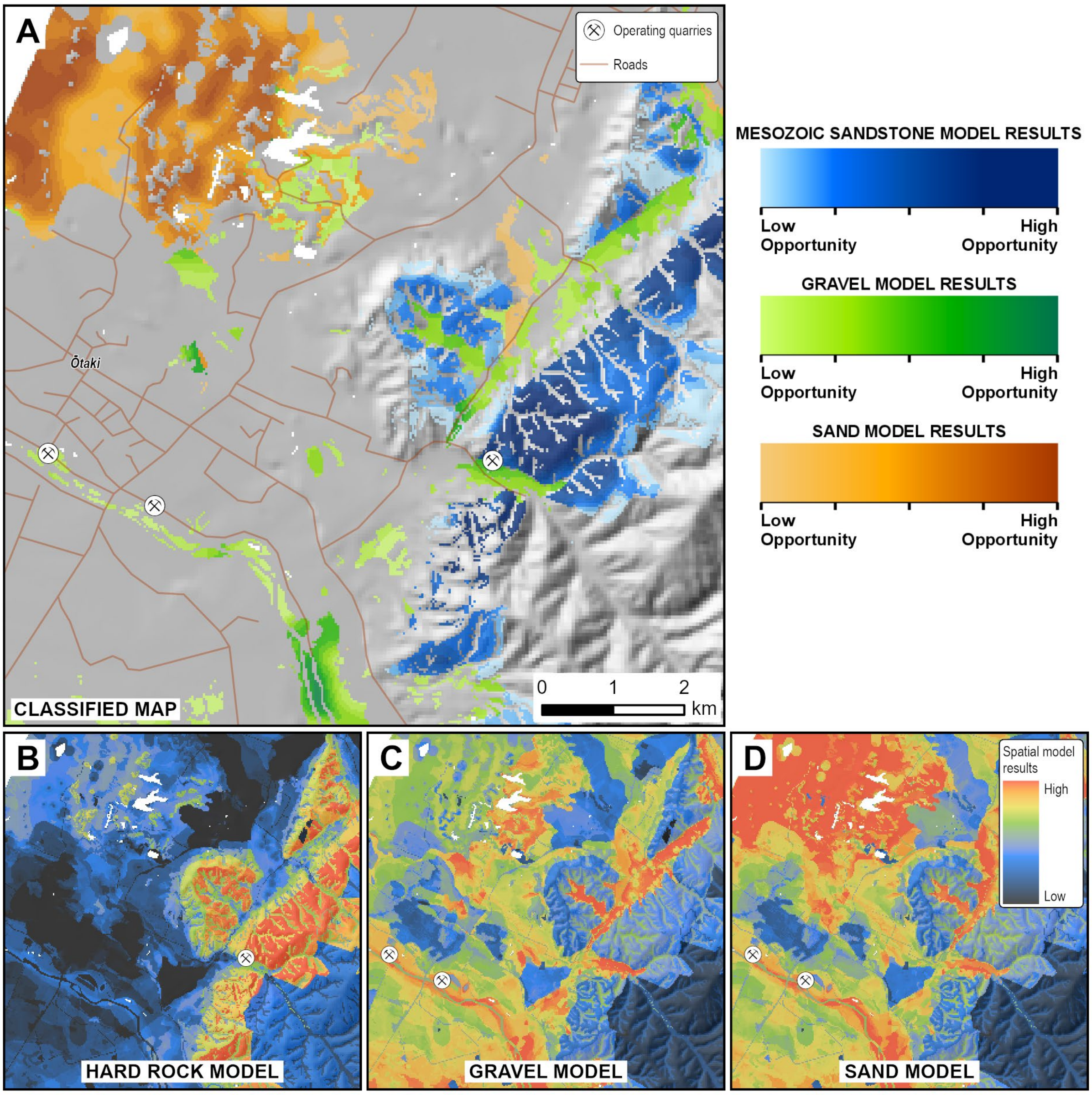

Figure 3.5 Example of an aggregate opportunity model (A) created from spatial model maps (B–D) for the Otaki area of Wellington. Mapped data are derived from the Level 3 spatial modelling results and reduced to only values above a significance threshold that represent areas with aggregate opportunity. Model areas above the threshold are grouped and coloured by aggregate type class (see Figure 1.1) and the colour gradient maps show low to high aggregate opportunity.

