Other Pumped Hydro and Other Hydro Options Initial Desktop Screening Study

PREPARED FOR MINISTRY OF BUSINESS, INNOVATION AND EMPLOYMENT | MARCH 2022

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Revision schedule

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Executive summary

MBIE have engaged Stantec to undertake a high-level assessment of the suitability of three hydro alternatives to the Lake Onslow pumped storage scheme. The aim of the study was to determine if any of the three identified sites presented development options that were technically and environmentally feasible and would materially help in solving New Zealand's "dry year" problem. The Stantec brief did not include an assessment of the economics of the schemes.

The key requirements were for the sites to provide storage at Tera-Watt hour scale, be able to deliver the energy over an approximately three-month period and for the storage to be refilled over an approximately two year period.

The three sites of interest nominated by MBIE were:-

- The Upper Moawhango river in the central North Island
- The Taruarau river in the central North Island
- Lake Pukaki in the South Island

Following our investigations Stantec have identified technically feasible schemes at all three sites that can deliver the key requirements.

- At Moawhango a scheme has been identified that could provide approximately 2.7TWh of storage, with 570 MW of new generation plant (low-capacity factor) at an estimated P_{50} cost of NZ$8.2 Billion. Filling the reservoir would require pumping water which would otherwise have been used by the existing Tongaririo and Waikato River hydro chains. To fully develop the identified scheme would require the expansion of assets owned by Genesis Energy Limited.

Site 1 Summary	
Storage Provided (TWh)	2.75
New generation (TWh)	0.83
Existing generation expanded (TWh)	0.49
Existing generation (TWh)	1.42
Capacity of new generation (MW)	570
Capacity of existing generation supported (MW)	1460
Total generation capacity supported (MW)	2030
Volume of Reservoir (Mm^3)	1714
Live Storage of Reservoir (Mm^3)	1199
Volume of materials in main reservoir dam (Mm^3)	4.3
Length of tunnels (km)	29.3
Generation time to empty (Months)	3
Flow rate for filling over 2 years as per scope (m^3/s)	19
Flow rate to fill in 9 months of each year (m^3/s)	25
Indicative Cost (P_{50}) (NZ$ Billion)	8.18
Cost/TWh (NZ$ Billion)	2.97
Project Duration (Years)	5.2

- At Taruarau a scheme has been identified that could provide approximately 1.1TWh of storage, with 500MW of new generation plant (low-capacity factor) at an estimated P_{50} cost of $8.9 Billion. The scheme is entirely within a river system covered by a Water Conservation Order and would require pumping of water over significant distances.

Site 2 Summary	
Storage Provided (TWh)	1.15
Capacity of new generation (MW)	523
Volume of Reservoir (Mm^3)	1290
Live storage of reservoir (Mm^3)	710
Volume of materials in main reservoir dam (Mm^3)	5.5
Length of tunnels (km)	22.5
Generation time to empty (Months)	3
Flow rate for filling over 2 years as per scope (m^3/s)	11
Flow rate to fill in 9 months of each year (m^3/s)	14.7
Indicative Cost (P_{50}) (NZ$ Billion)	8.9
Cost/TWh (NZ$ Billion)	7.7
Project Duration (Years)	6

- The Pukaki dam raise could provide approximately 5.0TWh of storage, with approximately 105MW of additional generation at an estimated P_{50} cost of NZ$8.5 Billion. Filling the reservoir would require retaining water which would otherwise have been used by the Waitaki river hydro chain. To develop the identified scheme would require significant modification of assets owned by Meridian Energy Limited and rebuilding assets owned by Genesis Energy Limited. The scheme would also result in a loss of about 40MW of generation capacity for Genesis Energy.

Site 3 Summary	
Storage Provided (TWh)	5.0
Capacity of new generation (MW)	105
Capacity of existing generation supported (MW)	1553
Total generation capacity supported (MW)	1656
Live storage of Reservoir (Mm^3)	4400
Volume of materials in main reservoir dam (Mm^3)	10.7
Indicative Cost (P_{50}) (NZ$ Billion)	8.5
Cost/TWh (NZ$ Billion)	1.7
Project Duration (years)	6

All three schemes will present significant technical challenges that may impact their viability. In particular extremely large dams will be required, significantly larger than any existing New Zealand dams, plus long tunnels and under-ground power stations.

The sites will all present very significant challenges associated with Mana Whenua, water conservation, environmental and recreational values.

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Abbreviations and Glossary

Enter Term	Enter Definition
AACE	American Association of Cost Engineering
Dead Storage	The reservoir below MOL, not normally accessible for power generation
FSL	Full Supply Level. The normal maximum operating water level of a reservoir above NZ geodic datum
GIS	Geographic Information System
GWh	Giga-Watt hour
Live Storage	The volume of water stored in a reservoir between FSL and MOL, accessible for power generation
NIWA	National Institute of Water and Atmospheric Research
MBIE	Ministry of Business, Innovation and Employment
MCA	Multi-Criteria Analysis
MOL	Minimum Operating Level. The normal minimum operating water level of a reservoir
MW	Mega Watt
TWh	Tera-Watt hour
WCO	Water Conservation Order

Mihi

Tohi ki te wai, e Para,
Hei āhua te tāngaengae ko te wai i tēnei tāngaengae
Ki te mātāpuna o te wai
Kai te mahi kotahi o te wai
Kai te whatu whakapiri
Ki te hauora me te toiora o te wai
Tuku kiri o ngā tūpuna ki uta, kai mātaitai e
Homai, whakairi ora
Tūturu, whakamaua kia tina!
Haumi e, hui e, taiki e!

E tangi wiwini ana, e tangi wawana ana ki a Ranginui e tū iho nei ki a Papatūānuku e takoto mai nā. Ko ngā roimata a Ranginui me ngā waimamao a Papatūānuku te muriwai o ngā mātua tūpuna e kī ana ko te hono-i-wairua.

Kei ngā ihi, kei ngā wehi, kei ngā whakamataku tēnā koutou e tiaki mai nā i ngā taonga tuku iho a hākui mā, a hākoro mā. Tēnā hoki koutou e tiaki mai nā i ngā awaawa, i ngā maunga, i ngā roto, i ngā moana puta noa i te motu. Tēnā koutou kei whakatamarahi ki te rangi me aku whakateitei kei te whenua, tēnā hoki koutou katoa.

1 Introduction

1.1 General

Stantec have been engaged by the Ministry of Innovation, Business and Employment (MBIE) to undertake an initial high level desktop screening of three hydro alternatives to the Lake Onslow pumped storage scheme. The aim of the study was to determine if any of the three identified sites presented development options that were technically and environmentally feasible and would materially help in solving New Zealand's "dry year" problem.

The study was required to be conducted over a very short six-week period and to only make use of publicly available information sources or non-confidential information already held by Stantec. The locations of the three sites of interest were not disclosed to Stantec prior to commencement of the assignment.

The three sites selected by MBIE were chosen following a geographic information system (GIS) scan of New Zealand undertaken by NIWA. The GIS scan identified elevated basins that might potentially be suitable for development for pumped hydro and were within 30 km of a potential water source for reservoir filling. From the GIS scan MBIE selected two sites as being prospects for pumped hydro storage. The third selected site was not identified from the GIS scan but was chosen by MBIE as a potential location for increasing annual storage on an existing hydro cascade by raising an existing dam.

The three sites identified by MBIE are:-

1. The upper Moawhango River in the central North Island, upstream of the existing Moawhango reservoir (pumped storage option).
2. The Taruarau River in the central North Island, in the vicinity of Lake Horotea (pumped storage option).
3. Lake Pukaki in the South Island (dam raise option).

The three sites are not mutually exclusive of each other and are not interdependent. Each site is assessed individually, and a number of options have been considered for each site as detailed in the following sections.

1.2 The MBIE Study Brief

The overall objective of the study is to provide sufficient information to assess the viability of any of the options, and to support any stakeholder engagement should any option be selected for further consideration.

To meet these objectives the Consultant is required to identify potential design option(s) - the design(s) produced to allow an assessment of scheme costs, schedule, constructability, operational flexibility, high level environmental effects and potential risks. The engineering tasks include establishing upper and lower storage (if applicable) reservoir sizes and containment type, the diameter and alignment of tunnels, generation and pumping capacities. Key components of the study are:

- Determining if there is enough water either for the increased storage option or for pumping and upper reservoir fill times for the pumped hydro options, and time to refill after use in a dry period.
- For any of the pumped hydro schemes the advantages and disadvantages of discharging to, and pumping from, alternative waterways and reservoirs including the effect on the operation of any existing power stations
- Upgrades required to any existing scheme, including existing waterways (for example tunnels and canals, if applicable).
- Energy storage capacity for the dam raise option or in the upper reservoir for the pumped hydro options, in terms of TWh.
- Preferred dam option (straight or contour).

This initial desktop screening assessment was to be undertaken on the basis of the following leading metrics, with the goal of identifying key decision areas, potential breakpoints or step changes (e.g., in cost) presented by MBIE as a guide only as follows:

<u>For Pumped Hydro Options</u>

- Upper reservoir storage capacity assessed in steps that are sufficiently granular to identify key trends, trade-offs and breakpoints,
- Location of lower intake and lower reservoir storage capacity (if applicable) assessed in steps that are sufficiently granular to identify key trends, trade-offs and breakpoints,
- Generation and pumping capacity, in steps that are sufficiently granular to identify key trends, trade-off and breakpoints.

<u>For Dam Raise Option</u>

- Impacts on existing generation plant and structures,

- Increased energy storage capability as a function of increased dam height,
- Effect on infrastructure including surrounding roads, bridges and properties and potential impacts on other existing generation operations.

1.3 Methodology

1.3.1 Technical Assessment Approach

A three-step approach in assessing an outline technical suitability of each identified storage option was undertaken by assessing the following:

1. Reservoir live storage calculated for varying full supply level (FSL) and impoundment dam locations
2. Corresponding flow rates for filling the reservoir from minimum operating level (MOL) to FSL over a two year period (this flow rate is then used to assess the potential water sources available to fill the reservoir)
3. The potential generating capacity (and associated energy) of new and existing hydro-electric power plant made available by releasing the reservoir live storage over a three-month period.

The key parameters (FSL, refill rate and discharge rate) were then used as primary inputs to developing potential scheme configurations. Other influencing factors such as possible lower reservoir storage are considered on a site-by-site basis.

1.3.1.1 Key Criteria

In accordance with guidance provided by MBIE, in order to materially assist in solving the dry-year problem schemes were nominally anticipated to:-

1. Provide energy storage at a TWh scale
2. Permit exploitation of the storage (i.e., from full to empty) over a three-month period
3. Have storage refill (i.e., from empty to full) over a two-year period.

These three criteria provided the key parameters for assessing the storage capacity of each selected reservoir and the required refill and discharge rates that could be supported.

1.3.2 Kaupapa Māori Approach

For Māori, water is a taonga, a treasure, and is very highly regarded. Māori identify themselves in terms of their ancestors and their rivers and mountains. Māori consider water bodies to be their ancestor, a part of their family and a part of them. When a freshwater body is mismanaged, it hurts not only the water body itself, but the tangata whenua who identify with it.

In Māori environmental management, all resources have mauri (an energy which binds and supports life). The mauri of each water body is a separate entity and cannot be mixed with the mauri of another. This conflicts with the traditional western view that water can be diverted, dammed and used to take away waste. The pollution and alteration of a water body diminishes its mauri and affects its ability to provide food from this source.

Practices, or tikanga, are used to maintain the mauri of resources. The ongoing observation of these tikanga has led to the development of the ethic of kaitiakitanga. Kaitiakitanga is most simply translated as guardianship, but it also includes care, wise management and the use of resource indicators (where resources themselves indicate the state of their own mauri).

The degradation of the respective water body and its surrounding catchments is of concern to all tangata whenua who are connected to the lake and rivers by whakapapa (genealogy) within their rohe. The extent to which the land-use changes and declining water quality has impacted on tangata whenua values is currently unknown.

This report draws on a Kaupapa Māori approach. We recognise *mai i uta ki tai* or from the mountains to the sea. The cultural and spiritual significance of the land, rivers and entire ecosystems supporting each scheme have been determined through publicly available sources of information, noting that local values can only be determined by tangata whenua and kaitiaki. At this early stage, no iwi engagement or other consultation was able to be conducted.

The assessment is underpinned by the principles of Te Tiriti o Waitangi and Te Mana o te Wai, including:

- Mana whakahaere
- Kaitiakitanga
- Manaakitanga
- Governance
- Stewardship
- Care and respect
- Partnership
- Protection
- Participation

It is a Treaty obligation and a statutory obligation under the National Policy Statement for Freshwater Management (2020). This is partnered with a Matauranga Māori approach and te ao Māori values.

1.3.3 Environmental and Social Assessment

A desktop assessment was undertaken in order to determine the environmental and social values associated with each proposed scheme. The desktop assessment involved a review of available information and technical reports including:

- Aerial photographs from ArcGIS and Google Earth
- Publicly available reports
- Regional and District Council plans and planning maps
- Land ownership information (LINZ)
- Vegetation, Rivers, streams, wetlands
- Water quality e.g. Land Air and Water Aotearoa (LAWA)
- Biological databases e.g. NZ Freshwater Fish Database, NZ Herpetofauna Database

The desktop assessment, by its very nature, included the review of data, reports, and information produced by third parties. No independent verification of this information was conducted. Due to the very short timeframe from this work, this assessment is considered a "broad brush" to identify the key risks and opportunities of each scheme but does not provide a detailed environmental and social impact assessment of each site. Stakeholder consultation and field work including terrestrial and aquatic ecology surveys, water quality sampling etc. was not part of the scope of works but will be required should any site be taken further.

1.3.4 Multicriteria Analysis

As part of the review a Multicriteria Analysis (MCA) was undertaken. MCA is a set of systematic procedures for designing, evaluating, and selecting decision alternatives on the basis of selected criteria. For the purposes of this project, the objective of the MCA is NOT to select a preferred or best site, but rather to see at a high level, some of the key issues and risks associated with each site. This acknowledges that one or more sites may proceed, and each site has relative risks and benefits.

The MCA applied for this project was based on a summary of information collected for the purposes of this assessment. It included the following broad criteria:

- Engineering – terawatt hours of storage, indicative cost;
- Cultural Environment – iwi affiliations, Waitangi Tribunal claims, known wāhi tapu (sacred) sites, preserving te mauri o te wai (the life force of water), and mahinga kai (food and resource gathering);
- Social Environment – land ownership, regional and local council jurisdiction, water allocation (including the presence of Water Conservation Orders), impacts on existing infrastructure such as roads and power stations, recreational and commercial interests, landscape and visual impacts, short-term construction impacts, and dam safety risks.
- Physical Environment – protected areas, vegetation and flora, wetlands, avifauna habitat, bats, invertebrates, introduced mammals, water quality, fish and macroinvertebrates.

Each criterion was ranked from 1 to 3 based on which scheme is the lowest risk (1), to the highest risk (3). Cells were shaded accordingly from light to dark blue. For some criteria there was insufficient data to provide a ranking. Cultural aspects of each scheme were not ranked. This is because comparing schemes in different rohe is not appropriate and only local iwi have the mana whenua to determine cultural values.

A ranking approach provides an assessment of each scheme relative to each other. Care needs to be taken in interpreting the results as ranking can over (and under) state the differences between sites. Ranks were purposely not weighted, added or totalled as this would provide an over-simplification of the relative risks of each project.

1.3.5 Data Sources

As noted above, all information used in the study has been sourced from publicly available information. Confidentiality requirements on the project precluded obtaining information from sources where anonymity was not possible.

The following key information and sources have been relied upon in the execution of this study (not a complete list): -

- NIWA NZ Rivers Map (NZ River Maps (niwa.co.nz). Used for base hydrological information
- NIWA Aquarius web portal (hydrowebportal.niwa.co.nz). Used for base hydrological information.
- NIWA CliFlo database (cliflo.niwa.co.nz). Used for rainfall and evaporation data.
- NZ topographic maps (www.topomap.co.nz). Used for base topographic information.
- Genesis Energy website (www.genesisenergy.co.nz). Used for information on the existing Tongariro Power Development and, where available, short-term data on rivers flow and lake levels within the study area.
- NZ Electricity Authority website (emi.ea.govt.nz/Environment/Datasets). Used for historic hydropower operation and hydrology data.
- Transpower NZ Limited 2020 Planning Report
- Transpower NZ Limited 2020 System Security Forecast
- Inter-Area Transmission Capacity – by System Studies Group NZ Limited for Electricity Commission - Transmission Advisory Group

- Archived web information from Mighty River Power. Used for information on the existing Waikato River generating system operated by Mercury Energy.
- Evidence of Jarrod Bowler for Genesis Power Ltd on the Horizons Regional Plan
- District and Regional Plans for the Rangitikei, Ruapehu, Hastings, Taupō and MacKenzie District Councils and Horizons, Hawkes Bay, Waikato and Canterbury Regional Councils
- The National Policy Statement for Freshwater Management and Renewable Electricity Generation

The coordinate system used when describing locations of interest is NZGD2000.

1.4 Resource Management Legislation

Given the national significance of this project and the scale of potential effects, resource management approvals for any pumped hydro options may occur within the context of a bespoke framework or legislation. Despite this, it is considered relevant to outline some key elements of the current and proposed resource management regimes that will likely be critical no matter what regulatory process is used to review and approve the final proposal.

These elements are:

1. Matters of national importance
2. Water Conservation Orders, and more particularly the values these instruments seek to protect
3. Direction of the National Policy Statement for Freshwater Management
4. Direction of the National Policy Statement for Renewable Electricity Generation.

1.4.1 Matters of National Importance

Under the Resource Management Act, section 6 identifies matters of national importance which need to be recognised and provided for by all those exercising functions under the Act. All of the matters listed are of some relevance to the sites assessed in this report, however the following are likely to be of particular relevance:

> *a) The preservation of the natural character of the coastal environment (including the coastal marine area), wetlands, and lakes and rivers and their margins, and the protection of them from inappropriate subdivision, use, and development:*
>
> *(b) The protection of outstanding natural features and landscapes from inappropriate subdivision, use, and development:*
>
> *(c) The protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna:*
>
> *(e) The relationship of Maori and their culture and traditions with their ancestral lands, water, sites, waahi tapu, and other taonga.*

The values appear likely to be carried through the current resource management reform process and included within section 8 of the Natural and Built Environment Act. This section is proposed to set out 'environmental outcomes' that must be promoted in the national planning framework[1] and plans under the new Act.

All 3 sites assessed in this report have large scale impacts on these nationally important values, as is set out in the discussion on each site which follows.

1.4.2 National Policy Statement for Freshwater Management

The National Policy Statement for Freshwater Management (NPSFM) sets high level direction for the management of freshwater resources across the country.

Te Mana o te Wai

The NPSFM establishes Te Mana o te Wai as the fundamental concept upon which the management of freshwater is to be based. As a concept Te Mana o te Wai refers to the fundamental importance of water and the protection of the mauri of freshwater. It is 'about restoring and preserving the balance between the water, the wider environment, and the community. It is clear that Te Mana o te Wai will remain an important concept for the management of freshwater under the future resource management regime currently being developed by the government.

Underlying the broad concept described above, the NPSFM establishes a framework that includes principles relating to the roles of tangata whenua and other New Zealanders in the management of freshwater. The development of any electricity generation option that involves the use of freshwater resources should ensure that provision is made for these

[1] The national planning framework will draw together all current national direction, e.g. national policy statements and national environmental standard into a single integrated piece of nation resource management direction

roles to be fulfilled, including ensuring that the roles of government are met and that a mechanism is provided for tangata whenua to undertake their role. This is reinforced by Policy 2 of the NPSFM which directs that Tangata Whenua are actively involved in freshwater management and that Māori freshwater values are identified and provided for.

A second key element of Te Mana o te Wai is the hierarchy of obligations, which prioritises:

a. first, the health and well-being of water bodies and freshwater ecosystems
b. second, the health needs of people (such as drinking water)
c. third, the ability of people and communities to provide for their social, economic, and cultural well-being, now and in the future.

The only Objective of the NPSFM is ensure that natural and physical resources are managed in accordance with the hierarchy of obligations.

This hierarchy should be integrated into the assessment of sites so that options which provide for the health and well-being of waterbodies and their ecosystems are prioritised. It is considered that provision of further renewable electricity generation potential would fall under the third priority in the hierarchy of obligations.

Other Key Provisions

Other key provisions in the NPSFM that provide direction of critical importance to the sites are:

Policy 6 There is no further loss of extent of natural inland wetlands, their values are protected, and their restoration is promoted

Policy 7 The loss of river extent and values is avoided to the extent practicable.

Policy 8 The significant values of outstanding water bodies are protected.

Policy 9 The habitats of indigenous freshwater species are protected.

Policy 10 The habitat of trout and salmon is protected, insofar as this is consistent with Policy 9.

Policy 11 Freshwater is allocated and used efficiently, all existing over-allocation is phased out and future over allocation is avoided.

Again, it is considered that these directions are now well entrenched in the New Zealand resource management regime and alignment with them will be important to the success of any option.

1.4.3 National Policy Statement for Renewable Electricity Generation

The National Policy Statement for Renewable Electricity Generation (NPSREG) seeks:

> *To recognise the national significance of renewable electricity generation activities by providing for the development, operation, maintenance and upgrading of new and existing renewable electricity generation activities, such that the proportion of New Zealand's electricity generated from renewable energy sources increases to a level that meets or exceeds the New Zealand Government's national target for renewable electricity generation.*

It does this by setting several policies which require that:

- The benefits of renewable electricity generation activities to be recognised
- The practical implications of achieving New Zealand target for electricity generation from renewable resources is given particular regard
- The logistical and technical constraints associated with the development, operation, maintenance and upgrading of new and existing renewable electricity generation activities are also given particular regard.

These provisions tend to be general in nature and often receive less weight when they come in conflict with more location specific and strongly worded environmental protection provisions that exist in other resource management documents, including other national policy statements.

This current limitation may be overcome by the resource management reforms. The exposure draft of the Natural and Built Environments Bill includes an environmental outcome that must be promoted in the national planning framework:

> *o) the ongoing provision of infrastructure services to support the well-being of people and communities, including by supporting—*
>
> > *i) the use of land for economic, social, and cultural activities:*
> >
> > *ii)* ***an increase in the generation, storage, transmission, and use of renewable energy***

Given this, there is the potential going forward for the national planning framework to give clear direction to lower order resource management documents to provide for a specific pumped hydro project.

1.4.4 Overview

Based on the above discussion, if any pumped hydro site is advanced the follow key recommendations are made:

- Te Mana o te Wai must be a key concept that underpins the development of any pumped hydro site
- The site assessment process needs to integrate the key resource management issues identified above and in the specific site discussions
- The existing, and anticipated future, resource management framework protects key values and will likely prioritise the avoidance of adverse effects on very significant values. Directions to avoid adverse effects, prioritise the heath and well-being of water bodies and protect values should be integrated in the very early stages on any sites assessment
- Under the current resource management regime, only limited weight would likely be given to the NPSREG. The resource management reform process seems to offer the opportunity to ensure that the future legislation and proposed National Planning Framework provide clear direction relevant to the project and in particular about how to resolve conflicting resource management issues.

2 Site 1 Upper Moawhango

The MBIE GIS scan identified the Upper Moawhango catchment as a location of interest for development of a pumped hydro energy storage scheme.

A potential upper reservoir site was identified in the upper Moawhango river upstream of the Mt Azim Gorge (E1847625, N 5640736). A number of potential configurations were nominated by MBIE as detailed below.

2.1 MBIE Concept Configurations

Figure 1 below shows two reservoir options identified from the GIS Scan.

The first option "NIWA scan 2" (Figure 1, dark blue shading) considers a straight dam across the Ngawakaakauae Stream. Although the information provided by MBIE does not define a specific FSL it appears that an elevation around RL1200m is envisaged.

The second option "NIWA scan 5" (Figure 1, light blue shading) considers a series of three contour dams, with a main dam across the Moawhango river, upstream of Mt Azim gorge, with two containment (saddle) type dams to maintain a FSL of RL1160m.

The filling source for both options was identified as being the Tongariro River downstream of the existing Poutu Canal Intake (E1844011, N 5665128), via a tunnel some 30 km in length.

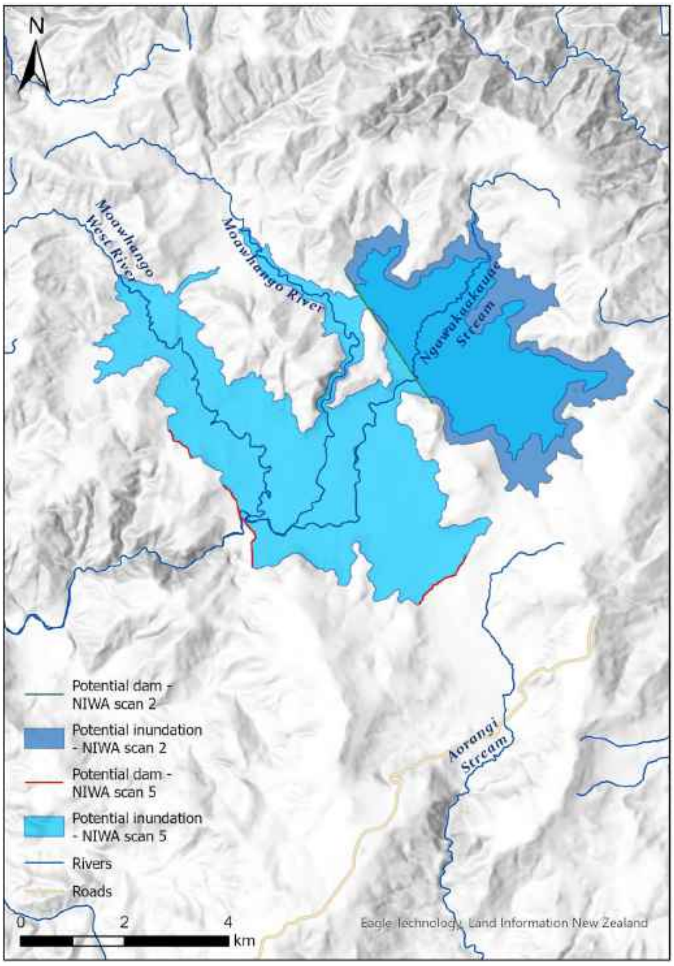


Figure 1: Site 1 NIWA GIS Scans

In addition to the two options identified by the GIS scan MBIE identified a third potential option based on an understanding of potential future developments identified at the time of the design of the Tongariro Power Development (TPD).

This third option is shown in **Figure 2**, described in the brief as the “Original TPD”, featuring a dam on the Moawhango River in the Mt Azim Gorge, a saddle dam to the North, plus a dam in an adjacent catchment - the Aorangi Stream. A FSL of RL1140m is envisaged.

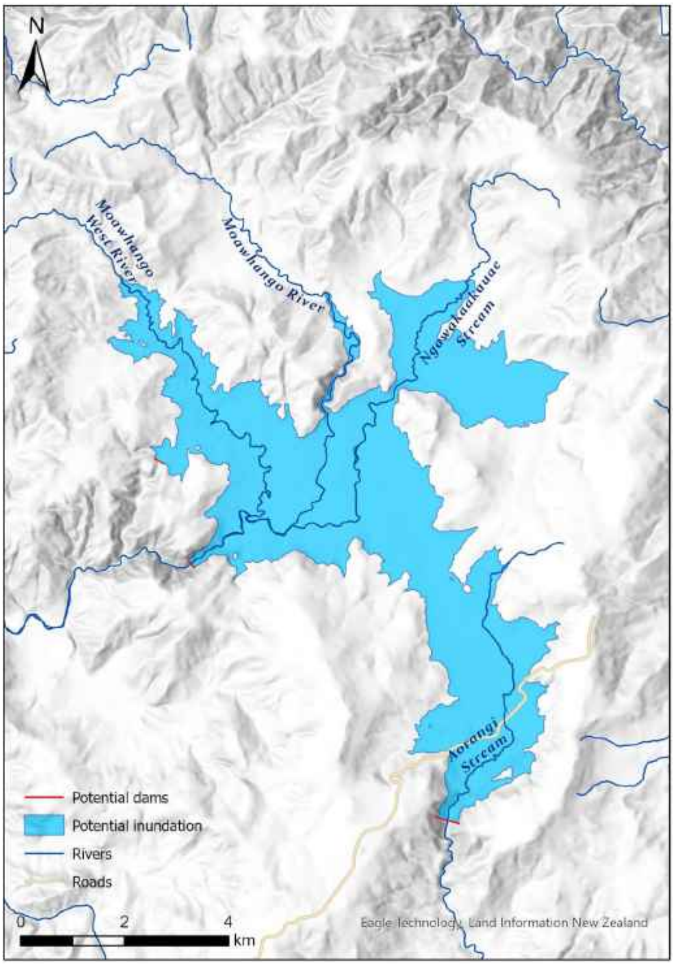


Figure 2 - Site 1 Original TPD

As with the other options it was identified that filling flows would be obtained from the Tongariro River downstream of the Poutu Intake - or alternatively from the existing Lake Moawhango (some 10 km distant).

The MBIE selection information provided no further information as to assumed scheme parameters such as discharge quantities, installed power plant capacities or scheme energy.

2.2 Configurations Considered

2.2.1 Dam/ Reservoir Configurations

For each of the three identified configurations reservoir area and storage volumes were calculated in 10 m increments from fully empty to 20 m above the FSL assumed by MBIE. At this stage a normal reservoir operating range of 40 m has been assumed for comparison purposes, as a sensible proportion of dam height.

Energy storage was established for each option based on an assumed discharge point at RL565m (just below the Poutu intake) and an assumed water-to-wire efficiency in generation mode of 85 per cent. A similar efficiency ratio has been used for pumping giving an overall baseline transfer efficiency of 72%. The net efficiency is better than this given some water is derived from within the storage sites so does not need to be pumped.

With the cost of the dam at this stage expected to be most influencing, for each option an estimated dam fill volume provides a metric of live storage volume vs dam volume allows a high-level value comparison between the various configurations. This metric - provided in

Table 2-1 below with associated key parameters - is a simple preliminary guide to where an optimised scheme size might lie (the two other main cost components will be the waterway (tunnels) and the powerhouse):

Table 2-1 - Site 1 Reservoir Comparisons

	Unit	NIWA Scan 2	NIWA Scan 5	Original TPD
Full Supply Level (FSL)	m	1200	1160	1140
Reservoir storage	Mm^3	660	1225	1022
Live storage	Mm^3	440	870	821
Potential stored energy	TWh	0.63	1.16	0.93
Dam fill volume	Mm^3	5.5	6.4	2.5
Storage vs dam fill volume	-	120	190	410
Live storage vs dam fill volume	-	80	135	330

It can be seen that the "Original TPD" provides significantly more storage per unit of dam volume than either of the other two options. This is primarily a function of the characteristics of the dam sites selected to impound the stored volume under each reservoir configuration. More efficient dam sites, in terms of fill required to build the dam, will provide better Storage vs Dam fill volume ratios. With the Original TPD dam locations considered at this stage more intuitive than either of the two NIWA scan options, the Original TPD configuration has been selected as the preferred reservoir upon which further refinement is undertaken.

Further assessment was undertaken of the Original TPD configuration to establish the storage, energy and refill parameters required for varying FSL levels. These, along with the storage volume/dam volume metric are presented in **Table 2-2**. For the purpose of this assessment the reservoir has been labelled the "Upper Moawhango".

Table 2-2 - Upper Moawhango - Impact of Varying FSL

	Unit	Upper Moawhango					
Full Supply Level (FSL)		**1110m**	**1120m**	**1130m**	**1140m**	**1150m**	**1160M**
Reservoir storage volume	Mm^3	340	515	746	1022	1350	1714
Live storage volume	Mm^3	324	473	639	821	1010	1199
Stored energy	TWh	0.15	0.46	0.68	0.93	1.19	1.47
Dam fill volume	Mm^3	1.01	1.35	1.83	2.45	3.53	4.26
Storage vs dam volume		337	381	407	417	382	402
Live storage vs dam volume		321	350	349	335	286	281
Energy vs dam volume	GWh/Mm3	148	340	371	379	337	345
Average refill rate required	m^3/s	5.1	7.5	10.1	13.0	16.0	19.0
Generation discharge supported	m3/s	41.1	60	81.1	104.2	128.2	152.0

For FSLs above RL1160m dam sizes increase markedly and at this stage a FSL in the range RL1140m to RL1160m is expected to be optimal.

2.2.2 Reservoir Fill

2.2.2.1 General

The MBIE modelling used the NIWA NZ Rivers database of flow information of rivers and tributaries in the project areas. As is discussed in Section 2.4.1 Stantec have been unable to locate better flow information for the Moawhango area and have therefore also used the same flow information source as MBIE. It is noted that Genesis Energy will have at least 50 years of flow records for the TPD, however such information will only be available on request, and likely subject to Genesis satisfying themselves that disclosure will be in their best commercial interests. Genesis do provide some flow information to the territorial authorities to verify that they operate the TPD within their consent requirements, but access to this information would also require disclosure as to the purpose of use.

The NIWA NZ Rivers data provides mean flow and flow duration information for rivers and tributaries at a large number of points along the river course. The information is synthetic, based on a limited number of flow recording stations throughout the NIWA network. The information also does not account for any modifications to the natural watercourses. For example, the river flow at a point below the Poutu intake as used in the MBIE water source assessment, does not account for the modification of natural river flows owing to the TPD - the impact of such modification is significant.

With the Original TPD option having a natural mean Moawhango River inflow of 3.1 m^3/s - and an additional inflow from the Aorangi Stream catchment of approximately 0.6 m^3/s – the new mean reservoir inflow would be 3.7 m^3/s. With the reservoir large in comparison with its catchment, it is anticipated at this stage that all inflows except for very infrequent major floods, would be captured by the reservoir. It is noted that although the Aorangi Stream is a tributary of the Rangitikei River it is understood that it is not directly covered by the WCO in place on that river.

2.2.2.2 Tongariro Power Development

The Moawhango river and existing Lake Moawhango are an important component of the Tongariro Power Development. As noted in the previous section the TPD significantly affects the flows in the Tongariro River and this needs to be considered when assessing water availability for the NZ Battery project. Unfortunately, readily accessible details on the TPD operation are difficult to find, other than “average” flow type information.

The 360 MW Tongariro Power Development (TPD) scheme – owned and operated by Genesis Energy – was developed over the period 1970 to 1983 and diverts snowmelt and runoff from the slopes of Mount Ruapehu via an interconnected system of river intakes, tunnels and canals (the Eastern and Western Diversions) and augments the mean discharge from Lake Taupō by 29 m^3/s which represents some 20 per cent of the average inflow to Lake Taupō.

The Moawhango and Tongaririo River catchment areas form part of the Eastern Diversion portion of the TPD, which takes water from the Eastern flanks of Mt Ruapehu and the Western Kaimanawa ranges for power generation purposes. **Figure 3** below shows the key elements of the TPD. Items highlighted in yellow are associated with the water stored in the existing Lake Moawhango reservoir.

The 120 MW Rangipo power station, commissioned in 1983, develops a head of some 200 m over a steep stretch of the Tongariro River and is capable of drawing flows quickly from the Eastern Diversion (Lake Moawhango) via the 20 km long Moawhango - Rangipo tunnel. The 240 MW Tokaanu scheme – developed first and commissioned in 1973 - receives the outflow from Rangipo and the Western Diversion at its headpond – Lake Rotoaira – and develops a head of 209 m discharging into Lake Taupō. Energy from the TPD is typically to the order of 1350GWh/annum (1.35TWh).

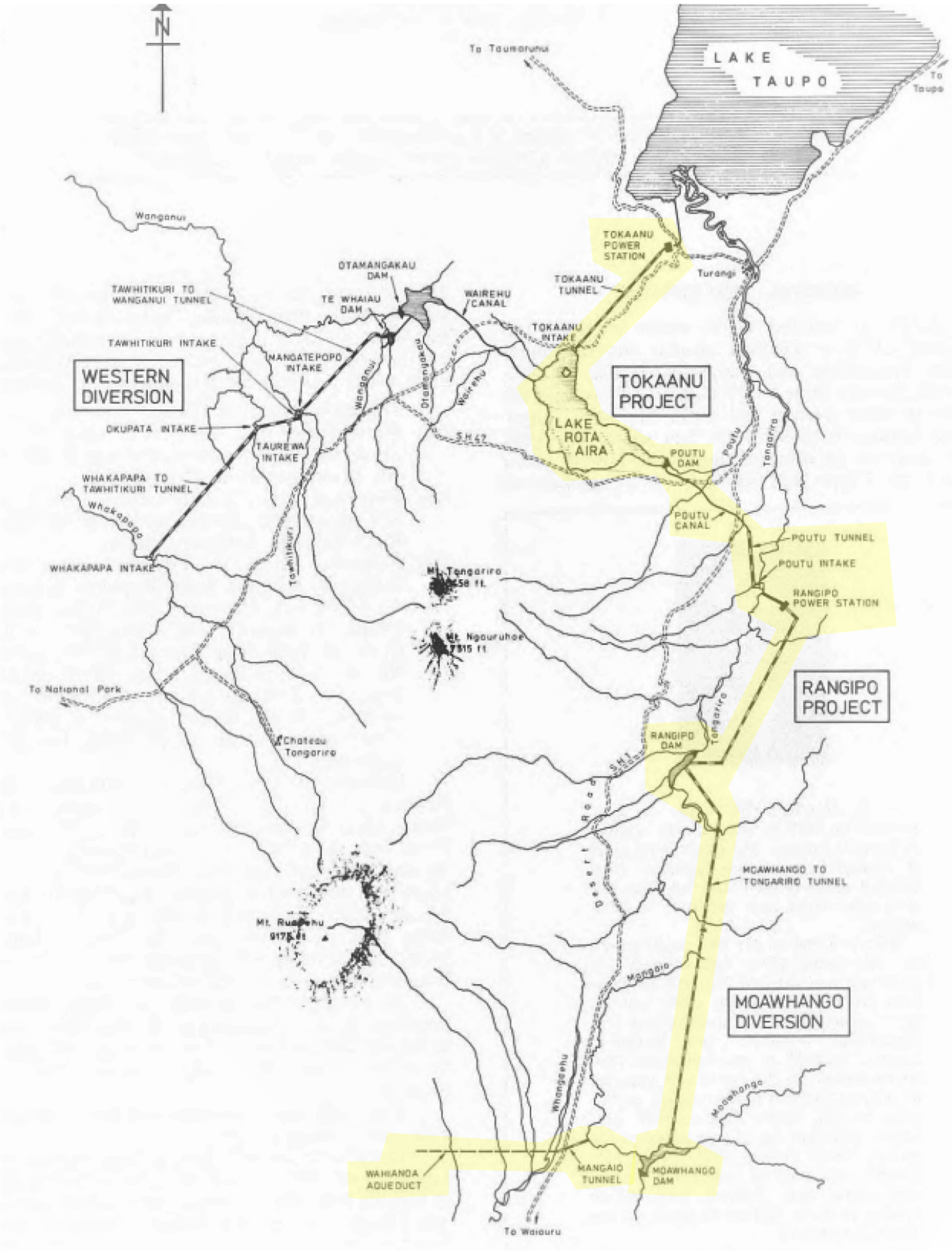


Figure 3 - Tongariro Power Development (From NZ Engineering November 1973)

Figure 4 shows the hydraulic configuration of the Eastern Diversion, with design (in blue) and average (in black) flows shown where available. This information was established from Genesis Energy information found online and NZ Rivers data.

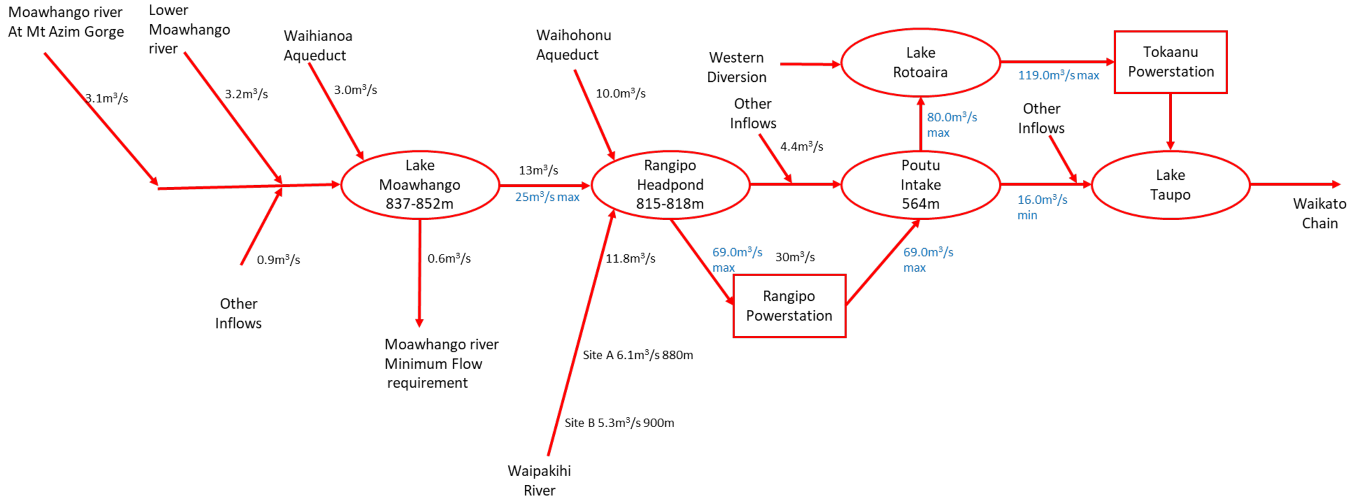


Figure 4 - TPD Eastern Diversion Flows

Key observations on the TPD Eastern Diversion are as follows: -

1. Lake Moawhango rarely spills and when it does the spill flows are quite small. Detailed information is difficult to find, but it is understood that, on average, the reservoir spills less than once per annum. From Genesis Energy environmental reports during the period 2009-2015 it appears there was just one spill of 39 m^3/s and the largest spill identified prior to this was 139 m^3/s. Therefore, the existing lake appears adequate for capturing flood flows in the Moawhango catchment and there is little scope for enhancing capture.
2. The mean outflow from Lake Moawhango is 13 m^3/s, whilst the Moawhango to Rangipo tunnel is designed for a maximum flow of 25 m^3/s (likely to be at high Lake levels when the driving head is high)
3. The average inflow at the Mt Azim gorge dam site is 3.1 m^3/s, well below the level required to fill the Upper Moawhango reservoir in the required period.
4. The Tongariro River flow below the Poutu intake has a minimum flow requirement of 16 m^3/s for environmental and recreational reasons. Flows above this level are typically diverted through the Poutu tunnel and canal to Lake Rotoaira where the water is used by the Tokaanu power station.
5. The NZ Rivers flow website indicates a mean flow of 23.1 m^3/s below the Poutu intake. However, this flow is the unmodified natural flow of the Tongariro river at this location and does not take into account the diversions from the Moawhango river into the Tongariro catchment, or the diversions from Poutu intake to Lake Rotoaira.

2.2.2.3 Waikato River Chain

Although the Waikato River chain is located well outside of the study area it's operation will be affected by developments on the Moawhango River as the TPD provides some 20% of the Waikato River discharge.

The Waikato River chain comprises eight dams and nine power stations with a total capacity of some 1100 MW on the Waikato River between Huka Falls and Cambridge. A total gross head of some 300 m is developed between headpond level of the uppermost scheme (Aratiatia – at around RL330 m) and the tailwater of the lowermost scheme (Karapiro - at around RL20 m). The hydro-electric assets are owned and operated by Mercury Energy. The generating stations operated by Mercury have very limited storage and generally operate with a capacity factor of about 50 per cent in a daily peaking role. Energy from the Waikato Chain is typically in the region of 4000GWh/annum (4TWh).

The TPD discharges into Lake Taupō which is the largest lake by surface area (616 km^2) in New Zealand and is drained solely by the Waikato River. The level of the lake is controlled by Mercury Energy via control gates just downstream of the town of Taupō. The gates are used for flood control, to conserve water and to ensure a minimum flow of 50 m^3/s in the Waikato River. The resource consent allows the level of the lake to be varied between RL355.85m and RL357.25 m (a range of 1.4 m) which represents a usable storage for electricity generation purposes of 850 Mm^3.

Other than major flood events spill flows on the Waikato River chain are rare. This means that any water impounded at the Upper Moawhango dam is unlikely to be spilled at any of the Waikato power stations. In turn this means that water impounded at the Upper Moawhango reservoir essentially represents a transfer of energy utilisation from the time of reservoir filling to the time of release as a dry year reserve.

2.2.2.4 MBIE Reservoir Fill Concept

The MBIE GIS model assumed that refill water would be taken from the Tongariro river downstream of the Poutu intake as depicted in **Figure 5**.

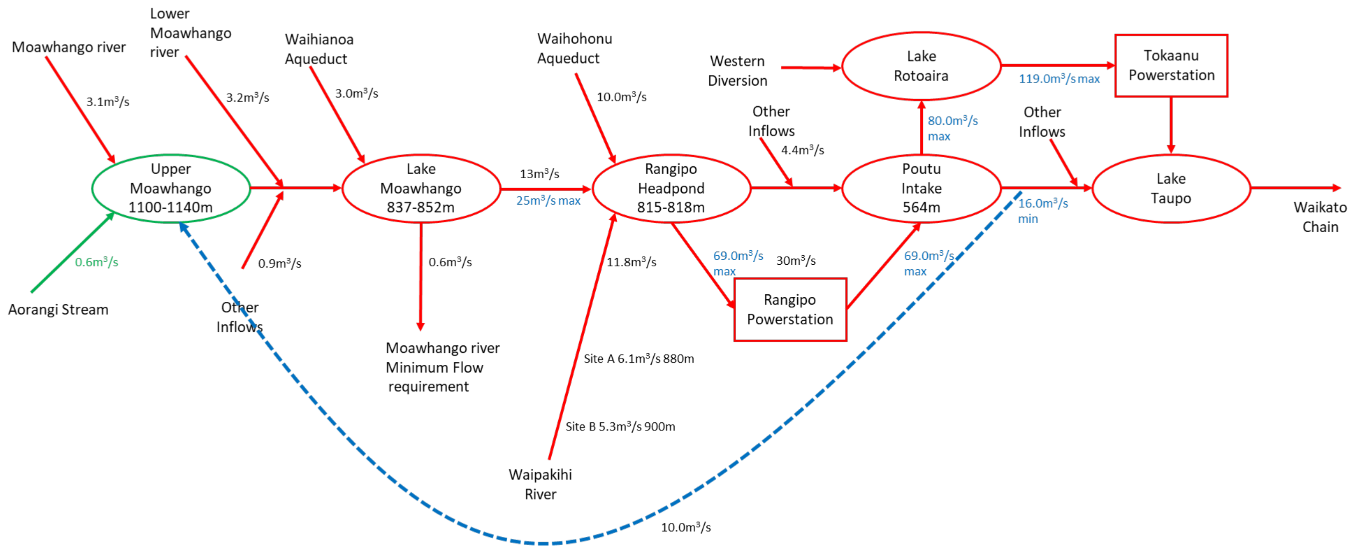


Figure 5 - MBIE Concept Refill

For a reservoir FSL of RL1140m an average refill flow of 13 m^3/s is required to achieve refilling in 2 years. Natural inflows will provide 3.7 m^3/s and the balance of approximately 10 m^3/s would need to be pumped from the Tongariro River. If a reservoir FSL of RL1160m were adopted, then the pumping flow would need to be approximately 15 m^3/s.

Pumping from this location would involve a static pumping head of around 580m and would require a water conveyance system of some 22 km length.

The average flow discharged from Rangipo power station is about 30 m^3/s and other flows of about 4 m^3/s enter the system between the Rangipo headpond and Poutu intake. A total mean river flow of about 35m^3/s just below the Poutu intake is assumed. Of this flow, 16 m^3/s needs to be retained within the Tongariro River for recreational purposes and the balance of 19 m^3/s would normally be transferred to Lake Rotoaira where it would be utilised by the Tokaanu power station.

Therefore, in order to pump a mean flow between 10 and 15 m^3/s to the Upper Moawhango reservoir, this water would need to be diverted from the flow to Tokaanu. As the majority of the potentially available flow (above the 16 m^3/s recreational requirement) will be derived from discharge from Rangipo it can be assumed it is occurring during periods of higher power prices as Genesis would be seeking to maximise the value from Rangipo. A run-of-river pump system would therefore tend to operate at higher than average prices as this is when water would be most available.

If pumping at a higher flow rate were required in order to best utilise periods of low power pricing, or capture flood flows, then a reservoir would need to be created to provide a buffer between inflow and periods of pumping. Given the gorge nature of the Tongariro River in this area it would be difficult to create a reservoir with any meaningful storage.

2.2.2.5 Refilling from Lake Moawhango

The Upper Moawhango (Original TPD) configuration identified by MBIE suggested using the existing Lake Moawhango as the refill source as depicted in **Figure 6**

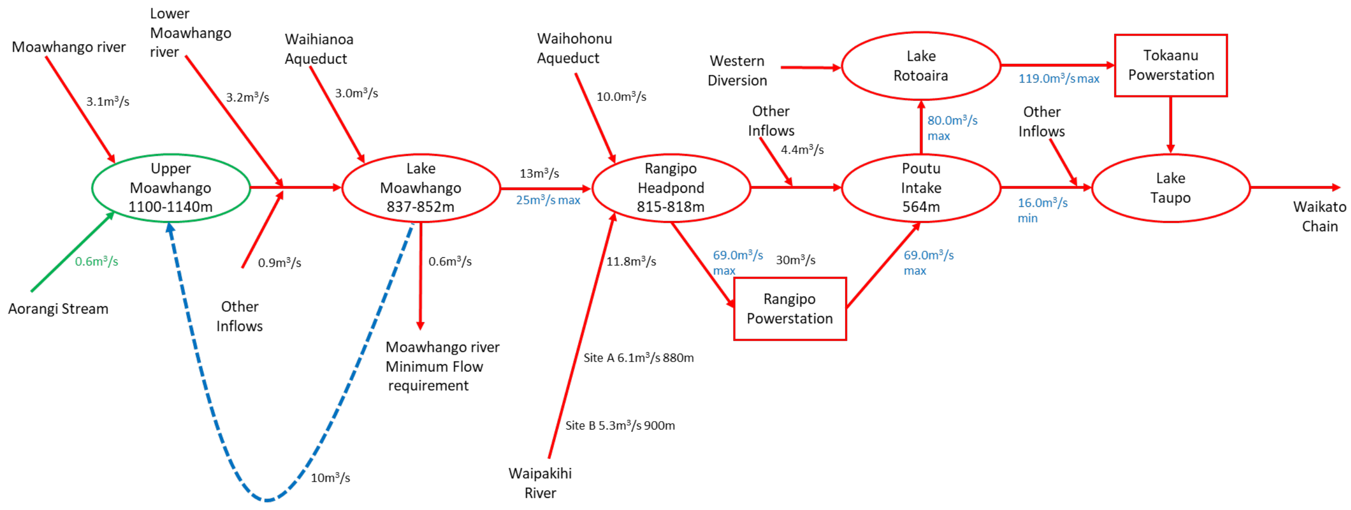


Figure 6 - Refill from Lake Moawhango

For a reservoir FSL of RL1140m an average refill flow of 13 m^3/s is required to achieve refilling in 2 years. Natural inflows will provide 3.7 m^3/s and the balance of approximately 10 m^3/s would need to be pumped from Lake Moawhango. If a reservoir FSL of RL1160m is adopted, then the pumping flow would be approximately 15 m^3/s.

Pumping from this location would involve a static head for pumping of some 300 m. Two potential locations for pumping plant exist:-

1. At Lake Moawhango, this would require a silo type pumping station and an approximately 10 km long pipeline (part cut and cover, part tunnel).
2. From the existing Moawhango – Rangipo tunnel. At its closest point this tunnel is located within approximately 3 km of the Upper Moawhango catchment area. An underground pumping station would be required.

Lake Moawhango has live storage of approximately 63 Mm^3 over a level range 837m to 852.2m, and an average discharge of 13 m^3/s. The reservoir has sufficient capacity for almost 60 days of average outflow and would therefore serve well as a buffer to permit short term, high flow pumping during low power price periods. A pump station located at the lake could have a pumping capacity significantly larger than average lake inflows flows.

The existing Moawhango – Rangipo tunnel is rated at 25 m^3/s, but it is understood that flows up to 30m^3/s are possible at high lake levels. Pumping from the Moawhango tunnel is therefore likely to be limited to a rate of up to 30 m^3/s, or about twice the required mean Upper Moawhango refill flow.

Examination of the last 5 years of power prices at the local Tokaanu Grid Exit Point allows a preliminary assessment of pump operation when there is the benefit of storage at the inlet side. With natural inflow of 3.7 m^3/s and a storage capacity of nearly 60 days in Lake Moawhango allows a 30 m^3/s pump station to operate almost entirely in the lower 50% of the price duration curve (i.e., below median price). Assuming the Upper Moawhango storage is used 12.5 % of the time for generation released (3 months every 2 years), over the last 5 years the average price during refill pumping would have been 64% of the average power price. In comparison the average price gained from generation would have been 210% of average, a price transfer ratio of 3.2:1 (generation : pumping).

2.2.2.6 Refilling from the Waipakihi River

The Waipakihi River is the main watercourse upstream of the Rangipo Dam. Below the dam the river is known as the Tongaririo River.

This option would source refill water from a location upstream of Rangipo Dam, as close to the Upper Moawhango reservoir as possible. **Figure 7** shows the configuration.

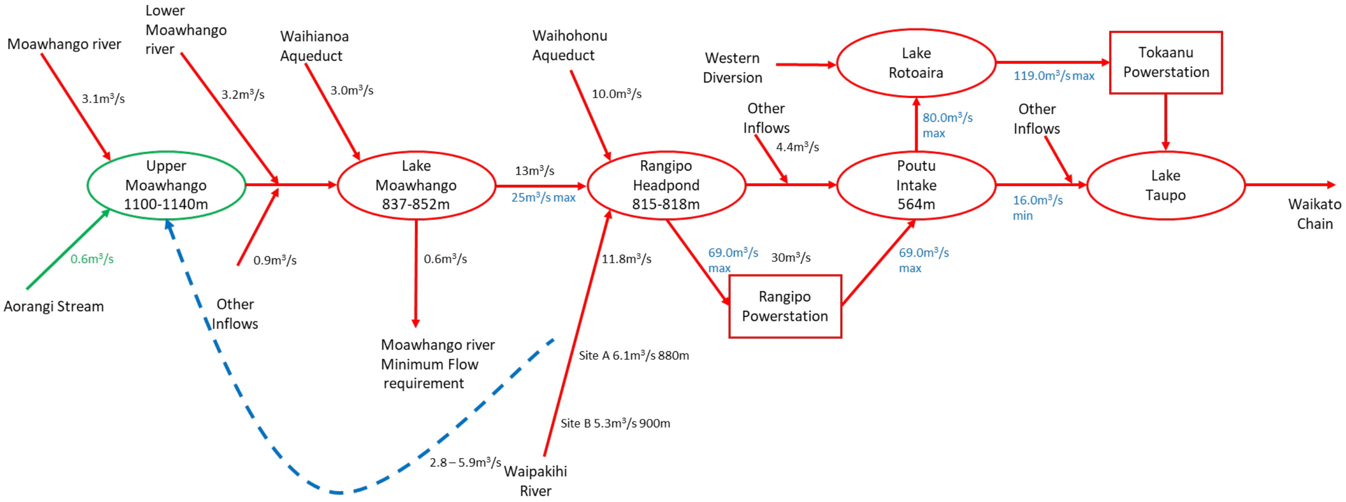


Figure 7 - Refill from Waipakihi River

Mean flows in the Waipakihi are in the range 11.8 m^3/s – 5.3 m^3/s depending on source location, with the higher flow being at a location immediately upstream of the Rangipo Dam. This option only considers sourcing flows higher up the catchment and a potential location was identified at "Site A" which is just downstream of the confluence with the Little Waipakihi Stream (E 1841571, N 5652774), which is also almost directly above the Moawhango – Rangipo tunnel.

On the basis of capturing 50% of the mean flow (as was used in the MBIE analysis) an average inflow of about 3 m^3/s could be sourced from this location. As a run-of-river intake significant pump capacity would be required to capture this relatively small average flow. The pumping head would be about 260 m and a conveyance system of approximately 5.5 km in length to the Upper Moawhango reservoir.

Creating storage at this location to capture flood flows or support peak pumping would be possible but could impact the recreational values of the Waipakihi River (trout fishing etc). It is unlikely that significant in-river storage could be provided at this location. As this source can only provide some 3 m^3/s of the required 10-15 m^3/s refill rate it could not provide the required refill water on its own and additional sources would be required.

2.2.2.7 Refilling from Rangipo Dam

The mean flow entering the Rangipo Dam reservoir is in the range 30-35 m^3/s. Of this flow about 20-25 m^3/s could be utilised, with the balance being used for the minimum flow requirements below Poutu dam.

The Rangipo Dam reservoir is small with just 0.3 hours storage of the Rangipo power station design flow (69 m^3/s). The reservoir therefore cannot provide significant flow buffering to capture flood flows or support peak pumping. Because of the sedimentation risk and required flushing regime, raising the Rangipo Dam would be unlikely to provide any significant live storage.

However, in conjunction with the Moawhango storage (via the Moawhango – Rangipo tunnel) peak pumping rates up to approximately 40 m^3/s could be supported, whilst still providing the required 16 m^3/s below the Poutu dam. This configuration is shown on **Figure 8**.

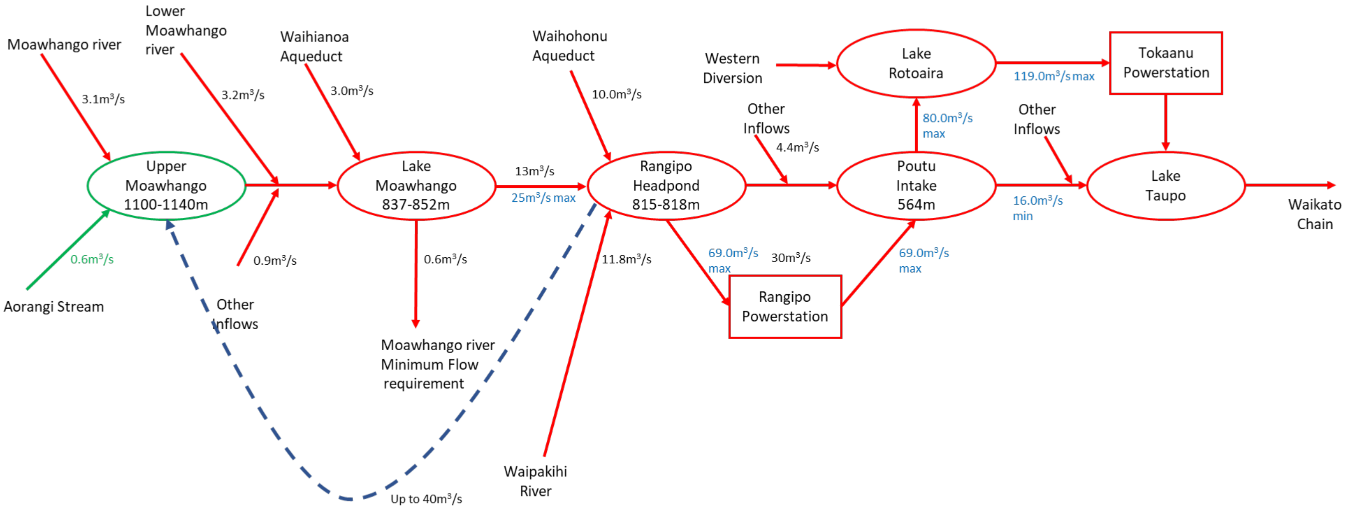


Figure 8 - Refill from Rangipo Dam

For this option a pumping head of approximately 325 m and a conveyance system approximately 9 km long is required.

2.2.2.8 Refilling from the Rangitikei River

The final option considered is to source refill water from the Rangitikei River. This option has an advantage that any water transferred from the Rangitikei will not offset generation in the TPD and Waikato chains and will therefore provide "new" energy throughout the system.

Potential downsides are that the upper Rangitikei River is covered by a water conservation order that expressly prohibits damming (refer Section 2.5.3) and also the transfer of water between catchments is contrary to Mana Whenua values as further outlined in Section 2.5.1).

Two sites on the Rangitikei were considered as shown on Figure 9. The first "Site E" is located at the confluence of the Otamateanui Stream (E 1857236, N 5649079) which is within 5 km of the proposed Upper Moawhango reservoir. At this location the mean river flow is 10.5 m^3/s, and an extraction of 5.2 m^3/s is considered available. The elevation at this site is 815 m, meaning a pump static head of 325 m would be required.

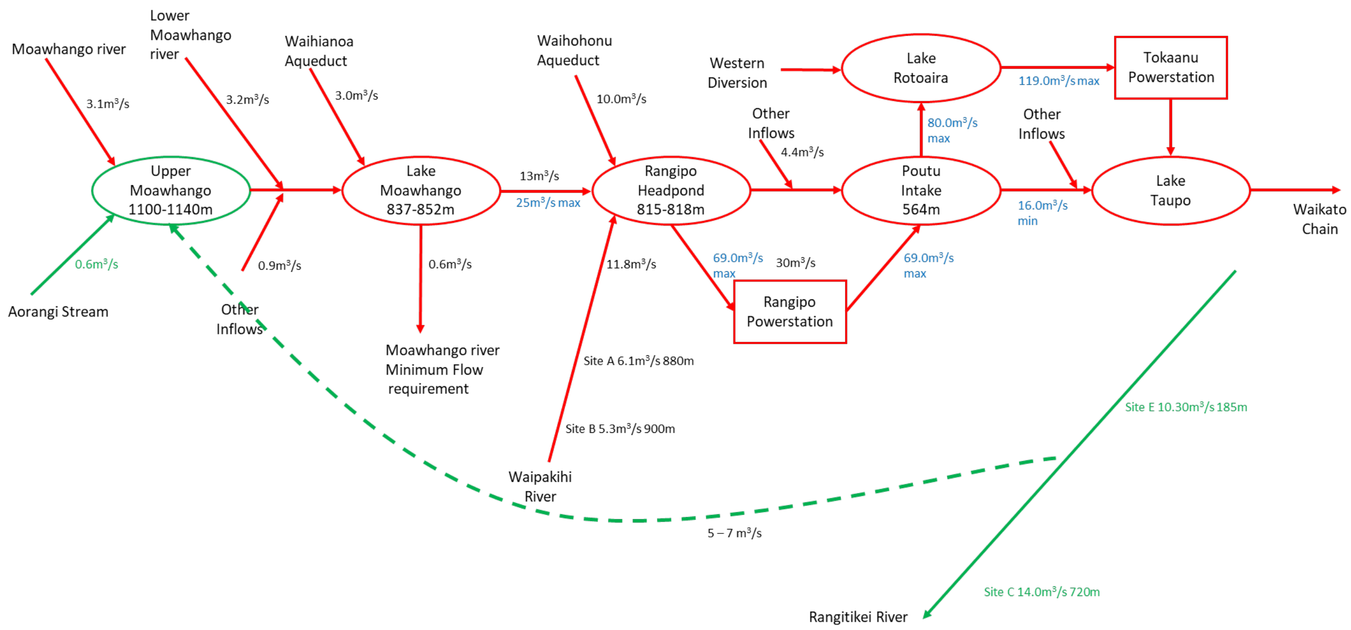


Figure 9 - Refill from Rangitikei River

The second site considered "Site C" is located at the confluence with the Oturua Stream (E 1861605, N 5639784) at which point the mean flow is 14 m^3/s, and an extraction rate of 7.0 m^3/s is considered available. The elevation at this site is 715 m, resulting in a pump static head of 425 m over a distance of about 7 km would be required.

Creating storage at these locations to capture flood flows or support peak pumping would be possible but could impact the recreational values of the Rangitikei River, especially considering the Water Conservation Order in place.

As this source can only provide between 5 and 7 m^3/s of the required 10 to 15 m^3/s refill rate it could not provide the required refill water on its own and additional sources would still be required.

2.2.2.9 Comparison of Fill Options

Table 2-3 compares key features of each fill option. Positive traits are highlighted in shades of green (darker = more desirable) and negative traits in orange/red (red = less desirable).

Table 2-3 - Comparison of Reservoir Fill Options (FSL=1140m)

Features	Refill from Poutu	Refill from Moawhango		Refill from Waipakihi	Refill from Rangipo	Refill from Rangitikei
		Pump at Lake	Moawhango Tunnel			
Mean refill flow available (m^3/s)	20-25	13	13	3	20-25	5-7
Peak refill flow (m^3/s)	40	Unlimited	30	3	40	5-7
Meet all fill requirements ?	Yes	Yes	Yes	No	Yes	No

Support peak pumping	Yes – 3 x mean	Yes > 10 x mean	Yes 2 x mean	No	Yes 3 x mean	No
Pump head (m)	575	290	290	260	325	325/425
Conveyance length (km)	20	10	3	5.5	9	5/7
Other positive features		Uses existing infrastructure	Uses existing infrastructure		Uses existing infrastructure	New energy
Other negative features						WCO

Insofar as refilling the reservoir is concerned, using the existing Moawhango (2 possibilities) or Rangipo dam appear preferable. As the infrastructure used for filling the reservoir may also form part of the infrastructure for generating from the infrastructure a clear selection as to the preferred filling choice cannot be made. Such selection is discussed in the following section.

2.2.3 Reservoir Discharge

2.2.3.1 MBIE Reservoir Discharge Concept

The MBIE GIS model assumed that a new generating facility would exploit the full head difference between the Upper Moawhango reservoir and the Tongariro River downstream of the Poutu intake.

With a reservoir level of RL1140m a gross head of some 575 m would be obtained, with the discharge elevation at about RL560 m. With discharge taking place over a three-month period, the reservoir live storage could support a generation flow of just over 100 m^3/s. This would represent a plant capacity of about 480 MW assuming a total water to wire efficiency of 85%. With a reservoir FSL elevation of RL1160 m a flow of 150 m^3/s could be supported, with generating capacity of about 740 MW. **Figure 10** shows this configuration for the RL1140 level:

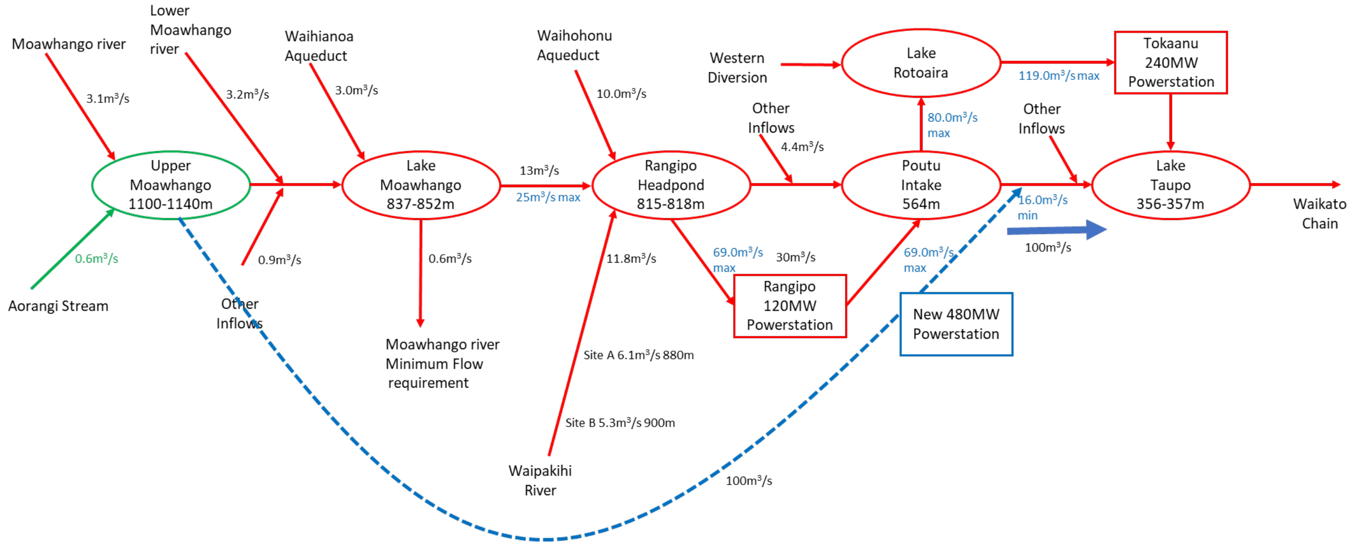


Figure 10 - MBIE Generation Concept (FSL=1140m)

Whilst simple in concept this option would bypass the existing 120 MW Rangipo and 240 MW Tokaanu power stations with some of the new power station capacity duplicating that of existing generating assets. There are a number of other challenges perceived also:

A flow of some 100 m^3/s would be present at times of normally low Lower Tongariro River flow, which might negatively impact its recreational value, especially for fishing. Discharging above the Poutu intake would be preferable, as then 80 m^3/s of the flow could be routed to Tokaanu power station via the Poutu canal. For the higher reservoir level (RL1160m) the situation would be more extreme with 150 m^3/s flowing in the Lower Tongariro. This could be reduced to 70 m^3/s if the discharge was made above the Poutu intake.

The conveyance system is required to cross the narrow Waipakihi River at somewhere around RL900m, the topography is not conducive to development of a hydro-electric or pump scheme in a single head step (and would require some storage to be formed) as shown in **Figure 11**:

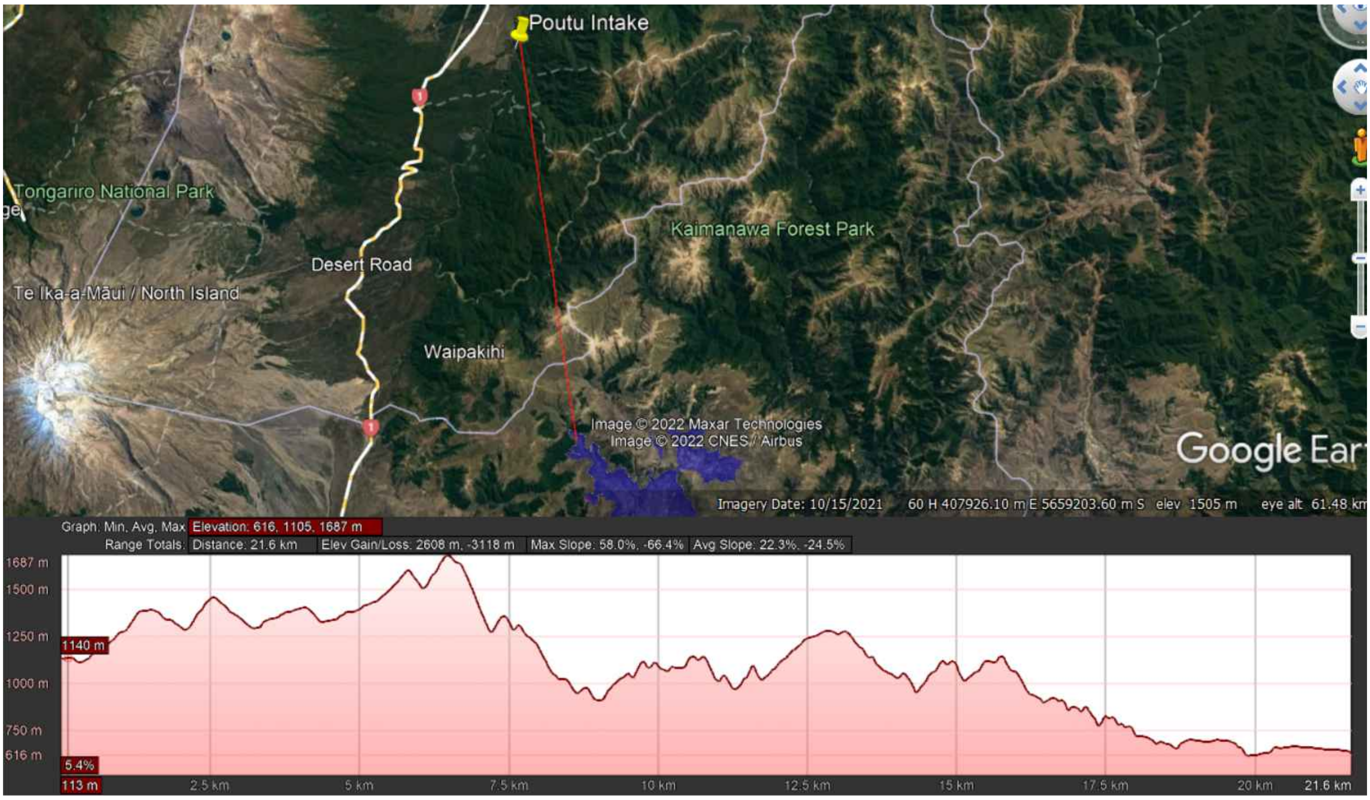


Figure 11 - MBIE Concept Locations

Whilst less direct alignments may exist for this concept, our investigations have not identified any obvious configurations that would:

- Avoid long sections of costly high-pressure tunnel.
- Avoid daylighting.
- Satisfy usual water column inertia requirements for stable operation
- Provide suitable access to reliable refill water.
- Provide the ability to respond quickly to market needs.

A scheme with an underground powerhouse near to the Upper Reservoir would be impractically deep to access and have a long and difficult tailrace tunnel.

2.2.3.2 Discharging to Lake Moawhango

The MBIE Upper Moawhango (Original TPD) option considered discharging downstream of the Poutu intake as per the GIS options, but also suggested discharging to the existing Lake Moawhango.

With a reservoir level of RL1140m a maximum gross head of some 300 m would be obtained, with the discharge elevation at RL837 (i.e. Lake Moawhango at MOL). This would represent a plant capacity of about 250 MW and a discharge of 100 m^3/s. With a reservoir FSL elevation of RL1160m a discharge of 150 m^3/s could be supported, with generating capacity of about 400 MW. **Figure 12** shows this configuration for the RL1140m level.

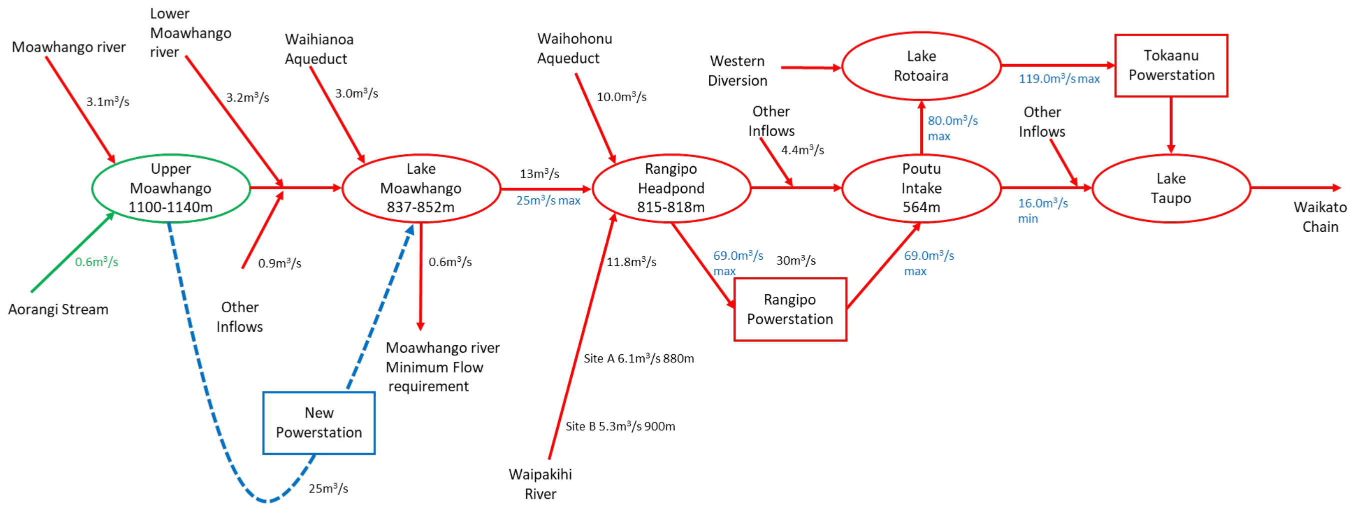


Figure 12 - Discharge to Lake Moawhango

The storage capacity of Lake Moawhango is 63 Mm^3, just 5% of the storage in Upper Moawhango, which represents 8 days inflow at 100 m^3/s and 5 days at 150 m^3/s. Therefore, unless downstream facilities on the Tongaririo system can take the additional dry year discharge a significant proportion of the water discharged into Lake Moawhango would need to be spilled at the Moawhango dam into the Rangitikei catchment. The generating potential of this water would then be lost to the entire TPD and Waikato generating systems.

The existing Moawhango-Rangipo tunnel is hydraulically limited to about 30 m^3/s which will allow some of the discharged water to be transferred into the TPD, however a balance of 70 m/^{3}s would remain, which would completely fill the Lake Moawhango reservoir in about 10 days. As the dry year storage is designed for a discharge period of 3 months (90 days) significant spill would occur inducing a combined net loss from the TPD and Waikato stations of between 1.5 and 1.8 TWh.

One solution would be to increase the size – or duplicate - the Moawhango – Rangipo tunnel to permit the full dry year discharge to be passed. Such upgrade would require an extended shutdown of the existing tunnel and may result in a loss of energy generation from the TPD and Waikato systems as water from Lake Moawhango may need to be spilled. With careful planning it may be possible to undertake the tunnel enlargement work in parallel with filling the Upper Moawhango reservoir, but it is most likely that constructing a parallel tunnel would be the most technically acceptable solution.

Once the water transfer capacity from Lake Moawhango is increased it will be possible to transfer the full Upper Moawhango storage into the TPD and Waikato systems. However not all of the water will be able to be used by the TPD as Rangipo power station is limited to approximately 69 m^3/s and the Poutu canal (which supplies Tokaanu power station) is limited to 80 m^3/s. These constraints could be overcome by expanding these existing facilities.

In addition, expanding the existing 19 km long Moawhango-Rangipo tunnel this option would require a new 10.5 km long tunnel between the Upper Moawhango and Moawhango reservoirs for the power generating facility at Lake Moawhango. Given the topography an underground power station with long tailrace tunnel is anticipated.

It is also noted that there is a head difference in the range of 19 to 37 m between Lake Moawhango and the Rangipo dam which would not be exploited by this option.

2.2.3.3 Discharging to the Waipakihi River

The Waipakihi River is quite close (8 km) to the proposed Upper Moawhango reservoir's northern extents and would represent a viable discharge location. The proposed discharge point is at "Site A" as considered for pumping of refill. **Figure 13** shows the discharge configuration:-

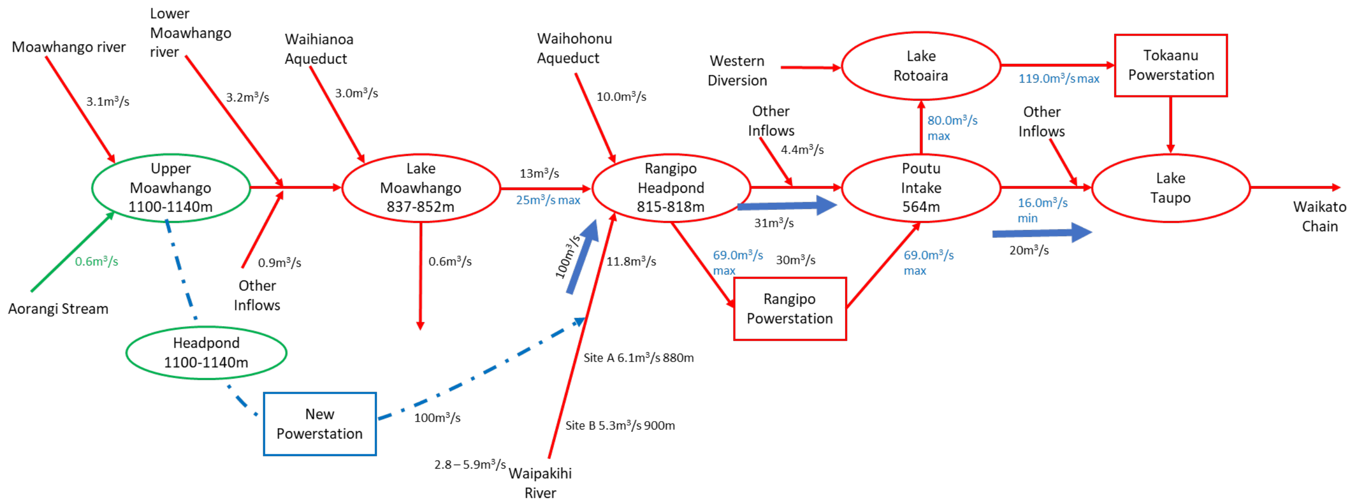


Figure 13 - Discharge to Waipakihi River

For this option a 4.8 km long low-pressure tunnel would link the Upper Moawhango reservoir to a small headpond created by damming the Waipahihi Steam. A second tunnel would then connect between this headpond and the powerhouse. The inclusion of the headpond improves the L/H ratio for the scheme, a default metric for hydraulic and economic performance. While this is less relevant for a scheme primarily designed for dry year release, a low L/H ratio is still desirable if achievable without adding undue complexity or cost. The powerhouse could either be surface type or underground, with the latter being preferred if pumping were also required. The second tunnel would be low pressure for part of its length possibly with a surface surge chamber and high-pressure steel lined type for the remainder with total length of about 4.6 km. Therefore, a total conveyance length of about 9.4km is required.

Figure 14 shows this scheme concept pictorially. It is noted that the tunnel alignment is close to the existing Moawhango-Rangipo tunnel. The power station has been given a name, “The Needles”, which is the name given to a nearby named peak.

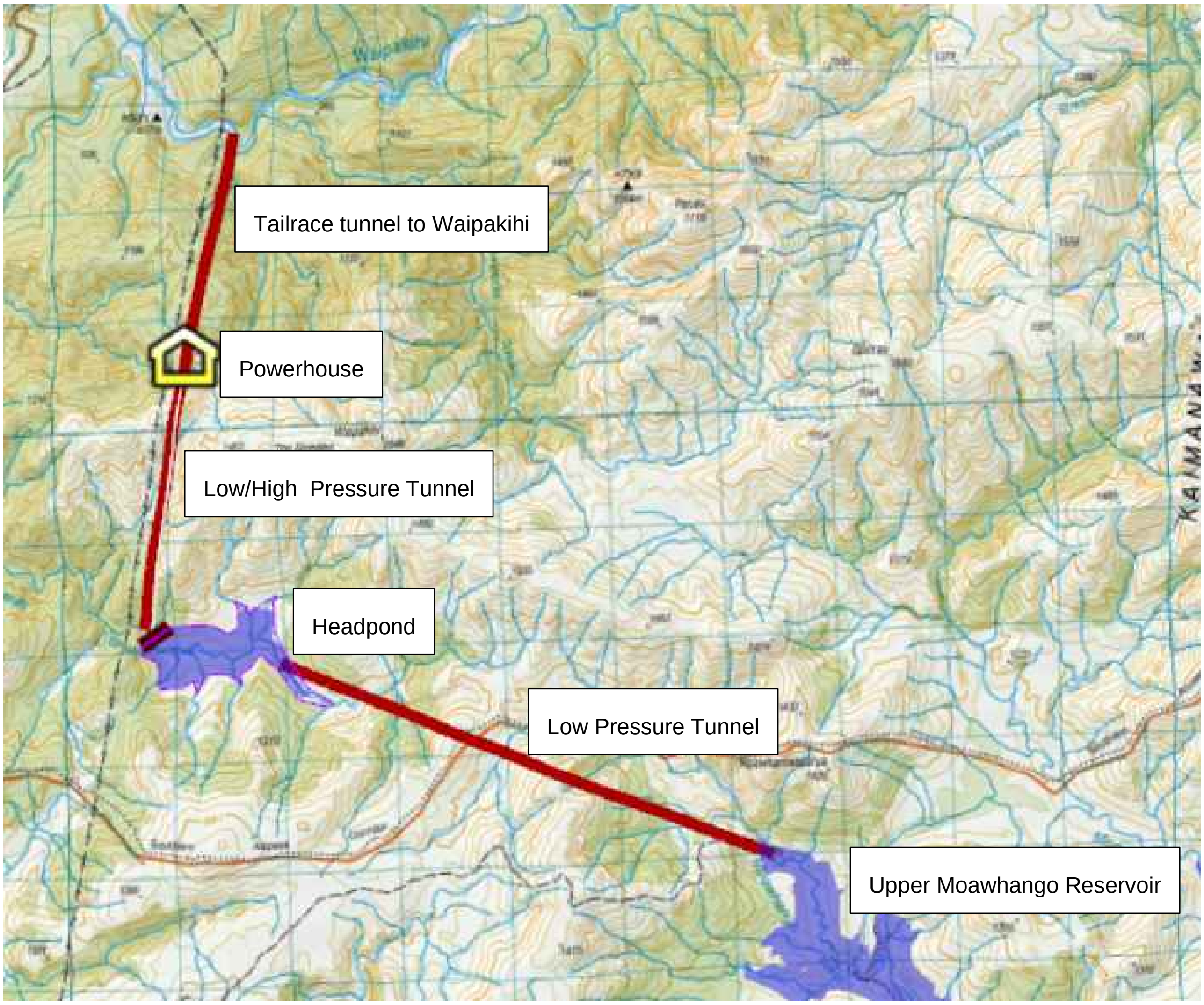


Figure 14 - Discharge to Waipakihi

The maximum gross head for this option would be approximately 260 m, which would support a generating capacity of about 220 MW, or 350 MW for an FSL of RL1160m.

When operating, a flow of 100 m^3/s or 150 m^3/s (depending on reservoir FSL) would flow in the Waipakihi River over the 6 km long section to Rangipo Dam. This flow would likely be disruptive for recreational activities on this section of the river. It would also be a significant hydrological change to the river system with periodic long duration high flow events during periods of release that the river does not currently experience.

As with discharging to Lake Moawhango not all of the water will be able to be used by the TPD owing to constraints at Rangipo power station and the Poutu canal.

2.2.3.4 Discharge to Rangipo Headpond

This option is a version of the previous configuration, with the discharge tunnel extended to the Rangipo dam.

This requires an additional 4 km of low-pressure tunnel but could achieve a further 60 m or so of head. It could avoid the issue of increased Waipakihi River discharge in generating mode. The 20 per cent gain in head for primarily the cost of 4 km of tunnelling would appear comparatively attractive financially.

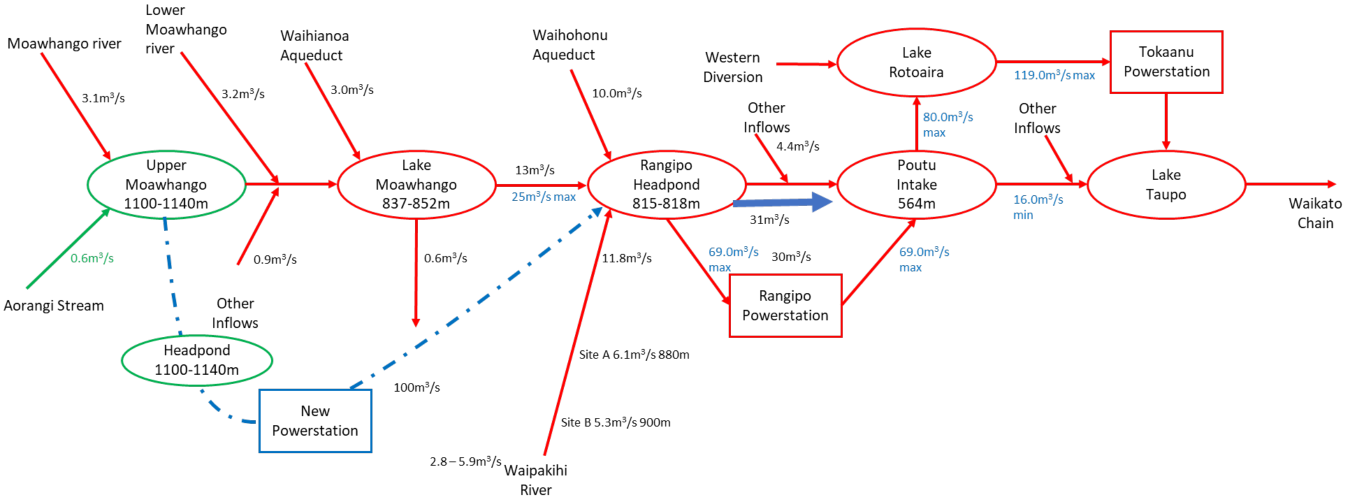


Figure 15 - Discharge to Rangipo

The maximum gross head for this option would be approximately 320 m, which would support a generating capacity of about 270 MW, or 430 MW for the FSL 1160m option.

As with discharging to Lake Moawhango not all of the water will be able to be used by the TPD owing to constraints at Rangipo power station and the Poutu canal.

2.2.3.5 Uprating Existing TPD Elements

The existing TPD exploits a gross head of some 420 m between the Rangipo Intake and Lake Taupō. The existing Rangipo power station is rated at 120 MW, and achieves this output using a flow of 69 m^3/s. Discharges from the Upper Moawhango upstream of the Rangipo intake will therefore supply more water than the existing station is able to accommodate.

In order to utilise this additional flow an expansion to the existing station could be considered, likely with a parallel intake, penstock tunnel and tailrace tunnel to the existing facility. This would allow construction to proceed with limited effect on the existing station. For the RL1140 Upper Moawhango dam option a flow of 100 m^3/s would be available for Rangipo, and any expansion would be required to utilise 31 m^3/s, from which approximately 54MW of generation could be expected. For an upper reservoir elevation of RL1160m a flow of 150 m^3/s would be available, and any expansion would utilise 81 m^3/s and provide an additional 140MW of generation.

The existing Tokaanu power station is rated at 240 MW from a flow of 119 m^3/s. However, the existing Poutu tunnel and canal can only transfer 80 m^3/s with flow above this spilled down the river. Upgrading this portion of the TPD would allow better utilisation of release flows from the Upper Moawhango through the Tokaanu Station. This upgrade would include a second tunnel from the Poutu Intake to the Poutu Canal and increasing the capacity of the Poutu Canal through a combination of size increase and hydraulic improvement.

2.2.3.6 Comparison of Discharge Options

Table 2-4 compares key features of each fill option. Positive traits are highlighted in shades of green (darker = better) and negative traits in orange/red (red = worse). For comparison purposes, under each option only the new "Upper Moawhango" scheme is directly considered (i.e. excludes upgrades to existing TPD schemes). The exception being the "Discharge to Moawhango" option which does include upgrade to the existing Moawhango Tunnel as a fundamental component. Without this upgrade the loss, through spill, to the TPD and Waikato Chain would induce a net loss in terms of energy production during a dry release event and hence is considered an invalid option.

Table 2-4 - Comparison of Reservoir Discharge Options (Assuming FSL 1140)

Features	Discharge to Poutu	Discharge to Moawhango	Discharge to Waipakihi	Discharge to Rangipo
Generation capacity (MW)	480	250	220	270
Existing TPD generation utilised (MW)	0	280[2]	280[2]	280[2]
Uprate potential of existing generating assets (MW)	0	94[3]	94[3]	94[3]
Total Useable Capacity with no upgrades to existing TPD stations (MW)	480	530	500	550
Total Useable Capacity with upgrades to existing TPD stations (MW)	480	624	594	644
Total tunnel length required (km)	22	29.5[4]	25.3	29.3
Conducive to responsive generation	No	Yes	Yes	Yes
High flows in Tongariro/Waipakihi?	Yes	No	Yes	No

Insofar as utilising the reservoir storage is concerned, discharging to the Rangipo dam or the Waipakihi River would appear preferable. These options require the shortest overall tunnel lengths and provide the highest accessible power output (and therefore GWh) irrespective of whether further upgrade works were carried out on the existing TPD elements. Given the low capacity factor, modifications to the Poutu tunnel/canal and Rangipo in particular, may be difficult to justify, these works are not essential to the main NZ Battery project and could be carried out as a separate project at a later date.

2.3 Configuration Selected for Costing

The selected project configuration must optimise both the fill and discharge cycles of the reservoir and, ideally, the same assets used for filling should also be used for discharging in order to avoid duplication.

As noted in Section 2.2.1 the preferred reservoir configuration is the Upper Moawhango (Original TPD) arrangement, with a nominal FSL in the range 1140-1160m. A long section of the selected configuration can be seen in **Appendix D.**

For filling the reservoir, the preferred solutions are to obtain water from the existing Lake Moawhango (two possibilities) or from Rangipo Dam. With the RL1160m reservoir level a mean refill rate of 19 m^3/s is required, of which it has been assumed that 3 m^3/s will be secured from natural inflows and the remaining 16 m^3/s will be pumped.

For discharging the reservoir, the preferred option is to construct a new power station discharging into the Rangipo Dam. A discharge flow rate of 150 m^3/s has been adopted. The scheme configuration is shown in **Figure 16**.

2 120 MW from Rangipo, plus 160 MW from Tokaanu (Tokaanu MW pro-rata according to flow from Poutu intake)

3 54 MW from Rangipo plus 40 MW from Tokaanu

4 Including uprated Moawhango-Rangipo tunnel

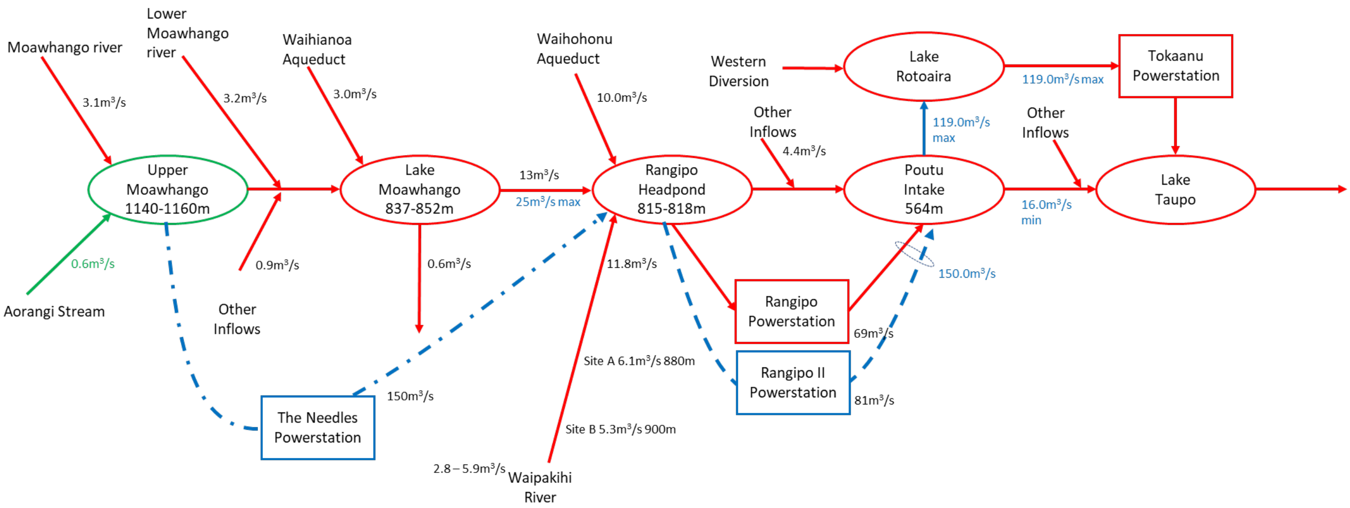


Figure 16 - Selected Configuration

For the purposes of this study the fill and discharge options considered would all be technically achievable. However, a configuration that can access water from the existing Moawhango dam and potentially the Waipakihi River, whilst utilising the full generation head available between the Upper Moawhango reservoir and the Rangipo Dam, would seem optimal. This configuration has been selected for costing purposes and is further detailed in Section 2.4.

Table 2-5 shows the anticipated energy available from the scheme by reservoir elevation and by generating element.

Table 2-5 - Energy Makeup of Preferred Option

Reservoir Elevation EL		Unit	1130	1140	1150	1160
Discharge		m^3/s	81.08	104.16	128.15	152.06
Energy						
New	**Upper Moawhango – (Discharge @ Rangipo Head Pond)**	TWh	0.44	0.57	0.70	0.83
Expanded	**Rangipo II**	TWh	0.05	0.13	0.23	0.32
	Tokaanu (max 119 m^3/s)	TWh	0.00	0.11	0.17	0.17
	Sub Total from Expanded	TWh	**0.05**	**0.24**	**0.40**	**0.49**
Existing	**Existing Rangipo Energy**	TWh	0.26	0.26	0.26	0.26
	Existing Tokaanu Energy	TWh	0.35	0.35	0.35	0.35
	Existing Waikato Energy	TWh	0.43	0.56	0.69	0.81
	Sub Total from Existing	TWh	**1.04**	**1.17**	**1.30**	**1.42**
Total	**New + Expanded + Existing**	TWh	**1.55**	**1.98**	**2.40**	**2.75**

Given the NZ Battery project is wanting to secure as much storage as possible an elevation of RL1160m has been selected for costing purposes as this provides the maximum energy. It is also likely that, apart from the dams, many of the components are less cost sensitive to capacity, the optimal economic configuration will lie toward the upper end of the RL1140m to RL1160m range. Further, as a battery, consideration would need to be given to the cost of developing a second site vs maximising the capacity at a single site.

It is noted that whilst the Upper Moawhango reservoir will provide approximately 2.75TWh of storage, only 0.83TWh will be generated from the new power station. A further 0.49TWh of additional energy is generated from expansions to the existing Rangipo and Tokaanu power stations and the balance of 1.43TWh is generated from the existing TPD and Waikato river systems.

Expansion to the existing Rangipo power station in particular would require analysis to determine if it is worth considering. Removal of the Rangipo expansion would reduce the overall energy output to about 2.4TWh.

2.4 Technical Considerations of Selected Configuration

2.4.1 Hydrology

Based on publicly available information from Genesis, the long-term mean inflow to Lake Moawhango is 13 m^3/s, of which 10 m^3/s is local runoff from the upper Moawhango River. The local drainage area at Moawhango dam is approximately 272 km^2, giving a mean yield of 37 l/s/km^2. There is no information on how this yield varies across the catchment.

The long-term mean discharge for the upper Tongariro (Waipakihi) River above Rangipo dam is approximately 7 m^3/s. A further 4.4 m^3/s flows into the river between Rangipo dam and Poutu intake. Flows at Rangipo are augmented by diversion of approximately 10 m^3/s from the Waihohonu stream.

The Electricity Authority flow dataset for Rangipo station shows a mean plant discharge of 35 m^3/s. The mean monthly discharge varies between 27 m^3/s and 43 m^3/s. The plant discharge capacity is 63 m^3/s, which is achieved about 8% of the time. The station is offline about 3% of the time. These flows are based on daily model results covering the period 1932-2020. It is noted that information from Genesis Energy has indicated that Rangipo has a discharge capacity of 69 m^3/s and this higher value has been used elsewhere in this report.

NIWA's CliFlo database has daily rainfall data for 5 stations near Waiouru, covering the period Jan 1967 to Dec 2021. Using data from the Waiouru Treatment Plant (station 3629), the annual direct rainfall onto the Moawhango reservoir is estimated to be 1076 mm, varying between 116 mm in July and 61 mm in February.

There is no evaporation data available for the central plateau, with the closest stations being in Turangi. Data from these stations is not suitable for use, due to the large elevation difference (about 600 m) between Turangi and Moawhango. Instead, reservoir evaporation was estimated using data from the Makahu Saddle 2 site (station 2934). The mean annual evaporation at Makahu Saddle is 885 mm. Using rainfall data from Waiouru, the reservoir would typically see a net rainfall of 333 mm between March and October, and a net evaporation loss of 141 mm during the remaining months. The net mean annual rainfall is 192 mm, equivalent to 0.19 Mm^3/km^2 of reservoir.

2.4.2 Geology

Reference is made to Appendix B for the findings of a completed geological study for the proposed option. The geological study summarises:
Its objectives, the completed scope of works, and the publicly available information that has been used to inform it.
A review of key geological hazards that may place a constraint on option design, construction, and operation.
The developed conceptual geological model that has been used as the basis for option development, its concept design, and the associated cost estimate.
The project area is largely underlain by basement rocks of the Kaweka Terrane, often informally known in New Zealand as 'greywacke' (Lee et al. 2011). The published geological map (Lee et al. 2011) describes the 'greywacke' as 'massive, fine to medium-grained quartzofeldspathic sandstone, alternating sandstone and mudstone, minor conglomerate, broken formation, and melange'.
Some metamorphic variability exists within the 'greywacke', with rocks in the western part of the project area of a higher metamorphic grade than those in the east, and are described as 'semi-schist', being locally known as the 'Kaimanawa Schist'. These rocks are of lower metamorphic grade to 'schist' seen elsewhere in New Zealand, such as Otago. Some other soils (alluvium) and rock occur locally, as discussed in the geological study.

These greywacke rocks form much of the upland areas of both the North Island and South Island and are therefore some of the better geologically characterised materials. Many major civil works have previously been designed, constructed, and operated on or in (i.e., tunnels) 'greywacke'. The most relevant to this option is the Tongariro Power Scheme.

It is noted volcanic rocks associated with the Tongariro Volcanic Centre (TVC) are not mapped as being present in the project area, with their mapped occurrence simplified as being the western side of SH1 and the Tongariro River. The TVC does still pose a hazard however that would need to be considered in future project stages. Together with other key geological hazards such as earthquake and slope instability.

The key findings of the geological study can be summarised as:
No geological fatal flaws have been identified based upon the currently available information:
The design, construction, and operation of the Tongariro Power Scheme provides significant engineering geological precedence of the feasibility of the proposed option. This includes the development of both surface and underground works.
Recommendations for the next stage of geological study should the proposed option proceed to the next stage of project development are:
The sourcing and review of relevant pre-existing site-specific geological information which is privately held. This would include that related to the design, construction, and operation of the Tongariro Power Scheme.

Development of geological study objectives and scope of works as required for the stage of project development as recommended by ICOLD (2005) and ANCOLD (2020).

2.4.3 Dam Configuration and Type

The geological and geotechnical setting for the Upper Moawhango reservoir potentially supports a number of dam types, concrete gravity, concrete faced rockfill (CFRD) and earthfill. For consistency a roller compacted concrete (gravity) dam (RCC) has been adopted for all dam locations. RCC dams has been adopted at this stage as it likely to be the most certain type in terms of feasibility given the inherent flexibility of this dam type. They are also simple in terms of providing for flood passage and stream diversion during construction. Should the scheme advance to subsequent feasibility phases alternative dam types can be considered that may provide more optimal solutions.

Four new dams are required for the concept design. Three collectively form the Upper Moawhango Reservoir with a fourth located on the Waipahihi Stream to form a headpond within the conveyance system.

Table 2-6: Summary of Site 1 Dams

	Dam 1 - Mt Azim Gorge Dam	Dam 2 - Aorangi Stream Dam	Dam 3 - Saddle Dam	Waipahihi Headpond Dam
Dam Type	RCC	RCC	RCC	RCC
FSL	1160	1160	1160	1160
Maximum height (m)	113	170	52	60
Crest length (m)	220	544	230	320
Dam volume (m^3)	690,000	3,345,000	224,000	280,000

2.4.4 Conveyance System

For the concept design the conveyance system serves as both refill and discharge mechanism. The total conveyance length is relatively long for the head developed (approximately 15 km for 320 m head). For reasons of hydraulic performance, the conveyance system has been configured to be predominately low pressure with a hydraulic disconnect provided by way of a head pond. This allows the scheme to respond faster to changes in the market and during favourable hydrological conditions for pumping.