Modelling results for aggregate opportunity are represented as a map of locations coloured by aggregate type class. Colour gradients represent the low to high areas of aggregate opportunity above the significance threshold (Figure 3.6 and Appendix 6). Charts of model results relative to the project area and operating quarries are available in Appendix 7. Digital files for the overall aggregate opportunity model, in GIS (GeoTIFF) and Google Earth™ (KML) formats, are provided in Appendix 8.

Areas of hard rock-type classes modelled with the best aggregate opportunity, as identified from this spatial modelling project, comprise only 8% of the project area; this model therefore reduces the exploration search area by 92%. The model has identified several areas in the west of the project area from Pukerua Bay to Otaki, in southern Wellington City, around the Pautahanui area, and along the western side of the Wairarapa region. There are also large areas of limestone aggregate opportunity in central parts of Wairarapa. In Wellington, many of the suitable rock types are near densely populated areas and therefore constrained by urban encroachment and related sensitivity to extractive activities. The validation of modelled high-opportunity places with existing quarries (Appendix 7) suggests that there are significant hard rock opportunities in the Wellington region.

Areas of gravel modelled with the best aggregate opportunity comprise only 3.5% of the project area; this model therefore reduces the exploration search area by 96.5%. Many of these gravel sites will also include sand as a companion material type. The central Wairarapa area is modelled with the most potential for gravel, as well as parts of the Kāpiti Coast. The model importantly highlights areas away from active river channels where gravel could be sourced. The validation of modelled high-opportunity places with existing extraction operations (Appendix 7) supports this modelling approach, and the mapped results suggest that there are limited gravel opportunities in the Wellington region.

Although areas of sand modelled with the best aggregate opportunity comprise only 1% of the project area; there are opportunities for sand at many of the gravel sites. The modelled sand areas represent sites where sand is the dominant material type. Sand opportunity in Wellington is concentrated in the Kāpiti Coast, where extensive sand dune deposits provide a suitable sand-only source rock as well as parts of southern Wairarapa.