The conveyance system consists of the following main components: -

Low Pressure Upper Tunnel. This 6.4km long tunnel connects the Upper Moawhango Reservoir to the Headpond. It would be more of less horizontal, 8-10m in diameter, and provide for flow in both directions (discharge and refill).

Headpond. A small storage formed in the head of the Waipahihi Stream provides a hydraulic disconnect approximately halfway along the conveyance system. It would be a passive storage with its level reflecting the level in the main Upper Moawhango Reservoir. The inclusion of this headpond reduces the ratio of conveyance length to operating head improving hydraulic performance.

Pressure Tunnel. A 2.4km, 6m diameter pressure tunnel would take flow from the headpond to the underground power station. Similarly, this pressure tunnel it would act as a pump riser during refill.

Lower Pressure Tailrace Tunnel. A 6.2km 8-10m diameter low pressure tunnel conveys discharge from the power station to the existing Rangipo Dam that feeds the Rangipo Power station. During pumping, water would be fed back along this tunnel to supply the pumps located at the power station.

In recognition that some of the components may be challenging to advance on environmental grounds the design concept has been formed to provide for localised alternatives that might be less ideal technically but achieve more acceptable environmental outcomes. These include: -

Headpond. As an alternative to the headpond one or more surge shafts could be provided along the conveyance system. While less ideal from a hydraulic performance perspective these would have smaller surface footprints and have some flexibility in where they are located.

Tailrace Tunnel. A shorter 2.4 km tailrace option would discharge to the Waipakihi River approximately 6 km upstream of the existing Rangipo Dam. Whilst saving 4 km of tunnel there is a net reduction in operating head of 55 to 60 m, The discharge would also impact on the flow regime in the river.

2.4.5 Plant Selection and Power Rating

Taking into account the need to avoid cavitation in pumping mode the powerhouse must be set well below the level of the Rangipo reservoir (and the Waipakihi River the tailrace tunnel crosses) at around RL750m. At this stage the layout is one incorporating the following:

A single vertical high-pressure shaft

A manifold and inlet pipes supplying conventional reversible pump-turbine units with inlet valves housed in a single powerhouse cavern

Draft tube extensions combining at the base of a large, vertical tailrace surge chamber with isolating gates for turbine maintenance
A single low pressure tailrace tunnel leading to the outfall.
The machine hall will nominally house three identical 140 MW reversible vertical shaft Francis pump-turbines to include some redundancy for security and a potential for ‘surge pumping’ (at times of low electricity price) should the lower storage hydraulics permit. Each machine will have a discharge in turbine mode of 50 m^3/s and a discharge in pumping of around 40 m^3/s.

2.4.6 Energy Storage and Reservoir Release / Refill Times

In assessing storage performance in terms of release and refill two broad approaches have been used, single use and market operation.

For the single use approach the full storage in the Upper Moawhango reservoir is released over a 3-month period. This is a dry year event scenario and sized the capacity of both release and refill mechanisms. Refill then occurs over the following 2 years targeting periods of higher flow and lower power price.

For the market operation at this preliminary stage the scheme is presumed to release 12.5% of the time (cumulatively 3 months in 2 years) with release based on periods of high price. Refill is then undertaken between periods of release and when prices are typically below median. This approach indicated that in the last 5 years there would have been three occasions where significant portions (20% or more) of the storage was used and several smaller uses.

A key aspect of operation under both scenarios is the relative pump capacity. A minimum of 20 m^3/s of pump capacity is required to be able to realistically refill the storage following an event that fully drains the reservoir. Pumping would need to be nearly continuous between events to achieve refill in time (2 years). Increased pump capacity allows discretion on when pumping can occur to better meet water availability and power price conditions.

Both scenarios produce similar results in terms of energy generation over any two-year period however the dry year event uses the entire storage in a single event whereas the market based operation only uses about 60% of the available storage as most events are less than 3 months in duration. This indicates the scheme has the potential flexibility to fulfil a combined role of both market operation and dry year reserve.

Under both release scenarios the existing TPD and Waikato Chain benefit in terms of releases being either timed to match periods of scarcity or high-power prices, which are likely to coincide. The combined energy output across the schemes is provided in **Table 2-7** for a single dry year event or for two years of market operation.

Table 2-7 - Site 1 Dry Year Event Cycle

	Release (GWh per event / 2 years)	Refill (GWh per event / 2 years)
Upper Moawhango “Needles”	830	-1040
TPD	1,110	-1110
Waikato	810	-810
Total	2,750	-2,960

The energy value transfer achieved is also similar for both single and market operation. For the single event it is assumed that generation is placed during the highest continuous 90-day period of high prices (i.e., highest 90-day average price). The two highest 90-day events are used in the 5-year period.

For the market operation generation occurs when the current price exceeds a threshold relative to the average price over the previous 60 days. To avoid pulsing a minimum 4-hour high price trigger period and 4-hour minimum run time is required. Pumping for both scenarios occurs when the price falls below a trigger relative to the previous 60 days average price.

Table 2-8 - Site 1 Market Operation

	Generation Price vs 5 year Average	Pumping Price vs 5 year Average
Single Event (90 Day Release)	210%	60%
Market Event	205%	60%

While the single event gives a slightly higher ratio, it presumes perfect knowledge of the event ahead of time. A more likely scenario is the storage is used over a period during which the 90-day price peaks and then fall away. If the 90-day peak price is centralised within the duration of the event (i.e., at day 45) the ratio of price gained vs 5-year average is 162%

The energy impact on the existing schemes (TPD & Waikato) is primarily a time shift however they will benefit from a similar price transfer although this will lessen within the Waikato Schemes given the existing storage in Lake Taupō.

2.4.7 Transmission

As noted in **Table 2-4** the maximum additional installed generating capacity of any of the options considered is 644 MW. This is in addition to the 360 MW capacity of the existing TPD. Therefore, the total capacity in the expanded TPD would be close to 1,000 MW.

The project area is in close proximity to the Transpower North Island backbone 220 kV system which comprises the following transmission circuits as also shown on **Figure 17**.
Bunnythorpe – Tokaanu 220kV line 1
Bunnythorpe – Tokaanu 220kV line 2
Bunnythorpe – Tangiwai - Rangipo 220kV line 1

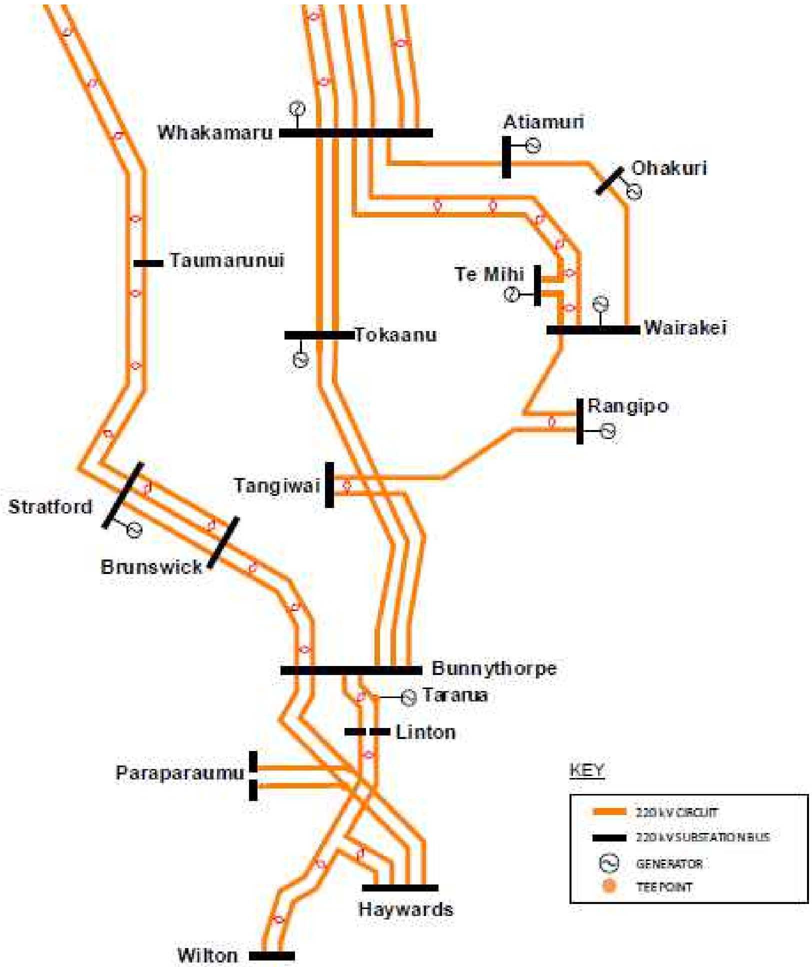


Figure 17 - Central North Island 220kV System

The project area is within Transpower's Grid Zone 7 which has a total of 390MW of hydro generation and 520MW of wind generation installed. Overall, the zone is a net exporter of energy. In addition, HVDC transfers from Haywards also contributed to loadings on this section of the network.

The Transpower 2020 Planning Report identifies that "*For north flow, the limiting constraint in these two transmission corridors depends on which regions contribute the highest generation. When generation is highest in the Central North Island and Wellington regions, the 220 kV Tokaanu–Whakamaru circuits and low capacity 110 kV Bunnythorpe–Mataroa circuit are the first to constrain generation export. When generation is highest in the Taranaki region, the 220 kV Huntly–Stratford circuit is the first to constrain generation export. The constraints in both transmission corridors become binding relatively soon after one another.*

The constraints in both transmission corridors are exacerbated if additional generation is developed in the Taranaki, Central North Island or Wellington regions. These regions have potential for a significant increase in wind generation, *and the Taranaki region has potential for more thermal peaking plants. Increasing reliance on South Island generation (via the HVDC link) to meet the North Island peak load will also exacerbate these constraints"*

"For south flow, the Rangipo–Tangiwai circuit constrains generation import into the Wellington region. This is followed closely by the Brunswick–Stratford and Bunnythorpe–Tokaanu constraints if thermal generation is being exported south"

Dry year storage/generation in the Moawhango area as envisaged by the NZ Battery project does not align with the modelling undertaken by Transpower and it is probable that such storage would materially affect power flows in the Central North Island, whether being to resolve a South Island dry year, North Island dry year, or a nationwide dry year scenario.

Transpower have however identified that the Bunnythorpe-Tokaanu-Whakamaru circuits in particular constrain South – North power transmission and an upgrade to these transmission lines is included in the 2025-2030 forecasts, with a budgeted cost in the region of $326M (duplexing option, whereby a second conductor is added to each transmission circuit. With duplexing it is understood that the capacity of each circuit will increase from 335/307 MVA (winter/summer) to 670/614MVA. At this early stage it would seem prudent to assume that the requirements for such upgrades would be accelerated by any developments at Moawhango.

It is anticipated that connection of "The Needles" power station a new switching station would be constructed at the power station site and the existing transmission circuits routed through the switching station.

2.5 Non-Technical Considerations of Selected Configuration

2.5.1 Kaitiakitanga

Ngāti Waewae, Ngāti Rangi, Ngāti Tūwharetoa, Ngāti Hikairo, Ngāti Hauiti, Mōkai Pātea, Ngāti Paki, Ngāti Hinemanu, Ngāti Tamakōpiri, Ngāti Whitikaupeka

Cultural Narrative:

Traditionally a significant place in which kaitiaki practiced their ancient rituals observing the rise of Rigel, Pleiades, and other key constellations. The area of Moawhango is also originally known as Te Riu o Puanga also the name of one of the local marae. (The valley of Puanga or Rigel constellation).

According to the custodians of Ngāti Tamakōpiri and Ngāti Whitikaupeka they claim the mouri of the Moawhanga river originates at Waipāhihi in the Kaimanawa forest – flowing southeast to the Rangitikei River near Taihape and they claim kaitiakitanga of the Moawhanga river.

In 1973 – Iwi lost 1500 acres for the creation of Lake Moawhango as part of Tongariro Power Development. The interconnectedness of Rangipō Waiū, Oruamatua Kaimanawa, Murimotu, Rangiwaea, Motukawa, Awarua and Moawhango blocks to the surrounding mountains of Tongariro, Ruapehu and Ngaruahoe and Ruahine as well as Lake Taupō, Moawhango and Rangitikei rivers are intertwined. Mai i te kahui maunga ki Tangaroa (Which personifies the relations the spiritual, cultural, physical and social connection iwi have with the entire ecology from the mountain ranges to the Tangaroa (to the sea).

Kaitiakitanga: Maintaining and enhancing the Mauri of the Moawhango catchment and its tributaries.

Tino Rangatiratanga: Self Determination and sovereignty over all associated taonga.

Manaakitanga: Duty of care to support Hapū and iwi.

Mana Atua: Recognising the guardians spiritual association with Te Taiao / environment.

Mana Tangata: Hapū and iwi can exercise authority and control over Te Taiao through ahi kā and whakapapa.

Hau: Replenish and enhance a resource when it has been used.

Mana Whakahaere: working collaboratively for the wellbeing of the river.

Traditionally iwi use to gather kiore, kiwi, weka, tītī, tuna, kokopu, koura, inanga, and other native species from the area.

Since colonisation introduced species such as the rainbow trout and the Kaimanawa horse(s) are prevalent in the Moawhango and Kaimanawa regions.

The Ministry of Works and the Electricity Department constructed a dam on the Moawhango River in 1965-1968 as part of the Tongariro Power Development project. The Defence Department, Ministry of Works and the Electricity Department did not consult Ngāti Tama Whiti about damming the Moawhango River. Ngāti Tama Whiti would have objected to dam construction for cultural and spiritual reasons.

The Moawhango dam has caused lower water levels downstream, affecting indigenous fish species that were once abundant food sources for Ngāti Tama Whiti. The Electricity Department had the ability to maintain the river levels by releasing water but chose not to. · Army training has desecrated sensitive areas containing wāhi tapu. The Kaimanawa Wild Horses Plan (1995) to cull the herd, as approved by the Minister of Conservation in May 1996, violates the right of Ngāti Tama Whiti to exercise rangatiratanga over their ancestral lands and the Kaimanawa Wild Horses as the products of those lands, and affects Ngāti Tama Whiti's rights over the tourist potential of the horses.

Te Pā o Waiū / ancient pā and battle site on the southern border. Fighting trenches can be seen today. Ngati Tamakōpiri and Ngāti Whitikaupeka were responsible for defending Rangipō Waiū from incursions. Te Ara tawhito / ancient walking track from Taupō to Heretaunga via Moawhango. Te Hautapu stream originates here. Waiōuru Army training has already desecrated sensitive areas containing wāhi tapū.
According to Ngāti Tūwharetoa and Te Kotahitanga o Ngāti Tūwharetoa and the Crown – Deed of Settlement of Historical Claims (July 2017):

"The Crown acknowledges that the construction and operation of the Tongariro Power Development scheme has had a destructive impact on the cultural and spiritual well-being of Ngāti Tūwharetoa.

The mixing of the waterways of Tongariro Maunga with one another and is considered by Ngāti Tūwharetoa to be inconsistent with the mauri of those waters. These breaches have caused distress and remains a significant grievance for Ngāti Tūwharetoa"

2.5.2 Environmental and Social

2.5.2.1 Land Ownership

This option would impact untitled land (Defence Land and Kaimanawa Forest Park) and in addition approximately 13 land titles. The majority of infrastructure, including the reservoir, is located on Defence Land. The headpond and parts of the duplicate tunnel are located within Reserve Land (Kaimanawa Forest Park).

Of the 13 land titles identified as being likely impacted by the conceptual option, four are owned by a power company and 9 are private land titles. These private titles related to the Moawhango Pipeline (2) and the widening of the existing Putu Canal.

Based on the conceptual configuration for this option, it would impact the least number of property owners of the three options.

2.5.2.2 Ecology

Site 1 can briefly be described as a 39 km^2 reservoir formed by 3 proposed dams on the Moawhango River and Aorangi Stream in the upper reaches of the Rangitikei River. Water will be sourced from Lake Moawhango, plus local inflows, with the option to add another intake on the Waipakihi River. A dam and headpond would be constructed on the mid-reaches of the Waipahihi Stream. Water would discharge to the headpond above the Rangipo Dam on the Tongariro River, and then be utilised by the existing Rangipo Power station that may be upgraded as part of the project. Water would then travel via a widened Poutu Canal into Lake Rotoaira,and be available to the existing Tokaanu power station and continue via Lake Taupō down the chain of hydropower plants on the Waikato River.

The reservoir for Site 1 is located on Defence Land east of the State Highway 1 (SH1) Desert Road. This is within the Moawhango Ecological District of the Moawhango Ecological Region. The headpond, existing and proposed pipelines and Rangipo Powerstation are located within the Kaimanawa Ecological District of the Kaimanawa Ecological Region and is crosses DOC land within the Kaimanawa Forest Park. The Poutu Canal (owned by Genesis Energy) is located within the Tongariro Ecological District of the Tongariro Ecological Region.

Approximately 3000 ha of predominantly native vegetation will be cleared for the scheme and 430 ha of wetland. These wetlands support rare plant and animal species such as turf communities and North Island brown mudfish (*Neochanna apoda*) (At Risk - Declining). Approximately 200 linear km of stream or river will be restricted due to the presence of new dams.

Table 2-9 - Vegetation Types Intersected by the Project (excluding tunnels and pumpstations)

Vegetation or Habitat Type (LCDB v5.0)	Area (ha)
Broadleaved Indigenous Hardwoods	1.7
Gorse and/or Broom	2.78
Gravel or Rock	58.08
Herbaceous Freshwater Vegetation	425.52
Indigenous Forest	7.4
Lake or Pond	0.4
Matagouri or Grey Scrub	1045
Mixed Exotic Shrubland	8.30
Sub Alpine Shrubland	742.79
Tall Tussock Grassland	1558.90
TOTAL:	**2910.34**
TOTAL NATIVE:	**2840.79**

There is existing 4WD road access to the main dam site on Aorangi Stream, but not for the three other proposed dams, headpond or transmission line. The proposed tunnel would be parallel to existing infrastructure, presumably along a somewhat modified route. The facilities within and downstream of the Rangipo Power Station and Poutu Canal are already highly modified. Approximately 2 km of new transmission lines will be built to connect the proposed new power station to the existing national grid to the west.

Further detail is provided in Appendix A.

2.5.2.3 Recreational and Commercial Land Use

There is currently no public access to the Defence land where the main reservoir will be created. This will limit any potential impacts on recreational and commercial interests at the site of the main reservoir. The dam and headpond on Waipahihi Stream is partly within DOC land and partly on private land. The headpond and reservoir will impact (intersect) with the Southern Access Corridor Track.

The scheme will reduce flows in the Rangitikei River catchment and increase flows in the Waikato River catchment.

The Rangitikei River supports a nationally significant trout fishery. It also supports canoeing, jet boating and white-water rafting. The Lake Taupō Fishery internationally renowned. The fishery is managed by DOC and includes Lake Taupō and its tributaries including the Tongariro River, Waikato River to Huka Falls; and Lakes Moawhango, Kuratau and Otamangakau. The scheme will increase flows in Lake Taupō and the Waikato River, and potentially the Tongariro River, but decrease flows in Moawhango River and Lake Moawhango.

The Tongariro River is internationally renowned for fly fishing. The Tongariro National Trout Centre and hatchery is located on the banks of the lower river. Tūrangi at the mouth of the Tongariro River used to market itself as the Trout Fishing Capital of the World. Lake Rotoaira, separately managed by the Lake Rotoaira Trust, is a distinct but important part of the Taupō Fishery. The scheme will increase flows in Lake Rotoaira.

The scheme will result in positive impacts to power generation for all existing downstream power stations.

2.5.3 Planning / Consents

The key consenting issues for this Site relate to:
The take and / or damming of water
The construction of dams in waterbodies
The flooding and construction of infrastructure within an outstanding natural landscape
Works within significant natural areas.
The catchments from which water will be taken or dammed to fill the reservoir are currently either fully allocated or overallocated, and / or are being managed in their 'natural state' by the relevant regional council. In this context the filling regime for the Site will need to be very carefully designed to ensure that it does not over-allocate water (e.g., by

only taking water in high flow conditions), does not impact on other users and maintains the natural state of the water body, where this is relevant.

The take of water will also need to align with the Rangitikei Water Conservation Order (WCO). This option would impact the 'Middle River' as defined in the WCO. In the Middle River the WCO seeks to protect outstanding scenic characteristics and outstanding recreational and fishery features. Of relevance to the option, the WCO seeks to achieve this by protecting the flow of water in the main stem of the Rangitikei River. The water takes from the Moawhango River and Lake and Aorangi Stream will need to be managed to ensure that the requirements of the WCO with respect to flow in the main stem of the river are met. Under the Resource Management Act, resource consent cannot be granted for an activity that would be contrary to the WCO.

The construction of the various dams and weirs that support this option will need to ensure that the high values of the water bodies are maintained. This will be particularly important for those rivers and streams being managed by the Regional Council in their natural state, including the upper Moawhango and Waipakihi Rivers.

All elements of the option fall within an outstanding natural landscape identified in either the Ruapehu or Taupō District Plan. The protection of these values is a matter of national importance under the Resource Management Act and will require careful assessment if the option is taken forward.

Finally, the option will impact identified significant natural areas in the Taupō District. The protection of these values is again a matter of national importance under the Resource Management Act. If the option is taken forward further work will be required to determine if adverse effects on these values can be avoided and if not whether these effects can be satisfactorily minimised or offset. It is noted that in the Horizons Region and Ruapehu District, significant natural areas are not currently mapped in the relevant resource management plans. The existence of these important areas needs to be identified by the applicant for resource consent by applying criteria set out in the planning documents. Given the desk top nature of this current assessment, it is not possible to identify whether those elements of the option within the Horizon Region / Ruapehu District will impact on significant natural areas.

2.6 Cost Estimate of Selected Configuration

The estimated P_{50} cost for the selected configuration is NZ$8.2 Billion as further detailed below.

The cost breakdown is provided in Appendix C and includes:-

- Site establishment and disestablishment
- Dams as required for the FSL1160 reservoir level
- "The Needles" underground power station and headpond (150 m^3/s option as per the FSL1160 level).
- Rangipo II power station (150 m^3/s option as per the FSL1160 level).
- Turbine and generating plant.
- Interconnecting tunnels including to Rangipo II
- Expansion of the Poutu tunnel and canal.
- Transmission and switchyards
- Access roads

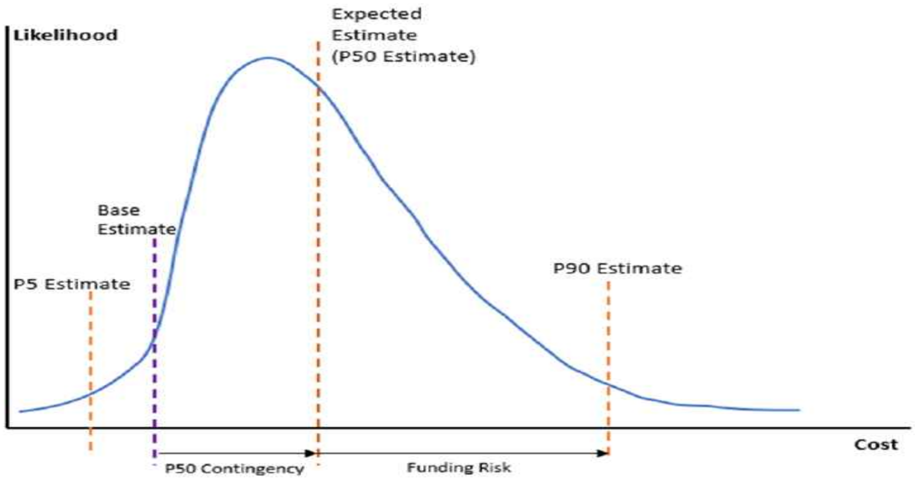
The cost estimate does not include upgrades to the Transpower core grid.

Land acquisition and related costs are not included.

Table 2-10: Cost Estimate Site 1

Item	Description	Base Estimate (NZ$ million)	P_{50} Contingency (NZ$ Million)
1.	Client Internal Cost	360.5	108.2
2.	Client's Design	558.6	167.6
3.	Consent preparation	114.3	34.3
4.	Site Investigations	152.3	45.7
5.	Property & Utilities	12.7	3.8
6.	Project Specific Insurances	76.2	22.9
7.	Construction	5,077.9	1,448.7
8.	Project Base Estimate (1+2+3+4+5+6+7)	6,352.4	
9.	Contingency (Assessed/Analysed)		1,831.1
10.	Total Project Expected Estimate (P_{50})		**8,183.5**
11.	Funding Risk	50%	4,091.7
12.	90th Percentile Estimate (P_{90})		12,275.2

The budgets have been prepared to AACE **class 5** with P_{50} contingencies between 25% and 30% depending on the particular cost items and P_{90} funding risk at an additional 50% in accordance with cost estimation practices generally applied in New Zealand (for example NZTA etc). and as depicted on the diagram below.

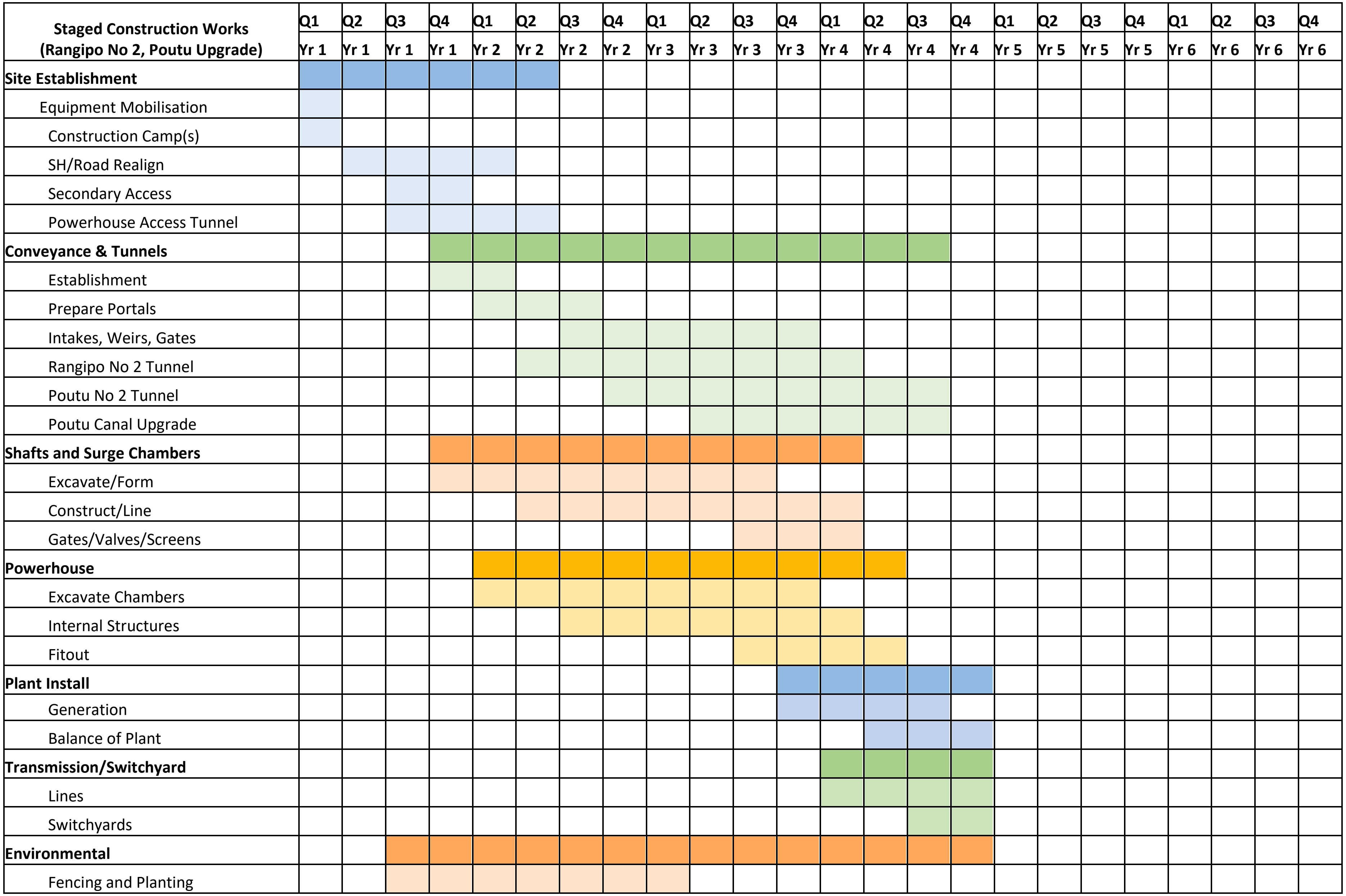


2.7 Project Schedule of Selected Configuration

The following programme was developed utilising comparison with some overseas examples. Where a range of programme times existed, the upper limit was typically adopted. It is anticipated that the critical path will be associated with the powerhouse excavation and subsequent machinery installation. As the current design is at a very preliminary conceptual state, caution was exercised against being to conservative in terms of programme development. Core items such as major tunnels and dams will not be optimal. Subsequent stages will seek to reduce component sizes and hence cost and construction time.

Staged Construction Works (New Scheme)	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	Yr 1	Yr 1	Yr 1	Yr 1	Yr 2	Yr 2	Yr 2	Yr 2	Yr 3	Yr 3	Yr 3	Yr 3	Yr 4	Yr 4	Yr 4	Yr 4	Yr 5	Yr 5	Yr 5	Yr 5	Yr 6	Yr 6	Yr 6	Yr 6
Site Establishment																								
Equipment Mobilisation																								
Construction Camp(s)																								
SH/Road Realign																								
Secondary Access																								
Powerhouse Access Tunnel																								
Dams and Storage																								
Site Prep & Stream Diversion																								
Dam Construction																								
Intakes, Spillways, Controls																								
Conveyance & Tunnels																								
Establishment																								
Prepare Portals																								
Tunneling																								
Lining/Finishing																								
Shafts and Surge Chambers																								
Excavate/Form																								
Construct/Line																								
Gates/Valves/Screens																								
Powerhouse																								
Excavate Chambers																								
Internal Structures																								
Fitout																								
Plant Install																								

Unit 1																								
Unit 2																								
Unit 3																								
Pumps																								
Balance of Plant																								
Transmission/Switchyard																								
Lines																								
Switchyards																								
Environmental																								
Fencing and Planting																								
Rehabilitation																								
Commissioning																								
Conveyance System																								
Pumps																								
Generation																								
Lake Fill (local only)																								
Lake Fill with Pumps																								
Dams/Spillways																								



Staged Construction Works
(Rangipo No 2, Poutu Upgrade)
Q1 Yr 1
Q2 Yr 1
Q3 Yr 1
Q4 Yr 1
Q1 Yr 2
Q2 Yr 2
Q3 Yr 2
Q4 Yr 2
Q1 Yr 3
Q2 Yr 3
Q3 Yr 3
Q4 Yr 3
Q1 Yr 4
Q2 Yr 4
Q3 Yr 4
Q4 Yr 4
Q1 Yr 5
Q2 Yr 5
Q3 Yr 5
Q4 Yr 5
Q1 Yr 6
Q2 Yr 6
Q3 Yr 6
Q4 Yr 6
Site Establishment
Equipment Mobilisation
Construction Camp(s)
SH/Road Realign
Secondary Access
Powerhouse Access Tunnel
Conveyance & Tunnels
Establishment
Prepare Portals
Intakes, Weirs, Gates
Rangipo No 2 Tunnel
Poutu No 2 Tunnel
Poutu Canal Upgrade
Shafts and Surge Chambers
Excavate/Form
Construct/Line
Gates/Valves/Screens
Powerhouse
Excavate Chambers
Internal Structures
Fitout
Plant Install
Generation
Balance of Plant
Transmission/Switchyard
Lines
Switchyards
Environmental
Fencing and Planting

Rehabilitation																								
Commissioning																								
Conveyance System																								
Generation																								

2.8 Summary

Key details of the selected configuration for Site 1 are as follows:-

Table 2-11: Site 1 Details

Site 1 Summary	
Storage Provided (TWh)	2.75
New generation (TWh)	0.83
Existing generation expanded (TWh)	0.49
Existing generation (TWh)	1.42
Capacity of new generation (MW)	570
Capacity of existing generation supported (MW)	1460
Total generation capacity supported (MW)	2030
Volume of Reservoir (Mm^3)	1714
Live Storage of Reservoir (Mm^3)	1199
Volume of materials in main reservoir dam (Mm^3)	4.3
Length of tunnels (km)	29.3
Generation time to empty (Months)	3
Flow rate for filling over 2 years as per scope (m^3/s)	19
Flow rate to fill in 9 months of each year (m^3/s)	25
Indicative Cost (P_{50}) (NZ$ Billion)	8.18
Cost/TWh (NZ$ Billion)	2.97
Project Duration (Years)	5.2

3 Site 2 Taruarau

The MBIE GIS scan identified the Taruarau catchment as a location of interest for development of a pumped hydro energy storage scheme.

A potential upper reservoir site was identified in the Taruarau River in the vicinity of Lake Horotea (E 1871122, N 5645735). Two number of potential configurations were nominated by MBIE as detailed below.

3.1 MBIE Concept Configurations

Figure 18 below shows two reservoir options identified from the GIS Scan.

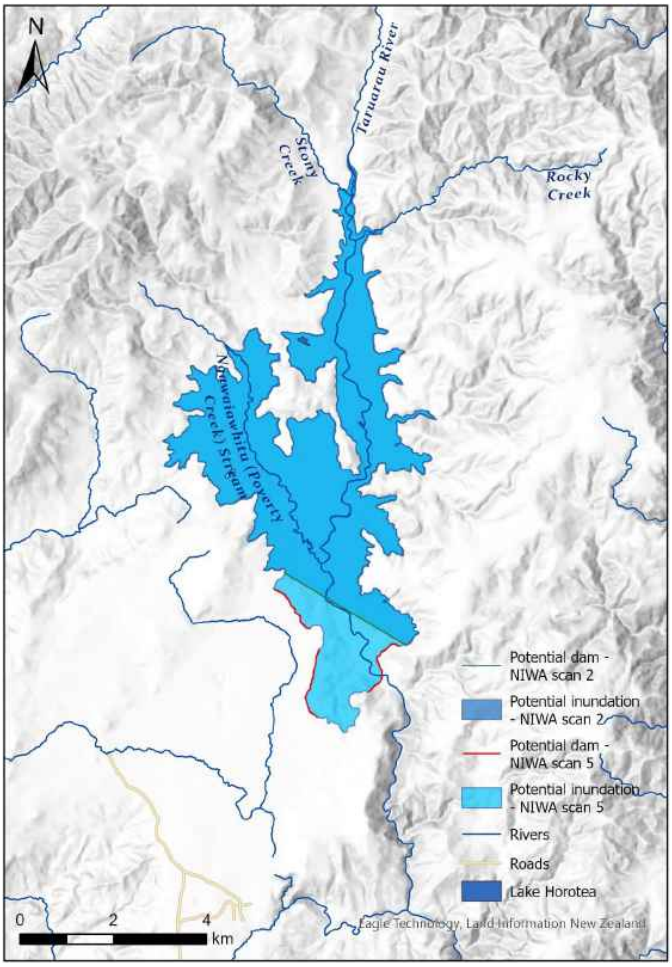


Figure 18 - Site 2 NIWA GIS Scans

The first option "NIWA scan 2" (dark blue shading) considered a straight dam across the Taruarau River just below the confluence with the Ngawaiawhitu Stream (E1871544, N 5640960). Although the information provided by MBIE did not define a specific FSL it appears a level of RL900m was envisaged.

The second option "NIWA scan 5" (light blue shading) considered a series of three contour dams, with a main dam across the Taruarau River with two containment (saddle) type dams to maintain a FSL of RL900m.

The water source for the reservoir was identified as being the Ngaruroro River at Whanawhana (E1891903, N 5615815), via a 30 km tunnel.

3.2 Configurations Considered

3.2.1 Dam / Reservoir Configurations

For each of the two identified configurations reservoir area and storage volumes were calculated in 10 m increments from fully empty to 20 m above the FSL assumed by MBIE. A live storage range of 30 m was assumed for comparison purposes. Note that this differs from the 40 m used for Site 1.

The energy stored by each option was established based on an assumed discharge point at RL200 m (Whanawhana) and an assumed conversion efficiency of 85%. A similar efficiency ratio has been used for pumping giving an overall baseline transfer efficiency of 72%. The net efficiency is better than this given some water is derived from within the storage sites so does not need to be pumped.

In addition, an estimate of the required dam volume for each option was calculated in order to provide a metric of live storage volume vs dam fill volume which will provide a high-level value comparison between the various configurations. Construction of the dams to form the reservoir will be one of the three main cost aspects of any option, the other two being conveyance and mechanical and electrical equipment. Calculating the Live Storage Volume vs Dam Fill Volume, as provided in Table 3-1, is a simple preliminary tool to guide where an optimised scheme size might lie.

Key details of the two options are shown in **Table 3-1**.

Table 3-1 - Site 2 Reservoir Comparisons

Heading	NIWA Scan 2	NIWA Scan 5
FSL	900m	900m
Reservoir storage volume	800 Mm^3	1010 Mm^3
Live storage volume	490 Mm^3	590 Mm^3
Stored energy	0.77 TWh	0.93 TWh
Dam material volume	8.7 Mm^3	7.7 Mm^3
Storage volume vs dam volume	90	130
Live Storage volume vs dam fill volume	55	75

From this comparison it is apparent that the "NIWA Scan 5" configuration provides significantly more storage per unit of dam volume than the straight dam option. In addition, assessment by Stantec dams and geological engineers identifies that the Scan 5 dam locations make more sense than the straight dam option. The NIWA Scan 5 configuration was therefore selected as the preferred reservoir arrangement upon which further refinement is undertaken.

Further assessment was undertaken of the NIWA Scan 5 configuration to establish the storage, energy and refill parameters required for varying FSL levels. These, along with the storage volume/dam volume metric are presented in **Table 3-2**. For the purpose of this assessment the reservoir has been labelled the "Taruarau Reservoir".

Table 3-2 - NIWA Scan 5 Impact of Varying FSL

Heading	NIWA Scan 5 – Tarurarau Reservoir					
FSL	**860**	**870**	**880**	**890**	**900**	**910**
Reservoir storage volume (Mm^3)	300	420	580	780	1010	1290
Live storage volume (Mm^3)	220	295	380	480	590	710
Stored energy (TWh)	0.33	0.44	0.58	0.74	0.93	1.10
Dam material volume (Mm^3)	0.5	0.7	0.9	2.0	3.2	5.5
Storage volume vs dam volume	600	600	644	390	315	235
Live Storage volume vs dam volume	440	420	420	240	185	130
Energy vs dam volume (GWh/Mm^3)	0.66	0.63	0.64	0.37	0.29	0.20
Refill flow required (m^3/s avg)	3.5	4.7	6.0	7.6	9.3	11.2
Generation flow supported (m^3/s)	28.0	37.3	47.9	60.9	74.6	89.8

It is noted that the energy yield per cubic meter of dam volume is significantly less than that for Site 1. As the dam operating level is increased the energy yield ratio drops indicating that less storage is more economic. However, given the NZ Battery projects goal is to find multi TWh storage options the RL910 m option has been taken forward for further analysis.

3.2.2 Reservoir Fill

3.2.2.1 General

The MBIE modelling used the NIWA NZ Rivers database of flow information of rivers and tributaries in the project areas.

As discussed in Section 3.4.2 Stantec have sourced flow information for the Taruarau River and a natural mean inflow upstream of the dam site of 3.4 m^3/s is anticipated. Given the large size of the reservoir in comparison to catchment area upstream it is anticipated all inflow, apart from infrequent major floods, would be captured by the reservoir.

3.2.2.2 Refilling from Whanawhana

The mean flow of the Ngaruroro at Whanawhana is in excess of 30 m^3/s. As the required mean refill flow for a reservoir FSL of RL910m is 11.0 m^3/s, of which just over 3.0 m^3/s would be provided by natural inflows. There would therefore appear to be ample refill water availability at the Whanawhana site. A lower storage reservoir to permit higher pumping rates during low power prices would provide some benefit but would not be essential given the high natural flow.

A key concern that will affect all elements of this Site is that a Water Conservation Order is presently being considered for the Ngaruroro River and all tributaries upstream of the Whanawhana cableway (E 1891903, N 5615815). This order is further discussed in Section 3.5.3. Whilst this order could be overcome by accessing water downstream of the cableway the proposed dam site on the Taruarau River will also be covered by the same WCO which expressly prohibits damming of the river.

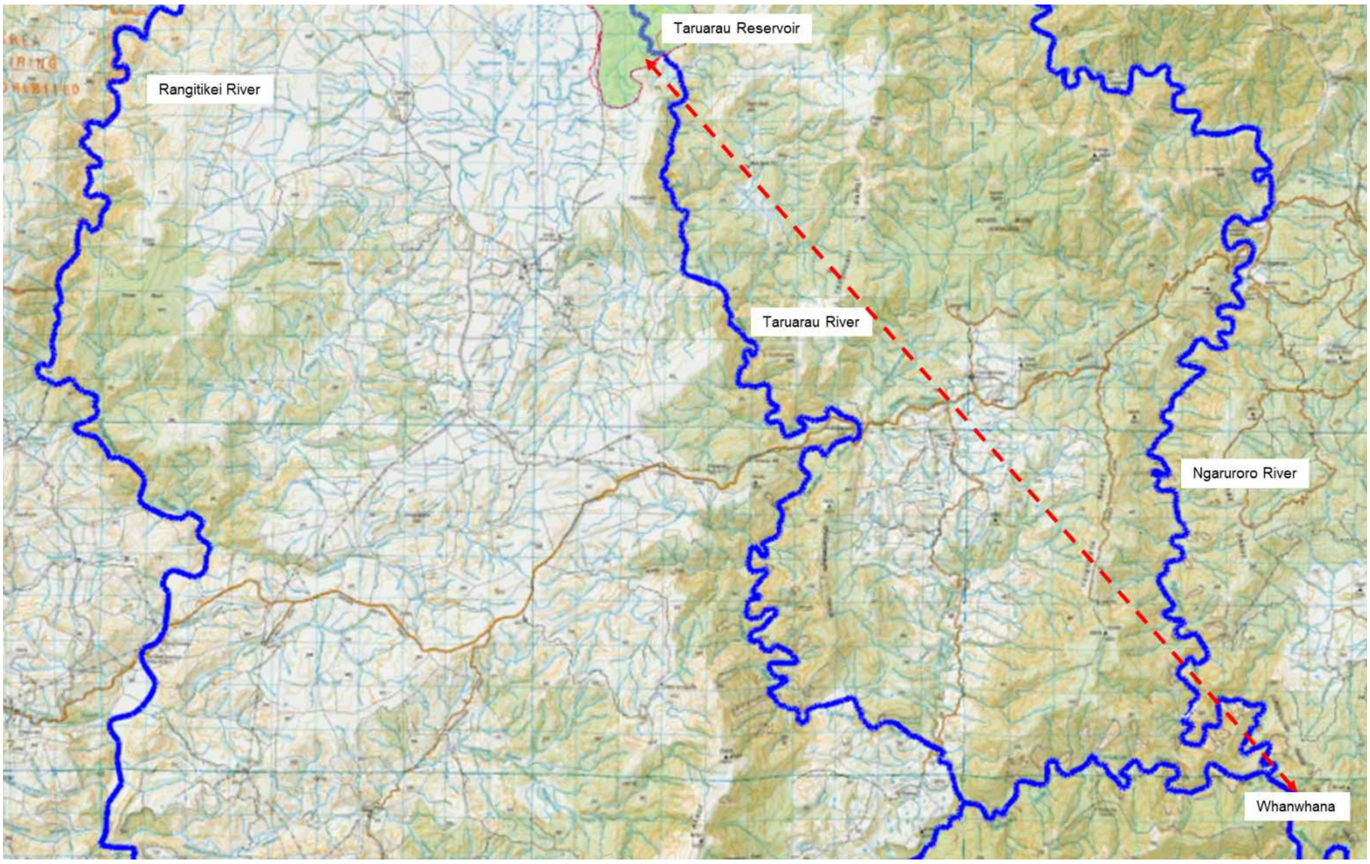


Figure 19 - MBIE Concept Refill

As noted earlier the water source at Whanawhana is some 30 km from the proposed dam site, over very undulating terrain. The pumping head would be in excess of 700 m. Construction of a single stage transfer system would be technically challenging and costly.

3.2.2.3 Refilling from the Rangitikei River

The Rangitikei River runs parallel with the Taruarau River along much of its upper range and is relatively close. A potential source of refill water would be to pump water from the Rangitikei near to the Springvale suspension bridge (E 1860902, N 5624654) as shown in **Figure 20**. At this location the mean river flow is 20.1 m^3/s which would be sufficient for the mean refill requirement even if only 50% of the mean flow were able to be taken.

It is noted that the Rangitikei River has a Water Conservation Order in place which would significantly impact the consentability of this source. A further downside is that the transfer of water between catchments is contrary to Mana Whenua values as further outlined in Section 3.5.1.

Pumping from this location would require a 19 km conveyance system and a pumping head of about 350 m.

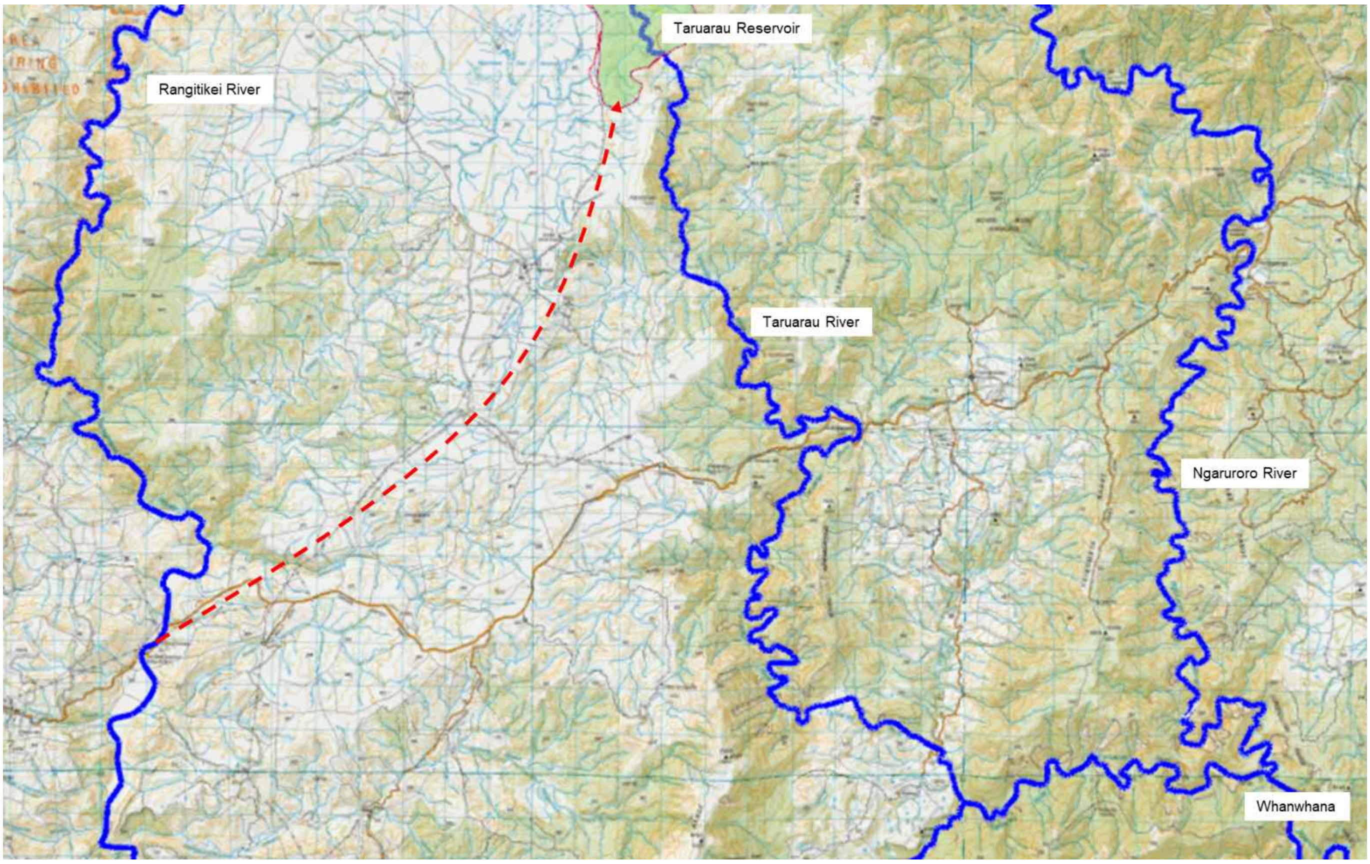


Figure 20 - Refilling from Rangitikei River

Creating storage at the pumping location to capture flood flows or support peak pumping would be possible but could significantly impact the recreational values of the Rangitikei River, especially considering the WCO in place.

3.2.2.4 Refilling from the Upper Ngaruroro River

The Ngaruroro River at Ngaawapura is relatively close to the Taruarau reservoir location. An 8 km long conveyance system with 100 m pumping head would be required. The mean flow at this location is about 4.2 m^3/s which would be insufficient to meet the reservoir filling requirements on its own. As with all sections of the Ngaruroro River, this source will also be covered by the WCO.

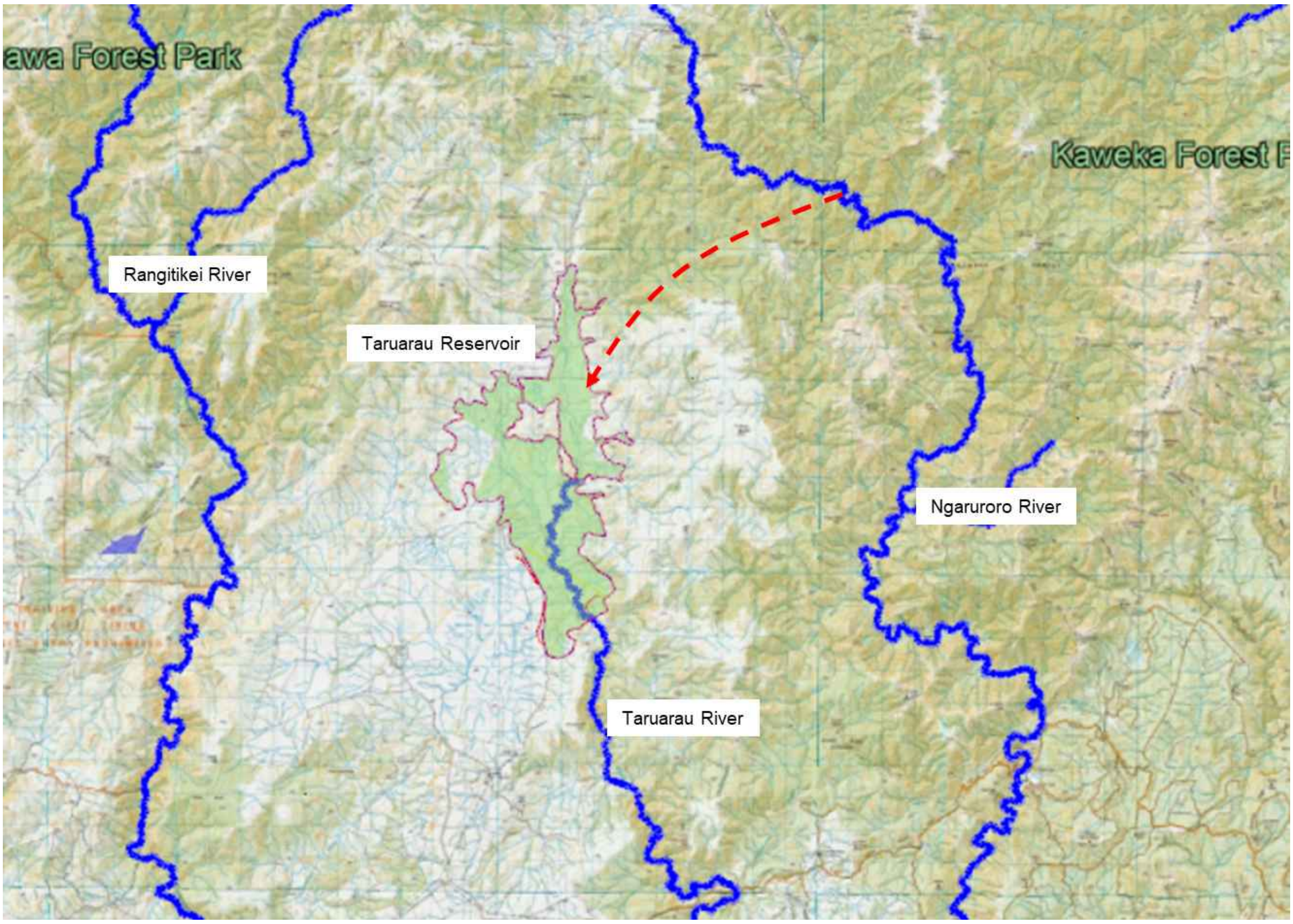


Figure 21 - Refilling from the Upper Ngaruroro River at Ngaawapura

An alternative to the Ngaawapura site would be to obtain water further downstream at Kuripapago, as shown on **Figure 22**. The mean flow at this location is approximately 15 m^3/s and would therefore provide an adequate supply for refill purposes. Creating storage at the pumping location to capture flood flows or support peak pumping would be possible.

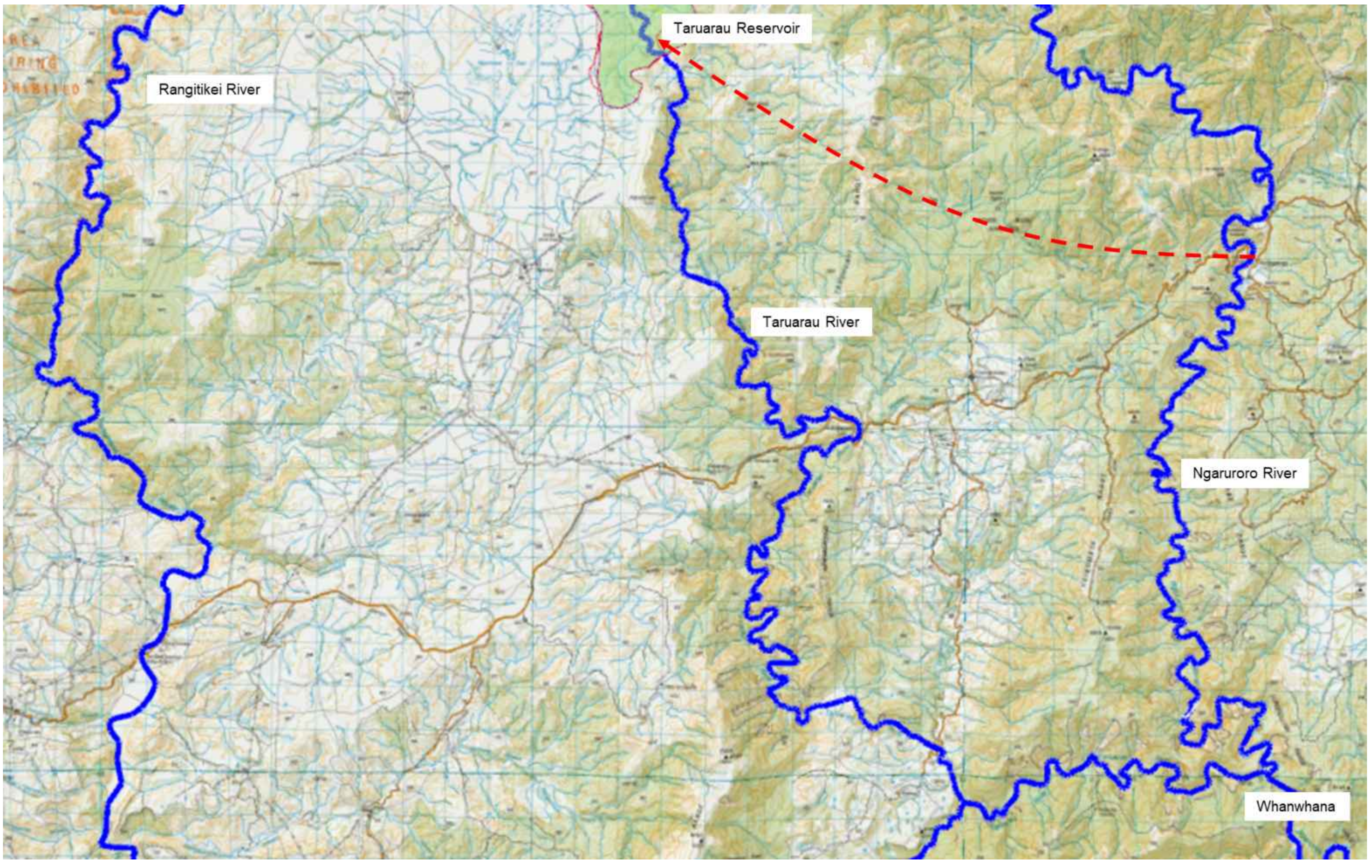


Figure 22 - Refilling from the Upper Ngaruroro River at Kuripapago

Pumping from this location would require a 16 km conveyance system and a pumping head of about 430 m.

3.2.2.5 Refill from Taruarau River

The final refill option considered was to take water from the Taruarau River at the Taihape Road crossing as shown in **Figure 23**. This location is some 12 km downstream from the dam and takes in two reasonably significant tributaries.

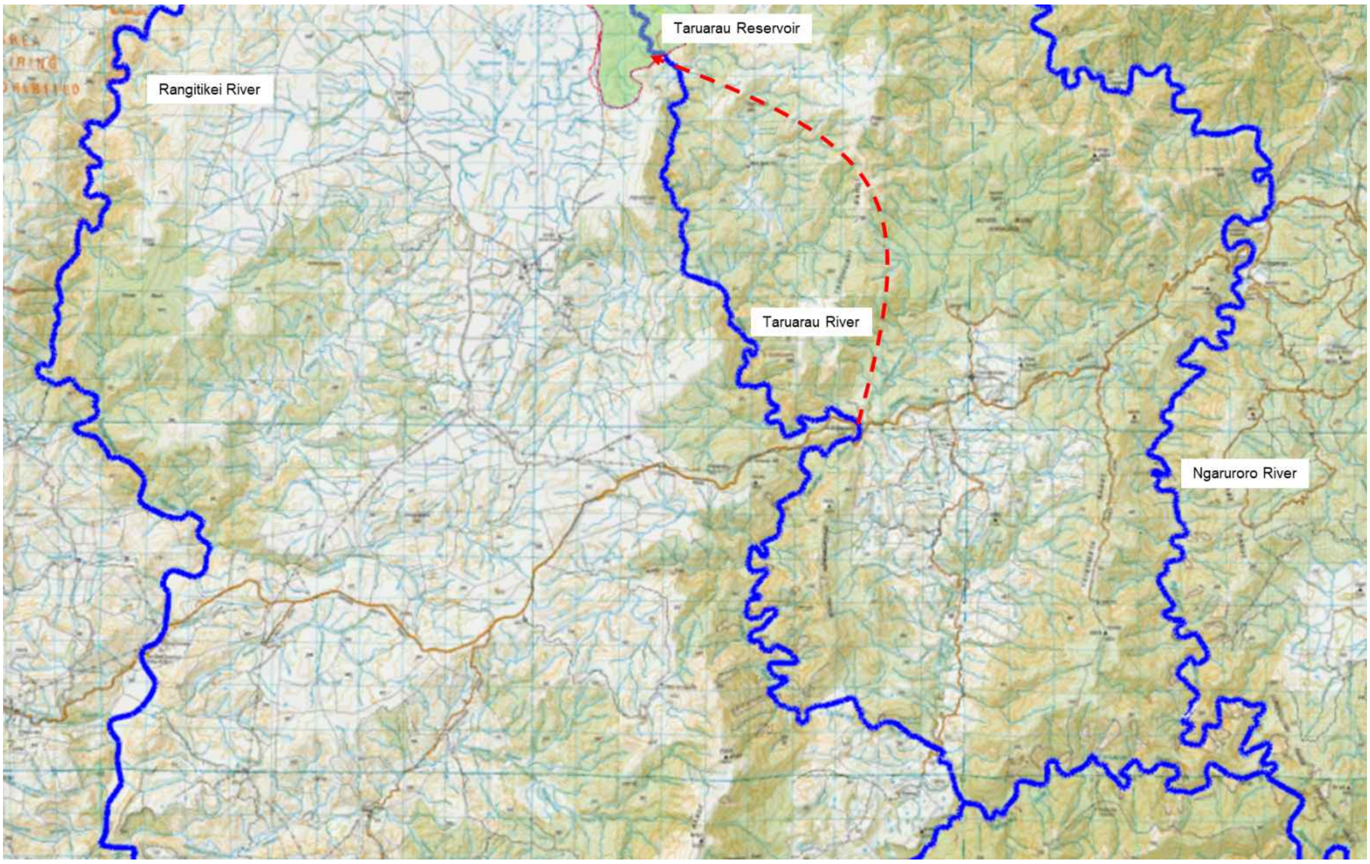


Figure 23 - Refilling from the Taruarau at Taihape Road

The mean flow at this location is 6.4 m^3/s which, one the flow at the dam site itself is subtracted, would result in just an additional 3 m^3/s. This option therefore does not provide sufficient water to make a meaningful contribution to reservoir filling.

3.2.2.6 Comparison of Fill Options

All of the fill options, as well as the Taruarau reservoir itself, are contrary to the protective measures implemented by a WCO or proposed WCO. As such there could be significant hurdles to be overcome in developing any of the Site 2 refill options identified.

The closest water source of any appreciable value is the Rangitikei River at the Springvale suspension bridge. This source could provide sufficient water to refill the reservoir in two years, is much closer than the MBIE alternative at Whanawhana, and requires a significantly reduced pumping head.

Table 3-3 compares key features of each fill option. Positive traits are highlighted in shades of green (darker = more desirable) and negative traits in orange/red (red = less desirable).

Table 3-3 - Comparison of Reservoir Fill Options

Featres	Refill from Whanawhana	Refill from Rangitikei	Refill from Ngaruroro at Ngaawapura	Refill from Ngaruroro at Kuripapago	Refill from Taruarau
Mean refill flow available (m^3/s)	34	20	4	15	3
Meet all fill requirements ?	Yes	Yes	No	Yes	No
Support peak pumping	Yes	Yes	No	Yes	No
Pump head (m)	700	350	100	430	330
Conveyance length (km)	30	19	8	16	12
Other positive features	Close to road	Close to road		Close to road	
Other negative features	WCO	WCO Different catchment	WCO	WCO	WCO

Overall refilling from the Rangitikei or from Whanawhana would appear preferable. However, both options would require significant infrastructure which needs to be considered in association with the generation options to identify a preferred arrangement. Such selection is discussed in the following section.

3.2.3 Reservoir Discharge

3.2.3.1 General

For the reservoir discharge the overriding aim is to develop as much head, over the shortest distance possible - the so-called length over head (L/H) ratio. As a rule of thumb for conventional greenfield reversible pumped-storage an L/H ratio of less than ten (10) is necessary for an economic cycle efficiency (and financial gearing) - meaning that the total length of the water conveyance system should be no more than ten times the available head - but this need not hold where reservoir components are existing or for the different seasonal storage duty under consideration here. For conventional reversible pump-turbines lower ‘unregulated’ L/H ratios are necessary (between free surfaces - namely reservoirs or surge chambers) to cater safely for hydraulic transients and to enable the plant to be responsive to power system changes and contribute positively to grid stability, as is required under the Grid Code.

A further desirable attribute, especially for pumped systems, is for the pumping and generating systems to use the same conveyance system and, ideally, the same plant. This helps avoid the need for duplication of assets and helps keep the overall cost as low as is possible.

Table 3-4 considers each of the preferred reservoir fill configurations in “reverse” in order to provide a measure as to their relative attractiveness as a generation site. The schemes are measured against the MBIE option that would utilise the available head down to RL200m which is the elevation at Whanawhana.

It is noted that the approach adopted for Site 2 is slightly different from Site 1. This is dues to the longer tunnel lengths required for the Site 2 MBIE option, plus the additional complexities at Site 1 owing to the existing TPD infrastructure
.

Table 3-4 - Comparison of Discharge Options

Feature	Discharge at Whanawhana	Discharge at Rangitikei	Discharge at Ngaruroro at Kuripapago
Generate gross head (m)	700	350	430
Head not utilised	0	350	270
Conveyance length (km)	30	19	16
L/H Ratio	43	63	37

As can be seen, the possible schemes have L/H ratios which are well over thirty. This combined with the sloping topography which tends to require schemes to be developed in multiple head steps suggests that they could be challenging to eventuate.

The conclusion is that a single stage scheme for Site 2 is not practicable and that a cascade scheme comprising a number of pumping and generating facilities in series (i.e. a cascade) would be required. Cascade systems are common (the Waitaki and Waikato River chains being good examples), but they do require significantly more infrastructure than single stage schemes.

3.3 Configuration Selected for Costing

As outlined in Section 3.2.3 none of the single stage discharge options were conducive to developing a generating facility. Similarly, none of the single stage refill options appeared technically appropriate. A multi-stage cascade development was identified as likely being required.

A potential cascade scheme has been identified that will:
Utilise the full 700 m gross head available
Permit refilling of the reservoir from Whanawhana
As an option, permit refilling from the Rangitikei River
Allow for responsive generating plant that can also operate in a daily peaking mode
Provide some baseload generation from exploiting the natural flows in the river once the reservoir is full.

This configuration is further outlined in Section 3.4 and a long section of the configuration in shown in **Appendix D.**

3.4 Technical Considerations of Selected Configuration

3.4.1 Basic Configuration

The proposed configuration exploits the relatively flat terrain to the West of the Taruarau River to create a conveyance system from the Taruarau reservoir to a point above the Taruarau River just South of the Napier – Taihape road (E 1872634, N 5625639). This conveyance system could be engineered to permit flow in both directions thereby supporting both reservoir refill and discharge (with appropriate pumping and generating plant). A small pump/power station would be installed at the Taruarau dam itself. The conveyance system would comprise an open channel canal and tunnel and will be approximately 14 km in length.

This discharge at RL880m could supply a second power station discharging into the Taruarau River approximately 3.5 km away. This power station would develop a gross head of some 420 m and would incorporate both pumping and generating equipment. As an option, a pumped water supply from the Rangitikei could connect to the conveyance system at the RL880m level.

Downstream of this second power station, and just upstream of the Waipiropiro hot springs (E 1877579, N 5623496) the Taruarau River would be dammed to create a reservoir. This reservoir would supply a third power station located at the confluence of the Taruarau and Ngaruroro rivers (E 1887164, N 5622036) approximately 9 km away. This power station will develop a gross head of some 200 m and would incorporate both pumping and generating equipment.

The final element would be a lower storage dam across the Ngaruroro River at Whanawhana with a conventional re-regulating power station located at the toe of dam.

Figure 24 and **Figure 25** below show the scheme configuration in diagrammatic and topographic form.

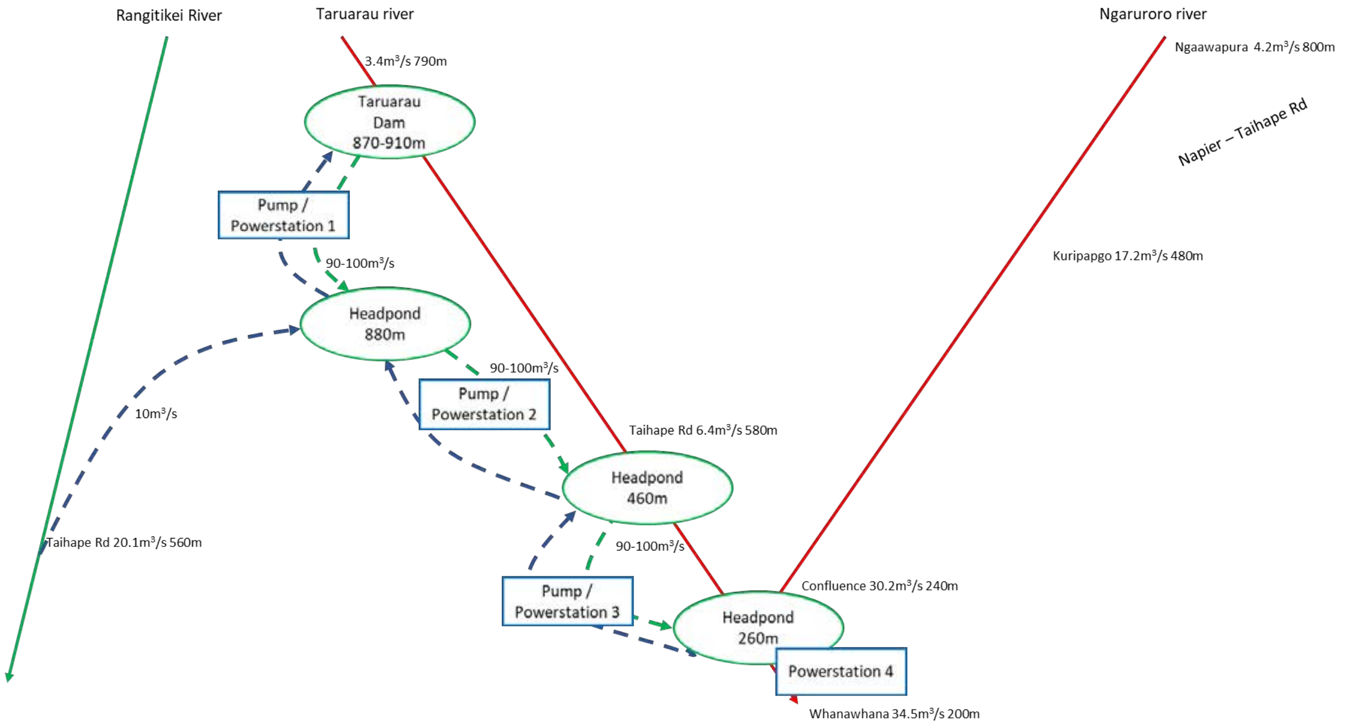


Figure 24 - Site 2 Proposed Cascade Scheme

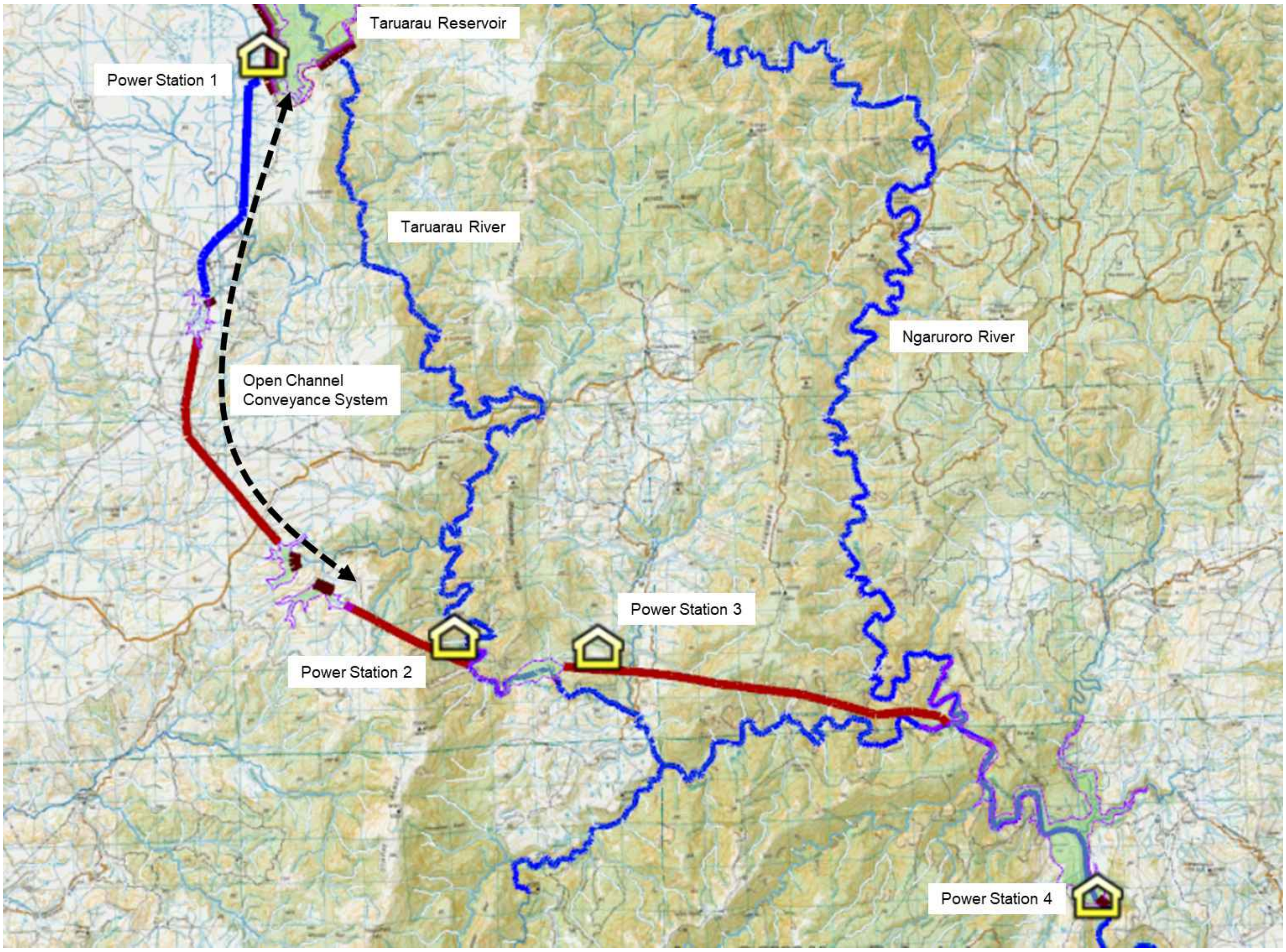


Figure 25 - Site 2 Proposed Cascade Scheme Plan

3.4.2 Hydrology

Hydrometric data is available for 2 sites near the proposed dam location: Taruarau at Taihape Rd (station 23106) and Ngaruroro at Kuripapango (station 23104). There are other hydrometric stations in the region, including stations on the Moawhango, Rangitikei and Ngaruroro rivers, but data for these stations is only available on request from Horizons and Hawkes Bay Regional Councils.

The Taruarau at Taihape Rd station was used as the primary hydrology data source for this location. The hydrometric station is located downstream of the dam site and has a catchment area of 259 km^2. The daily discharge record covers 37-years with some data gaps, starting in December 1963. The mean daily discharge is 6.2 m^3/s, which gives a mean yield of 23.9 l/s/km^2. Daily data was downloaded from NIWA's Aquarius database.

A flow-duration table was derived from the daily hydrometric data. This was then normalised into yield so it could be transposed to the upstream dam site. The yield was assumed to be constant across the gauged catchment, so there were adjustments for the reduced catchment area. The yield-duration curve is shown on **Figure 26**.

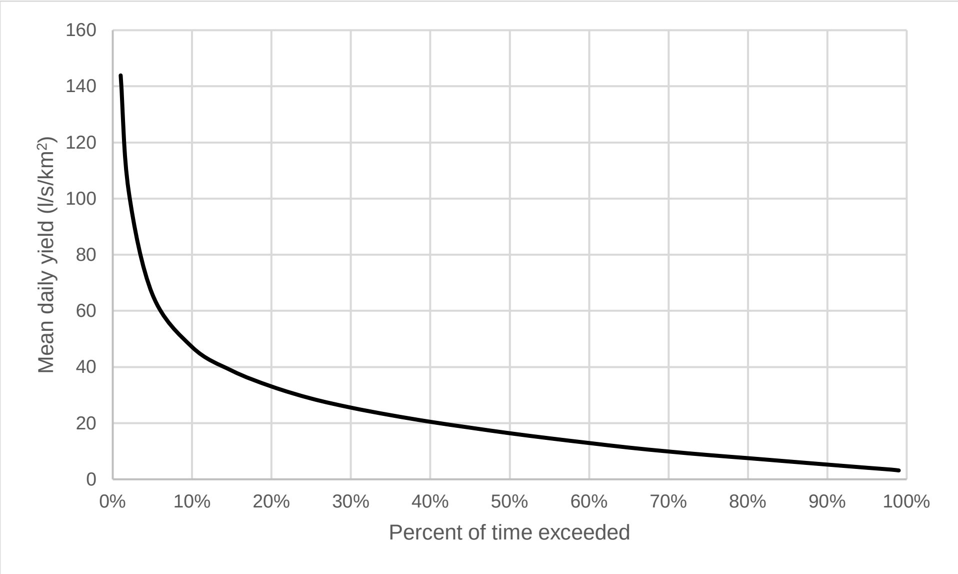


Figure 26 - Normalised flow-duration curve, Taruarau at Taihape Rd

NIWA's CliFlo database has daily rainfall and evaporation data at the Makahu Saddle 2 station (station 2934). The at-site data is short, covering only 6-years between June 1968 and December 1974, however this was the best data available for use. Longer rainfall records are available at other sites, but the data must be requested from Hawkes Bay Regional Council.

The annual rainfall and evaporation at the Makahu Saddle 2 station are 2482 mm and 885 mm respectively. Mean monthly rainfall exceeds evaporation for every month of the year. The net mean annual rainfall is 1597 mm, equivalent to 1.6 Mm^3/km^2 of reservoir.

3.4.3 Geology

Reference is made to Appendix B for the findings of a completed geological study for the proposed option. The geological study summarises:
Its objectives, the completed scope of works, and the publicly available information that has been used to inform it.
A review of key geological hazards that may place a constraint on option design, construction, and operation.
The developed conceptual geological model that has been used as the basis for option development, its concept design, and the associated cost estimate.
The geology of the project area is relatively complex. The basement rocks are formed by the Kaweka Terrane, often informally known in New Zealand as 'greywacke' (Lee et al. 2011). The published geological map (Lee et al. 2011) describes the 'greywacke' as 'massive, fine to medium-grained quartzofeldspathic sandstone, alternating sandstone and mudstone, minor conglomerate, broken formation, and melange'.

The basement 'greywacke' is overlain in some places by Tertiary-aged rocks (sediments). These rocks have been deposited in different depositional basins, including the Eastern Wanganui Basin in the western part of the project area, and the East Coast Basin in the eastern part of the project area. They can be generalised as increasing in extent, both in plan and depth, southwards through the project area. The Tertiary-aged rocks (sediments) belong to several different 'Groups' and 'Formations' and are therefore not individually listed here. They, therefore, present variable engineering geological characteristics. For example, in some instances, they likely display soil-like characteristics.

The greywacke and Tertiary-aged rocks (sediments) are also locally overlain by a variety of Pleistocene-aged deposits. These range from variably aged alluvium to landslide deposits, and to deposits associated with the Taupo Volcanic Zone (i.e. the Taupo Pumice Alluvium).

The key findings of the geological study can be summarised as:
No geological fatal flaws have been identified based upon the currently available information.
Less site-specific information is available for this option when compared to Options 1 and 3.
The design, construction, and operation of the Tongariro Power Scheme provides an engineering geological precedence of the feasibility of the proposed option for where ‘greywacke’ will be encountered. This includes the development of both surface and underground works.
Less engineering precedence exists for the development of surface and underground works associated with dam and hydropower engineering projects in the Tertiary-aged rocks (sediments). Other civil engineering precedence may exist, such as those associated with transport infrastructure or wind energy. Their engineering geological characteristics do present some engineering geological considerations which require further evaluation as part of the next stage of project development.
Recommendations for the next stage of geological study should the proposed option proceed to the next stage of project development are:
The sourcing and review of relevant pre-existing site-specific geological information which is privately held. This would include:

- For ‘greywacke’, that related to the design, construction, and operation of the Tongariro Power Scheme.
- For the Tertiary-aged rocks, any precedence which can be found for dam and hydropower engineering, or other major civil works such as transport infrastructure or wind energy.

Development of geological study objectives and scope of works as required for the stage of project development as recommended by ICOLD (2005) and ANCOLD (2020).

3.4.4 Dam Configuration and Type

The concept design for the scheme involves a number of dams. Three form the main reservoir, several provide portions of the conveyance systems and others are formed in the river system to provide buffer storage and flow capture for pumping.

Main Reservoir. The three dams that form the main reservoir consist of a high dam in the Taruarau River and two (4.8 km plus 1.1 km) long contour dams (saddle dams) along the watershed between the Taruarau River and the Woolwash Stream (a minor tributary of the Taruarau River). The high dam is likely to adopt a roller compacted concrete (RCC) or concrete faced rockfill dam (CFRD) type design and will be approximately 130 m high. The long contour dams would be up to 30 m high and most likely an earthfill or CFRD design. For consistency however at this concept stage for costing purposes all dams are considered RCC.

Small Conveyance Storages. Three small dams and associated storages are formed along the upper conveyance system. These fulfil two purposes, they form part of the conveyance length by utilising the natural landform, and they provided buffer storage within the comparatively long conveyance system to improve hydraulic performance. These will all most likely adopt a simple earthfill dam design.

Taruarau Storage. A storage will be formed in the Taruarau River approximately 2.5 km upstream of the confluence with the Timahanga Stream. This storage acts as a transfer storage between power stations 2 and 3 and as a flow capture location for improving refill. It will be formed by a 45 m high dam most likely of RCC or CFRD construction.

The combination of the Small Conveyance Storages and the Taruarau Storage provide a potential enhancement opportunity for the scheme. They contain sufficient storage capacity for Station 2 to operate as a classical daily pumped storage facility (8 hours generation, 12 to 14 hours refill) without any use of the main water storage reserved for dry year releases.

Ngaruroro River Storage (optional). A final storage could be formed in the Ngaruroro River approximately 7 km upstream of the confluence with the Poporangi Stream. This storage would be formed behind a 70 m dam of RCC or CFRD design and be primarily for the purpose of flow capture for refilling, allowing refill to be targeted to lowest power prices. It could also fulfil a flow balancing role reducing the impact of flow changes on the river downstream. If this reservoir was included a fourth and final generation station would be added to utilise the head developed. This station would also operate as a normal hydro generating plant from inflow not otherwise required for pumping.

Table 3-5 - Summary of Dams for Selected Configuration

	Taruarau Reservoir (Dam 1)	Taruarau Reservoir (Saddle Dam 1)	Taruarau Reservoir (Saddle Dam 2)	Tapuaengoto Stream Buffer Pond	Blowfly Gully Headpond (Dam 1)	Blowfly Gully Headpond (Dam 2)	Powerstation 2 Dam	Powerstation 4Dam
Dam Type	RCC	RCC	RCC	RCC	RCC	RCC	RCC	RCC
FSL	910	910	910	880	880	880	460	260
Maximum height (m)	130	35	30	10	25	30	45	70
Crest length (m)	550	4770	1100	225	450	500	110	250
Dam volume (m^3)	1,950,000	3,150,000	320,000	25,000	135,000	225,000	62,000	450,000

3.4.5 Conveyance

As discussed in Section 3.1 the original MBIE concept design involved a very long conveyance system to a single power station. This would have hydraulic performance characteristics that would limit the ability of the scheme to respond quickly to changing market conditions as well as being technically very challenging.

The approach adopted in this design concept is to utilise surface and low pressure conveyance for significant portions of the scheme. This shortens the high pressure length of conveyance and provides a more flexible design concept as the main station (No 2) is hydraulically much more efficient. This also provides hydraulic separation between power stations allowing Station 2 to respond quickly to market demands while the other smaller stations act in a more passive mode.

The conveyance system comprises the following main components;

Surface Canal and Low Pressure Upper Tunnel. Water is released from the main reservoir through a low head (30 m) power station (Station 1). This also acts as the final pump station when the reservoir is being filled. Flow is conveyed firstly via a 6 km long canal that discharges in to the first of three small buffer reservoirs. Flow is taken from this reservoir via 5.9 km long tunnel to the second small buffer storage. This second buffer storage is directly connected to the third and final buffer storage by a short 500 m section of cut and cover conduit.

This entire upper low pressure conveyance system would be designed for two-way flow to allow pumped refill water to flow back along the system to be pumped to the main storage through Station 1. The combined length of this low pressure portion of the total scheme accounts for 35% of the total length reducing the remaining length that potentially impacts station responsiveness and hydraulic performance.

Power Tunnel to Station 2. The conveyance to Station 2 is via tunnels. A 4.1 km long 5 m diameter low-pressure tunnel takes flow from the third buffer storage to a surge chamber and connected vertical drop shaft. The 4 m diameter, 420 m deep steel lined drop shaft conveys water down to the level of the powerhouse before a short, 700 m long steel line high pressure tunnel completes the power tunnel conveyance to the bifurcations that feed the individual generating units. Station 2 discharges via short 100 m long tailrace tunnels to the storage in the Taruarau Stream.

With a head of 440 m the combined conveyance length of 6.3 km gives a L/H ratio of 14, approaching the ideal of 10 or less. The inclusion of the surge chamber reduces the high-pressure system to only 1200 m giving a feasible ‘unregulated’ L/H of 2.7.

Power Tunnel to Station 3. Station 3 is also fed by tunnel. A 1.5 km long, 5 m diameter, low pressure tunnel takes water from an intake on the shore of the Taruarau Stream reservoir to a Surge tank and drop shaft. The 200 m deep, 4 m diameter, steel lined drop shaft conveys water to the power station level. A short 100 m long 4 m diameter steel lined pressure tunnel completed the conveyance to the individual turbine bifurcations at the power station.

Station 3 Tailrace Tunnel. A 9 km long 6 m diameter low pressure tailrace tunnel conveys discharge from the station to the lower most scheme storage within the Ngaruroro River. The discharge point also operates as the lower most intake for pumping operations. If the last reservoir was excluded a river discharge and pump intake structure would still be required at or about the location of the tunnel outlet.

If the last reservoir was included Station 3 could also operate as a daily pumped storage without need of any net release from the main reservoir.

With the inclusion of surge facilities on both the high-pressure and tailrace sides the L/H ratio for Station 3 can be reduced to close to 2. The long tailrace tunnel will however make the station less responsive to rapid changes in the market.

Station 4 Penstocks. The last portion of conveyance within the scheme consists of twin 200 m long surface penstocks, 3 m in diameter, that feed the individual units at power station 4. While of relatively low head (70 m) the short penstock length required to feed the station means that power station 4 could operate as a peaking station subject to likely flow manipulation constraints imposed for environmental reasons.

3.4.6 Plant Selection and Power Rating

As mentioned,3.2.3 the discharge available from the scheme based on a reservoir elevation of RL910m will be approximately 90 m^3/s over the required three month “dry” period.

Based on this flow, key details of the four power stations are as follows:

Table 3-6 - Site 2 Power Station Outputs

Power Station	1	2	3	4
Rated Head (m)	30	420	200	60
Rated Discharge (m^3/s)	90	90	90	90
Rated Output (MW)	23	300	150	50
Number of Units	One	Three	Three	Two

The total installed capacity would be about 500 MW.

It is noted that Power Stations 2, 3 and 4 could all provide daily peaking power if required and could support generating plant capacity at least 30% higher than shown if required.

Power Station 1 would need to shut down for low reservoir levels and it may prove to be uneconomic to develop this facility.

Pumping capacity will be required at Power Stations 1, 2 and 3 sites. At Power Station 1 separate pumps will be required, but at sites 2 and 3 one or more reversible pump turbines could be installed.

Given the storages provided at Whanawhana and upstream of Power Station 3 peak pumping during periods of low power pricing could be supported. For the purposes of this study, the cost estimates will assume that the generating units at Sites 2 and 3 are reversible pump turbine types, with notional pump flow equal to 45 to 50% of the rated generation flow. This equates to 2 units being reversible pump turbines with motor capacity equivalent to peak generation capacity meaning the flow per unit in pump mode is 70 to 75% of the flow in generation mode or approximately 22 to 24 m^3/s per unit. Retaining one unit as a dedicated hydro unit could improve the responsiveness of the station to changes in market demand as this unit does not need to be reversed from one mode to the other. If however, there was value in operating as a daily pumped storage facility then there would be merit in all units being reversible pump turbines.

The pumps at Power Station 1 site will be rated at twice the average required refill rate.

3.4.7 Energy Storage and Reservoir Release / Refill Times

As for Site 1 two broad approaches have been used, single use and market operation.

For the single use approach the full storage in the upper reservoir is released over a 3 month period to model a dry year event scenario and size the capacity of both release and refill mechanisms. Refill then occurs over the following 2 years targeting periods of higher flow and lower power price.

For the market operation the scheme is presumed to release 12.5% of the time (cumulatively 3 months in 2 years) with release based on periods of high price. Refill is then undertaken between periods of release and when prices are typically below median.

A key aspect of operation under both scenarios is the relative pump capacity. As a cascade scheme the pump capacity varies as flow is accumulated and conveyed back up the scheme. A minimum of 13 m^3/s of pump capacity is required to be able to realistically refill the storage following an event that fully drains the reservoir. Pumping would need to be nearly continuous between events to achieve refill in time (2 years). Increased pump capacity allows discretion on when pumping can occur to better meet water availability and power price conditions.

Presuming the station utilises 3 x 30 m^3/s generation units at the main stations (Station 2 and 3), if one unit in each station was installed as a pump turbine, and allowing for efficiency impacts between generation and pumping, the pumped flow would be between 22 and 24 m^3/s. As there is buffer storage within the system to improve flow capture 2 or all 3 units could be installed as pump–turbines lifting the capacity during pumping mode. It is questionable however if there is financial value in doing this if the scheme was to be for dry-year operation only. For the two operating scenarios a 40 m^3/s pump capacity has been presumed based on two pumped turbines operating at high efficiency.

Both scenarios produce similar results in terms of energy generation over any two-year period however the dry year event uses the entire storage in a single event whereas the market-based operation only uses about 60% of the available storage as most events are less than 3 months in duration. This indicates the scheme has some potential flexibility to fulfil a combined role of both market operation and dry year reserve.

The energy output across the schemes in provided in **Table 3-7**.

Table 3-7 - Site 2 Dry Year Event Cycle

	Release (GWh)	Refill
Single Event (3 months)	1150 (one per 2 years)	-1,073
Market Operation	590 per annum	-550

While there is an efficiency impact transferring energy from pumping to generation the scheme is slightly net positive in terms of energy production. This is because approximately 20% of refill flows directly into the upper storage (‘free energy’) and does not need to be pumped, and the remaining 80% is sourced from two location within the cascade resulting in an energy weighted net pumping head of 600 m compared to the generation head of 710 m.

The energy value transfer achieved is also similar for both single and market operation. For the single event it is assumed that generation is placed during the highest continuous 90-day period of high prices (i.e. highest 90 day average price). The two highest 90-day events are used in the 5-year period.

For the market operation generation occurs when the current price exceeds a threshold relative to the average price over the previous 60 days. To avoid pulsing a minimum 4-hour high price trigger period and 4 hour minimum run time is required. Pumping for both scenarios occurs when the price falls below a trigger relative to the previous 60 days average price

Table 3-8 - Site 2 Market Operation

	Generation Price vs 5-year Average	Pumping Price vs 5-year Average
Single Event (90-day release)	210 %	43 %
Market Event	205 %	43 %

While the single event gives a slightly higher ratio, it presumes perfect knowledge of the event ahead of time. A more likely scenario is the storage being used over a period during which the 90 day price peaks and then fall away. If the 90 day peak price is centralised within the duration of the event (i.e at day 45) the ratio of price gained vs 5-year average is 162%.

The higher relative pump capacity (45% of generation capacity) compared to Site 1 results in a reduced average pumping price as this greater capacity coupled with the storage between station improves the ability to time pumping to lowest price periods.

3.4.8 Transmission

The maximum installed generating capacity is about 500 MW. At this power output connection into the Transpower 220 kV core grid will be required.

As power station 2 represents the bulk of the installed generating capacity measurement of distance to transmission assets uses this power station as base point.

The closest existing Transpower assets are the North Island 220 kV backbone which consists of three 220 kV circuits running parallel to the Desert Road (43 km) and the Wairakei-Whirinaki-Redclyffe double circuit transmission line servicing the Hawkes’ Bay (51 km). Given that the Wairakei-Whirinaki-Redclyffe transmission circuit is further from the project site and is distant from the key North Island load centres it is not considered as a viable option.

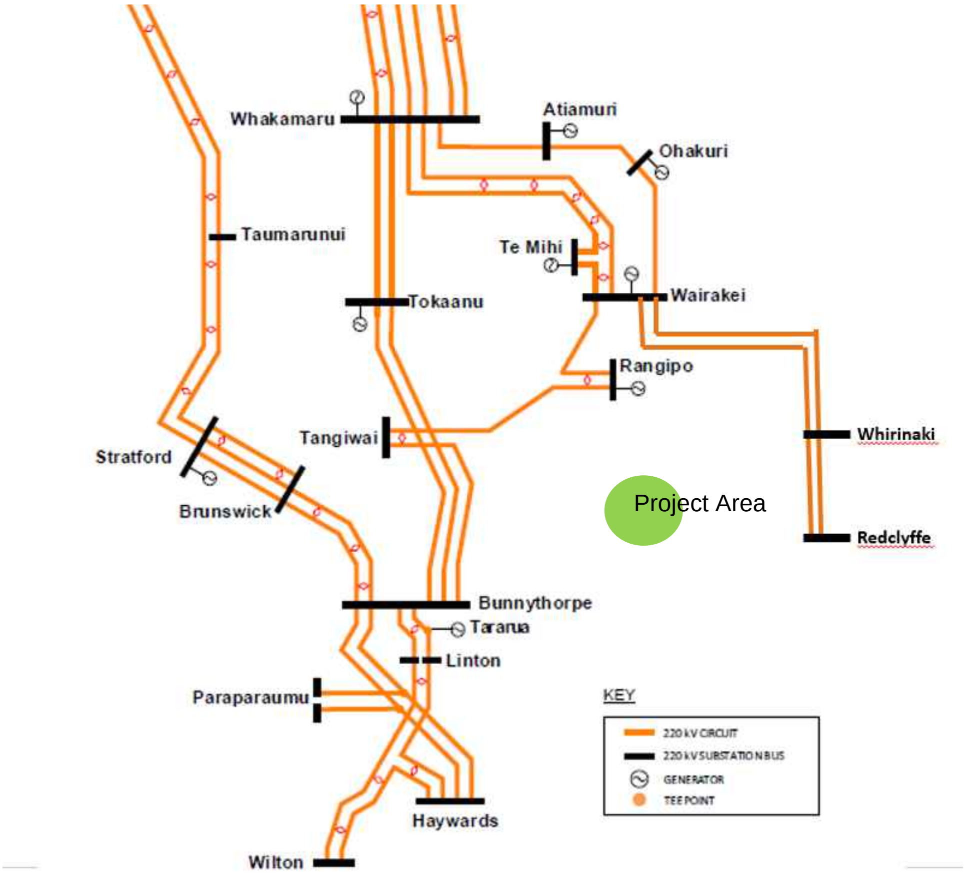


Figure 27 - Transpower 220kV Transmission

For a cascade type hydro development, a hub and spoke transmission system interconnecting the individual power stations, with a single connection to the core transmission grid is common and is envisaged for this Site, with power station 2 forming the hub. As with Site 1, the existing backbone transmission system will likely require upgrading in order to accept the power from the Taruarau scheme.

A new transmission line would be constructed from the project area to the backbone transmission system. For costing purposes, it has been assumed that the new line will be double circuit steel tower type and will generally follow the Napier – Taihapi road in order to limit the length of access roading required. To connect the new generating assets a new switchyard will likely be required, and it is envisaged that this would be located adjacent to Te Moehau Rd at approximately E 1842217, N 5612914. Given its importance in the National Grid the switchyard would be double bus design and would incorporate six (6) transmission line bays for the existing backbone grid, a bus coupler circuit breaker, plus two transmission line bays for the new transmission line to the Taruarau generation plant.

At power station 2 there would be a 220 kV switchyard, with a double circuit 220 kV spur to power station 3 and single circuit spurs to power stations 1 and 4.

3.5 Non-Technical Considerations of Selected Configuration

3.5.1 Kaitiakitanga

Heretaunga Tamatea (Ngāti Kahungunu), Ngāti Tūwharetoa

Cultural Narrative:

Tamatea Pōkaiwhenua great discover of the Takitimu waka who also travelled via Tāruarau river who also named key significant sites along the way. The upper reaches of the Tāruarau river are a significant water body providing cultural, physical, and spiritual sustenance for Ngāti Kahungunu and Ngāti Tūwhareroa peoples since the beginning of time. Great explorer Tamatea Pōkaiwhenua explored and frequented this river. Eponymous ancestor Kahungunu and his pet Ūpokororo is woven in the landscape narrative and now exists as spiritual and cultural kaitiaki of the river.

Taruarau is the main tributary that connects with the Ngaruroro River which heads out to Te Matau a Māui / Hawkes Bay. Taruarau spiritually, culturally, and physical which are not isolated or disconnected to Ngaruroro they are one and these water bodies share the same spiritual and cultural essence, whakapapa and mouri. Mai i uta ki tai. Important note to respect the cultural, spiritual, and physical significance and connection Tāruarau River has with Ngaruroro. The Tāruarau River is located within the traditional boundary of two Treaty Settlement Entities, being Heretaunga Tamatea and Ngāti Tūwharetoa.

The river is associated with the early origins of Kahungungu and associations with the Ruahine Range. From the deed of settlement documents: The connection of Heretaunga Tamatea hapū to the Ruahine Range dates to a journey made by Tamateapōkai-whenua, the father of Kahungunu, from Tūranga into Mōkai Pātea. Several accounts record that Kahungunu accompanied his father for part of the journey. Tamatea-pōkaiwhenua travelled down the east coast to Ahuriri before striking inland and travelling up the Ngaruroro River before entering the Ruahine Range. Tamatea named several places along the route of his journey. At one point he saw a tawai tree on the summit of a peak which was thereafter named Rākautaonga. Continuing, the party travelled up the Tāruarau River.

The Ikawetea River was also named by Tamatea. This was the place where seagulls appeared after Tamatea and Kahungunu undid the string which tied the basket of fish they were eating. At the place where the Ikawetea River flows into the Tāruarau River there is a large rock where it is said that Kahungunu sat and watched for upokororo. This place thereafter was named Te Upokororo-o-Kahungunu. Some accounts record that it was at Te Upokororo o Kahungunu that Tamatea’s mōkai named Pohokura escaped. Other accounts suggest Tamatea released Pohokura at this place. Pohokura has continued to inhabit the range and is a kaitiaki for Tamatea’s descendants - particularly for those hapū that inhabited the lower forest and foothills. The Deed of Settlement also identifies that a stone known as Te Tokatamahoutu marked the junction of the Tāruarau and Ikawetea Streams.

Tūpuna awa: We are our awa, our awa is us,

Kōtahitanga: working together for Collective Outcomes.

Kaitiakitanga: Maintaining and enhancing the Mauri of the river and its tributaries.
Tino Rangatiratanga: Self determination to develop and make our own decisions without impinging on the rights of others.

Manaakitanga: Duty of care to support Hapū and iwi where possible.

Mana Atua: Recognising the guardians spiritual association with Te Taiao / environment.

Mana Tangata: Hapū and iwi can exercise authority and control over Te Taiao through ahi kā and whakapapa.

Hau: Replenish and enhance a resource when it has been used. Mana Whakahaere: working collaboratively for the wellbeing of the river.

Mahinga kai (food gathering place), **Mahi Rongoa** (medicinal practising), urupā -burial places,

Nohoanga – settlements. Te Tokatamahotu rock, Te Upokororo o Kahungunu (Kahungunu’s rock)

Upokororo is Kahungunu’s / Māhu mōkai. Wāhi tapu, wāhi taonga, pā tuna…Is now a guardian of the Taruarau River. The Tokatamahotu’s rock two water bodies of Ikawetea and Taruarau marks the junction.

3.5.2 Environmental and Social

3.5.2.1 Land Ownership

The conceptual configuration of this option impacts approximately 19 private land titles plus untitled land (Kaiweka Forest Park). The majority of conceptual configuration is located on private land including the storage reservoir.

The number of titles impacted by this option is slightly higher than for Site 1, but significantly lower than Site 3.

The majority of titles for the infrastructure associated with Option 2 are known as the Owhaoko B&D Blocks administered by the Owhaoko B&D Trust. The Trust is an Ahu Whenua Trust under section 215 of Te Ture Whenua Maori Act 1993.

3.5.2.2 Ecology

The scheme crosses three Ecological Regions and Districts. The main reservoir, first two headponds and associated tunnels are located in the Moawhango Ecological District of the Moawhango Ecological Region. The downstream headpond and two middle pumpstations, and parts of the Ngaruroro reservoir, are located in the Ruahine Ecological District of the Ruahine Ecological Region. The downstream portion of the scheme is located in the Maungaharuru Ecological District of the Hawkes Bay Ecological Region.

The Owhaoko Blocks are formally protected by a Nga Whenua Rahui Kawenata which the Trust entered into with the Minister of Conservation in February 2005. The Kawenata or covenant confers a “Reserve” status that disqualifies the Trust from conducting farming, agricultural, horticultural or forestry activities. In return for compensation payments made by the Crown to the Trust, the Kawenata requires the Trust to manage the land:

"… so as to preserve the natural environment, the landscape amenity, the wildlife habitat, the freshwater habitat, the historical value of the land and the spiritual and cultural values which tangata whenua associate with the land."

The Kawenata also requires the Trust to:

"…Keep the land free from troublesome adventive plants and animal pests…"

There is limited information available about the ecology of the Owhaoko B&D Blocks. However available information indicates that the water quality and aquatic ecology of the streams and rivers is high. Further downstream the scheme crosses the Kaweka Forest Park which supports a diversity of plant and animal species.

Approximately 2,620 ha of predominantly native vegetation will be cleared for the scheme and 75 ha of wetland. These wetlands potentially support rare plant and animal species such as turf communities and North Island brown mudfish (*Neochanna apoda*) (At Risk - Declining). Approximately 1,750 linear km of stream or river will be restricted due to the presence of new dams.

Table 3-9 - Vegetation Types Intersected by the Project (excluding tunnels and pumpstations)

Vegetation or Habitat Type (LCDB v5.0)	Area (ha)
Broadleaved Indigenous Hardwoods	16.82
Depleted Grassland	0.412
Exotic Forest	0.319
Gorse and/or Broom	40.424
Gravel or Rock	30.763
Herbaceous Freshwater Vegetation	60.581
High Producing Exotic Grassland	159.11
Lake or Pond	3.009
Landslide	14.131
Low Producing Grassland	65.735
Manuka and/or Kanuka	579.697
River	47.902
Sub Alpine Shrubland	0.259
Tall Tussock Grassland	1958.235
TOTAL:	**2977.397**
TOTAL NATIVE:	**2615.592**

There is limited existing road infrastructure to the proposed reservoir and other infrastructure. Approximately 80 km of new transmission lines will be built to connect to the existing national grid to the west.

Further detail is provided in Appendix A.