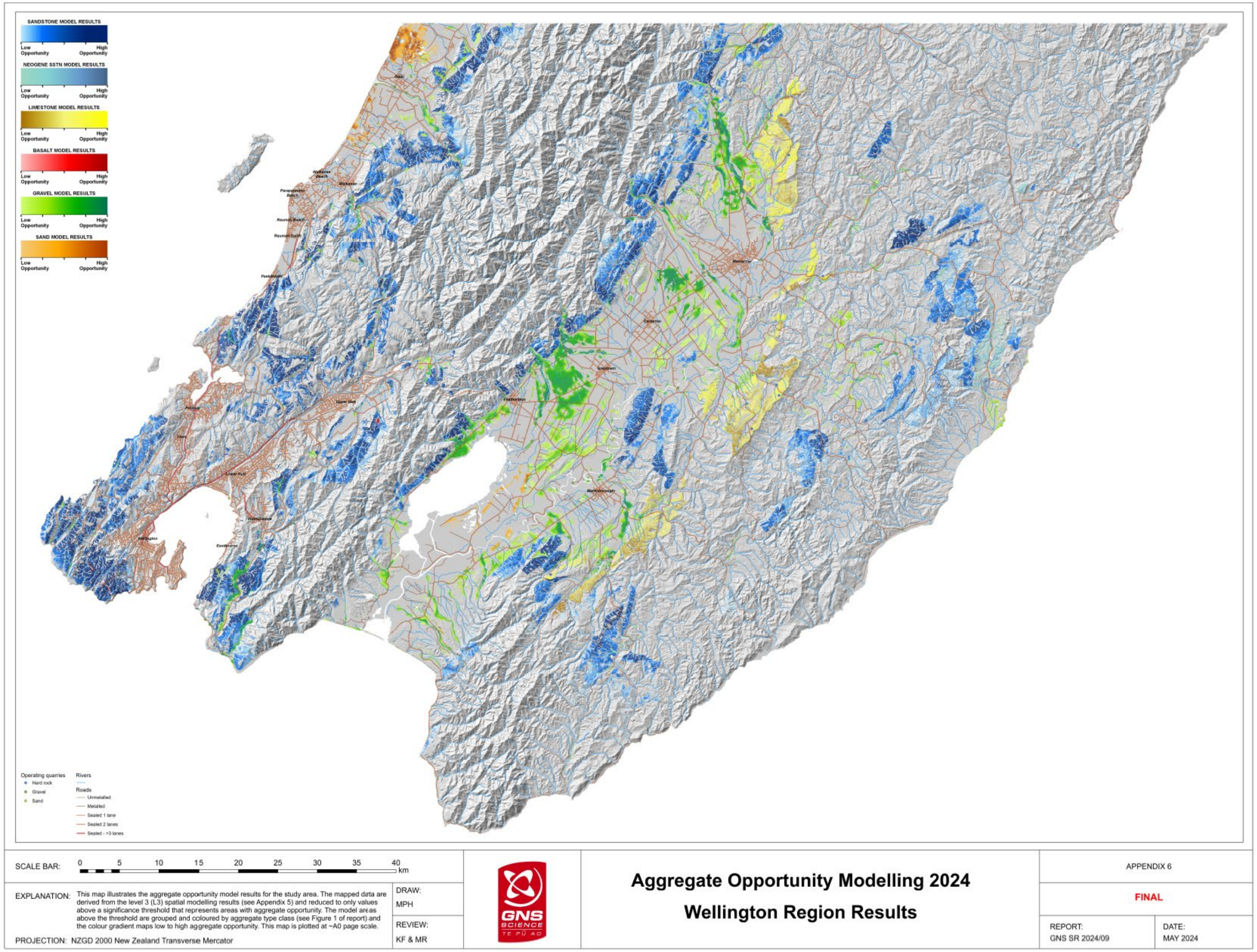

Figure 3.6 Illustration of aggregate opportunity model results poster for the Wellington region. Colours represent areas above the significance threshold for each aggregate-type class and are colour graded from low to high aggregate opportunity. This map is available in more detail at a larger A0 page-scale as part of Appendix 6.

4.0 SUMMARY AND CONCLUSIONS

The development of infrastructure in the Wellington region requires large quantities of hard rock and gravel aggregate material for roading and construction. These aggregates are ideally extracted locally to minimise the cost of transportation and emissions, but, unfortunately, the demand for aggregate for urban areas often conflicts with the urban population's sensitivity to quarrying, which places limitations on operators and developers.

An assessment of aggregate resources can be determined from geological databases (e.g. geological maps, rock property data), but land-use, infrastructure and cultural criteria should also be considered to find the most suitable areas for extraction and supply. New Zealand's domestic production of aggregate is 45 Mt per year, and this amount is forecast to increase in the future. Identifying new aggregate sources is therefore important for the continued development of our communities and infrastructure.

This project has developed an aggregate opportunity concept that identifies several critical or highly important features that must be present for a quarry to succeed but also, importantly, contra-indicators that detrimentally affect the viability of a quarry or impose restrictions on its development. While the location of the raw material is an important component of the modelling process, this project has also utilised datasets that represent quarry feasibility – such as distance to road infrastructure, driving distance along the road network to end-users of the aggregate and terrain suitability analysis – as well as cultural sensitivity indicators. The sensitivity of people to quarrying can impose significant constraints on operators. This project includes maps that represent population density and cultural artefacts, as well as residential, urban and rural land classes. An analysis has also estimated the line-of-sight visual impact on communities, and this impact can be incorporated into the project.

Modelling is undertaken in three steps: (1) The input data is classified into mappable criteria representing all components of the aggregate opportunity concept. Each map is re-classified to quantify the suitability of a new aggregate quarry at any given location. The suitability range (0–100) is defined based on spatial statistics and advice from industry and local government experts. (2) Predictive component maps representing the four parts of the aggregate opportunity concept (source material, land use, quarry feasibility and cultural sensitivity) are created by combining the mappable criteria. (3) Spatial model maps are combined from predictive component maps for hard rock types (sandstone, limestone and basalt), gravel (as well as gravel-associated sand) and sand sites for which there is likely to be aggregate opportunity. The output maps highlight the most suitable locations from combination of the various input feature layers and therefore where there are the best opportunities for aggregate quarrying.