3.5.2.3 Recreational and Commercial Land Use

There is currently limited public access to the land where the reservoir will be created. While there is a long history of sheep grazing on the site, the Nga Whenua Rahui Kawenata under which the site is managed specifically prohibits the use of the land for grazing livestock. Hunting, trout fishing and related recreational activities are permitted. There are also tourism ventures in the wider area such as accommodation, hunting, fishing and tramping.

Further downstream, the Taruarau and Ngaruroro Rivers support trout fisheries and are used for kayaking and white-water rafting.

Parts of the scheme, including parts of Ngaruroro Dam will impact commercial farming operations on private land. Reductions in flows may negatively impact existing water users and operators in the downstream catchment

3.5.3 Planning / Consents

The key consenting issues for this option relate to:

- The take and / or damming of water
- The construction of dams in waterbodies
- The flooding and construction of infrastructure within an outstanding natural landscape
- Works within significant natural areas.

The upper Ngaruroro catchment from which water will be taken or dammed to fill the reservoir is currently over-allocated and is identified in the Regional Plan as an outstanding water body. In this context the filling regime for the option will need to be very carefully designed to ensure that it does not further over-allocate water (e.g. by only taking water in high flow conditions), does not impact on other users and maintains the outstanding nature of the water bodies. Any filling regime reliant on 'high-flow' takes will need to be cognisant of the Hawkes Bay Regional Council policy to allocate 20% of the water available at high flow to activities such as papakāinga, marae, and the development of land returned through a Treaty Settlement.

The construction of the dams required for this option is currently a prohibited activity under the Hawkes Bay Regional Plan. This means that at present the option could only be pursued by first changing this aspect of the Regional Plan. Until the Regional Plan is changed, an application for resource consent for the dams cannot be made. It is expected that given the identification of these water bodies as 'outstanding', changing the prohibited status in the Regional Plan would be difficult.

It is also noted that a Water Conservation Order (WCO) for the upper Ngaruroro River and tributaries (including the Taruarau River) has been applied for. This is currently undergoing an Environment Court enquiry. The draft WCO identifies the outstanding characteristics and values of the upper Ngaruroro and tributaries as being:

- Amenity and intrinsic values afforded by natural state
- Habitat for rainbow trout
- Rainbow trout fishery
- Angling amenity and recreation
- Whitewater rafting and kayaking amenity and recreation
- Wild and scenic characteristic
- Natural characteristics – water quality

If confirmed, this WCO will further strengthen the prohibition on damming already in the Regional Plan and will require that any takes of water have no more than minor impacts on the values listed above. Under the Resource Management Act, resource consent cannot be granted for an activity that would be contrary to the WCO.

The combination of the existing Regional Plan provisions and the WCO would present a significant hurdle for this option.

Significant elements of the option, including the main storage reservoir fall within an outstanding natural landscape identified in either the Rangitikei or Hastings District Plan. The protection of outstanding landscape values is a matter of national importance under the Resource Management Act, and will require careful assessment if the option is taken forward.

Finally, the option will impact an identified Recommended Area for Protection under the Hastings District Plan. If the option is taken forward further work will be required to determine if adverse effects on these values can be avoided and if not whether these effects can be satisfactorily minimised or offset. It is noted that significant natural areas are not currently mapped in the Rangitikei District Plan. The existence of these important areas will still however need to be identified if this option is taken further.

3.5.4 Impact on Existing Power Schemes and Other Infrastructure

There are no existing power stations that would be impacted by the Taruarau scheme.

Existing roads, in particular the Napier Taihape Road may require some upgrading to cater for construction traffic and loads, but existing bridges are not affected by the development, including reservoirs.

3.6 Cost Estimate of Selected Configuration

The estimated P_{50} cost for the selected configuration is NZ$8.9 Billion as further detailed below.

The cost breakdown is provided in Appendix C and includes:-

- Site establishment and disestablishment
- Dams as required for the FSL910 reservoir level
- Power stations one thru four (90 m^3/s).
- Turbine and generating plant.
- Interconnecting canals and tunnels
- Expansion of the Poutu tunnel and canal.
- Transmission and switchyards
- Access roads

The cost estimate does not include upgrades to the Transpower core grid.

Land acquisition and related costs are not included.

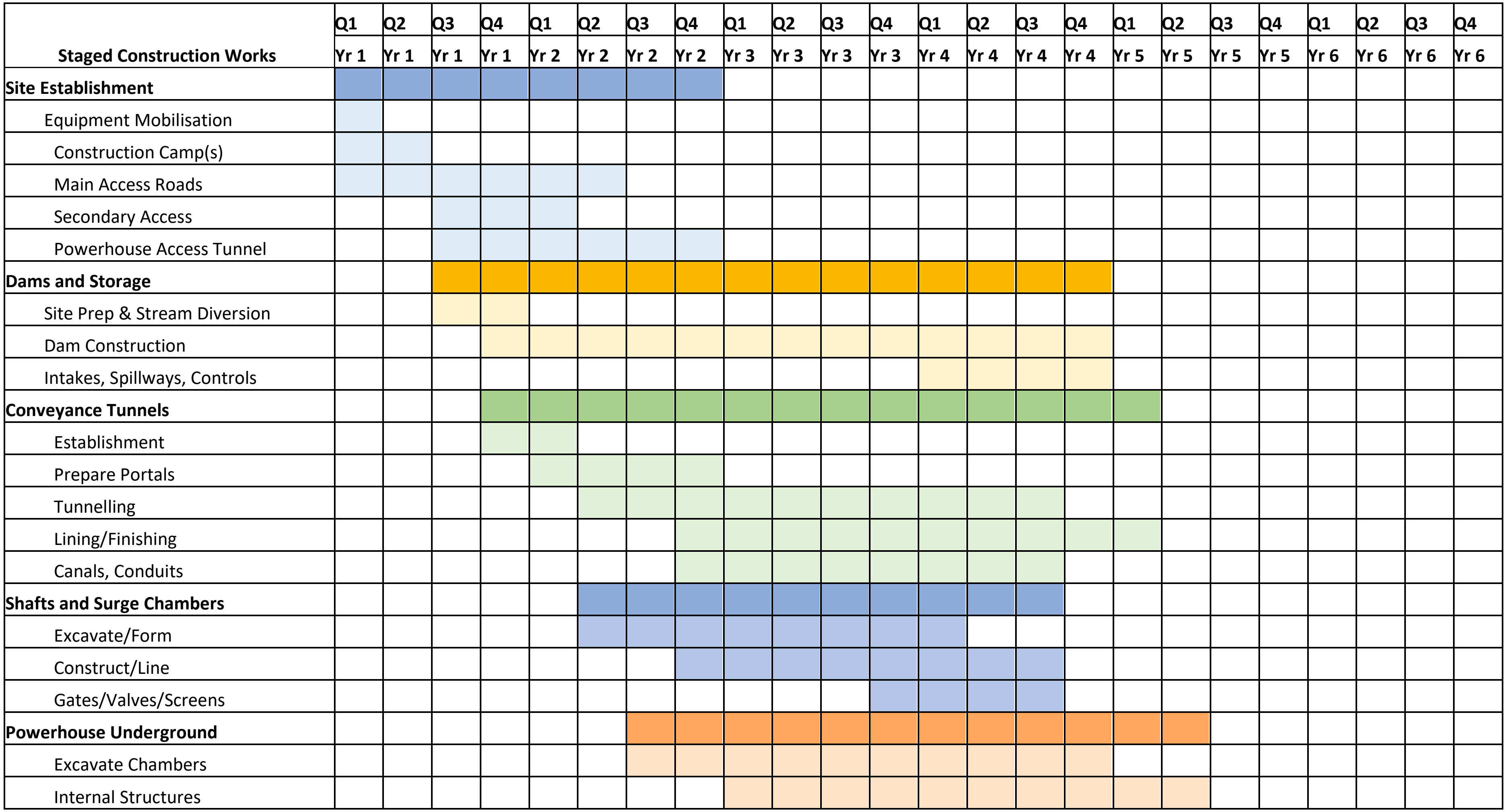
Table 3-10: Cost Estimate Site 2

Item	Description	Base Estimate (NZ$ million)	P_{50} Contingency (NZ$ Million)
1.	**Client Internal Cost**	389.8	116.9
2.	**Client's Design**	603.9	181.2
3.	**Consent preparation**	123.5	37.1
4.	**Site Investigations**	164.7	49.4
5.	**Property & Utilities**	13.7	4.1
6.	**Project Specific Insurances**	82.3	24.7
7.	**Construction**	5,489.9	1,570.6
8.	**Project Base Estimate (1+2+3+4+5+6+7)**	6,867.8	
9.	**Contingency (Assessed/Analysed)**		1,984.0
10.	**Total Project Expected Estimate (P_{50})**		**8,851.8**
11.	**Funding Risk**	50%	4,425.9
12.	**90th Percentile Estimate (P_{90})**		13,277.7

The budgets have been prepared to AACE **class 5** with P_{50} contingencies between 25% and 30% depending on the particular cost items and P_{90} funding risk at an additional 50% in accordance with cost estimation practices generally applied in New Zealand (for example NZTA etc).

3.7 Project Schedule of Selected Configuration

The following programme was developed utilising comparison with some overseas examples. Where a range of programme times existed, the upper limit was typically adopted. It has been presumed that the overall scheme will be advanced as a series of parallel construction programmes within which it is anticipated that the critical path will be associated with Station 2 powerhouse excavation and subsequent machinery installation. As the current design is at a very preliminary conceptual state, caution was exercised against being too conservative in terms of programme development. Core items such as major tunnels and dams will not be optimal. Subsequent stages will seek to reduce component sizes and hence cost and construction time.



Fitout
Powerhouse Surface
Excavate Chambers
Construct
Fitout
Plant Install
Station 1 (Gen + Pumps)
Station 2 (Pump Turbs)
Station 3 (Pump Turbs)
Station 4 (Gen)
Balance of Plant
Transmission/Switchyard
Lines
Switchyards
Environmental
Fencing and Planting
Rehabilitation
Commissioning & Lake Fill
Conveyance System
Pumps
Generation
Lake Fill (local only)
Lake Fill with Pumps
Dams/Spillways

3.8 Summary

Key details of the selected configuration for Site 2 are as follows:-

Table 3-11: Site 2 Details

Site 2 Summary	
Storage Provided (TWh)	1.15
Capacity of new generation (MW)	523
Live storage of reservoir (Mm^3)	710
Volume of materials in main reservoir dam (Mm^3)	5.5
Length of tunnels (km)	22.5
Generation time to empty (Months)	3
Flow rate for filling over 2 years as per scope (m^3/s)	11
Flow rate to fill in 9 months of each year (m^3/s)	14.7
Indicative Cost (P_{50}) (NZ$ Billion)	8.9
Cost/TWh (NZ$ Billion)	7.7
Project Duration (Years)	6

4 Site 3 Pukaki

The MBIE GIS scan identified raising Lake Pukaki to provide additional dry year storage. This site is not a pumped storage option and would use the existing generation infrastructure (owned by Meridian) in the Waitaki system plus any new generation constructed as part of the dam raise.

4.1 MBIE Concept Configurations

Figure 28 below shows the option that was identified from the GIS Scan. The 'new' full supply level to provide suitable storage (within the conditions of the GIS Scan) was identified as RL560m which represents a 28 m raise of Lake Pukaki. The raised Lake level equates to approximately 5 TWh of total storage, including the existing volume.

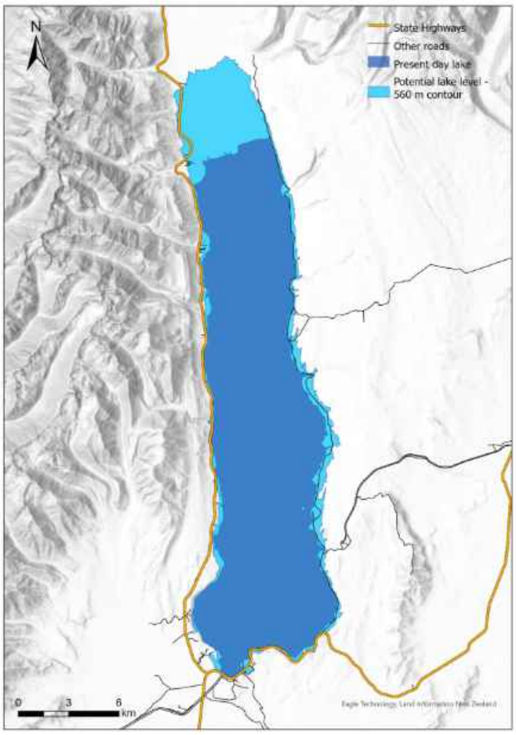


Figure 28 - NIWA Raised Pukaki Option

4.2 Existing Infrastructure

4.2.1 General

Descriptions of existing project elements are contained in the following sections. Key levels and operational data include the following:

Table 4-1 - Existing Pukaki Dam Details

Description	Unit	
Dam crest level	m	536.5
Full supply level	m	530.7
Minimum operational level	m	518.2
Lowest consented level (emergency storage)	m	518.0
Spillway crest level	m	520.38
Probable maximum flood (PMF)	m^3/s	3649
Reservoir level at PMF	M	535.19
Minimum Flow in Pukaki Canal	m^3/s	0
Maximum Flow in Pukaki Canal	m^3/s	560
Existing live (usable) storage volume	Mm^3	2325
Existing energy storage	GWh	1680

4.2.2 Pukaki Dam

The Pukaki Dam comprises two earth embankment dams - the main Pukaki Dam and the right-hand wing dam, as shown in **Figure 29**.

The main Pukaki ('high') Dam is an earth embankment dam with a crest length of approximately 820 m with a maximum height of 76 m. The dam crest is approximately 12 m wide and supports a paved State Highway (SH8). The key components of the main embankment dam include:

- A zoned embankment with an upstream sloping core flanked by gravel shoulders as shown in Figure 30
- An impermeable (low permeability) blanket upstream to reduce seepage under the upstream shoulder. The blanket is connected to the low permeability core material
- Sand filters upstream and downstream of the core material to protect and to prevent migration of fines content
- Drainage materials placed on the downstream of the chimney sand filter connecting with a blanket drainage within the downstream shoulder
- The embankment upstream slope protected against wave action by a layer of riprap over the full extent of the slope (from RL518 m)
- A low-level outlet culvert (diversion culvert) conducted through the embankment as shown in Figure 31 (invert elevation approximately RL476m).

The right-hand wing dam is an earth embankment dam with a total dam crest length of 640 m and a maximum height of 35 m. The right-hand wing dam zoned geometry is similar to the main dam, a typical section of the right-hand wing dam is shown in **Figure 32**.

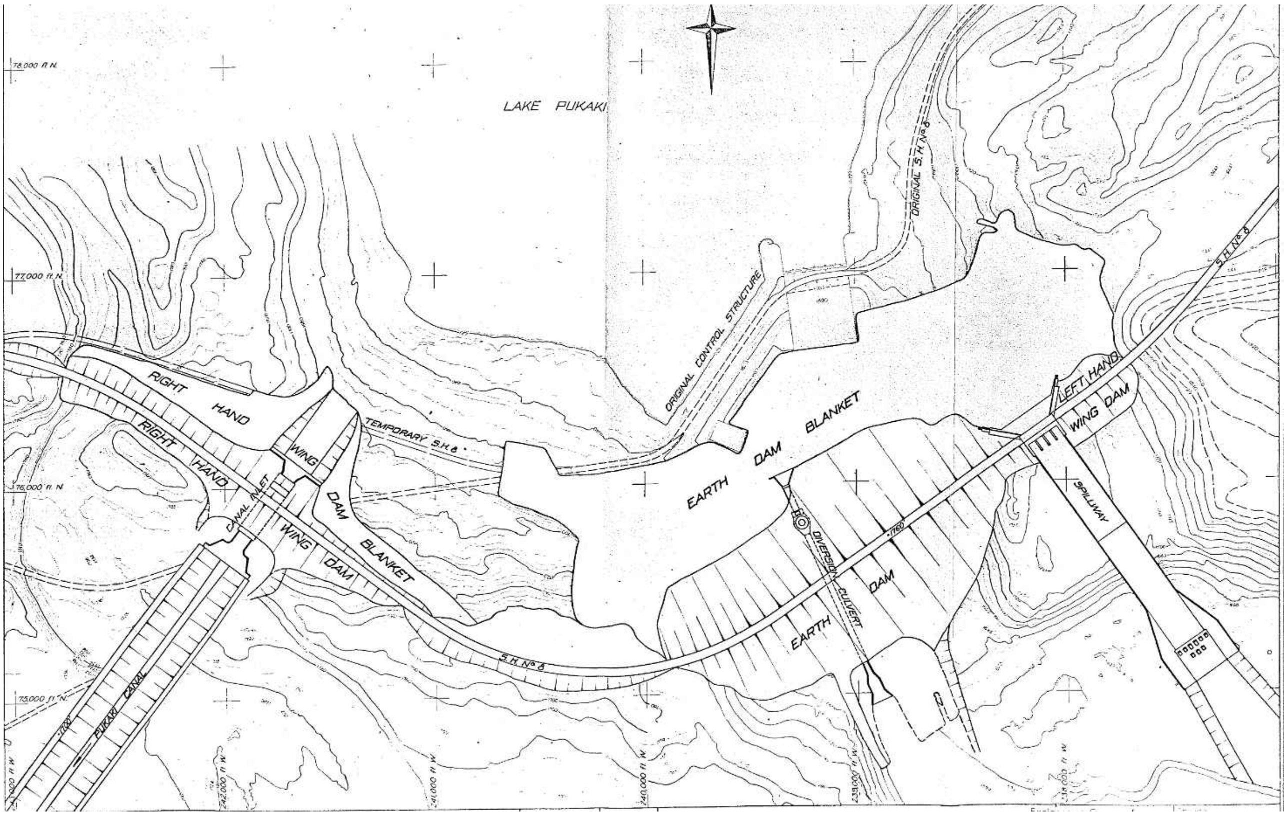


Figure 29 - Layout of Pukaki Dam Features (Engineering Geological Completion Report, 1976)

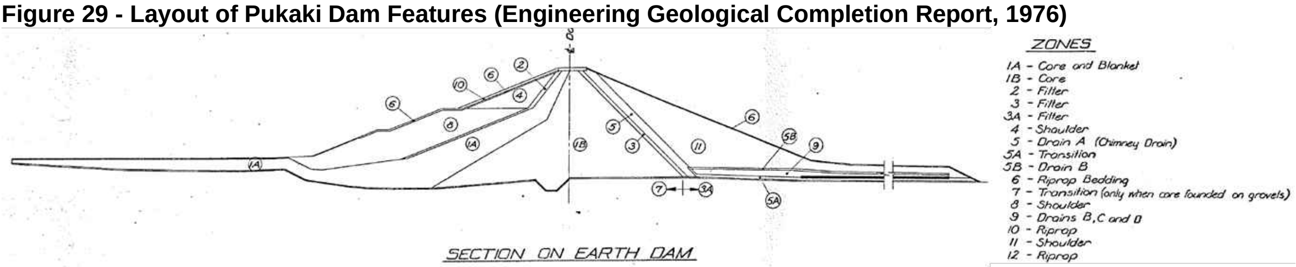


Figure 30 - Typical Section of the Main Dam (Engineering geological completion report, 1976)

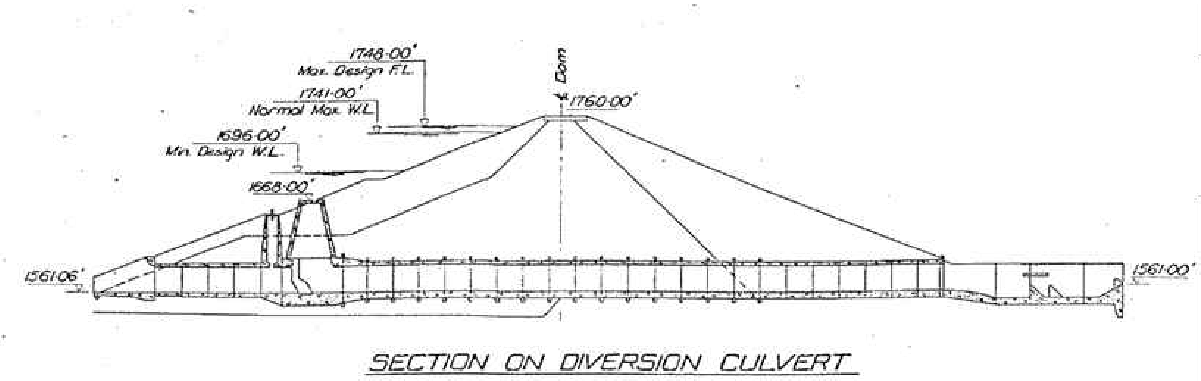


Figure 31 - Typical Section of the Low-level Outlet Culvert (diversion culvert) (Engineering Geological Completion Report, 1976)

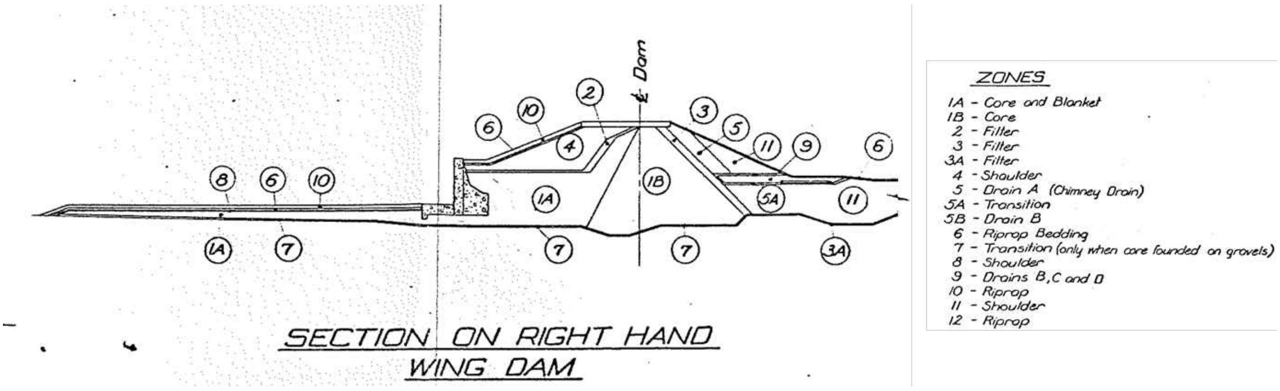


Figure 32 - Typical Section on Right Hand Wing Dam (Engineering Geological Completion Report, 1976)

4.2.3 Spillway

The spillway is located on the left abutment of the main dam. The structure is underlain by core materials and incorporates a concrete cut-off wall. The exterior side walls incorporate a vertical concrete cut-off wall into the core. The level at the invert of the spillway gate structure is RL520.38m, with the dam crest road some 18 m above. The design flood for the spillway is 3400 m^3/s.

The spillway has four radial gates, each 10.7 m wide and 12.2 m high. The gates open to a reinforced concrete chute 50 m wide and 365 m long discharging to a reinforced concrete stilling basin with stepped side walls, baffle blocks, an end sill and a deep cut-off wall. The downstream channel is protected by riprap and a rock weir to maintain a suitable tailwater level during spillway discharges.


Photo 1 - Pukaki Spillway Gate

4.2.4 Canal Inlet Structure (Gate 18)

The canal inlet structure is located beneath the canal inlet dam. It is a three-barrel structure that incorporates a gate chamber towards its upstream end a transition structure between the downstream ends of the barrels and the Pukaki canal.

Gate 18 consists of three identical, conventional submerged radial gates each approximately 6 m wide x 6 m high. The structure regulates flows from Lake Pukaki to the Pukaki canal downstream (and thereafter into the Ohau A and B power stations and the rest of the Meridian Energy Waitaki River cascade). Gate 18 may also be used to supplement spillway discharges during a flood event or to lower the lake level if required.

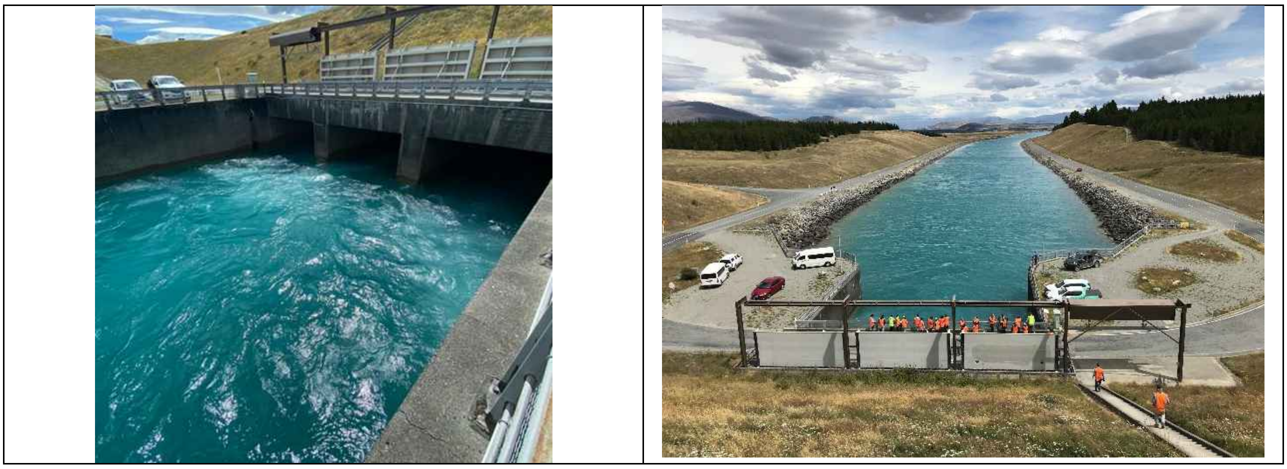


Photo 2 - Pukaki Canal Inlet Structure

Energy dissipation is provided within independent concrete barrels downstream and a concrete-lined entrance to the earth lined Pukaki Canal.

Photo 3 - Pukaki Gates 18

The Pukaki Canal just downstream of Gate 18 features a ‘toppling block’ spillway which in emergency would spill flows to the Pukaki River.

Photo 4 - Pukaki Canal Spillway

As the canal provides a significant proportion of generation flows to the Ohau A, B and C power stations (of combined capacity 708 MW, owned by Meridian) its operation would preferably – or at least to the maximum extent possible - remain uninterrupted during any dam raise works If an outage on the canal was required for any reason then flows can be sent down the Pukaki River to Lake Benmore (but bypassing the Ohau A , B and C power stations). However, it should be noted that these will still be in operation using flows from Lake Ohau.

4.2.5 Tekapo B

The existing Tekapo B station is owned and operated by Genesis Energy. The scheme diverts flows from Lake Tekapo along the 26 km long Tekapo Canal to a headpond and develops a gross head of around 150 m. From the headpond two penstocks (see figures below) convey flows to a powerhouse located on the shores of Lake Pukaki which houses two 80 MW Francis turbine driven generating sets. The powerhouse is subject to a significantly variable tailwater over the Lake Pukaki range.

Photo 5 - Tekapo B Power Station

As the Tekapo diversion provides a significant volume of water for generation in Lake Pukaki comes from Tekapo means minimising any outages of this infrastructure during construction is essential.

4.2.6 Roads

There are two State Highways (SH) around Lake Pukaki. SH8 between Tekapo and Twizel runs along the Southern edge of Lake Pukaki and over the dam crest which will be inundated with the proposed new lake level and impacted by construction. The other is SH80 on the Western side of Lake Pukaki, the only road access to Aoraki Mount Cook, as large sections will be inundated with the proposed new lake level. There are also a couple of driveways or access tracks around the lake that will be inundated, but only the access road to Tekapo B powerhouse will be reinstated as the others lead to properties that will also be inundated or have alternative access.

4.2.7 Other Significant Infrastructure

There are about 40 structures within the inundation zone (up to RL566 m) including houses, barns and Glentanner aerodrome. Another two properties at the North Eastern corner of Lake Pukaki would have no access available and new access would be difficult to arrange. There are many farms scattered across the hills to the East and South of Lake Pukaki that are above RL566 m that may have limited access once the lake level is raised. The information centre located on Pukaki dam will also have to be relocated.

4.3 Options Considered

Unlike Sites 1 and 2, Site 3 is essentially a dam raise and therefore there are limited options/ configurations available. At an early stage a number of alternatives were brainstormed and discounted. The reasons for discounting are summarised.

Table 4-2 - Site 3 Raise Options

Option Description	Reason Discounted
Upstream new dam within existing lake	Complexities with sealing new dam foundations – anticipate significant groundwater inflows. Volumes of material likely to be significantly greater than raised dam option (Lake bed levels unknown). Challenging and unknown foundation conditions (deep lake deposits).
Downstream new dam	Volumes of material likely to be significantly greater than raised dam option. Significantly larger footprint. The significant environmental impact at the new dam location and surroundings (larger inundation area). Complexities of interacting with existing infrastructure (canal). Dealing with floods during construction.

For the reasons as noted above the option that was considered the most 'feasible' was a traditional dam raise which is described below.

4.3.1 Dam Raise

The dam raise option involves raising the dam crest level 30 m from the existing crest elevation of RL536.5 m to RL566 m. The works comprise a 2800 m long embankment up to RL566 m incorporating the existing main dam embankment, the right-hand wing dam, and the removal of the existing spillway.

Figure 33 shows the conceptual dam raise section and the following elements are assumed for the conceptual design:

- The new proposed full supply level is at RL560.0 m
- The new freeboard is approx. 6 m
- The new dam crest elevation is at RL566.0 m
- The new proposed raise core upstream slope inclined with 2.5H:1V
- The new proposed raise upstream shoulder slope is 2.5H:1V
- The new proposed downstream shoulder slope is 3.0H:1V
- The existing diversion culvert is extended to the new downstream toe, with filter diaphragms wrap around the diversion culvert.

Several restricted elements influence the dam raise conceptual design, and are discussed as follows:

- The normal reservoir level: the reservoir levels fluctuate at between RL530.7 m and RL532.0 m. It is critical to maintain the FSL at RL530.7 m during the dam raise construction, this is to secure the water storage for power generation. For conceptual design, it is assumed the reservoir level is at RL531.0 m.
- The existing dam crest excavation elevation: with the consideration of the parked reservoir level at RL531.0 m during the construction, the lowering of the existing embankment is to RL532.0 m. One meter freeboard is between the parked reservoir level and the excavation elevation.
- The width of the core: with the inclined core in the existing embankment dam, the width of the core is narrower in the upper section of the existing dam. The minimum width of 18 to 20 m of the core is considered in the conceptual design to control seepage through the dam.

For the conceptual design, no geotechnical interpretation or modelling was undertaken. The following assumptions are made for the conceptual design of the dam raise option:

- Dam Foundation:
  - The existing cut-off is effectively controlling the seepage and internal erosion. No deepening or new additional cut-off is required.
  - No piping and internal erosion risk in the existing dam foundation (within the dam footprint).
  - No erodible material presented in the existing foundation footprint and new proposed downstream shoulder footprint.
  - The foundation material has no liquefaction potential.
- The Existing Embankment:
  - No piping and internal erosion risk associated with the existing embankment.
  - The filter is compatible with core material, upstream shoulder material, and drainage material.
  - The filter is in full operation with no clogging.
  - No slope instability of the existing embankment.

- Reservoir Rim:
  - There are potentially some relatively steep slopes on the west side of Lake Pukaki (SH80 towards Mt Cook) and fan deposits are also observed in the aerial photos. It is assumed the potential slope instabilities are localised and not impacting the overall reservoir security.

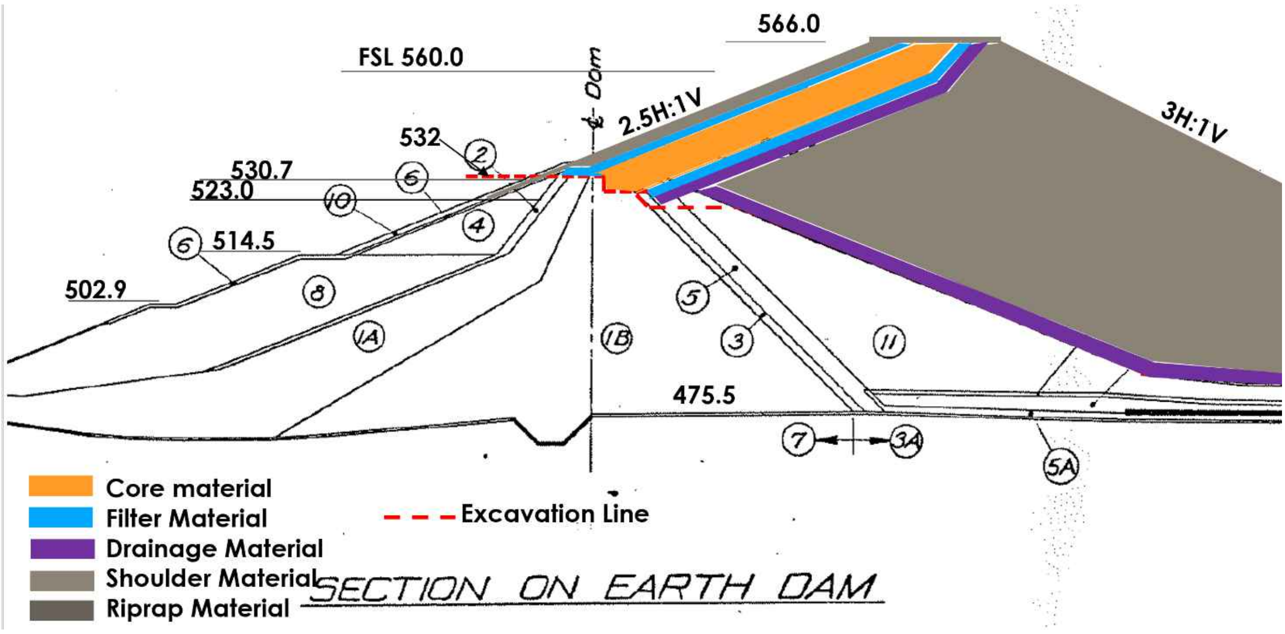


Figure 33 - Dam Raise Concept - Section Through Earth Dam

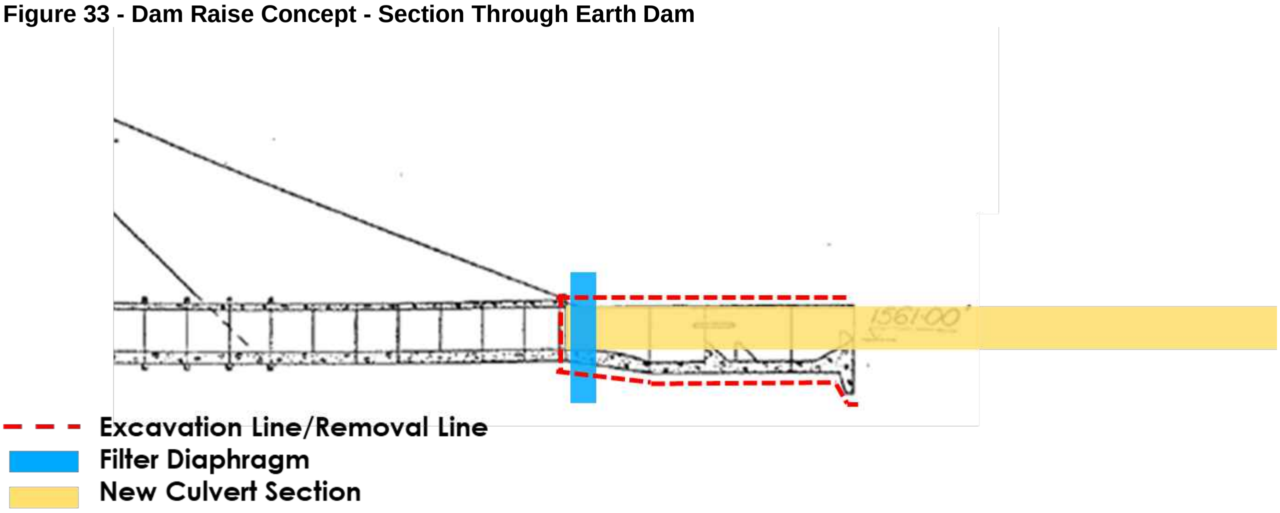


Figure 34 - Diversion Culvert Extension Concept - Section

4.3.1.1 Construction Staging

High level construction staging of the embankment raise is outlined as follows and illustrated in **Figure 35**. The staging has been developed to minimise construction flood risks by reducing the time where the embankment is lower than its current level.

1. Foundation preparation of the new footprint (including stripping of unsuitable and loose material) and excavation at the toe to expose and tie into existing drainage zones. The existing diversion culvert can be extended.
2. Staged construction of the new downstream shoulder and drainage zones. Any loose and unsuitable material on the existing downstream shoulder shall be removed prior to placing the new shoulder material.
3. Excavation on the downstream side of the drainage, filter and core material to RL532.5 m. A good key-in and contact surface between the new core and existing dam core is required to avoid cracking and potential internal erosion. Construction of the downstream section of the new dam to RL536.5 m.
4. Excavation on the upstream section of the existing core material, filter and upstream shoulder material to RL532.0 m.
5. Construction of the upstream dam section to RL536.5 m.
6. Construction of the dam raise to RL566.0 m.

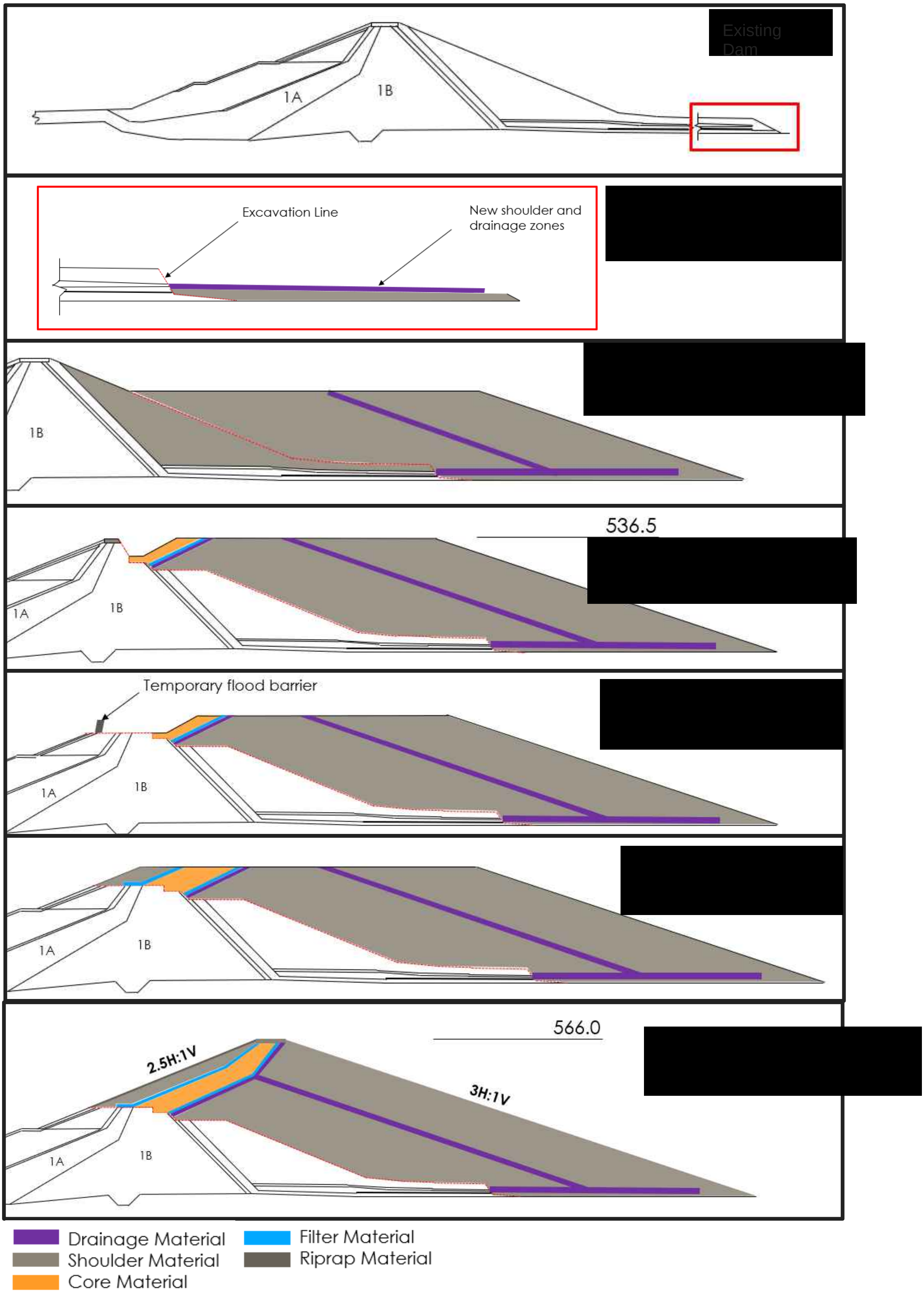


Figure 35 - Pukaki Dam Raise Dam Raise Construction Staging

4.3.1.2 Construction Risk

There are two significant flood risk issues as part of the dam raise construction works. The issues are summarised as follows:

- The staging of the construction works. Staging of the spillway works relative to embankment works to maintain an acceptable level of risk against dam breach due to flood overtopping; and
- The construction risk associated with excavation to expose the earthfill core of the embankment dam.

Raising the existing main embankment and wing dam require excavation to expose the earthfill core and filter zones of the existing embankment. To excavate down to the earthfill core potentially exposes Pukaki Dam to an unacceptable level of flood risk during construction.

A thoughtful construction staging, a new diversion tunnel, and a detailed dam safety inspection schedule during construction can minimise the construction risk associated with flooding.

Excavating into an existing earth dam may generate the embankment instability. Temporary working platforms may be needed to support some of the earthworks. A detailed stability assessment and temporary work design are needed in later design phases.

The economic (energy) risk associated with construction is discussed in Section 4.5.3.

4.3.1.3 Dam Raises Considered

A number of dam raises were checked to see if there was an obvious break point. From the graph below it can be seen that the storage increases linearly with elevation. However, above a FSL of 560, a sharp increase in the dam crest length is observed. This would make FSL 650 the optimal choice when considering dam size and storage gained. A small saddle dam will be required for the dam with FSL 560. For higher levels, both the number of saddle dams and size of saddle dams increases.

In order to capture the current spilled volume of 534 Mm^3 / annum, an FSL at about RL 541.2 m would be required (raise of 10.5 m).

The preferred option of FSL 560 will provide 4400 Mm^3 additional storage which equates to a total of approximately 5 TWh.

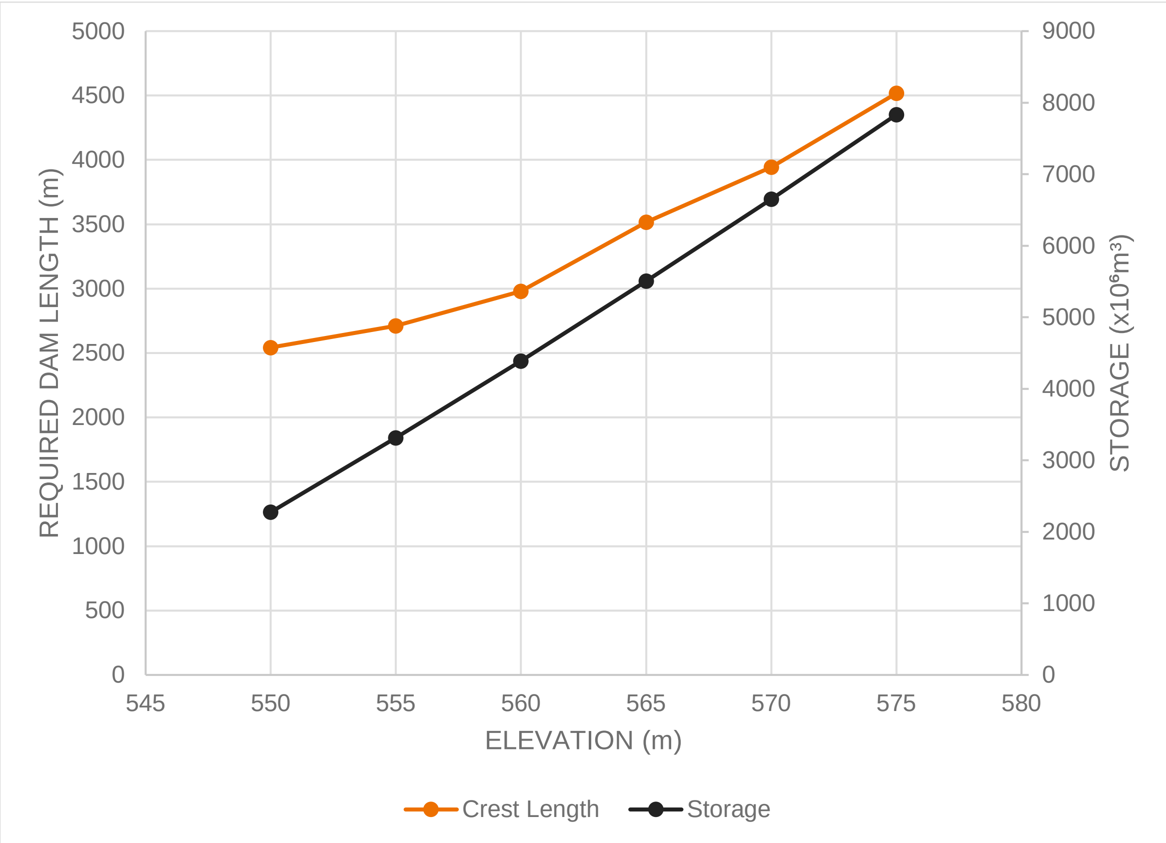


Figure 36 - Pukaki Dam Raise Storage vs FSL Elevation

4.3.2 Diversion Structure

A new diversion structure is required for the dam raise to minimise the risk of dam overtopping during construction, in particular to protect a continuous connection between the existing and new dam cores at around RL532 m. A new diversion structure is considered required at this stage, capable of diverting the PMF during construction. The concept would be for a 4 x 12 m diameter, 2 km long, gate-controlled concrete lined diversion tunnels located to the left side of the existing spillway.

Any floods reaching RL531m during the dam raise will be diverted to the Pukaki River via the diversion tunnels.

The diversion tunnels and gate shaft arrangement as the follow figure.

Figure 37 - Concept Diversion Arrangement

4.3.3 Spillway

A location considered suitable for a new spillway is located 5 km away from the existing spillway along SH8. The new spillway consists of reinforced concrete spillway gate structure and its four radial gates, about 700 m long chute and a stilling basin connects to the Pukaki River. The new spillway will have the following parameters:

- Spillway Crest Level: RL569 m
- Spillway Invert Level: RL552 m
- Stilling Basin Invert Level: RL538 m
- Peak Maximum Flood (PMF): 3650 m^3/s

Figure 38 - Concept Spillway Arrangement

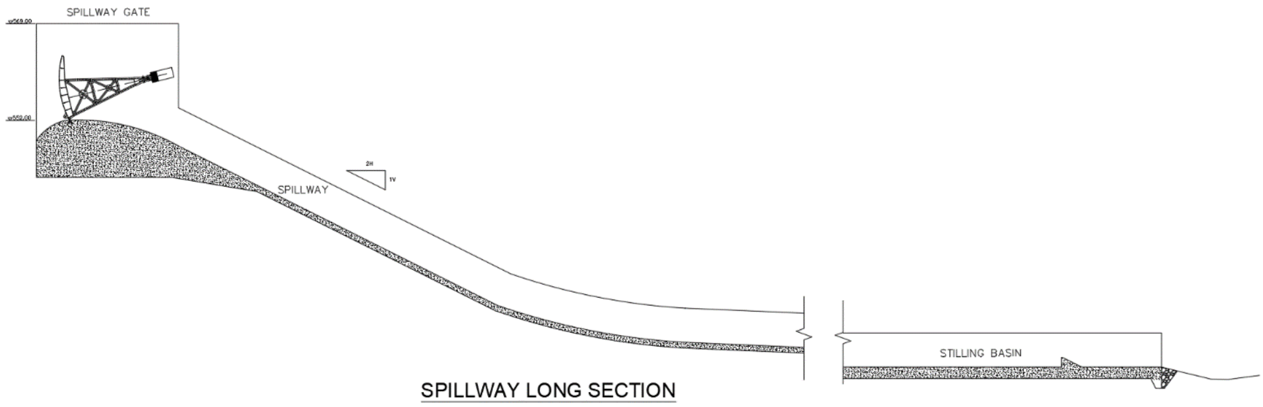


Figure 39 - Concept Spillway Long Section

4.3.4 Canal Inlet Structure

As noted above one of the main challenges of the dam raise will be to configure an energy dissipation structure to pass generation flows to the Pukaki Canal over the full range of discharge and heads prevailing.

At this stage it is assumed that the existing Gate 18 structure will finally be decommissioned and plugged with concrete and that a new canal inlet structure will be constructed between it and the right abutment. The structure will comprise an inlet structure to a tall gate shaft with a steel lined tunnel under the dam leading to a conventional energy dissipation basin and a canal connecting to the existing Pukaki canal as shown in the figures below.

Figure 40 - Concept Canal Inlet Arrangement

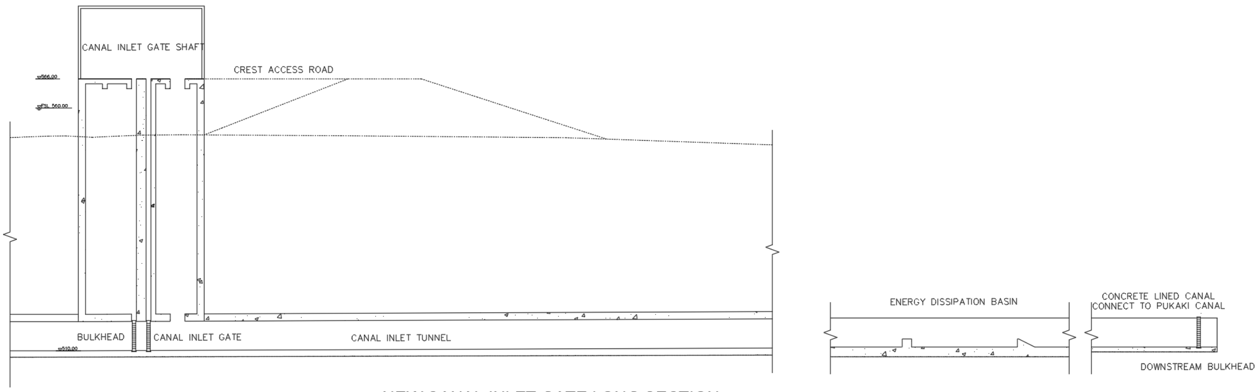


Figure 41 - Concept Canal Inlet Long Section

This option will minimise the impact on Pukaki canal inflow. The existing Gate 18 will keep discharging during the new Pukaki canal inlet structure construction period. A minimal outage would be required when the final connection to the Pukaki canal is required.

An alternative option considered included strengthening the existing Gate 18 structure with the three barrels extended to match the raised Pukaki dam footprint, with a new stilling basin and the three radial gates and their structure replaced to cater for the increased head. As this option would be subject to significant uncertainties and could compromise discharge capability during the construction period and require significant shutdowns of the Pukaki canal it was eliminated.

4.3.5 Hydro-electric Power Stations

4.3.5.1 General

In the absence of information on how any new storage might be operated, at this stage a basic assumption is made that the newly realised normal live storage would be available for power generation, that the existing storage would be retained for dry year discharge and in the event of release such flows (at relatively low heads at Pukaki and requiring a particularly tall powerhouse structure for Tekapo) would be uneconomic to exploit for power generation. Release of the Pukaki storage below RL532 m would then be achieved at Pukaki dam via a new gated canal inlet control structure similar to the existing Gate 18 and at Tekapo the powerhouse discharge would pass to the Lake via a concrete tailrace energy dissipation structure in steps.