Wellington Region is fortunate to have large areas of hard rock and gravel deposits that potentially can be utilised for aggregate supply. Much of this material is only weakly weathered and exposed at or near the surface, providing access to good-quality resources. Hard rock aggregate is dominated by greywacke, gravel is extractable from river gravels and sand is extractable from dune and river deposits. However, the region is densely populated in flat areas and many steep areas are not very accessible. These areas have reduced opportunity based on land use, feasibility and sensitivity factors. The best hard rock aggregate opportunity occurs from Pukerua Bay to Otaki, in southern Wellington City, around the Pautahanui area, and along the western side of the Wairarapa districts. Highest gravel aggregate opportunity occurs in the central Wairarapa area, as well as parts of the Kāpiti Coast. Highest sand aggregate opportunity is concentrated on the Kāpiti Coast, where extensive sand dune deposits provide a suitable sand-only source rock, as well as parts of southern Wairarapa. This project's findings facilitate informed decision-making for sustainable resource utilisation and infrastructure development in the Wellington region.

Although there is a wealth of data that can be used to understand geology, land use, economics and community sensitivity to extractive activities relating to aggregate opportunity, there is still a lot of information that is not possible to map, not available or not evenly distributed over the project area. New data that could improve aggregate opportunity modelling in the Wellington region include fine-scale geological maps and rock property distribution data (density, impurity, weathering, fractures, etc.) and consistently mapped local and regional council zoning. Mapping the less-quantifiable values of local communities and Māori custodians of land areas, as well as scenic and tourism values, will always be a challenge; however, these are important factors that should always be investigated early on as part of any aggregate exploration or quarry development.

This project for Wellington Region is part of a series of regional-scale aggregate opportunity models. Other studies for the Bay of Plenty, northern Auckland, southern Auckland and Central Otago areas (Hill and Chilton [2024a, 2024b, 2024c, 2024d], respectively) follow very similar modelling processes as those utilised in this project to understand the aggregate opportunity in these regions.

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APPENDICES

The appendix files for this report are provided as a downloadable dataset from the GNS Science Dataset Catalogue using the link below:

https://doi.org/10.21420/7HYM-J851

APPENDIX 1: Summary table of source data and spatial modelling techniques.

APPENDIX 2: Tables of mappable criteria grid and class weight values (GRID : CWV).

APPENDIX 3: Mappable criteria layers (Level 1 maps) – 18 x A3-scale maps.

APPENDIX 4: Predictive component maps (Level 2 maps) – 7 x A3-scale maps.

APPENDIX 5: Spatial model results maps (Level 3 maps) – 3 x A3-scale maps.

APPENDIX 6: Aggregate opportunity modelling results poster – 1 x A0-scale map.

APPENDIX 7: Charts of model results relative to the project area and operating quarries.

APPENDIX 8: Digital spatial data of model results.

The results from this project are provided as digital data, which include the spatial model results (Level 3 maps) and aggregate opportunity model results (areas above the significance threshold) that can be used in GIS mapping software such as ArcGIS or QGIS, as well as in Google Earth™.

Table A.1 List of Appendix 8 digital geographic information system (GIS) map files, provided in the GeoTIFF grid format or as files that can be loaded and visualised using Google Earth (KML format).

GIS File Name	Description	Format
AOM24_WGTN_L3_HARDROCK	Spatial model results for hard rock	GeoTIFF
AOM24_WGTN_L3_GRAVEL	Spatial model results for gravel	GeoTIFF
AOM24_WGTN_L3_SAND	Spatial model results for sand	GeoTIFF
AOM24_WGTN _MZSANDSTONE	Aggregate opportunity model for Mesozoic sandstone	GeoTIFF
AOM24_WGTN_NGSANDSTONE	Aggregate opportunity model for Neogene sandstone	GeoTIFF
AOM24_WGTN _LIMESTONE	Aggregate opportunity model for limestone	GeoTIFF
AOM24_WGTN _BASALT	Aggregate opportunity model for basalt	GeoTIFF
AOM24_WGTN _GRAVEL	Aggregate opportunity model for gravel	GeoTIFF
AOM24_WGTN _SAND	Aggregate opportunity model for sand	GeoTIFF
AOM24_WGTN _MZSANDSTONE	Aggregate opportunity model for Mesozoic sandstone	KML
AOM24_WGTN _NEOSANDSTONE	Aggregate opportunity model for Neogene sandstone	KML
AOM24_WGTN _LIMESTONE	Aggregate opportunity model for limestone	KML
AOM24_WGTN _BASALT	Aggregate opportunity model for basalt	KML
AOM24_WGTN _GRAVEL	Aggregate opportunity model for gravel	KML
AOM24_WGTN _SAND	Aggregate opportunity model for sand	KML

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