4.3.5.2 Pukaki Powerhouse

Presently there is no power generation facility at Pukaki Dam – with flows discharged to the Pukaki Canal under widely varying head and flow combinations via Gate 18. With the normal operating gross head range between dam and Pukaki Canal much increased (to be in the range 40 m to 15 m) and with a strongly constant discharge characteristic in releases made to the schemes in cascade downstream, the dam raise presents a likely opportunity for new power generation. A new powerhouse would be located in the natural till section between the high and low dams, with a new intake constructed in the area of the visitor's car park and penstocks routed at mid-level under the new dam. The intake works requires an excavation/ cofferdam to be constructed to existing dam crest level later to be encapsulated with the existing clay blanket. Defensive design methods would be incorporated into the penstocks to prevent seepage.

The new powerhouse is conceived comprising 3 x 40 MW vertical Kaplan turbine driven generating sets, in combination capable of passing a discharge of 500 m^3/s at a mean net head of around 27 m, with a new tailrace passing flows to the Pukaki Canal, as follows:

Table 4-3 - Potential Pukaki Power Station Parameters

Heading	Description	Unit	
1	FSL	m	560
2	TWL	m	518
3	Maximum gross head	m	42
4	Rated gross head	m	28
5	Rated net head	m	27
6	Minimum operating head	m	14
7	Minimum operating level	m	532
8	Unit output	MW	41
9	Number of Units	-	3
10	Total discharge	m^3/s	500
11	Discharge per Unit	m^3/s	167

4.3.5.3 Tekapo Powerhouse

The only option considered is a new powerhouse constructed on the shores of Lake Pukaki – similar to the existing powerhouse but operating under a reduced head. The new powerhouse would make use of the existing intakes and penstocks and be constructed alongside the penstocks whilst they remain operational (the existing Tekapo B power station would not lose generation until the new Tekapo powerhouse is connected).

The power station is conceived comprising 2 x 70 MW vertical Francis turbine driven generating sets, in combination capable of passing the same discharge as the existing machines a reduced mean net head of around 20 m, with a new tailrace passing flows to the Pukaki Canal, as follows:

Table 4-4 - Potential Replacement Tekapo B Power Station Parameters

Heading	Description	Unit	
1	FSL	m	675
2	TWL	m	532
3	Maximum gross head	m	143
4	Rated gross head	m	129
5	Rated net head	m	124
6	Minimum operating head	m	115
7	Minimum operating level	m	675
8	Unit output	MW	71
9	Number of Units	-	2
10	Total discharge	m^3/s	124
11	Discharge per Unit	m^3/s	62

The power station would be very similar in layout to the existing power station – essentially the same but at a higher elevation and thus developing less head – with the generating capacity correspondingly lower, by some 20 MW, to around 140 MW.

Figure 42 - Concept Replacement Tekapo B Power Station Layout

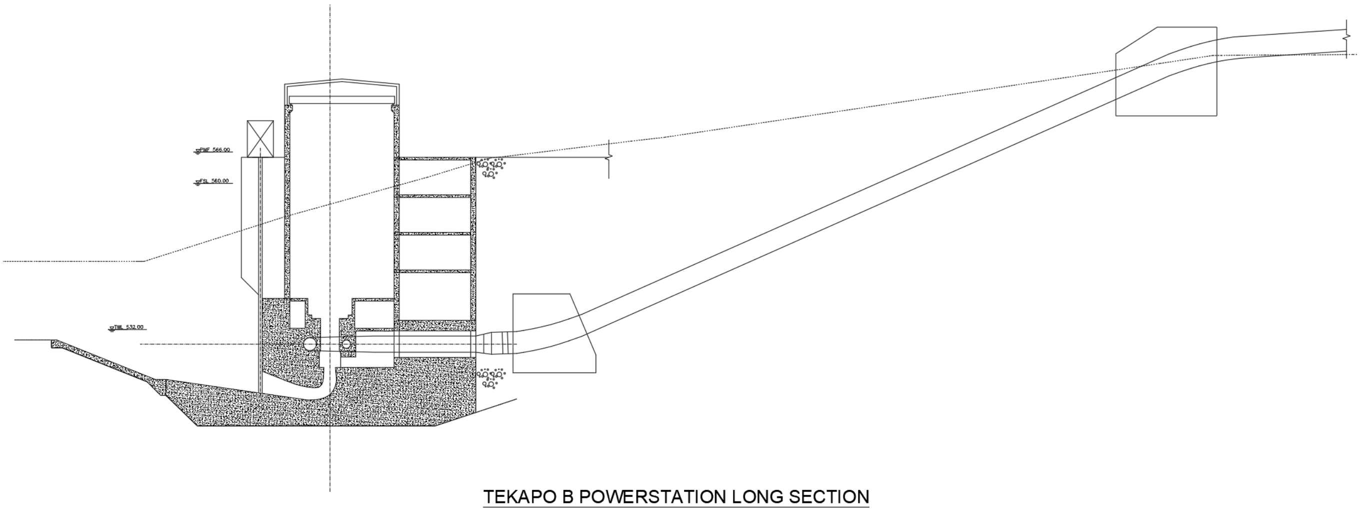


Figure 43 - Concept Replacement Tekapo B Power Station Long Section

A new switchyard would be provided connecting into the existing transmission line.

4.3.6 Access Roads

During construction, access to the site must be restricted for the public so SH8 will have to be diverted. The proposed diversion route will turn off from the current SH8 around 4.6 km before the road reaches the lake coming from Tekapo. This 4.6 km stretch of SH8 to the lakefront will still be open to the public for access to the track along the Eastern side of Lake Pukaki. The 8.6 km to the Pukaki dam crest will be used for construction traffic. The SH8 realignment away from Lake Pukaki would re-join the existing road to Twizel about 4.5 km South of the Pukaki dam. This 4.5 km stretch would remain open to the public for access to SH80. After construction, the diversion could be used as a permanent realignment since a new road along the lakefront at a higher elevation would require a lot of construction.

Large sections of SH80 run along the lakefront and so would be inundated with the new proposed lake level. These sections of road, approximately 17 km in total, will have to be relocated further up the hillside. The rest would be made up of existing road but may require wave protection in areas that come close to the new lake level and the existing bridges may need to be re-evaluated for the higher water level.

On the Eastern side of Lake Pukaki, the access road will be used for construction traffic for the Tekapo B powerhouse and a new access road at higher elevation will be required for continued access to the powerhouse once the lake level is raised. The other tracks on the Eastern lakefront will not be reinstated but consideration should be given to upgrading the track from Tekapo over the hills as that will be the only access to the remaining farms.

4.4 Configuration Selected for Costing

As a base case a raise of RL560 was chosen with the following key features:

- Provides 5 TWhs of ‘storage’ or 4,400 Mm^3 of water.
- Raised embankment dam of 28 m
- New ‘Gate 18’ and energy dissipation structure on the right bank connecting back to the Pukaki Canal
- New powerhouse at the toe of the Pukaki dam connecting back to the Pukaki Canal.
- A new temporary spillway (tunnels) through the left bank.
- A new concrete spillway.
- A new Tekapo B power station.
- Access roads and associated infrastructure.

4.5 Technical Considerations of Selected Configuration

4.5.1 Hydrology

Flow data for Lake Pukaki is available from the Electricity Authority environmental dataset. Mean daily inflow, reservoir storage, spill discharge and lake level data are available. The daily inflow is available for the period 1932-2020, while the other datasets are available for a shorter period of 1980-2020. The datasets were created using hydrologic modelling and flow routing through the Tekapo-Pukaki-Waitaki system. Daily discharge from Lake Pukaki to the Ohau canal is not available, so it was back-calculated from daily inflows and change in storage.

Using the 1980 to 2020 period, the mean annual inflow to Lake Pukaki is 6193 Mm^3. This comprises 4010 Mm^3 in runoff from the local catchment (1356 km^2) and 2183 Mm^3 diverted from Lake Tekapo through the Tekapo canal. The annual spill volume is 524 Mm^3 (equating to an energy loss of 378 GWh) and the estimated release to the Ohau canal is

5774 Mm^3. The average discharge (6298 Mm^3) is slightly higher than inflow over this 43-year period (this is based on the long-term EIA hydrology model data; raw data was not available to confirm if this is correct).

The Electricity Authority dataset shows the Lake spills on average every other month (246 months with spill in a 492-month record). This is based on modelling data and could not be confirmed using actual spill records.

NIWA's CliFlo database has daily rainfall and evaporation data at the Lake Pukaki MWD station (station 4981). The at-site data is relatively short, covering the period Jan 1970 to Dec 1984. Longer data records are available at other sites, but they were not used due to differences in elevation or distance from Lake Pukaki. Meridian and Environment Canterbury also operate a rainfall station at Mount Cook; this data wasn't used because it is only available on request.

The annual rainfall at Lake Pukaki MWD is 656 mm. The annual evaporation is 1199 mm, giving a mean annual net loss of 592 mm. This is equivalent to 0.59 Mm^3/km^2 of reservoir; the lake surface area is approximately 178 km^2, so the mean annual loss is around 105 Mm^3.

4.5.2 Geology

Reference is made to Appendix B for the findings of a completed geological study for the proposed option. The geological study summarises:

- Its objectives, the completed scope of works, and the publicly available information that has been used to inform it.
- A review of key geological hazards that may place a constraint on option design, construction, and operation.
- The developed conceptual geological model that has been used as the basis for option development, its concept design, and the associated cost estimate.

The existing Pukaki Dam area, and the reservoir shoreline of Lake Pukaki, are mapped to be underlain by varying glacial (i.e. 'till', 'moraine'), fluvioglacial (i.e. 'outwash'), and alluvial soils ranging in age from approximately Late Otiran (45,000 years) to recent. The soils reflect varying glacial conditions from the Late Otiran times to the end of the last major glaciation, around 12,000 years ago. The two key periods of glaciation during this time, known as the Mount John and Tekapo Formations, are those most relevant to this option. Deposits associated with older glaciations do occur in the Mackenzie Basin (i.e. Early Otiran and earlier), but are not directly relevant to this study as they do not occur at Pukaki Dam or immediately around the reservoir shoreline.

Post-glacial alluvium has subsequently been deposited, and continues to be deposited, within and adjacent to watercourses, which includes the Pukaki River at the dam site and the Tasman River at the head of Lake Pukaki. Lake sediments have and will continue to accumulate in Lake Pukaki.

A key reference that has been sourced and used in this study is Read (1976). This report, which describes the encountered foundation conditions and embankment materials used during the construction of Pukaki Dam, provides site-specific geological information for this option. Read (1976) summarises the foundation conditions for Pukaki Dam as 'The outlet to Lake Pukaki (i.e. the dam site) is located at the snout of glaciers which advanced to that point between 17,000 and 14,000 years before present. These advances have resulted in a complex site geology in which lower permeability glacial till and pro-glacial lake deposits overlie higher permeability ice contact and fluvioglacial outwash deposits.

The key findings of the geological study can be summarised as:

- No geological fatal flaws have been identified based upon the currently available information.
- The design, construction, and operation of the Upper Waitaki Power Scheme provides significant engineering geological precedence of the feasibility of the proposed option. This includes the existing Pukaki Dam (foundation conditions, dam materials and design, and reservoir watertightness).

Recommendations for the next stage of geological study should the proposed option proceed to the next stage of project development are:

- The sourcing and review of relevant pre-existing site-specific geological information which is privately held. This would include that related to the design, construction, and operation of the Upper Waitaki Power Scheme.

Development of geological study objectives and scope of works as required for the stage of project development as recommended by ICOLD (2005) and ANCOLD (2020).

4.5.3 Energy Storage and Reservoir Release / Refill Times

The current live storage volume of Lake Pukaki is 2325 Mm^3, in the 13.8 m normal operating range between RL532m and RL518.2m – representing an energy storage of approximately 1.7 TWh – or an equivalent specific energy of 0.72 kWh/m^3. Raising the FSL by 28 m to 560 m would increase the live storage by approximately 4400 Mm^3. Using the same specific energy implies an energy storage increase of around 3.2 TWh – or a total stored energy of approximately 4.9 TWh.

Refill times could vary between 2 years and 13 years, depending on the refill strategy. The longest refill time would rely only on the mean annual spill volume (524 Mm^3). In this case, the lake would be operated as usual and continue to release the long-term average discharge into the Pukaki canal, but high inflow events that would normally cause spill would be captured to refill the lake. Shorter refill times would be possible with reduced discharge to the Pukaki canal, but this comes with a lowering of annual energies at existing power stations in the Waitaki River cascade downstream due to the reduction in available water. Energy losses by refill time are:

- 2-year refill: 2122 GWh loss
- 3-year refill: 1288 GWh loss
- 4-year refill: 872 GWh loss

These energy losses have been calculated based on the annual reduction in discharge volume to the Pukaki canal and the mean annual energy at downstream stations. It does not account for any new generation capacity at Pukaki.

The potential increase or decrease in energy during construction depends on how quickly Lake Pukaki can be lowered, the duration it is held low for construction and coordination with downstream operators to avoid spill at other dams in the Waitaki system. During initial drawdown, there would likely be an increase in downstream generation as water is released from Lake Pukaki. Assuming the lake can be emptied from FSL to LSL within a year and all water can be released into the Pukaki canal, the potential increase in energy is 1680 GWh. If the lake is held low during construction so discharge is equal to inflow, the potential increase in energy is 303 GWh/yr, calculated as the difference between mean annual inflow to the lake and release to the Pukaki canal.

4.5.4 Construction Staging

A staged construction is required for:
Minimising the flooding risk during the lowering of the existing embankment and the removal of the existing spillway.
Phasing the works in such a way as to not increase the current dam safety risk.
Reducing the impact of existing generating infrastructure (i.e. Ohau A, B, C and Tekapo B).
Construction would therefore be phased in the following sequence:
Site setup and establishment.
New public access road diversion across Pukaki River (at 1 km away from the nominated construction haul roads).
Construction of cofferdams at the proposed new gate 18 location and at the new Pukaki hydro intake location.
Construction of new gate 18 and connection to the existing Pukaki canal.
Construction of new Pukaki hydro and connection to the existing Pukaki canal (connection could be done concurrently with new gate 18 connection to minimise outage.
Construction of the temporary diversion tunnels and construction of the new downstream shoulder of the embankment.
Commencing lowering the existing embankment dam crest and raising the embankment to design level.
Construction of new spillway (this could be done concurrently with the dam raise work).
Construction of new access roads on western and eastern sides of Lake Pukaki.
Block temporary diversion tunnels.
Commencing filling
The construction of the new Tekapo B power house can commence later in the programme however this should be completed before raising of the Lake commences.

4.5.5 Transmission

The installed capacity of the proposed Pukaki and replacement Tekapo B power stations is only slightly changed from the existing Tekapo B power station. Therefore, the existing transmission assets are expected to be adequate for the change configuration.

The replacement Tekapo B power station would be reconnected to the Twizel – Tekapo B - Islington 220kV transmission line as with the existing arrangement.

The Pukaki power station would be connected to the Twizel – Tekapo B 220kV transmission line by means of a short 5 km diversion of the existing transmission line. The Pukaki switchyard would incorporate three generation bays, plus two transmission bays.

4.6 Non-Technical Considerations of Selected Configuration

4.6.1 Kaitiakitanga

Waitaha, Ngāti Mamoe, Ngai Tahu Whānui
Te Rūnanga o Ngai Tahu, Te Rūnanga o Arowhenua. Te Papatipu Rūnanga.

Cultural Narrative:

Pūkaki is one of the lakes referred to in the tradition of ''Ngā Puna Wai Karikari o Rākaihautū'' which tells how the principal lakes of Te Wai Pounamu were dug by the Rangatira (chief) Rākaihautu. Rākaihautū was the captain of the canoe, Uruao, which brought the tribe, Waitaha, to New Zealand. Rākaihautū beached his canoe at Whakatū (Nelson). Rākaihautu then travelled inland southward and used his famous kō (traditional spade) to dig the lakes of Te Waipounamu.
Another prominent story according to the guardians of Moeraki and the descendants of Arai-te-uru (waka atua) relates to original ancestors such as Aoraki and Kakeroa who were turned to stone Kakeroa is marked on the southern slopes of Lake Pūkaki and Aoraki to the north of Pūkaki at Te Manahuna Valley. According to Ngāi Tahu creation story, Aoraki is the eldest son of Raki (the Sky Father). Aoraki and his brothers brought the canoe (Te Waka o Aoraki) down from the heavens to visit Papatūānuku (the Earth Mother) – their stepmother. Pūkaki is also referred to in Ngai Tahu tradition as the basin that captures the sacred tears of Aoraki: a reference to the meltwaters that flow from Aoraki into the lakes in the springtime. As well as its association with Aoraki, Pūkaki is also a mahinga kai, noted particularly for its waterfowl. The tūpuna had considerable knowledge of whakapapa, traditional trails and tauranga waka, places for gathering kai and other taonga, ways in which to use the resources of the lake, the relationship of people with the lake and their dependence on it, and tikanga for the proper and sustainable utilisation of resources. All of these values remain important to Ngāi Tahu today.

Te Mauri o te wai o Pūkaki:

The mauri of Pūkaki represents the essence that binds the physical and spiritual elements of all things together, generating and upholding all life. All elements of the natural environment possess a life force, and all forms of life are related. Mauri is a critical element of the spiritual relationship of Ngāi Tahu Whānui with the lake.

Wāhi Nohoanga / Ancestral Sites of Occupation

Nohoanga entitlements, Ana uku / Clay & rock cave paintings, burial caves, nohoanga sites along the southern and western side of the lake. Kakeroa and Aoraki landmarks that demarcate Lake Pūkaki and Te Manahuna Valley.

4.6.2 Environmental and Social

4.6.2.1 Land Ownership

Based on the conceptual configuration and estimate of the increased lake levels, this option would impact approximately 41 land titles. Approximately 9 of these titles are owned by the Crown, 1 owned by District Council, 4 owned by power companies, the remaining are private land. The increase in reservoir footprint will affect approximately 27 private properties.

This option would impact the greatest number of properties and therefore require negotiation with the greatest number of landowners.

4.6.2.2 Ecology

The scheme is located in the Pukaki and Tekapo Ecological Districts of the Mackenzie Ecological Region.

The scheme would result in the raising of water level of Lake Pupuki, and increasing the lake area from approximately 17870 ha to 21805 ha. This is an increase in area of approximately 22%. Raising the dam wall would drown approximately 3,955 ha of lakeside habitat including glacial morraines at the head of the lake.

Lake Pukaki is a site of international significance, in large part due to it's environmental and scenic values. The lake has very high water quality, with the exception of turbidity from glacial flour, a result of being feed by meltwater. The lake and surrounding area support a number of rare and threatened species, and is the type locality for several plant and insect species. The lake supports a population of lacustrine koaro (*Galaxias brevipinnis*) (At Risk - Declining) that have unique morphological characteristics and may even be a distinct sub-species.

Approximately 300 ha of predominantly native vegetation will be cleared for the scheme and 185 ha of wetland. In addition, the scheme would drown approximately 1300 ha of glacial moraines at the head of the lake. This area provides nesting and feeding habitat for threatened and at risk birds including black stilt, wrybill and banded dotterel.

As the project is raising an existing dam, no new fish passage restrictions will be created.

Table 4-5 - Vegetation Types Intersected by the Project (excluding tunnels and pumpstations)

Vegetation or Habitat Type (LCDB v5.0)	Area (ha)
Built-up Area (settlement)	1.689
Deciduous Hardwoods	44.385
Depleted Grassland	74.367
Exotic Forest	316.461
Fernland	3.44
Forest - Harvested	42.667
Gravel or Rock	1296.665
Herbaceous Freshwater Vegetation	168.278
High Producing Exotic Grassland	450.209
Indigenous Forest	0.458
(Lake or Pond)	(17849.059)
Low Producing Grassland	1054.385
Manuka and/or Kanuka	1.497
Matagouri or Grey Scrub	100.418
Mixed Exotic Shrubland	26.715
River	332.65
Sand or Gravel	1.5
Short-rotation Cropland	6.248
Surface Mine or Dump	1.205
Tall Tussock Grassland	22.484
Transport Infrastructure	3.671
Urban Parkland/Open Space	5.756
TOTAL:	**21804.207**
TOTAL NATIVE:	**296.575**

The construction footprint of the scheme would be limited to the dam and surrounding area, which is already modified, however the reservoir will cover a large area and a number of roads that would need to be relocated. No new transmission lines are required so no potential impacts for bird strike will be created.

Further detail is provided in **Table 4-5** and Appendix A.

4.6.2.3 Recreational and Commercial Land Use

Lake Pukaki is a drawcard for national and international tourists. The scheme would potentially have significant short-term impacts on tourism during and immediately post-construction, due to the extent of the construction footprint and the need to relocate a number of roads, including popular tourist routes. The Tekapo powerstation would also need to be relocated.

The scheme would permanently drown tourist infrastructure around the edge of Lake Pukaki including most viewing areas, the Glentanner Reserve, aerodrome and campsite, and parts of several DOC reserves.

Longer-term, possible restrictions in flows may negatively impact existing water users and operators in the downstream catchment. This includes potential impacts on salmon farming in canals downstream.

4.6.3 Planning / Consents

Like all of the options the key consenting issues for this option relate to:

- The take and / or damming of water
- The construction of dams in waterbodies
- The flooding and construction of infrastructure within an outstanding natural landscape
- Works within significant natural areas.

The upper Waitaki catchment is already fully allocated to the existing power scheme and other users. In this context the filling regime for the option will need to be very carefully designed to ensure that it does not over-allocate water (e.g. by only taking water in high flow conditions) and does not impact on other users. Any filling regime reliant on 'high-flow' takes will need to be cognisant of the existing significant impacts that have occurred on the flow of the Pukaki River.

The construction of the dam that supports this option will need to ensure that the high values of Lake Pukaki are maintained and that flooding of upstream water bodies aligns with the relevant objectives and policies. Of note, the water bodies upstream of Lake Pukaki, which will be impacted by flooding from the dam, are identified in the Waitaki Catchment Water Allocation Regional Plan as having high natural character worthy of a high level of protection.

The entire MacKenzie Basin is identified in the MacKenzie District Plan as an outstanding natural landscape. The protection of these outstanding landscape values is a matter of national importance under the Resource Management Act, and will require careful assessment if the option is taken forward. The MacKenzie District Plan identifies that the particular characteristics of this landscape include the undeveloped lakesides. Further the Plan identifies 'Lakeside Protection Areas and 'Significant Natural Areas' as specific areas that assist in the protection and enhancement of the overall landscape. These specific areas will be impacted by the flooding associated with this option. Finally, the District Plan identifies the Lake's edge as having high visual vulnerability. The combination of these factors indicate that landscape considerations will be critical to this option if it is taken forward.

The option will impact identified Significant Natural Areas under the MacKenzie District Plan. These identified areas include Lake Pukaki itself and the Tasman River, as well as various smaller sites around the Lakes edge. If the option is taken forward further work will be required to determine if adverse effects on these values can be avoided and if not whether these effects can be satisfactorily minimised or offset.

4.6.4 Impact on Existing Power Schemes and Other Infrastructure

Based on current maximum storage volumes of 2325 Mm^3 and 1680 GWh in Lake Pukaki (from Meridian website), a cubic metre of water stored in Lake Pukaki represents 0.72 kWh of generation in the downstream Waitaki hydro system. The mean daily discharge from Lake Pukaki to the Pukaki canal has been back-calculated from storage and inflow data at Lake Pukaki. The mean discharge is estimated to be 182.6 m^3/s, which represents 11.4 GWh of downstream generation.

Discharge from Lake Pukaki varies through the year. For cost estimation purposes, energy loss during construction is based on the mean daily value. Each day of outage could cost 11.4 GWh in lost energy, however it might be possible to reduce this loss by increasing release from Lake Ohau during construction. This would depend on available storage in Lakes Ohau and Benmore and would require advance planning.

The mean annual generation at Tekapo A and B is 960 GWh. The mean annual discharge from Lake Tekapo to Lake Pukaki is 2183 Mm^3, so each cubic metre of water generates 0.44 kWh at the Tekapo stations. The mean daily discharge and generation values are 69 m^3/s and 2.6 GWh respectively. If construction at Tekapo B is planned in advance (for example, by increasing discharge from Pukaki to compensate for the outage at Tekapo B), it might be possible to limit the daily energy loss to just the 2.6 GWh at Tekapo B.

4.7 Cost Estimate of Selected Configuration

The estimated P_{50} cost for the selected configuration is NZ$8.5 Billion as further detailed below.

The cost breakdown is provided in Appendix C and includes:-

- Site establishment and disestablishment
- Dams as required for the FSL560 reservoir level
- Spillway and canal inlet structure
- Pukaki and Tekapo B power stations
- Turbine and generating plant.
- Transmission and switchyards
- Access roads

Land acquisition and related costs are not included.

Table 4-6: Cost Estimate Site 3

Item	Description	Base Estimate	P_{50} Contingency
1.	**Client Internal Cost**	378.9	113.7
2.	**Client's Design**	587.0	176.1
3.	**Consent preparation**	120.1	36.0
4.	**Site Investigations**	160.1	48.0
5.	**Property & Utilities**	13.3	4.0
6.	**Project Specific Insurances**	80.0	24.0
7.	**Construction**	5,336.6	1,462.0
8.	**Project Base Estimate (1+2+3+4+5+6+7)**		6,676.1
9.	**Contingency (Assessed/Analysed)**		1,863.8
10.	**Total Project Expected Estimate (P_{50})**		**8,539.9**
11.	**Funding Risk**	**50%**	4,270.0
12.	**90th Percentile Estimate (P_{90})**		12,809.0

The budgets have been prepared to AACE **class 5** with P_{50} contingencies between 25% and 30% depending on the particular cost items and P_{90} funding risk at an additional 50% in accordance with cost estimation practices generally applied in New Zealand (for example NZTA etc).

4.8 Project Schedule of Selected Configuration

A high-level construction staging is summarised in Section 4.5.4. Based on the high-level construction staging, a high-level project schedule is generated with the consideration of the following staged work. A tabulated project schedule is presented in:

- Site setup and establishment.
- New public access road diversion across Pukaki River (at 1 km away from the nominated construction haul roads).
- Construction of cofferdams at the proposed new Gate 18 location and at the new Pukaki hydro intake location.
- Construction of new Gate 18 and connection to the existing Pukaki canal.
- Construction of new Pukaki hydro and connection to the existing Pukaki canal (connection could be done concurrently with new Gate 18 connection to minimise outage.
- Construction of the temporary diversion tunnels and construction of the new downstream shoulder of the embankment.
- Commencing lowering the existing embankment dam crest and raising the embankment to design level.
- Construction of new spillway (this could be done concurrently with the dam raise work).
- Construction of new access roads on western and eastern sides of Lake Pukaki.
- Block temporary diversion tunnels.

	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Staged Construction Works	**Yr 1**	**Yr 1**	**Yr 1**	**Yr 1**	**Yr 2**	**Yr 2**	**Yr 2**	**Yr 2**	**Yr 3**	**Yr 3**	**Yr 3**	**Yr 3**	**Yr 4**	**Yr 4**	**Yr 4**	**Yr 4**	**Yr 5**	**Yr 5**	**Yr 5**	**Yr 5**
Site Establishment																				
Equipment Mobilisation																				
Construction Camp																				
Access Roads																				
State Highway relocation																				
SH8 Divsersion																				
New Bridge across Pukaki River																				
SH82 (to Mt Cook)																				
Canal Inlet Structure																				
Cofferdam																				
Intake structure																				
Tunneling																				
Canal and Stilling Basin																				
Diversion Tunnel																				
Cofferdam																				
Tunneling																				
Diversion gates																				
Powerhouse																				
Cofferdam																				
Intake structure																				
Penstocks																				
Powerhouse structure																				
Tailrace canal																				
Dam																				
Stage 1: Downstream Shoulder Foundation Preparation - expose and tie into existing darinage zone - extend the existing diversion culvert.																				
Stage 2: Construction of the new downstream shoulder																				
Stage 3: Construction of downstream shoulder to RL536.5 m																				
Stage 4: Upstream shoulder removal																				
Stage 5: Completion of upstream core raise to RL536.5 m.																				
Stage 6: Dam raise to RL566.0 m																				
Spillway																				
Excavations																				
Concrete																				
Stilling basin excavations																				
Installation of gates																				
Tekapo B																				
New powerhouse structure																				
New penstock																				
Connection to existing intake																				
Tailrace																				
Demolition of existing infrastructure																				
Lake Commencing																				

4.9 Summary

Key details of the selected configuration for Site 3 are as follows:

Table 4-7: Site 3 Details

Site 3 Summary	
Storage Provided (TWh)	5.0
Capacity of new generation (MW)	105
Capacity of existing generation supported (MW)	1553
Total generation capacity supported (MW)	1656
Live storage of Reservoir (Mm^3)	4400
Volume of materials in main reservoir dam (Mm^3)	10.7
Indicative Cost (P_{50}) (NZ$ Billion)	8.5
Cost/TWh (NZ$ Billion)	1.7
Project Duration (years)	6

5 Multicriteria Analysis

Table 5-1 - Multicriteria Analysis (sites ranked from 1 to 3, lower to higher risk; higher to lower benefit)

	SITE 1 MOAWHANGO (FSL 1160)	Rank	SITE 2 TARUARAU (FSL910)	Rank	SITE 3 RAISING LAKE PUKAKI (FSL560)	Rank
ENGINEERING						
Tera-Watt Hours of Storage	• 2.75	2	• 1.15	3	• 5.0	1
MW of new generation	• 570	1	• 523	2	• 105	3
MW of existing generation supported	• 1460	1	• 0	3	• 1553	1
Total MW supported	• 2030	1	• 523	3	• 1656	2
Live Volume of Reservoir	• 1199	N/A	• 710	N/A	• 4400	
Area of Reservoir (km2)	• 29.7	1	• 28.9	1	• 220	3
Volume of materials in main reservoir dam	• 4.3	1	• 5.5	2	• 10.7	3
Length of tunnels	• 29.3	3	• 22.5	2	NA	1
Requires pumping to fill?	Yes	3	Yes	3	No	1
Requires GWh from existing generation to fill?	Yes	3	No	1	Yes	3
Indicative Cost (P_{50})	NZ$8.2 Billion	1	NZ$8.9 Billion	3	NZ$8.5 Billion	2
Cost per TWh	NZ$3.0 Billion	2	NZ$7.7 Billion	3	NZ$1,7 Billion	1
CULTURAL						
Ngā Kaitiaki / Iwi affiliations	• Ngāti Waewae, Ngāti Rangi, Ngāti Tūwharetoa, Ngāti Hikairo, Ngāti Hauiti, Mōkai Pātea, Ngāti Paki, Ngāti Hinemanu, Ngāti Tamakōpiri, Ngāti Whitikaupeka	N/A	• Heretaunga Tamatea (Ngāti Kahungunu), Ngāti Tūwharetoa	N/A	• Waitaha, Ngāti Mamoe, Ngai Tahu Whānui • Te Rūnanga o Ngai Tahu, Te Rūnanga o Arowhenua. Te Papatipu Rūnanga.	N/A
Waitangi Tribunal Claims	• Ngāti Waiwai clam (Wai 1260) • Ngāti Tūwharetoa claim (Wai 575) • Ngāti Tamakōpiri & Ngāti Whitikaupeka (Wai 588) • Mōkai Pātea (Wai 1705, 1639) • Rotoaira Forest Trust (Wai 61) • Ngāti Hikairo (Wai 1262) • Ngāti Paki & Ngāti Hinemanu (Wai 1835)	N/A	• Wai 201 – Mōhaka ki Ahuriri	N/A	• Ngai Tahu claims settlement act 1998	N/A
Wāhi tapu	• Te Pā o Waiū / ancient pā and battle site on the southern border. Fighting trenches can be seen today. Ngati Tamakōpiri and Ngāti Whitikaupeka were responsible for defending Rangipō Waiū from incursions. Te Ara tawhito / ancient walking track from Taupō to Heretaunga via Moawhango. Te Hautapu stream originates here. Waiōuru Army training has already desecrated sensitive areas containing wāhi tapū.	N/A	• Mahinga kai (food gathering place), Mahi Rongoa (medicinal practising), urupā -burial places, nohoanga – settlements. Te Tokatamahotu rock, Te Upokororo o Kahungunu (Kahungunu's rock) Upokororo is Kahungunu's / Māhu mōkai. Wāhi tapu, wāhi taonga, pā tuna is now a guardian of the Taruarau River. The Tokatamahotu's rock two water bodies of Ikawetea and Taruarau marks the junction.	N/A	• Nohoanga entitlements, Ana uku / Clay & rock cave paintings, burial caves, nohoanga sites along the southern and western side of the lake. Kakeroa and Aoraki landmarks that demarcate Lake Pūkaki and Te Manahuna Valley.	N/A
Te mauri o te wai	• Cross-catchment diversions. Water from the Rangitikei River catchment is being transferred to the Waikato River catchment. • Diminishes the life force of the water by taking water from one catchment and transferring it to another. • Further diminishes the flows and mauri of the Maowhango River, which has already been dammed.	N/A	• No cross-catchment diversions. All water is from the Ngaruroro River catchment (assuming the optional Rangikei intake does not proceed). • Diminishes life force by creating artificial impediments to the downstream flow of water.	N/A	• No cross-catchment diversions. All water is from the Tasman River catchment. • Further desecration of a sacred site and lake that has been dammed and raised twice.	N/A

	SITE 1 MOAWHANGO (FSL 1160)	Rank	SITE 2 TARUARAU (FSL910)	Rank	SITE 3 RAISING LAKE PUKAKI (FSL560)	Rank
	• Dams and diminishes the life force of the Rangitikei River. • Dams and diminishes the life force of the upper Tongariro River (head pond)					
Mahinga kai	• Traditional food gathering place. • Kiore, kiwi, weka, tītī, tuna, kokopu, koura, inanga, and other native species from the area.	N/A	• Tradtional food gathering place. • Tuna, kokopu, koare, matamata, inanga, koura, upokororo	N/A	• Traditional food gathering place • Kokopu, tuna, inanga, koare, koura wai, kakahi, toetoe, raupō, wiwi, kuta, korare, native flora & fauna • Historically, the lake has been used for mahinga kai (gathering or cultivating). Punatahu, at the southernmost point of the lake, is a kāinga mahinga kai (place of gathering) where tuna (eels) and birds were gathered	N/A
SOCIAL						
Land ownership	• Crosses approximately 13 land titles plus untitled land (Defense Land and Kaimanawa Forest Park) • Majority of infrastructure, including the reservoir, located on Defense Land • Headpond and parts of the duplicate tunnel located within Reserve Land (Kaimanawa Forest Park). • 4 titles owned by a power company and 9 private land titles for Moawhango Pipeline (2) and to widen the existing Poutu Canal (7 including neighbours for temporary access)	1	• Crosses approximately 19 land titles plus untitled land (Kaiweka Forest Park) • Majority of infrastructure, including the reservoir, located on private land • All 19 land titles are private land	2	• Crosses approximately 41 land titles • Approximately 9 titles owned by the Crown, 1 owned by District Council, 4 owned by power companies, the remaining are private land. • Increase in reservoir footprint will affect approximately 27 private properties.	3
Regional and local council	• Scheme located within 2 regions and 3 districts: o Manawatu-Wanganui (Horizons) – Rangitikei, Ruapehu o Waikato Region - Taupō • Changes in downstream flows potentially affect several districts within the Waikato Region, including Hamilton City, and the Waikato River intake for Auckland.	3	• Scheme located within 2 regions and 1 district: o Manawatu-Wanganui (Horizons) – Rangitikei o Hawkes Bay Region - Rangitikei • A small change in the route of one tunnel would keep all infrastructure within the Hawkes Bay Region. • Changes in downstream flows potentially affect Napier and Hastings districts within Hawkes Bay Region.	2	• Scheme located within 1 region and 1 district: o Canterbury Region – Mackenzie • Changes in downstream flows potentially affect several districts within the Canterbury Region and borders the Otago Region downstream.	1
Water allocation	• Freshwater Management Units (x2) are fully allocated and over-allocated. Partial allocation to hydropower. • The Rangitikei River downstream of the proposed scheme is subject to an existing Water Conservation Order.	2	• Freshwater Management Unit is fully allocated. • Scheme is within the Ngaruroro River catchment which is subject to a draft (proposed) Water Conservation Order. • There is a prohibition on damming within the catchment in the Regional Plan and Draft Water Conservation Order. • Rangitikei Intake Option: The Rangitikei River at the optional intake site is subject to an existing Water Conservation Order (excluded from further assessment).	3	• Freshwater Management Unit is fully allocated. Full allocation is to hydropower. • The only Water Conservation Order in the catchment is the Ahuriri River Conservation Order. The Ahuriri River converges downstream of Lake Pukaki and will not be impacted by the proposed scheme.	1
Existing infrastructure	• Will result in the upgrade of the Rangipo Powerstation and Poutu Canal. No significant shutdowns to the powerstation would be expected. During the canal upgrade water would need to be diverted down Tongariro River for a period. • The project will allow increased efficiency of existing power stations at Lake Taupō and Waikato River.	2	• No changes or impacts to existing infrastructure. All pumpstations and power stations will be new.	1	• Would result in drowning and relocation of existing roads (SH80, SH8, Hayman Road), Tekapo B powerstation, and modifying existing hydropower infrastructure at Lake Pukaki and Pukaki powerstation	3

	SITE 1 MOAWHANGO (FSL 1160)	Rank	SITE 2 TARUARAU (FSL910)	Rank	SITE 3 RAISING LAKE PUKAKI (FSL560)	Rank
Recreation	• There is currently no public access to the Defense land where the reservoir will be created. • The dam and headpond on Waipahihi Stream will impact (intersect) the Southern Access Corridor Track. • Lake Taupō attracts anglers from around NZ and the world. The fishery is managed by DOC and includes Lake Taupō and its tributaries including the Tongariro River, Waikato River to Huka Falls; and Lakes Moawhango, Kuratau and Otamangakau. The scheme will increase flows in Lake Taupō and the Waikato River, and potentially the Tongariro River, but decrease flows in Moawhango River and Lake Moawhango. Flows may increase or decrease within Waipakihi River upstream of the Rangipo dam, depending upon the final design. • The Tongariro River is internationally renowned for fly fishing. The Tongariro National Trout Centre and hatchery is located on the banks of the lower river. Tūrangi at the mouth of the Tongariro River used to market itself as the Trout Fishing Capital of the World. • Lake Rotoaira, separately managed by the Lake Rotoaira Trust, is a distinct but important part of the Taupō Fishery. The scheme will increase flows in Lake Rotoaira. • The Rangitikei River supports a nationally significant trout fishery. It also supports canoeing, jet boating and white-water rafting. The scheme will reduce flows down in the Rangitikei River catchment. • Kaimanawa horses occur in this area, although are largely confined south of the project footprint (Veltman, 2001).	2	• There is currently limited public access to the private land where the reservoir will be created. However, there are tourism ventures in the wider area such as accommodation, hunting, fishing and tramping. • The tourist route along SH49 from Taihape to Hastings is known as Gentle Annie, after the steep decent down to the Taraurua River. The Springvale Suspension Bridge is located on the Rangatikei River. • The Ngaruroro and Taruarau Rivers support trout fisheries and are used for kayaking and white water rafting.	1	• Lake Pukaki is a drawcard for national and international tourists • Would drown tourist infrastructure around the edge of Lake Pukaki such as Glentanner Reserve, aerodrome and campsite	3
Commercial interests	• Location of the reservoir on Defense land limits adverse impacts to business and farming. • Likely positive impacts to power generation for all existing downstream powerstations. • Impacts on Taupō fishery minimal so long as additional flows are discharged via the Rangipo Powerstation and flows are not significantly changed in the Tongariro River. • Potential short- and long-term impacts on tourism on the Rangitikei River, depending upon the reduction in flow.	1	• The main reservoir and some of the downstream infrastructure is on land administered by the Owhaoko B&D Trust. There is a rahui in place which prevents farming, agricultural, horticultural or forestry activities. • Some smaller parts of the scheme, including parts of Ngaruroro Dam will impact commercial farming operations on private land. • Reductions in flows may negatively impact existing water users and operators in the downstream catchment.	2	• Potential significant impacts on tourism during and immediately post-construction • Short term impacts on the Tekapo B powerstation that will need to be relocated. • Potential impacts on salmon farming in canals downstream. • Possible restrictions in flows may negatively impact existing water users and operators in the downstream catchment.	3
Landscape and visual	• The scheme is likely wholly or partly located within an Outstanding Natural Landscape as defined in the RMA 1991 • The Horizons One Plan Regional Policy Statement (RPS) identifies a number of outstanding and regionally significant features and landscapes in or near the project:	2=	• The scheme is likely wholly or partly located within an Outstanding Natural Landscape as defined in the RMA 1991 • In 1981, the New Zealand Recreational River Survey assigned the scenic value of the Taruarau	2=	• Entire project area is located within the Mackenzie Basin Outstanding Natural Landscape. • Entire project area is identified as an Area of Visual Vulnerability (either high, medium or low) in the District Plan • Lake Pukaki has very high landscape and visual values (Head, 2018) and is a drawcard for national and international tourists. • Construction works will be highly visible to local population and will impact tourist amenity.	3

	SITE 1 MOAWHANGO (FSL 1160)	Rank	SITE 2 TARUARAU (FSL910)	Rank	SITE 3 RAISING LAKE PUKAKI (FSL560)	Rank
	o The Kaimanawa Ranges, in particular the skyline and the south eastern side of the ranges, in part due to - Visual and scenic characteristics, particularly the visual prominence of the skyline in much of the Region - Ecological significance, including the Ranges' contribution to the national conservation estate o Rangitikei River and river valley from Mangarere Bridge to Putorino, and from Mangarere Bridge to the confluence of Whakaurekou River and Ohutu Stream • The project is located partly within the Kaimanawa Ranges and will potentially impact the Rangitikei River due to reductions in flows.		River as '"impressive", the second highest rating (HBRC, 2018). • In 2012, the Taruarau River was identified as nationally significant in the Hawke's Bay RiVAS assessments for natural character. Specifically, the reports states the Taruarau River had a high degree of natural character, owing to its very low level of modification (HBRC, 2018). • The Ngaruroro River is subject to a Water Conservation Order. The upper part of the Ngaruroro River, above the Whanawhana Cableway is considered to have "outstanding amenity and intrinsic values" (DOC, 2017). • The project will directly impact the Taruarau and Ngaruroro Rivers. The Ngaruroro Dam is proposed to be sited upstream of the Whanawhana Cableway.		• Lake Pukaki has several formal and informal viewing areas which will be drowned as a result of the works (although can be re-established at a higher elevation). • The realignment of SH8 may impact Scenic Viewing Areas: o SV16 Simons Pass: Provides view to south of Lake Benmore o SV18 Pukaki: Provides view to south and south east indicating the scale of the Basin o SV19 Pukaki: Provides view to west and north of Ben Ohau Range.	
Construction impacts (trucks, noise, dust, vibration)	• Construction largely in unpopulated areas owned by the Crown (Defense and DOC land) and Genesis Energy. • Few sensitive receptors such as residential areas, churches, schools, hospitals etc. • Consideration for construction impacts on Kaimanawa horses may be required.	1	• Construction largely in unpopulated areas owned by private landowners and some DOC land. • Few sensitive receptors such as residential areas, churches, schools, hospitals etc.	2	• Small construction footprint, although flooding a wide area. • Large disruption to local people due to flooding of private land, some homes, existing roads and hydropower infrastructure etc. • Approximately 7 km from the construction site to the town of Twizel.	3
Dam safety	• "High" Potential Impact Category as per NZSOLD (NZSOLD, 2015), the highest risk rating. • Potential for significant loss and damage downstream in the unlikely event of a dam failure	2=	• "High" Potential Impact Category as per NZSOLD (NZSOLD, 2015), the highest risk rating. • Potential for significant loss and damage downstream in the unlikely event of a dam failure	2=	• "High" Potential Impact Category as per NZSOLD (NZSOLD, 2015), the highest risk rating. • Potential for significant loss and damage downstream in the unlikely event of a dam failure • By far the largest storage volume of the 3 options • Waitaki cascade of electricity generation at risk downstream	3
PHYSICAL ENV.						
Threatened Environment Classification	• The entire project is located within TEC 6 (>30% left and >20% protected)	1	• The majority of project infrastructure is located within TEC 6 (>30% left and >20% protected) with parts of the Ngaruroro Dam being located within TEC 2 (10–20% indigenous cover left). There are also small areas of TEC1 (<10% indigenous cover left) in the main reservoir and dam.	2	• The dam and most of the reservoir inundation area is classified as TEC 3 (20–30% indigenous cover left) with small areas of TEC 4 (>30% left and <10% protected). • The glacial moraines at the head of Lake Pukaki are unclassified.	3
Protected Areas and Reserves	• Majority of infrastructure on Defense land. • Parts of the project pass through Kaimanawa Forest Park (DOC) • The main reservoir and Waipahihi Stream headpond will impact (intersect) the Southern Access Corridor Track on DOC and/or Defense land.	1	• The majority of the project is located on land administered by the Owhaoko B&D Trust. The land is formally protected by a Nga Whenua Rahui Kawenata which the Trust entered into with the Minister of Conservation in February 2005. The Kawenata (covenant) confers a "Reserve" status on the land. • Downstream tunnel and part of the downstream reservoir behind the Ngaruroro dam located within Kaweka Forest Park (DOC) • Main reservoir and majority of other infrastructure in private land	2	• Lakeside sections of the following conservation areas will be drowned by the project: o Mid-Tasman River Conservation Area (southern area) o Mount Cook Station Conservation Area (southern area) o Ruataniwha Conservation Area (mouth of Twin Stream, Whale Stream and Boundary Stream) o Irishman Creek Conservation Area o The Wolds Conservation Area o Lake Pūkaki Terminal Moraine Conservation Area • The proposed realignment of SH8 will cross through the Ben Ohau Conservation Area. • Lake Pukaki is part of the Te Manahuna Aoraki Project protecting a 310,000 ha area in the Upper Mackenzie Basin and Aoraki Mount Cook National Park. • Several Sites of Natural Significance are listed in the District Plan that are within or near the project area.	3

	SITE 1 MOAWHANGO (FSL 1160)	Rank	SITE 2 TARUARAU (FSL910)	Rank	SITE 3 RAISING LAKE PUKAKI (FSL560)	Rank
Vegetation Types	• Approximately 3000 ha of mapped native vegetation (LCDB v5.0) to be cleared or inundated. • The main reservoir is predominantly native vegetation: tall tussock grassland and subalpine shrubland with some wetland vegetation and matagouri scrub. • The headpond and pumpstation on Waipahihi Stream is predominantly native vegetation: tall tussock grassland with a small area of subalpine shrubland and indigenous forest. • The new tunnels and associated portals are predominantly native vegetation: indigenous forest • The Poutu Channel is predominantly exotic vegetation: exotic forest with native manuka/kanuka shrubland. Adjacent to Lake Rotoaira there are small areas of gorse, broom and native broadleaf indigenous hardwoods.	1	• Approximately 2,620 ha of mapped native vegetation (LCDB v5.0) to be cleared or inundated. • The main reservoir is predominantly native vegetation: tall tussock grassland with some wetland vegetation and manuka/kanuka shrubland • The Ngaruroro Dam reservoir is predominantly native vegetation: manuka/kanuka shrubland with a small area of broadleaf indigenous hardwoods. • The new tunnels and associated portals are predominantly exotic vegetation: exotic grassland.	3	• Approximately 300 ha of mapped native vegetation (LCDB v5.0) to be cleared or inundated. • The construction footprint at the south of Lake Pukaki (dam and SH8) is predominantly exotic vegetation: exotic grassland. • The edges of Lake Pukaki that will be inundated include a wide range of native and exotic vegetation types including: exotic forest, exotic grassland, deciduous hardwoods; and native herbaceous freshwater wetland and tall tussock grassland. • The glacial moraines at the head of Lake Pukaki are predominantly non-vegetation: gravel and rock with some exotic grassland.	2
Threatened Flora	• The northern Moawhango Ecological Region is considered to possess the highest concentration of biogeographically significant plants in New Zealand (NZ Army, 2000). • Herbfields containing a diverse flora of high conservation value are present in wetland areas (NZ Army, 2000). Turf communities support *Carex berggrenii*, *Gnapphalium ensifer* and *Myosotis pygmaea* var. *glauca* (Veltman, 2001). • Several locally or nationally rare and threatened plant species occur in the Kaimanawa Forest Park in or near the project area (Lund, 2003): o *Acaena emmittens*, bidibid (At Risk – Naturally Uncommon; Regionally Rare) o *Epilobium pychnostachyum*, willow herb (Not Threatened; Regionally Rare) o *Melicytus* aff. *Alpinus* (Not Classified; Data Deficient) o Myosotis australis “yellow” (Not Classified; Regionally Rare) o *Myosotis* aff. *pygmaea* “Volcanic Plateau”, forget-me-not (Not Classified; Nationally Endangered) o *Stackhousia minima* (Not Threatened; Gradual Decline) o *Vittadinia australis* , white fuzzweed (Not Threatened; Data Deficient) • River flats and open riparian margins are likely habitats for *Melicytus* aff. *alpinus* and *Acaena emittens.* Dry gravel terraces and short tussocklands may support *Vittadinia australis* and Stackh*ousia minima*, with *Hypericum* aff. *japonicum* on frost flats. This includes possible locations at the Waipakihi, Rangitikei, Moawhango and Ngaruroro Rivers (Lund, 2003).	Insufficient data for comparison	• There are 193 threatened and at risk plants, and 30 species of threatened and at risk bryophytes in the Hawkes Bay Region (HBRC, 2014). • Woodrose (*Dactylanthus*) and mistletoe occur in the Kaweka Range (DOC, 2005). • River flats and open riparian margins are likely habitats for *Melicytus* aff. *alpinus* and *Acaena emittens.* Dry gravel terraces and short tussocklands may support *Vittadinia australis* and *Stackhousia minima*, with *Hypericum* aff. *japonicum* on frost flats. This includes possible locations at the Waipakihi, Rangitikei, Moawhango and Ngaruroro Rivers (Lund, 2003). • The Owhaoko B&D blocks are dominated by 3 broad vegetation types: alpine tussock grasslands and herbfields (5,830 ha), scrubland (2,529 ha) and beech forest (5,244 ha). Small areas of alpine gravel, rock and scree fields are also present (33 ha). Locally there are smaller areas of more specific vegetation types related to geological and hydrological influences. These include small areas of wetland (at a range of altitudes), pumice bluffs and rocky cliffs, which provide specific habitat for specialised plant species	Insufficient data for comparison	• There are 400 vascular plant species recorded on the shores of Lake Pukaki, including 4 type localities and 11 species with restricted distributions (Macmillan, 1979). • There are several Sites of Natural Significance with important vegetation communities that may be impacted by the project: o 16 Pukaki Flats: Fescue tussock grassland, formerly the most extensive association in the district. o 17 Southern Pukaki: Native broom and prostrate kowhai on terminal moraine. Threatened plants *Coprosma intertexta* and *Crassula multicaulis*. o 19 Western Pukai: One of the only stands of montane scrub of its type on this landform left in the district. Also a good example of tarns and tarn edge vegetation. *Hebe cupressoides* present. o 20 Big Rock / Little Rhoboro: Area containing a wetland and group of tarns surrounded by grazed tussock. o 23 Tasman River: Threatened plants *Carmichaelia kirkii* (vulnerable), *Luzula celata*, *Coprosma intertexta* (vulnerable), and *Triglochin palustre* are found here. o 25 Irishman Creek: Complex of red tussockland is the largest in the Ecological Region. An area of matagouri/*Coprosma*/*Olearia* subalpine scrub is the only example in the district.	Insufficient data for comparison
Wetlands	• The scheme will drown approximately 480 ha of identified wetland (LCDB v5.0),	3	• The scheme will drown approximately 75 ha of identified wetland (LCDB	1	• The scheme will drown approximately 185 ha of identified wetland (LCDB v5.0). on the edge of Lake Pukaki	2

	SITE 1 MOAWHANGO (FSL 1160)	Rank	SITE 2 TARUARAU (FSL910)	Rank	SITE 3 RAISING LAKE PUKAKI (FSL560)	Rank
	mainly located at the site of the main reservoir.		v5.0), mainly located at the site of the main reservoir.		• The scheme will also drown a large area of glacial morraines at the head of the Lake.	
Avifauna	• Large (39 km^2) reservoir to be created will provide habitat for lake and (eventually) wetland birds. • Loss of approximately 480 ha of existing wetlands that may provide avifauna habitat. Over time it is expected that wetland habitats will re-establish on the fringes of the reservoir. Whether this will be a loss or gain in overall area is unknown, and wetland type will no doubt change. • Threatened or at risk birds recorded in the Kaimanawa Forest Park include but are not limited to (DOC, 2012): o Bush falcon o Kaka o Kakariki o Kiwi o North Island fernbird o NZ pipit o Rifleman o Whio o Whitehead • (Transmission line risk covered under Bird and Bat Strike.)	Insufficient data for comparison	• Very large (61 km2) reservoir to be created will provide habitat for lake and (eventually) wetland birds. • Loss of approximately 75 ha of existing wetlands that may provide avifauna habitat. Over time it is expected that wetland habitats will re-establish on the fringes of the reservoir. Whether this will be a loss or gain in overall area is unknown, and wetland type will no doubt change. • The Ngaruroro River is considered to be of regional importance for native birds (HBRC, 2014). • Threatened or at risk birds recorded in the Kaweka Ranges include but are not limited to (HBRC, 2014; DOC, 2005): o Bush falcon o North Island brown kiwi o North Island fernbird o North Island kaka o North Island kokako (presumed locally extinct) o NZ pipit o Whio o Whitehead o Yellow-crowned kakariki • (Transmission line risk covered under Bird and Bat Strike.)	Insufficient data for comparison	• Raising the lake will result in an increase in open water habitat in the order of 4,000 ha but will result in the loss of approximately 185 ha of wetland and drown the glacial morraines at the head of the Lake which provide valuable avifauna feeding and breeding habitat. • There are several Sites of Natural Significance with important bird habitat that may be impacted by the project: o 18 Lake Pukaki: Large deep glacial moraine dammed lake with numerous wildlife habitats. Tasman River delta at north end and lake margins provides overwintering areas for black stilt. Feeding and breeding area for black stilt, other waterfowl and waders o 19: Western Pukai: Black stilt feeding area. o 20 Big Rock / Little Rhoboro: Wetlands and tarn habitat that provide feeding area for black stilt. o 21 Boundary Stream: Streambed and sides providing habitat for birds, insects and lizards. o 23 Tasman River: Very valuable habitat for waders and waterfowl including breeding area for wrybill, black stilt, black fronted tern and banded dotterel. o 45 Tekapo / Pukaki Rivers: Wide, braided alluvial riverbeds providing important habitat for waterfowl, waders, passerines and aquatic and terrestrial insect fauna. Breeding areas for black stilts, banded dotterels, black fronted terns, black backed gulls and wrybills. A series of artificial ponds on margin of Pukaki River also provide a habitat for waterfowl and waders.	Insufficient data for comparison
Bats	• Long-tailed bats (*Chalinolobus tuberculatus*) (Threatened -Nationally Critical) are known to occur in the Kaimanawa Forest Park. Felling or drowning of mature trees has the potential to affect bat roosts. • Short-tailed bats (*Mystacina tuberculata rhyacobi*) (At Risk -Declining) are known to occur in intact forest in the Kaimanawa ranges (Lloyd, 2001) • (Transmission line risk covered under bird and bat strike.)	3	• Long-tailed bats are known to occur in the Kaimanawa Forest Park and Kaweka Forest Park. Felling or drowning of mature trees has the potential to affect roost trees • In the Hawkes Bay Region, short-tailed bats are only known from Te Urewera National Park (HBRC, 2014) located outside of the project area. • (Transmission line risk covered under bird and bat strike.)	2	• No known population of long-tailed bats at or near Lake Pukaki (ECan, 2021). • The closest short-tailed bat population is in Fiordland.	1
Herpetofauna	• 21 records in the NZ Herpetofauna Database. • 7 herpetofauna species have been recorded within 20km of the project area within the last 15 years (DOC, 2022): o 3 native gecko species o 3 native skink species o 1 introduced frog species • Includes 1 Threatened and 3 At Risk species	Insufficient data for comparison	• 32 records in the NZ Herpetofauna Database. • 4 herpetofauna species have been recorded within 20km of the project area within the last 15 years (DOC, 2022): o 2 native gecko species o 2 native skink species o 0 introduced frog species • Includes 1 Threatened and 2 At Risk species	Insufficient data for comparison	• 172 records in the NZ Herpetofauna Database. • 11 herpetofauna species have been recorded within 20km of the project area within the last 15 years (DOC, 2022): o 2 native gecko species o 9 native skink species o 0 introduced frog species • Includes 4 Threatened and 5 At Risk species • Lake Pukaki is the southern limit for the Mackenzie Skink (*Oligosoma prasinum*) (Threatened - Nationally Vulnerable)	Insufficient data for comparison
Terrestrial invertebrates	• Giant land snails (*Powelliphanta marchanti*) are found in the headwaters of the Rangitīkei River (DOC, 2012).	Insufficient data for comparison	• Limited information was available on terrestrial invertebrates. • Hawke's Bay has 3 large land snail (*Powelliphanta*) species, all of which are either Threatened or At Risk and	Insufficient data for comparison	• The glacial moraines at the head of Lake Pukaki provide habitat for three moth species endemic to Mackenzie Basin (*Gelechia lenis, Cremnogenes honesta* and *Ericotenes pukakiense*) (Mackenzie District Plan). • Western Lake Pukaki Scrub supports uncommon Ruaparaha's copper butterfly (*Lycaena ruaparaha*)	Insufficient data for comparison

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			very localised in their distribution (HBRC, 2014)		• The endemic stiletto fly *Anabarhynchus albipennis*has (Data Deficient) is only known from Lake Pukaki • Surveys in the Tasman braided riverbed has found 4 new species - a fly, bee, bug and beetle (DOC, 2022)	
Bird and bat strike	• Single 2km transmission line. • Risk of bird and bat strike.	2	• Multiple transmission lines totalling approximately 80 km • Higher risk of bird and bat strike.	3	• No additional transmission lines required.	1
Introduced mammals	• Kaimanawa horses are known to impact turf vegetation communities, including threatened plant species (DOC, 2006). • Red deer, sika deer, possums, rats, feral cats, stoats, ferrets and weasels are present in the Kaimanawa Forest Park (DOC, 2012).	Insufficient data for comparison	• Deer are known to be impacting mountain beech regeneration in the Owhaoko B&D Block (WMA, 2009). • Other pest species recorded or likely to be present include mice, rats, possums, mustelids, rabbits, hares and feral cats (WMA, 2009). • Hedgehogs are known to occur in the Kaweka Ranges (HBRC, 2019).	Insufficient data for comparison	• Limited information was available on introduced mammals. • DOC and Te Manahuna Aoraki have been conducting pest control for hedgehogs, feral cats and stoats to protect nesting birds on the Tasman River. Te Manahuna Aoraki has the aspiration of turning the Mackenzie Basin into a predator-free zone (TMA, 2019).	Insufficient data for comparison
Water quality	• Water quality in the upper Rangitikei River and the upper Moawhango River is very high, being clear, cool and well oxygenated, with relatively low conductivity, moderate hardness, low chloride, moderately alkaline pH and low faecal coliform bacteria (NZ Army, 2000). • From LAWA: o Rangitikei Catchment: The closest monitoring sites to the scheme are Moawhango on the Moawhango River at Te Moehau Road and Rangitikei at Pukeokahu. Both sites are monitored for swimming and show “poor” water quality with periodically elevated *E. coli* levels. The Rangitikei site is monitored for a wider range of parameters. Most show high water quality (A band) but have mixed trends over time. o Waikato River Catchment: The closest monitoring sites to the scheme are Tongariro at Turangi; and the Tokaanu Powerstation Tailrace Canal. The Tongariro site shows declining water quality while the Tokaanu site shows mixed results. o Lakes: There are several monitoring sites on Lake Taupō, the nearest at Stump Bay east of Tongariro River mouth. This is monitored for swimming and has good water quality.	Insufficient data for comparison	• Limited information is available on the upstream catchment but water quality is expected to be high given the kawenata in place and low level of development or farming • Water quality monitoring by HBRC on the Ngaruroro River at Kuripapango (upstream of the proposed scheme) as part of the TANK report in 2013-2014 indicated excellent water quality (HBRC, 2018). • From LAWA: o There are 11 water quality monitoring sites in the Ngaruroro catchment. The closest is Ngaruroro at Whanawhana downstream of the Ngaruroro Dam. This site shows generally high (A band) and improving water quality for most monitored parameters.	Insufficient data for comparison	• Lake Pukaki is fed by glacial meltwater from the Tasman River and generally has high water quality. The Lake does have elevated turbidity from glacial flour. • From LAWA: o Lake Pukaki is monitored Mid Lake at the Southern End. However there is insufficient data to assess attribute bands or trends over time. o The Trophic Level Index (TLI) combined water clarity, chlorophyll a, total phosphorus and total nitrogen. The TLI for Lake Pukaki is 1.9 which is “very good” (0-2) and considered to be microtrophic. • It is likely that there is water quality data available for Lake Pukaki and/or downstream areas held by Genesis Energy. This was not available for this review.	Insufficient data for comparison
Aquatic macroinvertebrates	• The macroinvertebrate fauna on the Defense land is dominated by species characteristic of upland streams with high water quality (NZ Army, 2000). • From LAWA: o Tongariro Trib at Tree Trunk Gorge Road (D/S of Rangipo Powerstation) shows high (A band) but declining indices: 5 year median MCI 130.0; QMCI 7.24; ASPM 0.710 o Tongariro at Turangi shows moderate (B band) indices with an improving MCI score and others undetermined: 5 year median MCI 122.1	Insufficient data for comparison	• The HBRC has monitored macroinvertebrate health in the Taruarau River (location unknown) in 2013 and 2014 associated with the TANK plan. Results showed excellent macroinvertebrate health with high MCI and EPT scores (HBRC, 2018). • From LAWA: o Ngarararoro at Whanawhana downstream of the proposed scheme shows moderate (B band) but declining indices. 5 year median MCI 116.0; QMCI 5.78; ASPM 0.518	Insufficient data for comparison	• Nationally uncommon species occur in the Tasman River, such as the caddisfly Psilochorema folioharpax (DOC, 2022)	Insufficient data for comparison

	SITE 1 MOAWHANGO (FSL 1160)	Rank	SITE 2 TARUARAU (FSL910)	Rank	SITE 3 RAISING LAKE PUKAKI (FSL560)	Rank
	• Rangitikei at Pukeokahu shows moderate (B band) but declining indices: 5 year median MCI 112.0; QMCI 5.46; ASPM 0.519					
Fish	• A total of one exotic species (brook char) has been recorded within or upstream of the proposed scheme (NZFFD). • Five species of fish have been recorded from the Moawhango River and its tributaries: the native longfinned eel and upland bully, and the introduced brown trout, rainbow trout and brook trout (NZ Army, 2000). • DOC records list Brown mudfish (At Risk – Declining) as occurring in or near the project area • Almost all rivers, streams and lakes within and downstream of the project are internationally and/or nationally significant for trout fishing including Lake Taupō, Tongariro River and tributaries, Lake Rotoaira and the Rangitikei River.	Insufficient data for comparison	• A total of six native and two exotic species have been recorded within or upstream of the proposed scheme (NZFFD). • A fisheries survey in the Owhaoko B&D Block found only longfin eel (*Anguilla dieffenbachii*) (At Risk - Declining) and exotic rainbow trout (WMA, 2009). • DOC records list 3 species of indigenous fish that have been found in or near the project area. All have a threat status of At Risk - Declining • In 2004, the Taruarau River was identified as a Potential Water Body of National Importance for aquatic biodiversity values by the Ministry for the Environment • The Taruarau River is a high-quality wilderness trout fishery which is regionally significant (HBRC, 2018). • The Ngaruroro River is considered to be of national importance for native fish (HBRC, 2014).	Insufficient data for comparison	• A total of seven native species and two exotic have been recorded within or upstream of the proposed scheme (NZFFD). • The NZFFD records the following species from Lake Pukaki: o At Risk – Declining: Longfin eel, koaro, Canterbury galaxias o Not Threatened: Common bully, upland bully o Exotic: Brown trout, rainbow trout • Lake Pukaki supports a rare, non-migratory, lacustrine population of kaoro, sustained in part by the high lake turbidity creating a scarcity of trout (MfE, 2002). • The non-migratory Upland long-jaw galaxias (*Galaxias* aff. *prognathus* 'Waitaki') (Threatened – Nationally Vulnerable) is found in the catchment • Small numbers of brown and rainbow trout occur in the Lake, with salmon fingerlings being released by salmon farmers periodically. Sports fish are common in the canals. • There are no aquatic macrophytes in Lake Pukaki due to the large seasonal drawdown by hydropower generation (8m), high turbidity from glacial flour, and wave action (Macmillan, 1979).	Insufficient data for comparison
Fish passage	• Proposed Moawhango Reservoir and headpond will restrict fish passage to approximately 200 km of stream and river. • Fish passage will be restricted in 2 catchments: o Rangitikei River o Waikato River • Fish passage on the upper Moawhango River (Rangitikei catchment) is already restricted by the Moawhango Dam	2	• The Ngaruroro dam will restrict fish passage to approximately 1,750 km of stream and river. • Fish passage will be restricted in 1 catchment: o Ngaroroa River	3	• No change in fish passage (existing dam in place to be raised)	1

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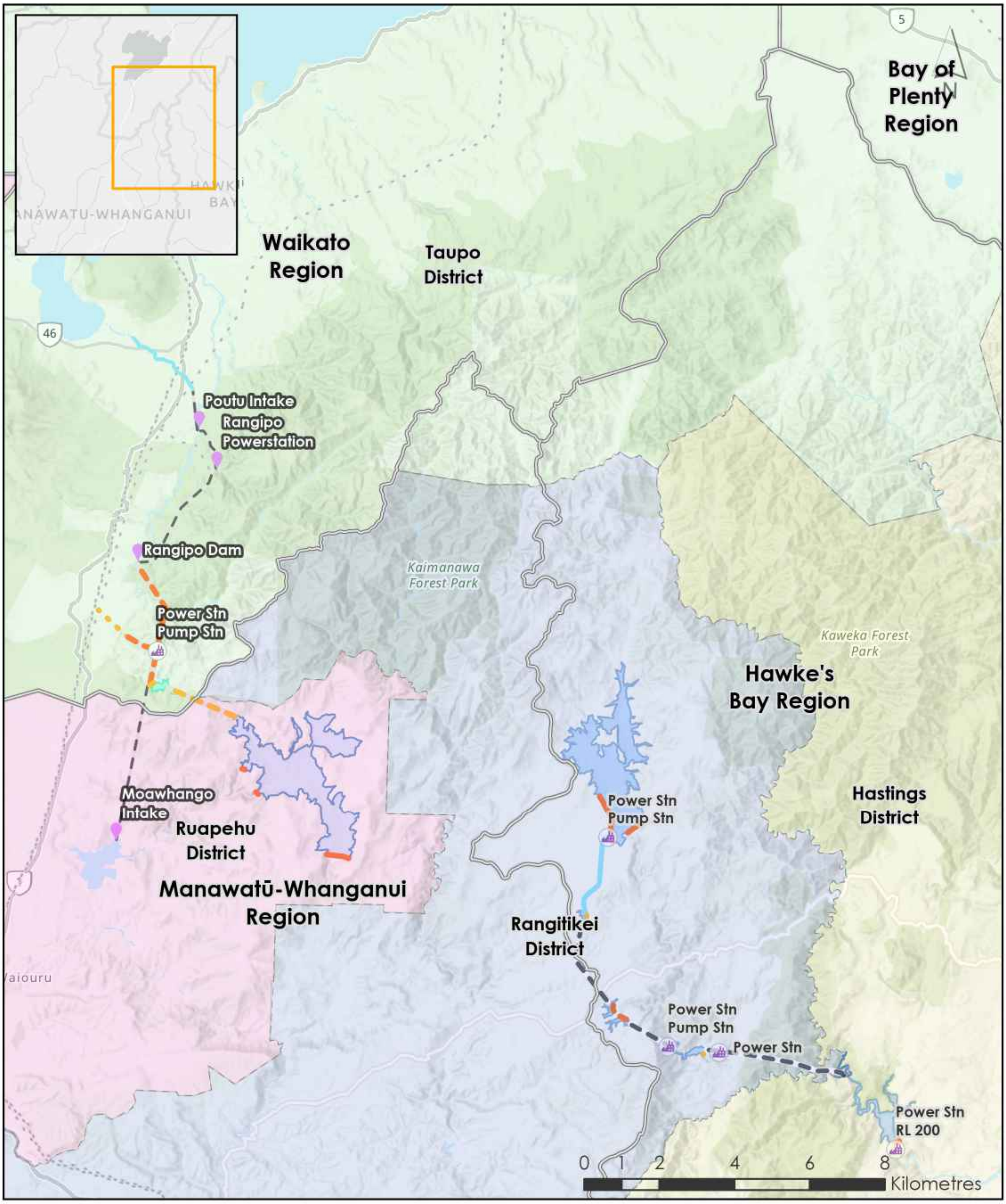
Appendices

We design with community in mind

Appendix A GIS Maps



Regional and District Boundaries

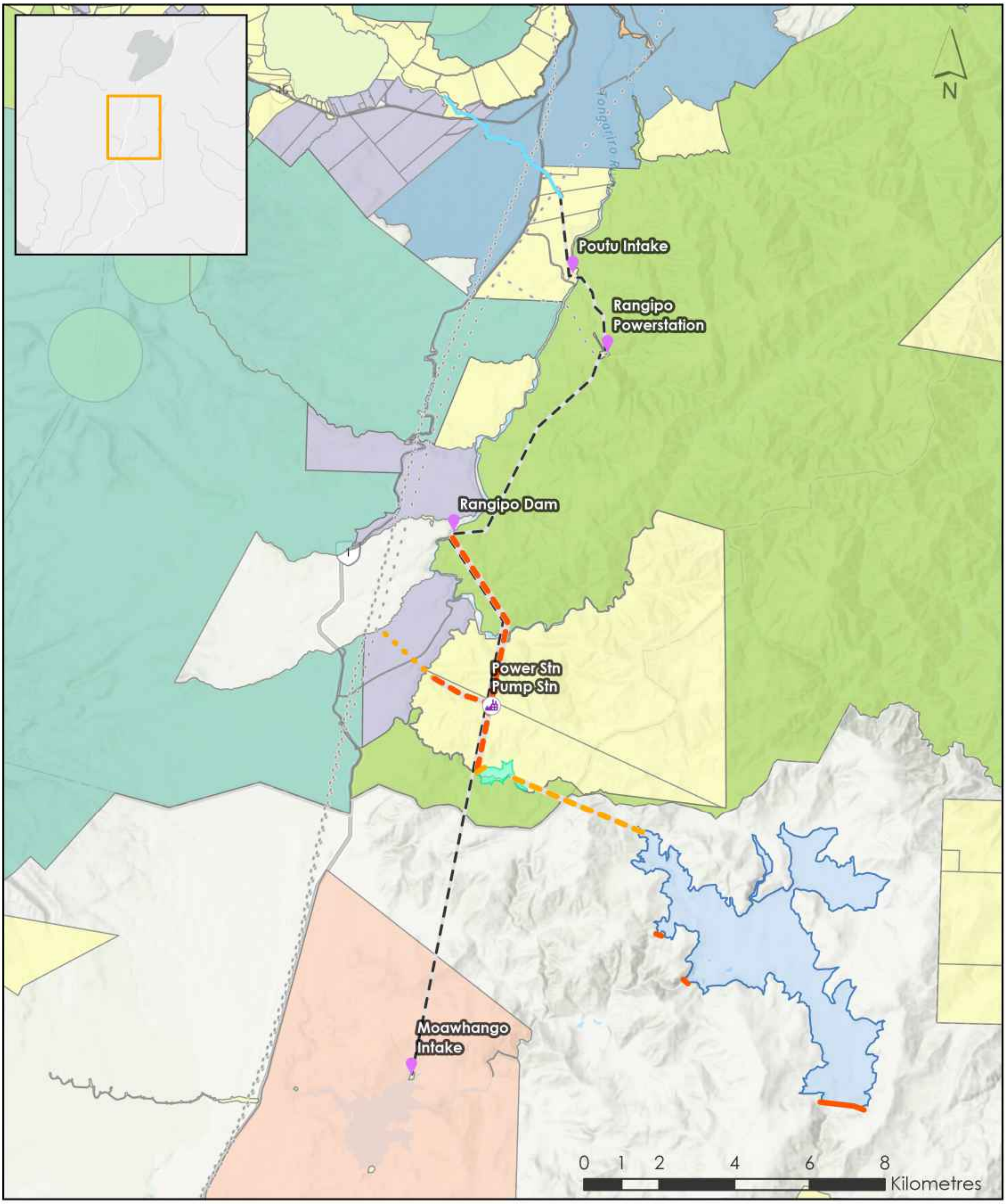
This map shows the Regional and Territorial Authority Boundaries that interact with Site One and Site Two.

Scale: 1:350,000
Data Sources: Stantec, StatsNZ
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: CD, Stantec (2022)

Regional Council Boundary
Territorial Authority
Hastings District
Rangitikei District
Ruapehu District
Taupo District

New Main Reservoir 1140
New Regulating Pond
New Dam
New Regulating Dam
New Powerhouse Access Tunnel
New 220kV Transmission Line
Existing Tunnel
Canal

Stantec



Land Ownership - Site One

This map shows land titles, and land classified as Protected Areas such as national parks and reserves.

Scale: 1:180,000
Data Sources: Stantec, LINZ
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: CD, Stantec (2022)

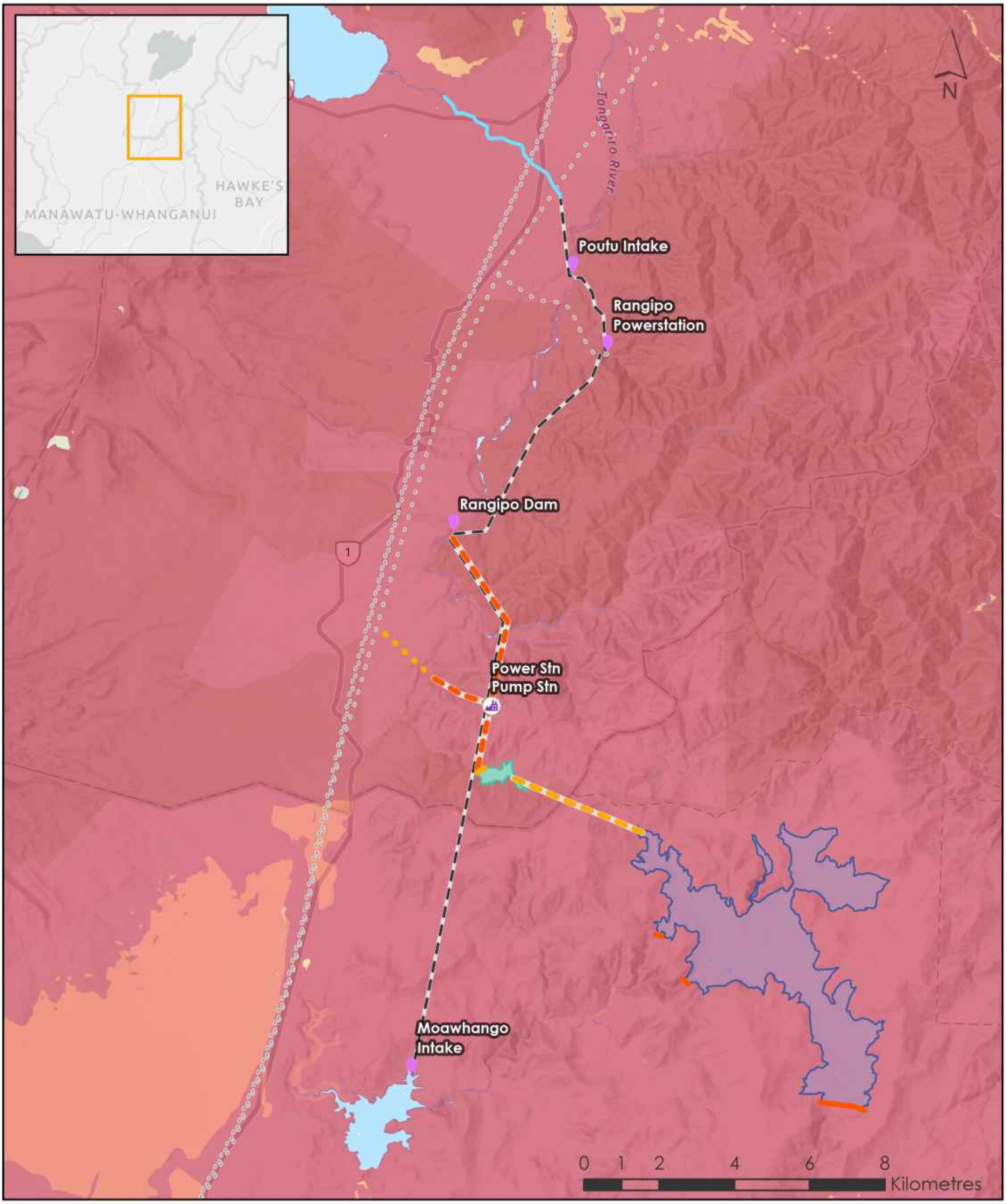
Protected Areas
- Conservation Area
- Marginal Strip
- National Park
- Reserve

NZ Property Titles - Type
- Cross lease
- Freehold
- Gazette Notice
- Leasehold
- Records Embodied in the Register
- Supplementary Record Sheet
- Timeshare
- Unit Title

- Existing Facilities
- New Facilities

- New Main Reservoir 1140
- New Regulating Pond
- New Dam
- New Regulating Dam
- New Powerhouse Access Tunnel
- New 220kV Transmission Line
- Existing Tunnel
- Poutu Canal

Stantec



Threatened Environment Classification - Site One

This map shows the Threatened Environment Classification (TEC 2012) for the area.

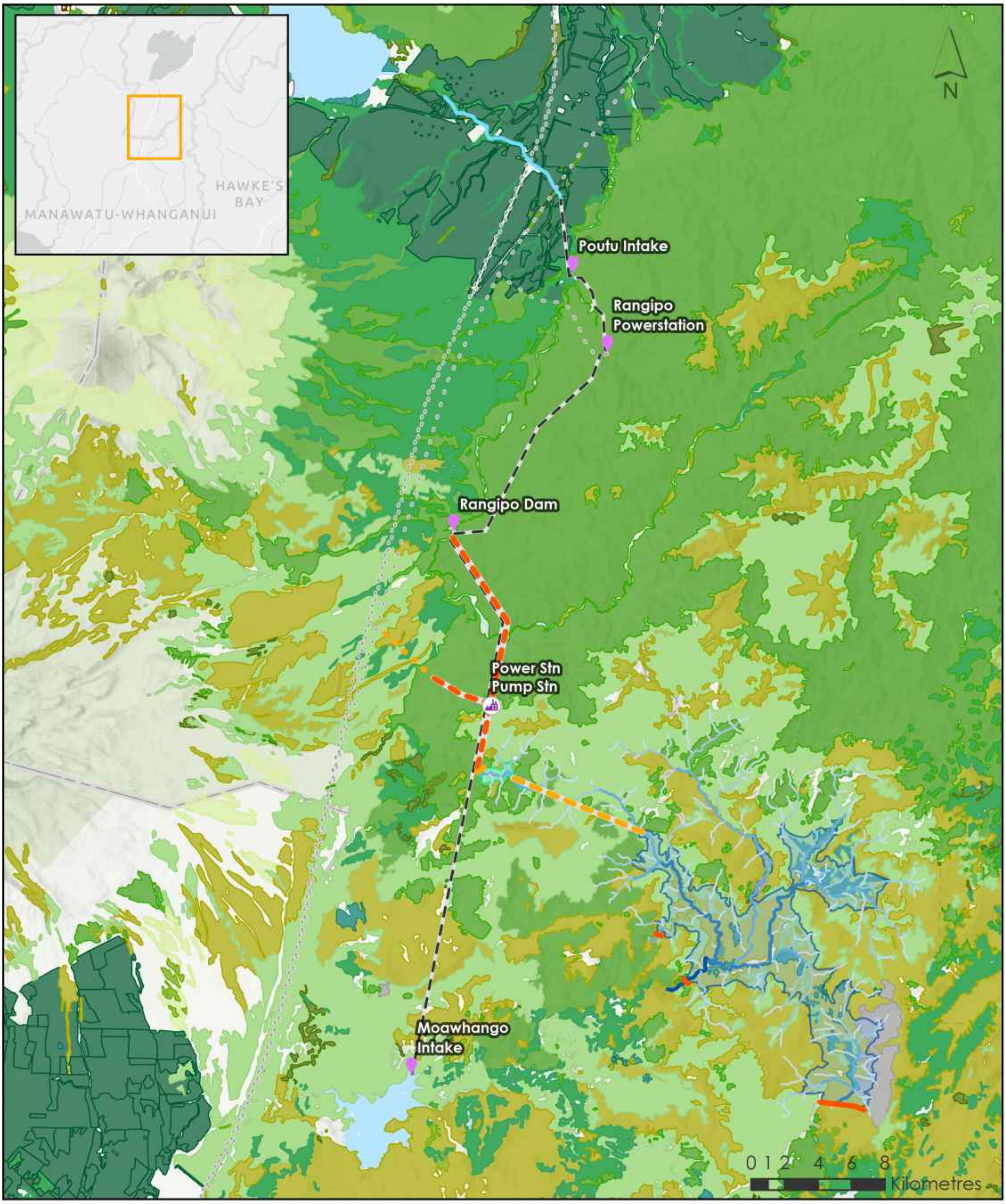
Scale: 1:180,000
Data Sources: Stantec, Landcare Research
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: CD, Stantec (2022)

TEC 2012
- 0
- 1
- 2
- 3
- 4
- 5
- 6

- Existing Facilities
- New Facilities

- New Main Reservoir 1140
- New Regulating Pond
- New Dam
- New Regulating Dam
- New Powerhouse Access Tunnel
- New 220kV Transmission Line
- Existing Tunnel
- Poutu Canal

Stantec



Vegetation - Site One

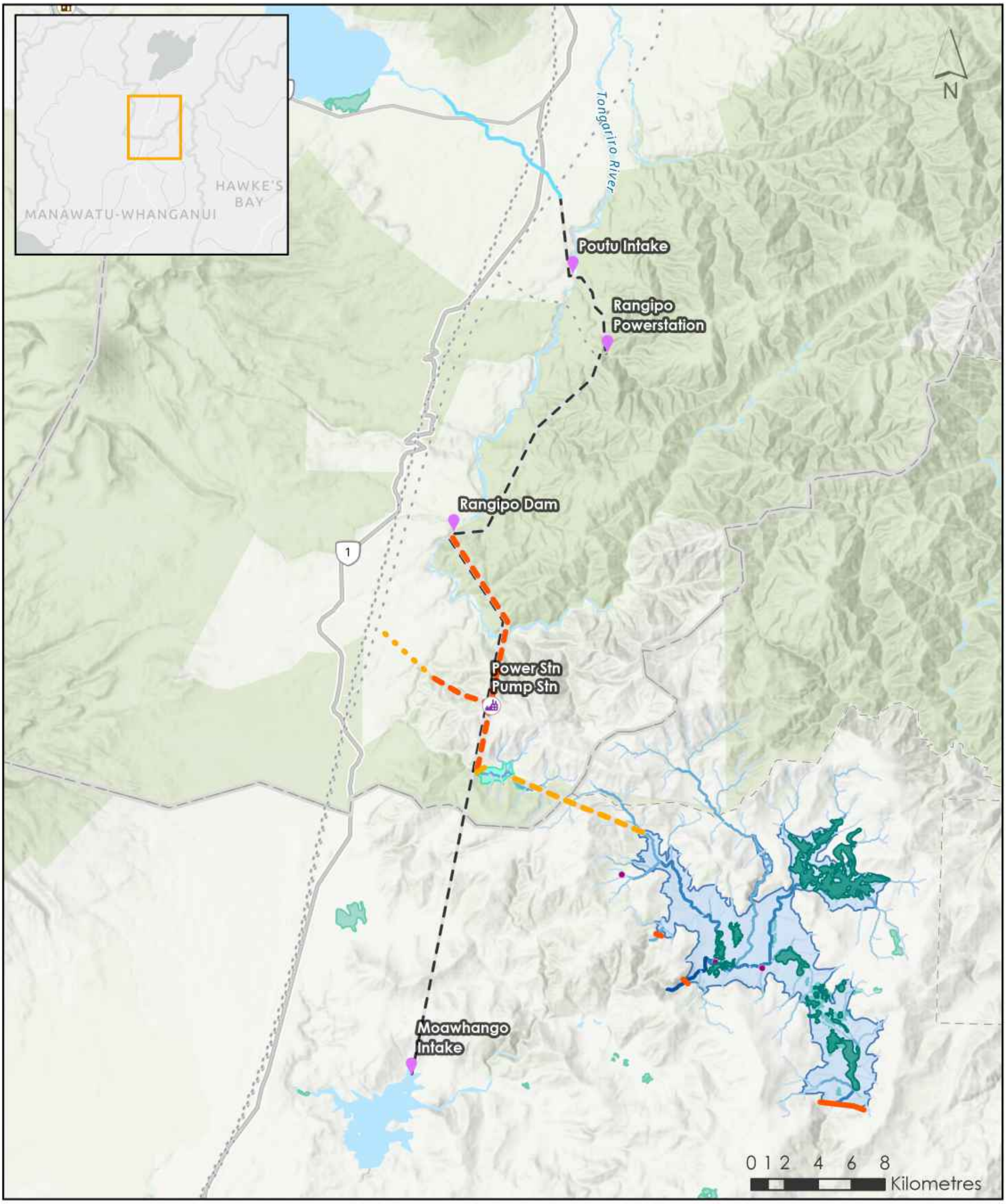
This map shows the areas of native vegetation in the LCDB 5.0 dataset that may be impacted by Site One.

Scale: 1:180,000
Data Sources: Stantec, Land Cover Database (LCDB), MfE
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in coordinate system.
Author: CD, Stantec (2022)

LCDB 2018
- Alpine Grass/Herbfield
- Broadleaved Indigenous Hardwoods
- Exotic Forest
- Fernland
- Flaxland
- Herbaceous Freshwater Vegetation
- Indigenous Forest
- Manuka and/or Kanuka
- Matagouri or Grey Scrub
- Sub Alpine Shrubland
- Tall Tussock Grassland

- New Main Reservoir 1140
- New Regulating Pond
- Existing Facilities
- New Facilities
- New Powerhouse Access Tunnel
- New Regulating Dam
- New 220kV Transmission Line
- Poutu Canal
- New Dam
- Existing Tunnel

Stantec



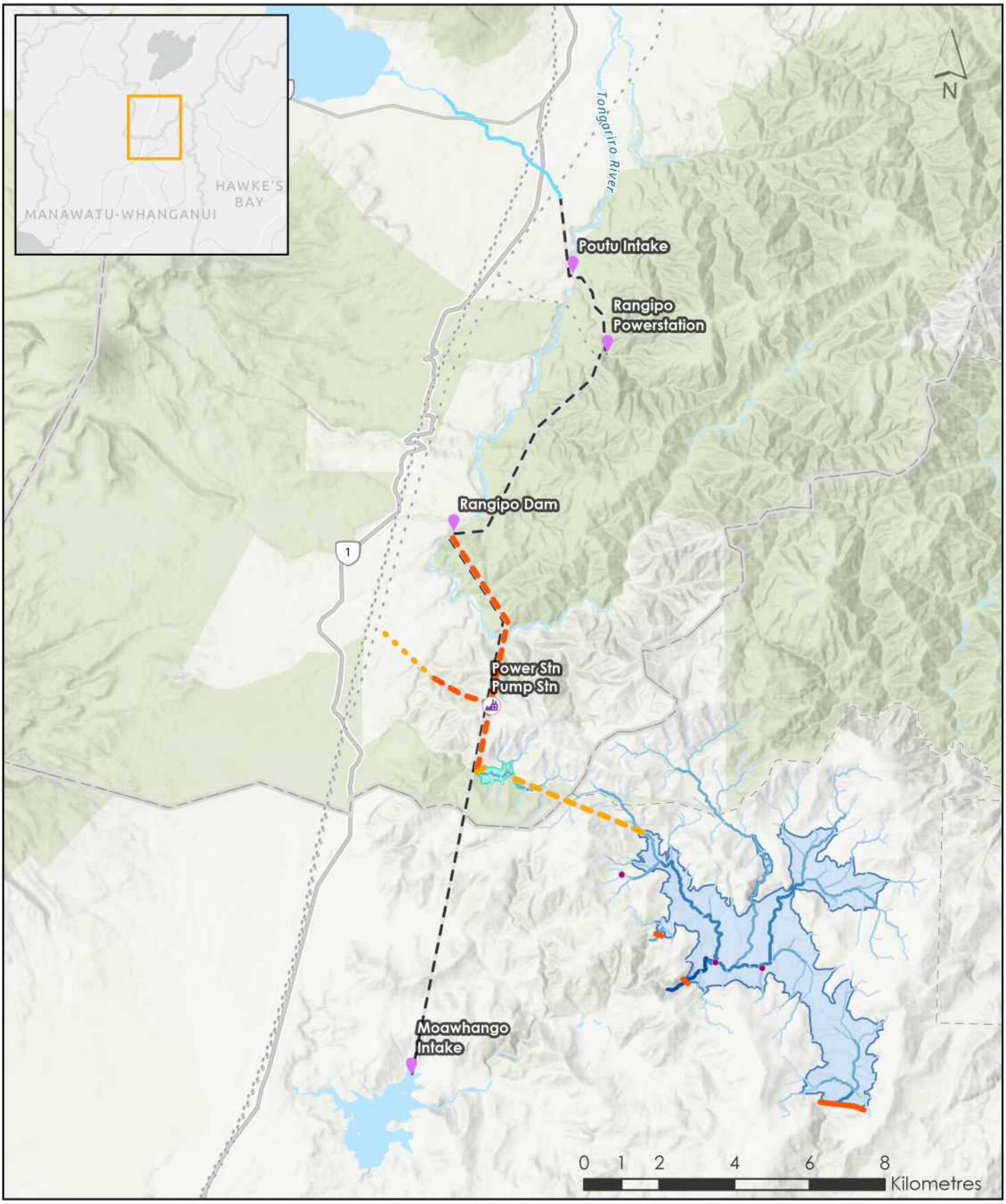
Wetlands - Site One

This map shows the areas of wetlands in the LCDB 5.0 and MfE datasets that are impacted by Site One.

Scale: 1:180,000
Data Sources: Stantec, Land Cover Database (LCDB), MfE
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in coordinate system.
Author: CD, Stantec (2022)

- LCDB Herbaceous Freshwater Vegetation
- MfE Wetland Extent
- Existing Facilities
- New Facilities
- New Main Reservoir 1140
- New Regulating Pond
- New Dam
- New Regulating Dam
- New Powerhouse Access Tunnel
- New 220kV Transmission Line
- Existing Tunnels
- Poutu Canal

Stantec



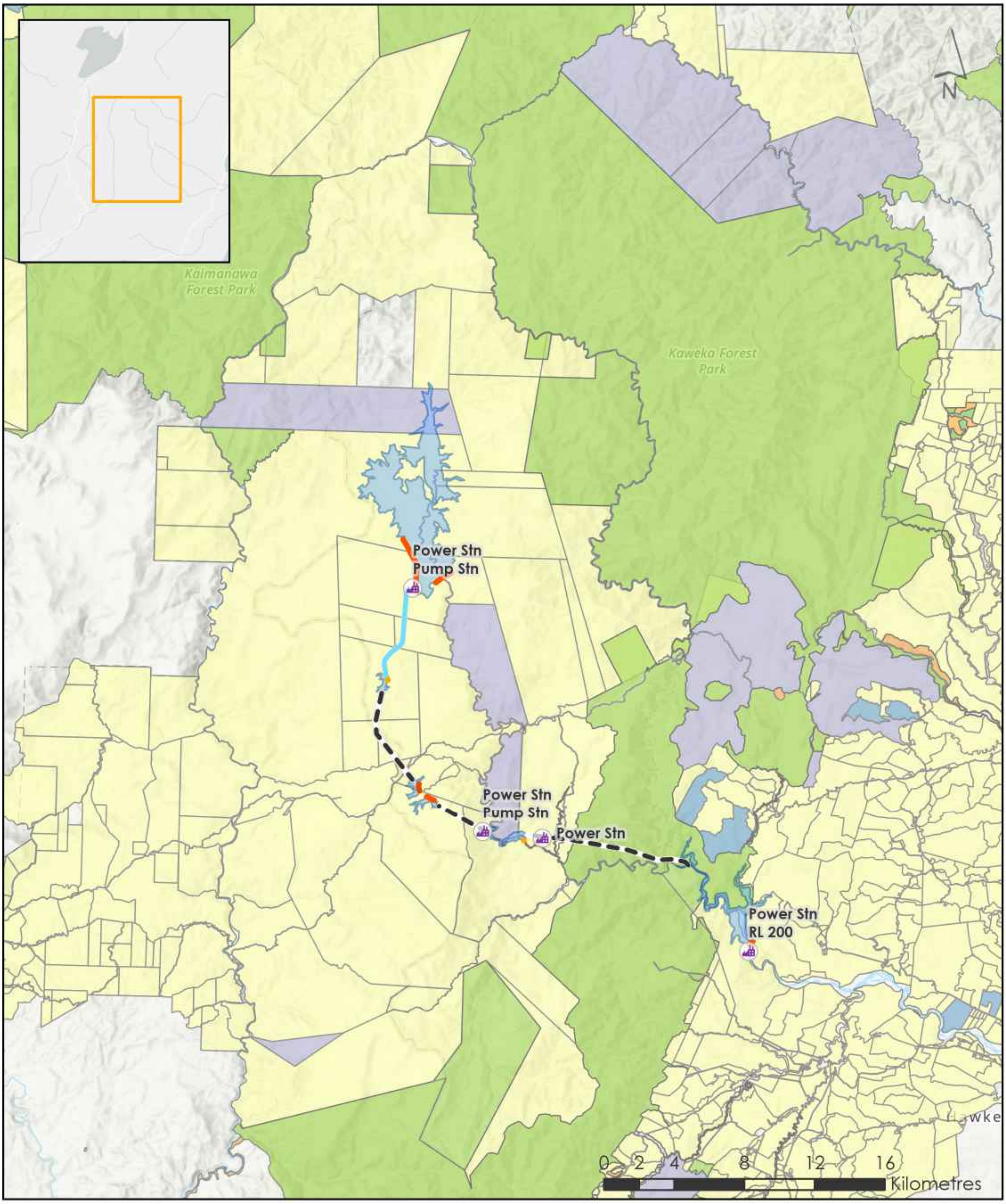
Fish Passage - Site One

This map shows the length of streams cut off by the proposed schemes including NZ Freshwater Fish Database (NZFFD).

Scale: 1:180,000
Data Sources: Stantec, NIWA
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: CD, Stantec (2022)

- NZFFD Survey Location
- NIWA River Stream Order
  - 1
  - 2
  - 3
  - 4
  - 5 - 6
- Existing Facilities
- New Facilities
- New Main Reservoir 1140
- New Regulating Pond
- New Dam
- New Regulating Dam
- New Powerhouse Access Tunnel
- New 220kV Transmission Line
- Existing Tunnel
- Poutu Canal

Stantec



Land Ownership - Site Two

This map shows land titles, and land classified as Protected Areas such as national parks and reserves.

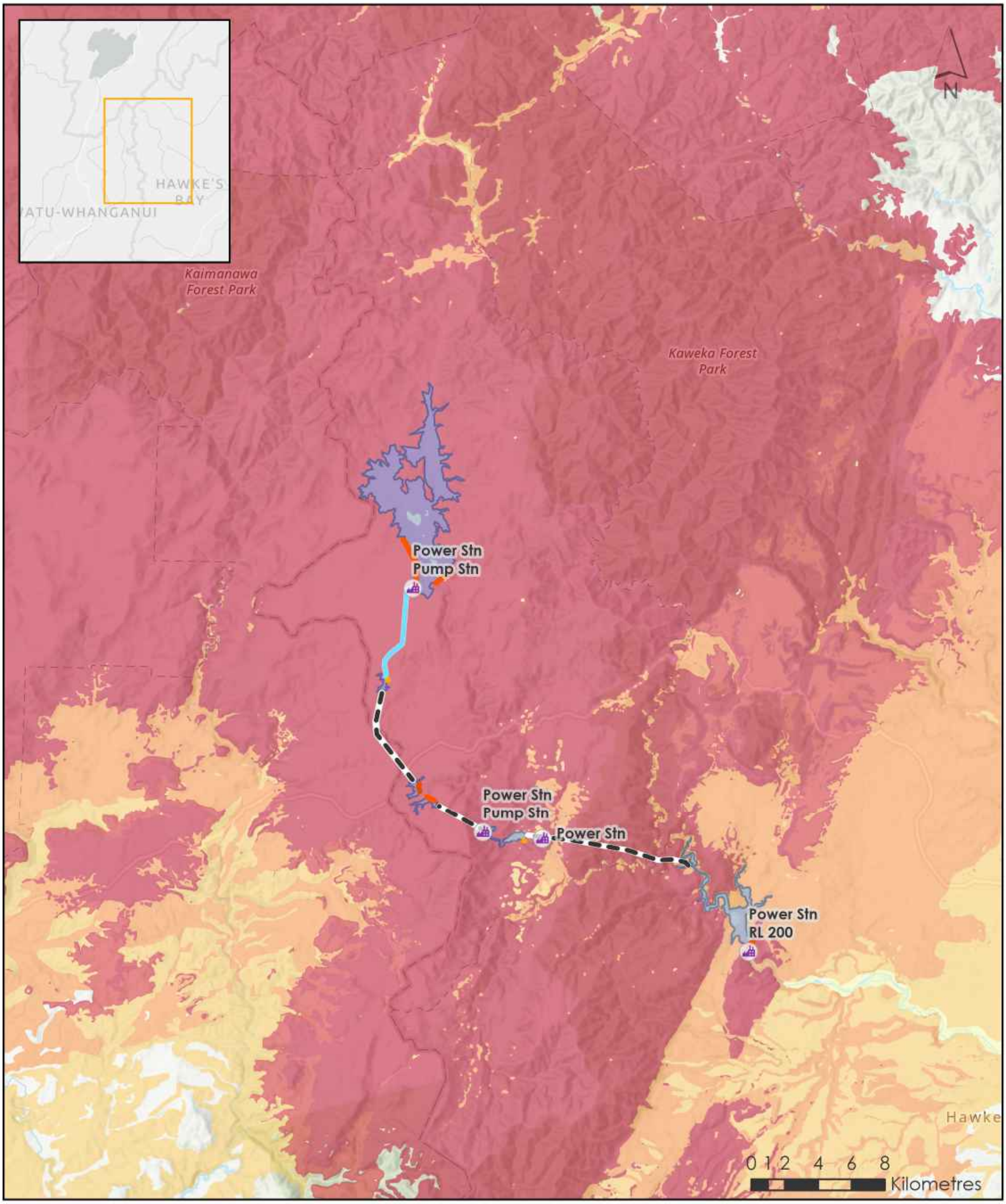
Scale: 1:300,000
Data Sources: Stantec, LINZ
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: CD, Stantec (2022)

Protected Areas
- Conservation Area
- Marginal Strip
- National Park
- Reserve

NZ Property Titles - Type
- Cross lease
- Freehold
- Gazette Notice
- Leasehold
- Records Embodied in the Register
- Supplementary Record Sheet
- Timeshare
- Unit Title

- New Facilities
- Reservoir
- New Dam
- Weir
- Power Tunnel
- Canal

Stantec



Threatened Environment Classification - Site Two

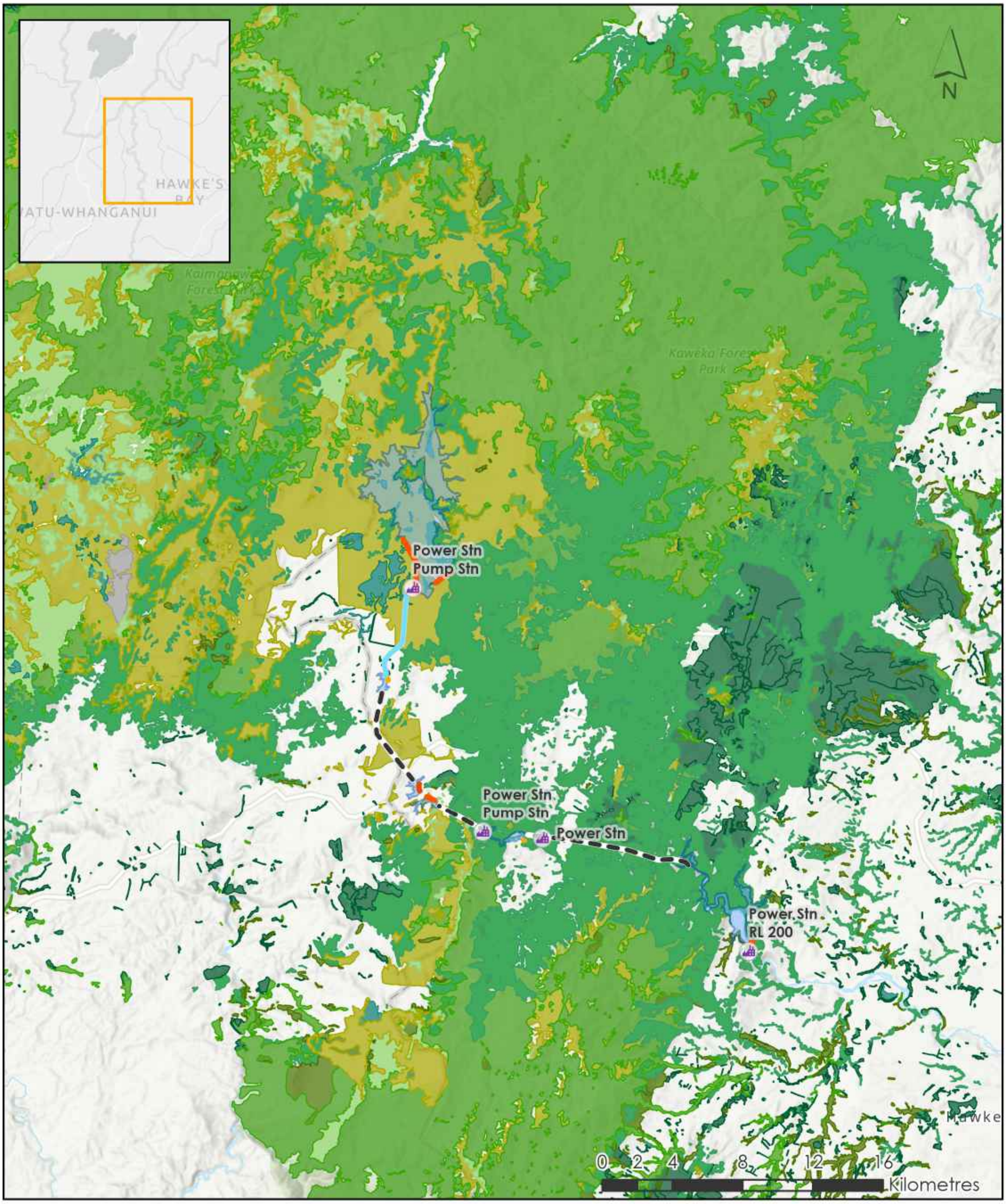
This map shows the Threatened Environment Classification (TEC 2012) for the area.

Scale: 1:300,000
Data Sources: Stantec, Landcare Research
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in coordinate system.
Author: CD, Stantec (2022)

TEC 2012
- 0
- 1
- 2
- 3
- 4
- 5
- 6

- New Facilities
- Reservoir
- New Dam
- Weir
- Power Tunnel
- Canal

Stantec



Vegetation - Site Two

This map shows the areas of native vegetation in the LCDB 5.0 dataset that may be impacted by Site Two.

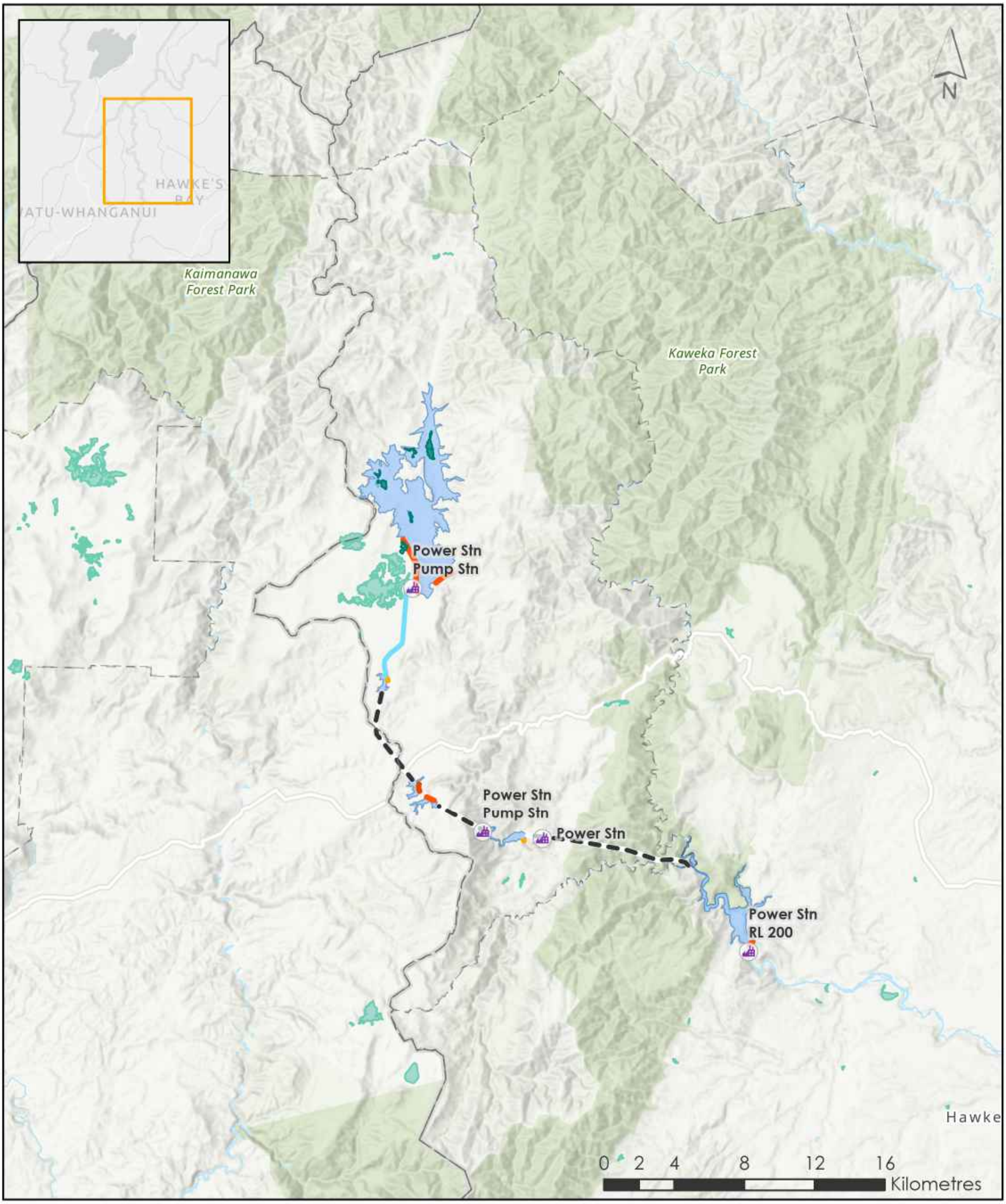
Scale: 1:300,000
Data Sources: Stantec, New Zealand Land Cover Database (LCDB), MfE
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: CD, Stantec (2022)

LCDB 2018

- Alpine Grass/Herbfield
- Broadleaved Indigenous Hardwoods
- Exotic Forest
- Fernland
- Flaxland
- Herbaceous Freshwater Vegetation
- Indigenous Forest
- Manuka and/or Kanuka
- Matagouri or Grey Scrub
- Sub Alpine Shrubland
- Tall Tussock Grassland

- New Facilities
- New Dam
- Weir
- Power Tunnel
- Canal
- Reservoir

Stantec



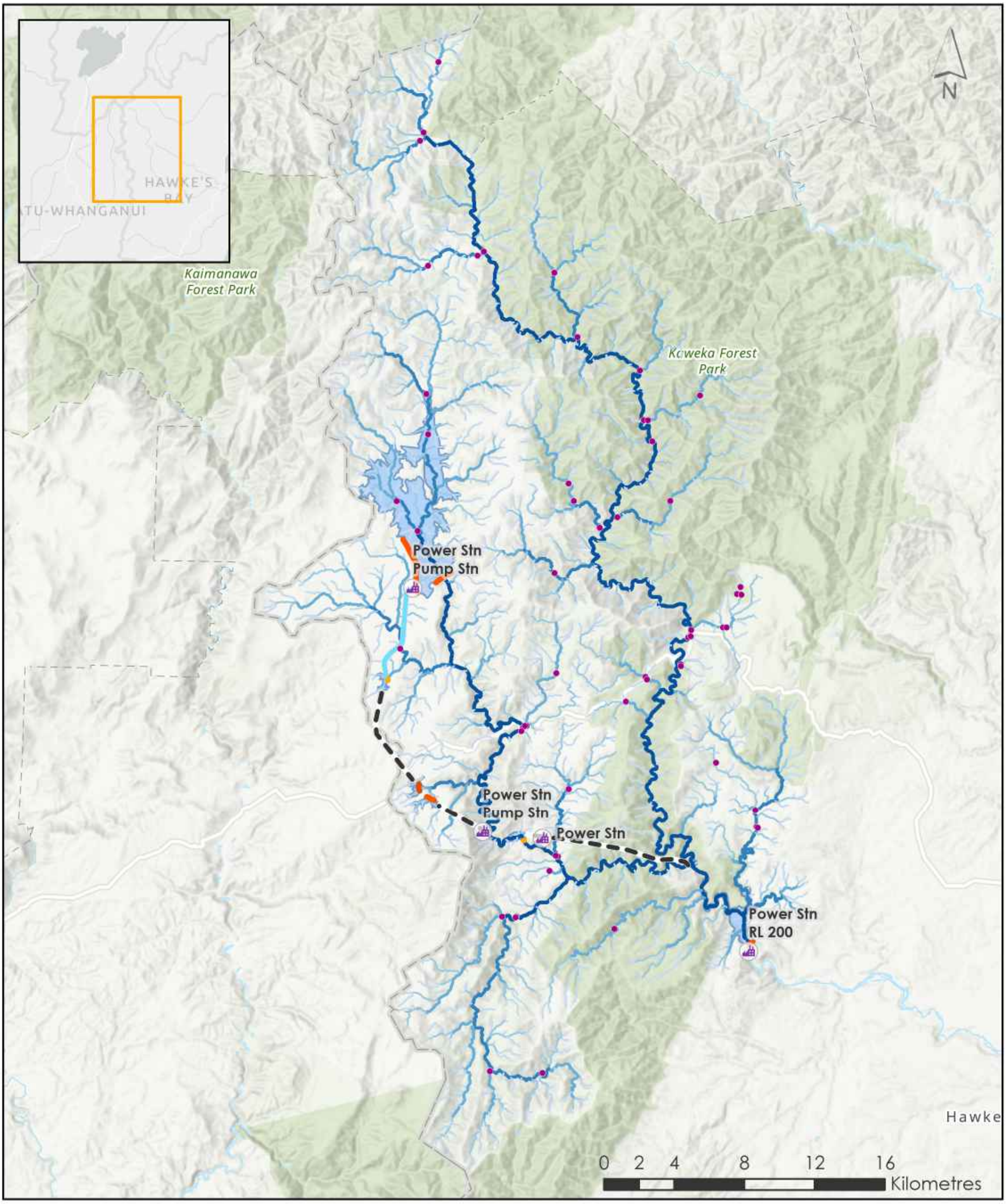
Wetlands - Site Two

This map shows the areas of wetlands in the LCDB 5.0 and MfE datasets that are impacted by Site Two.

Scale: 1:300,000
Data Sources: Stantec, New Zealand Land Cover Database (LCDB), MfE
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: CD, Stantec (2022)

- LCDB Herbaceous Freshwater Vegetation
- MfE Wetland Extent
- New Facilities
- Dam
- Weir
- Power Tunnel
- Canal
- Reservoir

Stantec



Fish passage - Site Two

This map shows the length of streams cut off by the proposed schemes including NZ Freshwater Fish Database (NZFFD).

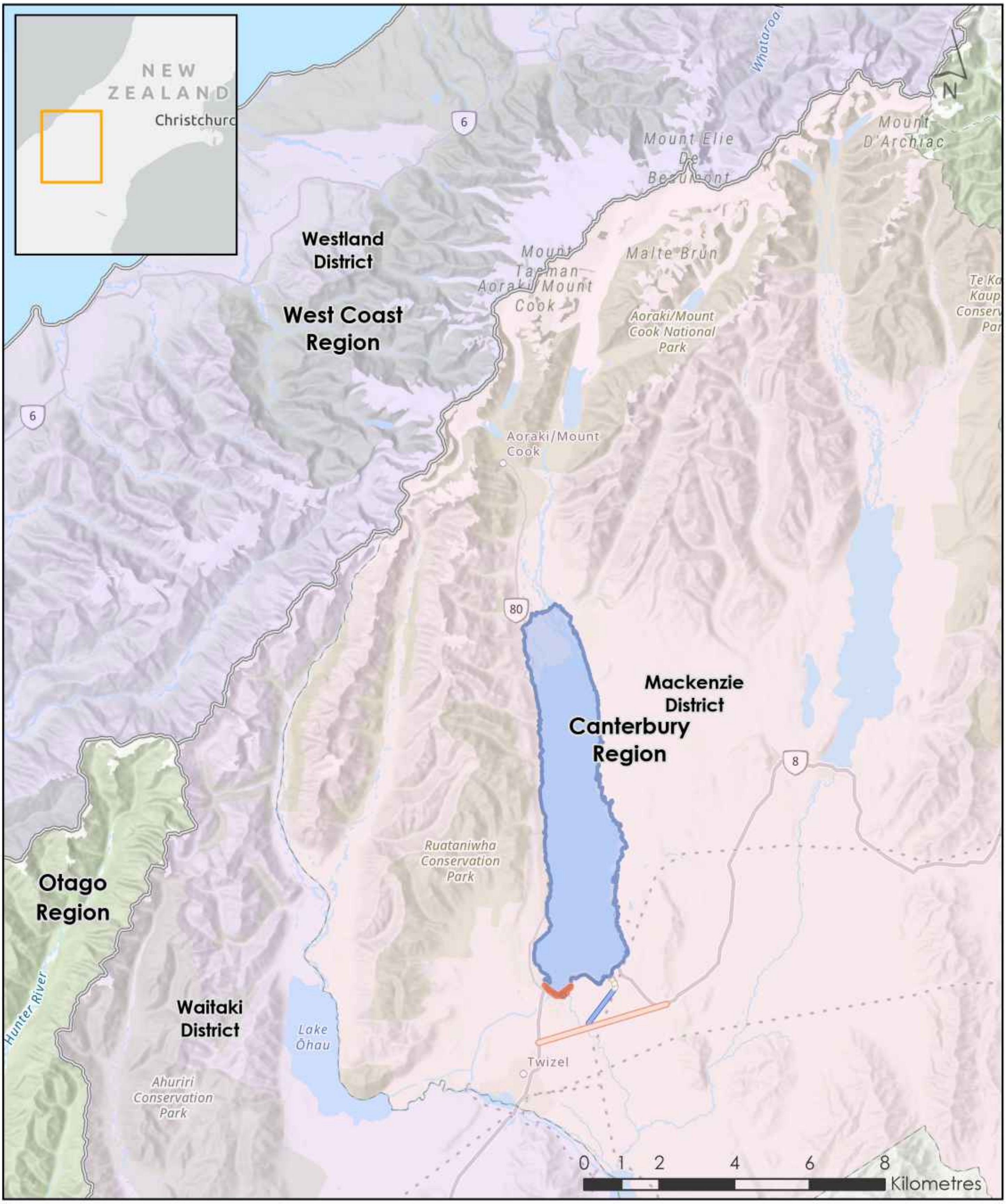
Scale: 1:300,000
Data Sources: Stantec, NIWA
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: CD, Stantec (2022)

- NZFFD Survey Location

NIWA River Stream Order
- 1
- 2
- 3
- 4
- 5 - 6

- New Facilities
- Reservoir
- New Dam
- Weir
- Power Tunnel
- Canal

Stantec



Regional and District Boundaries

This map shows the Regional and Territorial Authority Boundaries that interact with Site Three.

Regional Council Boundary

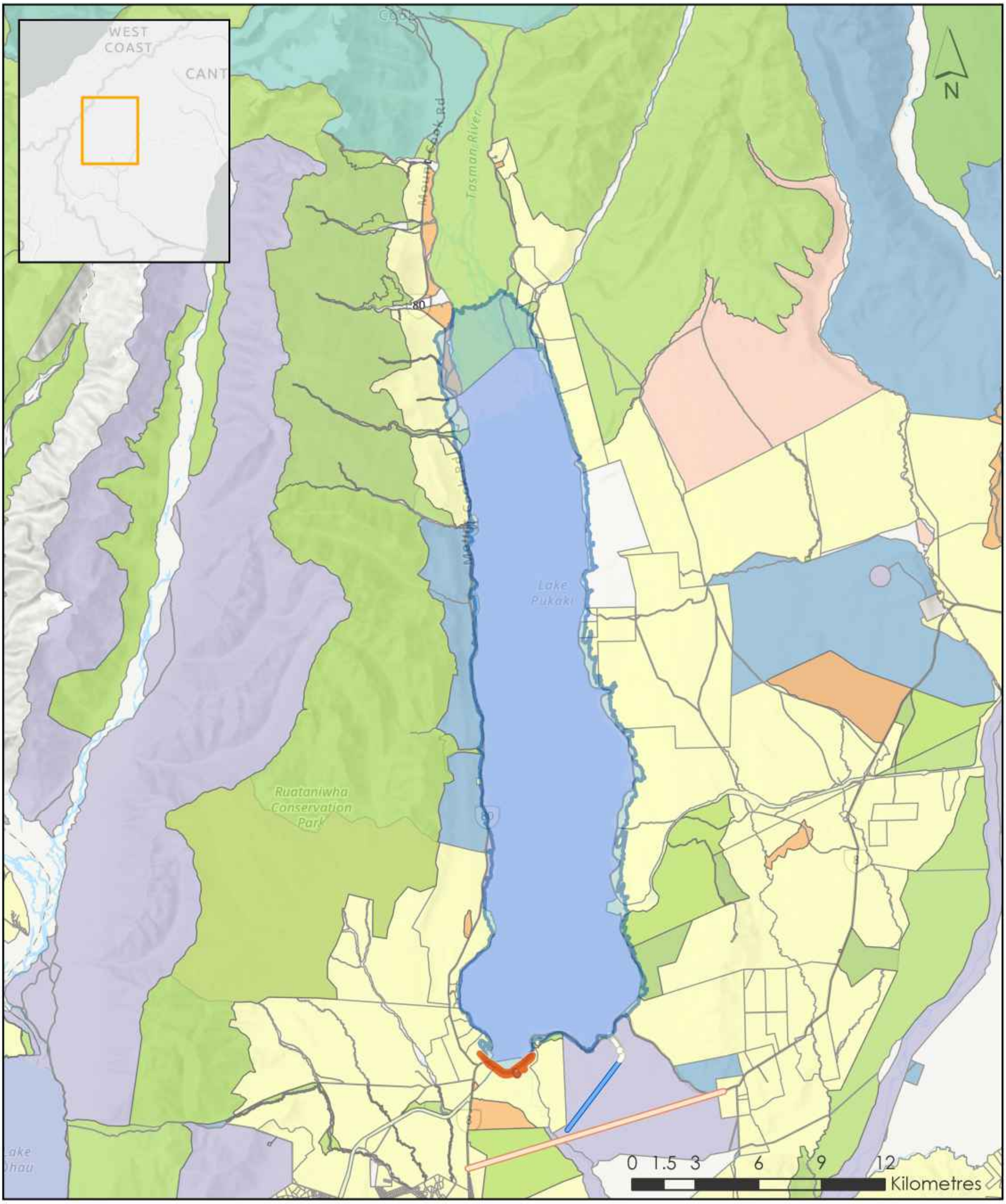
Territorial Authority

- Mackenzie District
- Timaru District
- Waitaki District
- Westland District

- Reservoir
- SH8 Road Realignment
- Spillway
- Dam Footprint
- Diversion Culvert Extension

Scale: 1:500,000
Data Sources: Stantec, StatsNZ
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: CD, Stantec (2022)

Stantec



Property Ownership - Site Three

This map shows land titles, and land classified as Protected Areas such as national parks and reserves.

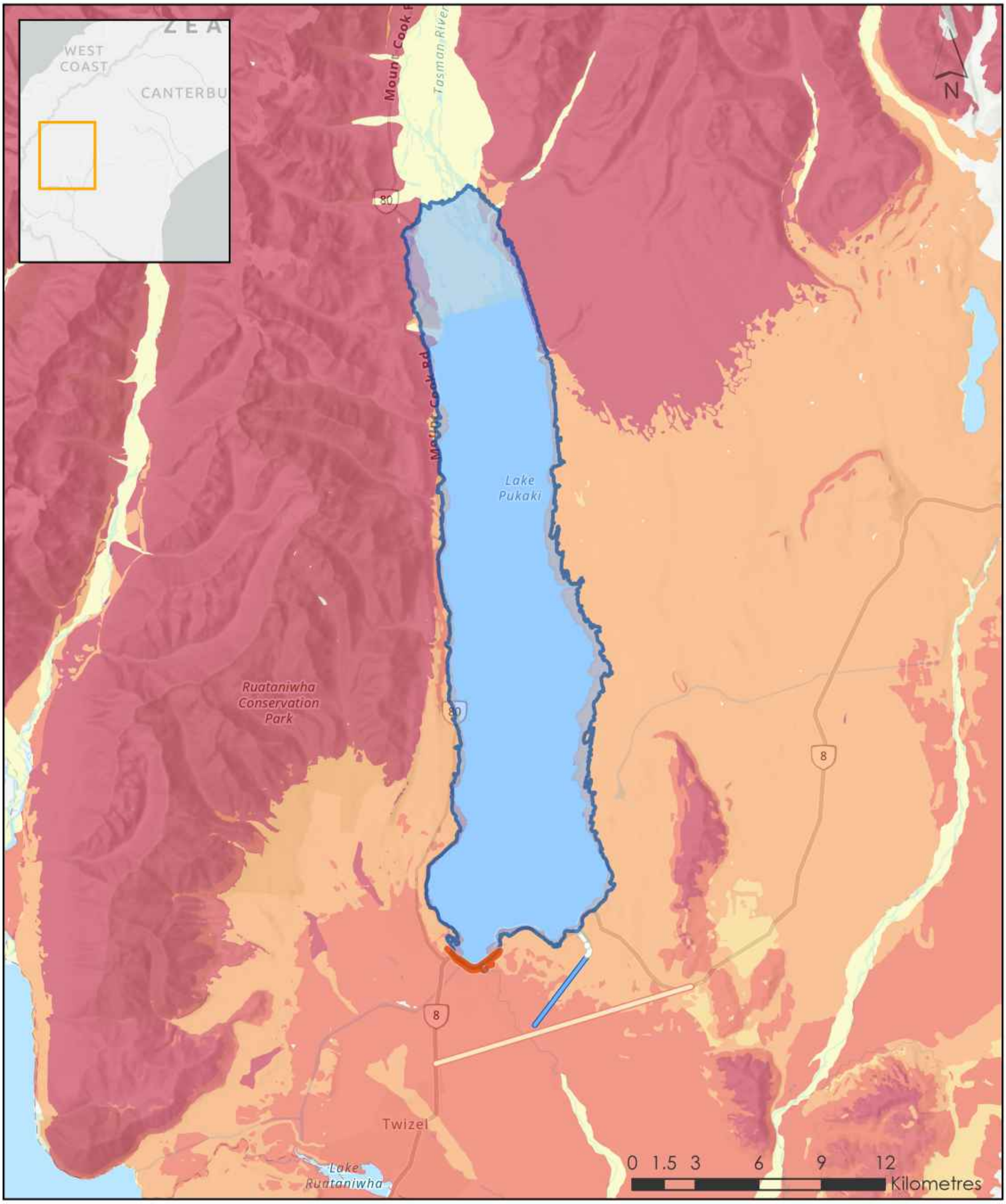
Scale: 1:250,000
Data Sources: Stantec, LINZ
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: CD, Stantec (2022)

Protected Areas
- Conservation Area
- Marginal Strip
- National Park
- Reserve

NZ Property Titles - Type
- Cross lease
- Freehold
- Gazette Notice
- Leasehold
- Records Embodied in the Register
- Supplementary Record Sheet
- Timeshare
- Unit Title

- Reservoir
- SH8 Road Realignment
- Spillway
- Dam Footprint
- Diversion Culvert Extension

Stantec



Threatened Environment Classification - Site Three

This map shows the Threatened Environment Classification (TEC 2012) for the area.

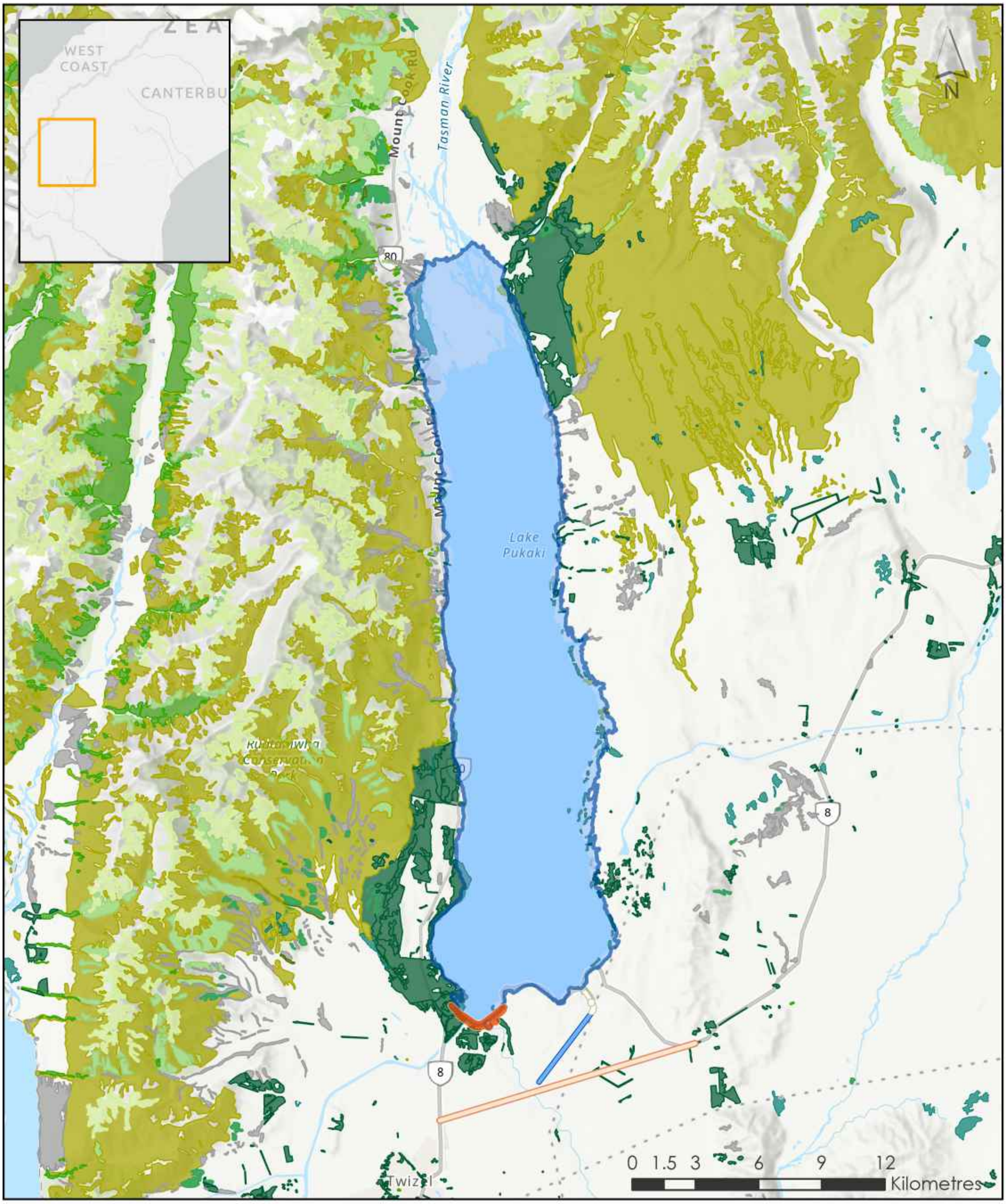
Scale: 1:250,000
Data Sources: Stantec, New Zealand Land Cover Database (LCDB)
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: CD, Stantec (2022)

TEC 2012

0
1
2
3
4
5
6

Reservoir
SH8 Road Realignment
Spillway
Dam Footprint
Diversion Culvert Extension

Stantec



Vegetation - Site Three

This map shows the areas of native vegetation in the LCDB 5.0 dataset that may be impacted by Site Three.

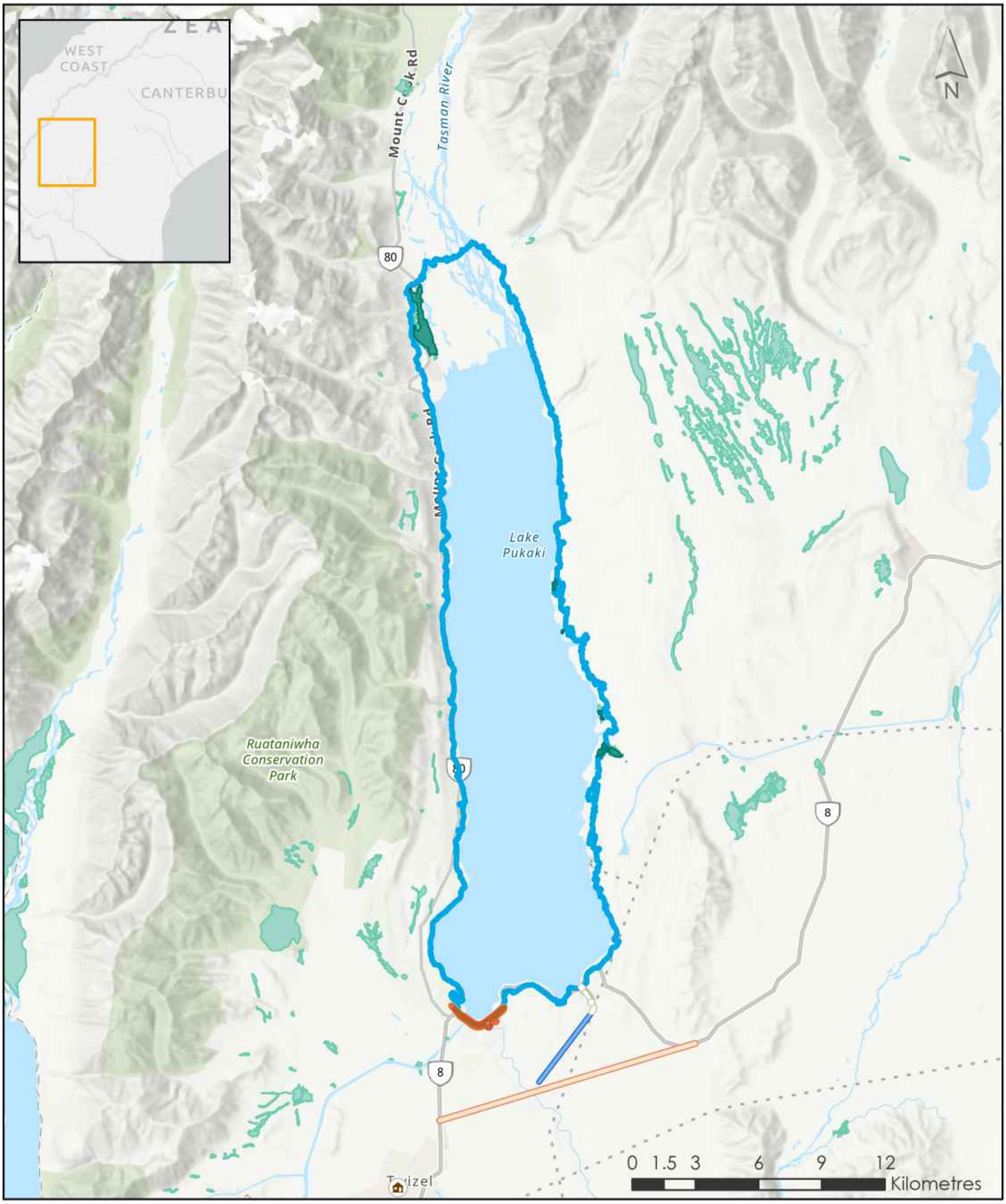
Scale: 1:250,000
Data Sources: Stantec, New Zealand Land Cover Database (LCDB), MfE
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: CD, Stantec (2022)

LCDB 2018

- Alpine Grass/Herbfield
- Broadleaved Indigenous Hardwoods
- Exotic Forest
- Fernland
- Flaxland
- Herbaceous Freshwater Vegetation
- Indigenous Forest
- Manuka and/or Kanuka
- Matagouri or Grey Scrub
- Sub Alpine Shrubland
- Tall Tussock Grassland

- Reservoir
- SH8 Road Realignment
- Spillway
- Dam Footprint
- Diversion Culvert Extension

Stantec



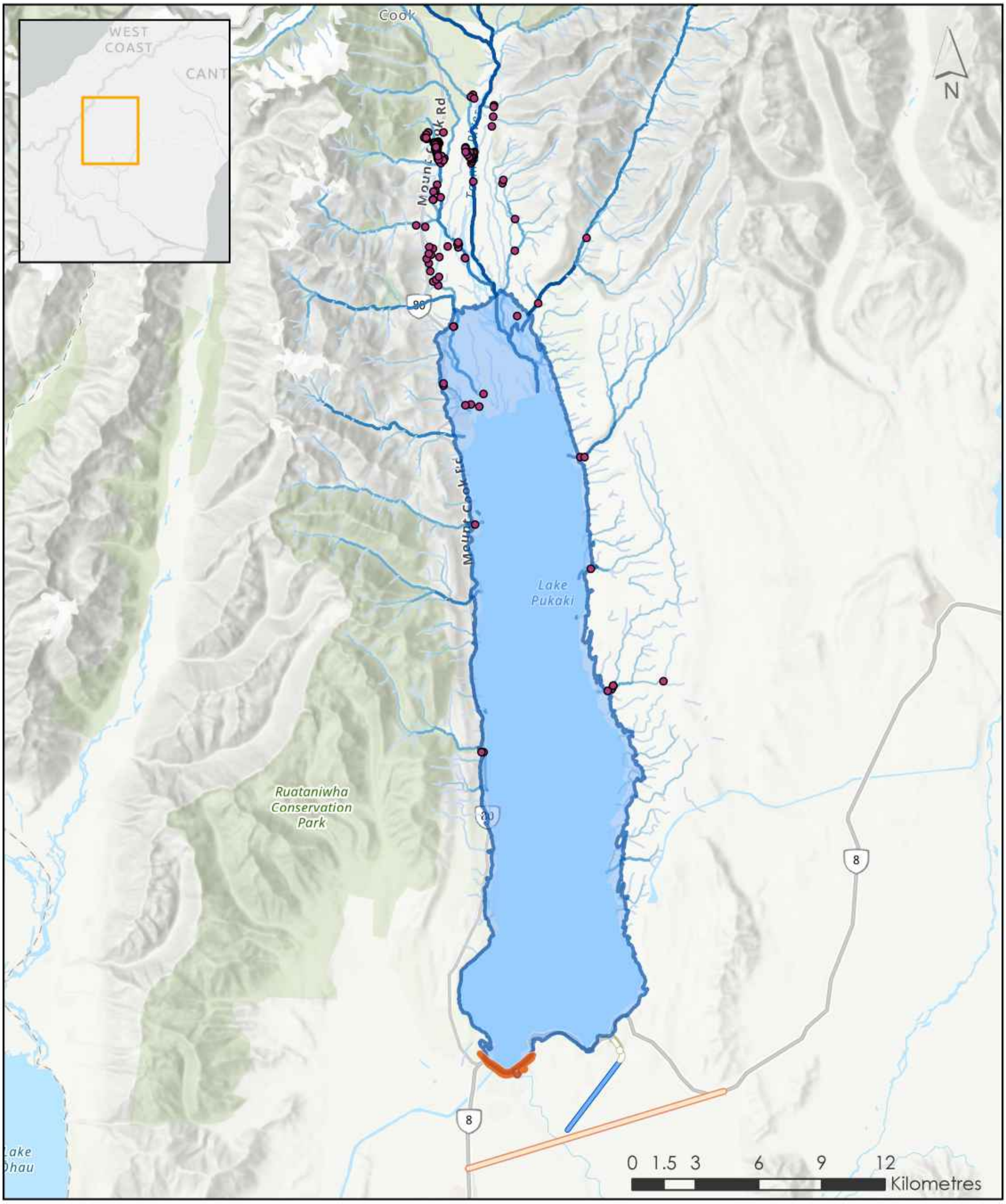
Wetlands - Site Three

This map shows the areas of wetlands in the LCDB 5.0 and MfE datasets that are impacted by Site Three.

Scale: 1:250,000
Data Sources: Stantec, New Zealand Land Cover Database (LCDB), MfE
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: CD, Stantec (2022)

- LCDB Herbaecous Freshwater Vegetation
- MfE Wetland Extent
- Reservoir Extent
- Dam Footprint
- SH8 Road Realignment
- Diversion Culvert Extension
- Spillway

Stantec



Fish passage - Site Three

This map shows the length of streams upstream of the proposed schemes including NZ Freshwater Fish Database (NZFFD).

Scale: 1:250,000
Data Sources: {list data sources}
Basemap Service Credits: Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors., Eagle Technology, Land Information New Zealand, Esri, HERE, Garmin, FAO, NOAA, USGS
Map displayed in NZGD 2000 New Zealand Transverse Mercator coordinate system.
Author: {author name}, Stantec (2022)

NZFFD Survey Location

NIWA River Stream Order
- 1
- 2
- 3
- 4
- 5 - 6

Reservoir
SH8 Road Realignment
Spillway
Dam Footprint
Diversion Culvert Extension

Stantec

Appendix B Geological Study

Appendix B Geology

The following subsections summarise the methodology and findings of the completed geological study as part of the screening study. It is arranged as follows:

- Sections C.1 to C.4 – the objectives and methodology for the study.
- Section C.5 – Site 1 Upper Moawhango.
- Section C.6 – Site 2 Taruarau.
- Section C.7 – Site 3 Pukaki.
- Section C.8 – recommendations for the next step of geological studies should any of the proposed options proceed to a subsequent stage of development.

B.1 Standards and Guidelines

The geological study has been completed in general accordance with industry recognised guidelines for studies such as this. Key relevant standards/guidelines are:

- ANCOLD, 2020, Geotechnical Investigations of Dams, Their Foundations and Appurtenant Structures.
- Fell et Al. 2015, Geotechnical Engineering of Dams.
- ICOLD 2005. Dam foundations, Bulletin 129.
- NZGS 2005. The field classification and description of soil and rock for engineering purposes.
- NZS1170.5:2004. Structural Design Actions Part 5 Earthquake Actions.
- NZSOLD 2015. New Zealand Dam Safety Guidelines.

The terminology used in this report is based upon the above references.

0 shows the typical objectives and scope of work for pre-feasibility geological studies (from ICOLD 2005). This reference has been used to develop the study objectives and scope of work.

1. Prefeasibility stage			
DECISION GOALS	DESIRED ACHIEVEMENTS	COMMON ACTIVITES	COST EVALUATION
• Preliminaty selection of dam site • Type(s) of dam and tentative layout with appurtenant structures	• General appraisal of dam site as related to geological environment • Global and regional geology • General seismicity and seismotectonics • Lithostratigraphy • Terrain instabilities • Karst features • Weak and potentially problematic zones • Depth of weathering	• Study of all relevant geologic maps and reports • Airphoto interpretation to determine major geologic structures, geomorphology • Geologic field reconnaissance and mapping • Preliminary classification of foundation materials • General groundwater conditions • Selection of exploration geophysical surveys • Few judicious drill holes • Preliminary report on regional and site-specific geology	• Preliminary evaluation for purpose of comparison with alternatives (foundation type, foundation treatment)

Figure 1 - Typical objectives and scope of works for pre-feasibility (or earlier) geological studies (from ICOLD 2005)

0 shows the different types of geological models and their association to different project development stages (from ANCOLD 2020). The geological models developed for this project are therefore defined as a 'conceptual geological model'. The conceptual geological model consists of two key elements, as defined by Fell et al. (2015):

- A sufficiently detailed three-dimensional picture or model of the site geological situation, showing the occurrence of different materials.
- The characteristics of the materials, relevant for analysis, design, and construction.

The conceptual geological model largely draws upon pre-existing information and the experience and the judgement of the engineering geologist(s) who completes it. It is founded on the philosophy of 'total geology', which is based upon experience of similar materials in similar settings (i.e. engineering precedence), with an understanding of the processes which created the materials, and those processes which have occurred after their creation. Reference is made to Fell et al. (2015) for a summary of engineering geological characteristics for different geological environments and their associated key considerations for dam engineering.

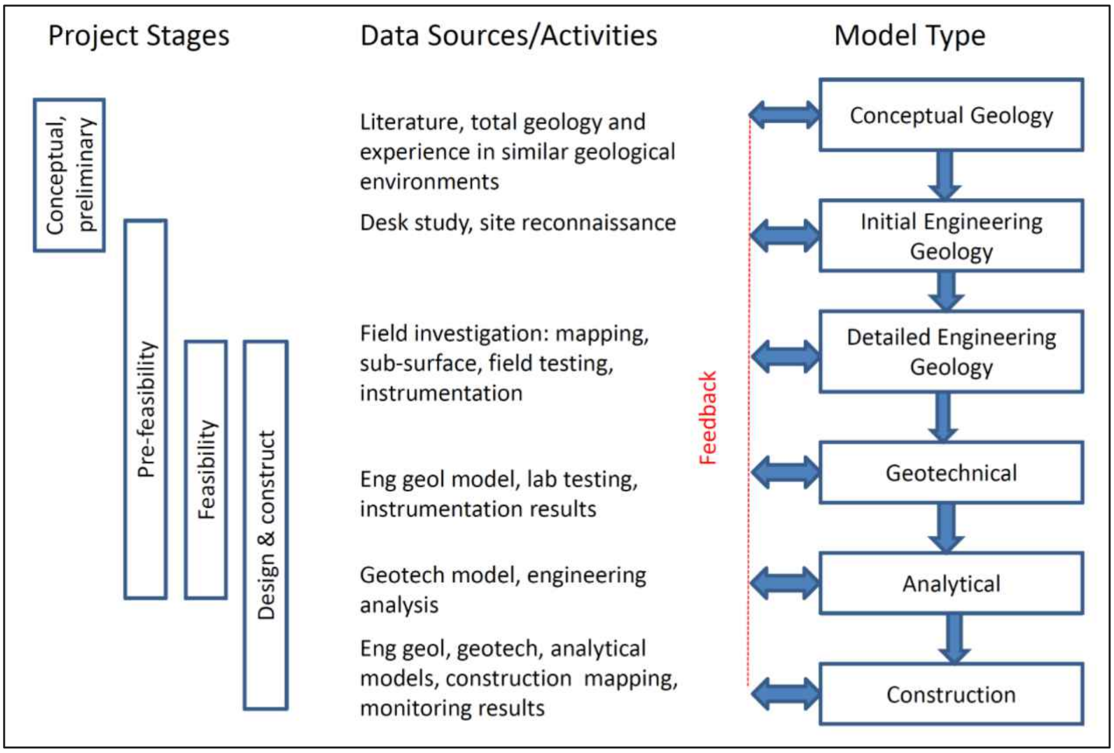


Figure 2 - Types of geological model relative to project development stage (from ANCOLD 2020)

B.2 Objectives

The key objectives of the geological study were to:

- Identify geological fatal flaws with the proposed sites. The fatal flaws may be associated with key geological hazards such as:
  - Earthquakes. Such as:
    - Surface fault rupture and associated effects (such as tsunami if it occurs within a body of water).
    - Shaking.
    - Liquefaction and associated effects.
    - Seiche.
  - Slope instability – both at infrastructure locations and proposed reservoir shorelines, with an emphasis on pre-existing landslides and not first-time failures.
  - Volcanic - including lava flows, pyroclastic flows, lahars, other ejecta (tephra), tsunami, gas etc.).
  - Geothermal.
  - Water losses from a reservoir due to foundation conditions comprising:
    - Soluble materials – such as limestone, gypsum, and anhydrite.
    - Non-soluble materials:
      - Alluvium.
      - Glacial and fluvioglacial.
      - Underground mine workings.
      - Higher permeability rocks – such as lavas (caves, etc.), 'loosened' rock mass, etc.

- Determine the likely geological conditions at each site so that:
  - A preferred scheme arrangement can be developed, including the locating of key infrastructure.
  - Key infrastructure types, such as the dam type, surface or tunnelled waterways, etc.) can be selected.

- Develop key geological and geotechnical assumptions required for concept design development and its associated high-level cost estimate. Examples include:
  - Surface works – excavatability of materials, founding levels and required foundation preparation/treatment for structures, surface slope design, and stabilisation (if required), and the sources of suitable construction materials etc.
  - Underground works – excavatability of materials, excavation stabilisation required, groundwater management, spoil disposal, etc.

Several other ground-disturbance hazards exist. Examples include:

- Unexploded ordnance.
- Contaminated land/fill.
- Acid sulphate soils.
- Acid mine drainage.
- Existing underground services.

These hazards, and other ground disturbance hazards not specifically listed, are not discussed in this geological study.

B.3 Scope of Works

The scope of works completed as part of the geological study was:

- Data mining and review. Key data sources are those published/freely available and include:
  - Topographical.
  - Aerial imagery (both current, and historic).
  - Geological maps and papers.
  - Information relating to geological hazards – such as that held by local and regional councils, government research institutes etc.
  - Papers relating to the design, construction, and operation of similar civil works in similar materials (i.e. relevant engineering precedence).
- Reporting.

The data mined and used in this study is individually listed below for each site.

The information allowed for use in the study was limited to that which is publicly available. For this reason, limited site-specific information was available and therefore has been used. This is important, as significant site-specific information is available for some of the sites and this presents a key limitation of the study.

No site visit was permissible as part of the scope of works.

B.4 Data Characteristics

The mined data has been assumed as being accurate unless it has been identified as otherwise.

The data which has been mined has been acquired for different objectives, by different authors, using different methods, other a significant period. This may be important for its reliability and representativeness. This needs to be considered in the applicability of the data and its general trustworthiness. No standardisation or modernisation of the data has been completed as part of the study.

B.5 Site 1 – Upper Moawhango

The following subsections summarise the findings of the geological study for Site 1.

B.5.1 Scheme Description

The scheme description is presented in the main study report.

B.5.2 Available Information

The key references which have been used in this study are:

- Published geological maps:
  - Lee, J.M.; Townsend, D.; Bland, K.; Kamp, P.J.J. (compilers) 2011: Geology of the Hawke's Bay area: scale 1:250,000. Lower Hutt: Institute of Geological & Nuclear Sciences Limited. Institute of Geological & Nuclear Sciences 1:250,000 geological map 8. 86 p. + 1 folded map.
- Geological hazards:
  - Froggatt, P. 1997. Volcanic hazards at Taupo Volcanic Centre. Ministry of Civil Defence. Volcanic hazards information series 7. 26 p.
  - GNS Science Active Fault Database (https://data.gns.cri.nz/af/).
  - GNS Landslide Database (http://data.gns.cri.nz/landslides/).
  - Hurst & Smith 2010. Volcanic ashfall in New Zealand – probabilistic hazard modelling for multiple sources, New Zealand Journal of Geology and Geophysics, 53:1, 1-14.
  - Neall, V.E.; Houghton, B.F.; Cronin, S.J.; Donoghue, S.L.; Hodgson, K.A.; Johnston, D.M.; Lecointre, J.A.; Mitchell, A.R. 1999. Volcanic hazards at Ruapehu Volcano. Wellington: Ministry of Civil Defence. Volcanic hazards information series 8. 30 p.
- Published and unpublished geological papers:
  - Atkins, R.A.E 1976. Rangipo Power Project seismic determination of elastic properties in powerhouse investigation drives. Ministry of Works and Development Central Laboratories Report No. 2-76/2
  - Beetham, R.D & Watters, W.A 1985. Geology of Torlesse and Waipapa terrane basement rocks encountered during the Tongariro Power Development project, North Island, New Zealand, New Zealand Journal of Geology and Geophysics, 28:4, 575-594, DOI: 10.1080/00288306.1985.10422534
  - Bryant, J.M 1977. Rock deformation investigations at Rangipo. Ministry of Works and Development Central Laboratories Report No. 2-77/4
  - Bryant, J.M 1977. Shear strengths of joints in Rangipo rocks. Central Laboratories Report No. 2-77/2
  - Bryant, J.M 1977. Some properties of Kaimanawa Greywacke. Ministry of Works and Development Central Laboratories Report No. 2-77/1
  - Duder, J.N, et al. 1977. Engineering Geology and Foundation Engineering of the Moawhango Arch Dam.
  - Hegan, B.D 1977. Engineering geological aspects of Rangipo underground powerhouse. New Zealand Institute of Engineers. Papers presented to the Symposium on Tunnelling in New Zealand. Hamilton
  - Millar, P.J 1977. The design of Rangipo Underground Powerhouse. Ministry of Works and Development.
  - Prebble, W.M 1983. Investigations in an active volcanic terrain.
  - Spörli, K.B & Barter, T.P 1973. Geological reconnaissance in the Torlesse super-group of the Kaimanawa Ranges along the lower reaches of the Waipakihi River, North Island, New Zealand, Journal of the Royal Society of New Zealand, 3:3, 363-379, DOI: 10.1080/03036758.1973.10421862
  - Spörli, K.B & Bell, A.B 1976. Torlesse mélange and coherent sequences, eastern Ruahine range, North Island, New Zealand, New Zealand Journal of Geology and Geophysics, 19:4, 427-447, DOI: 10.1080/00288306.1976.10423538
  - Williams, J.K 1994. Some aspects of the Cenozoic Geology of the Moawhango River region. Master of Science Thesis, Massy University.

B.5.3 Published Geology

The project site lies near the eastern margin of the Taupo Volcanic Zone (TVZ), an area of crustal extension and associated crustal thinning, which extends from approximately Mount Ruapehu in the south to offshore of the Bay of Plenty. The area has developed by extensional (normal) faulting and is characterised by its volcanic and geothermal activity. The eastern margin of the TVZ is defined by the active Rangipo (Desert road) Fault in the general project area, which is approximately defined by the location of SH1 near Lake Moawhango and the Tongariro River further north in proximity to the existing Rangipo Dam and Power Station.

Figure 3 shows the project area is in an area defined as 'Eastern greywacke basement rocks' described as being between 300 to 100 million years old. A more detailed geological map of the project area is shown in 0 (from Lee et al. 2011) and a simplified version of this geological map relative to the proposed scheme infrastructure is shown in 0. 0 is a geological section of the approximate site location, also from Lee et al. (2011).

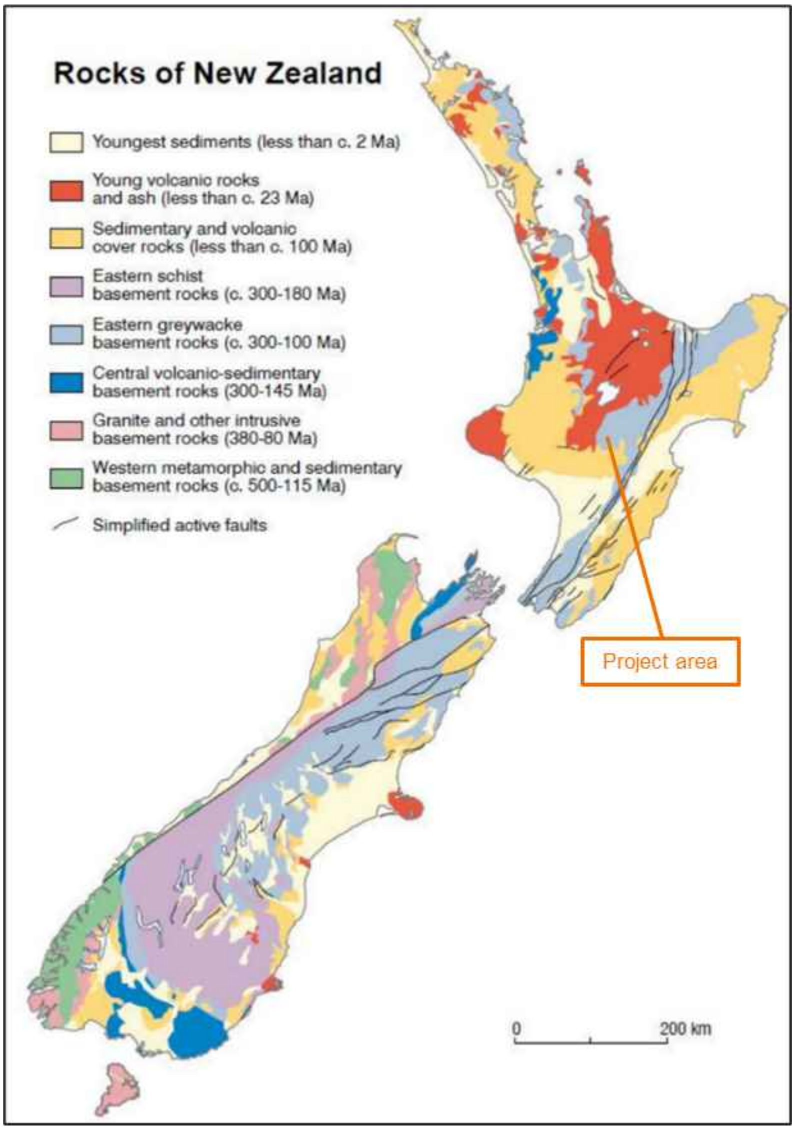


Figure 3 - Simplified geological map of New Zealand (from GNS undated)

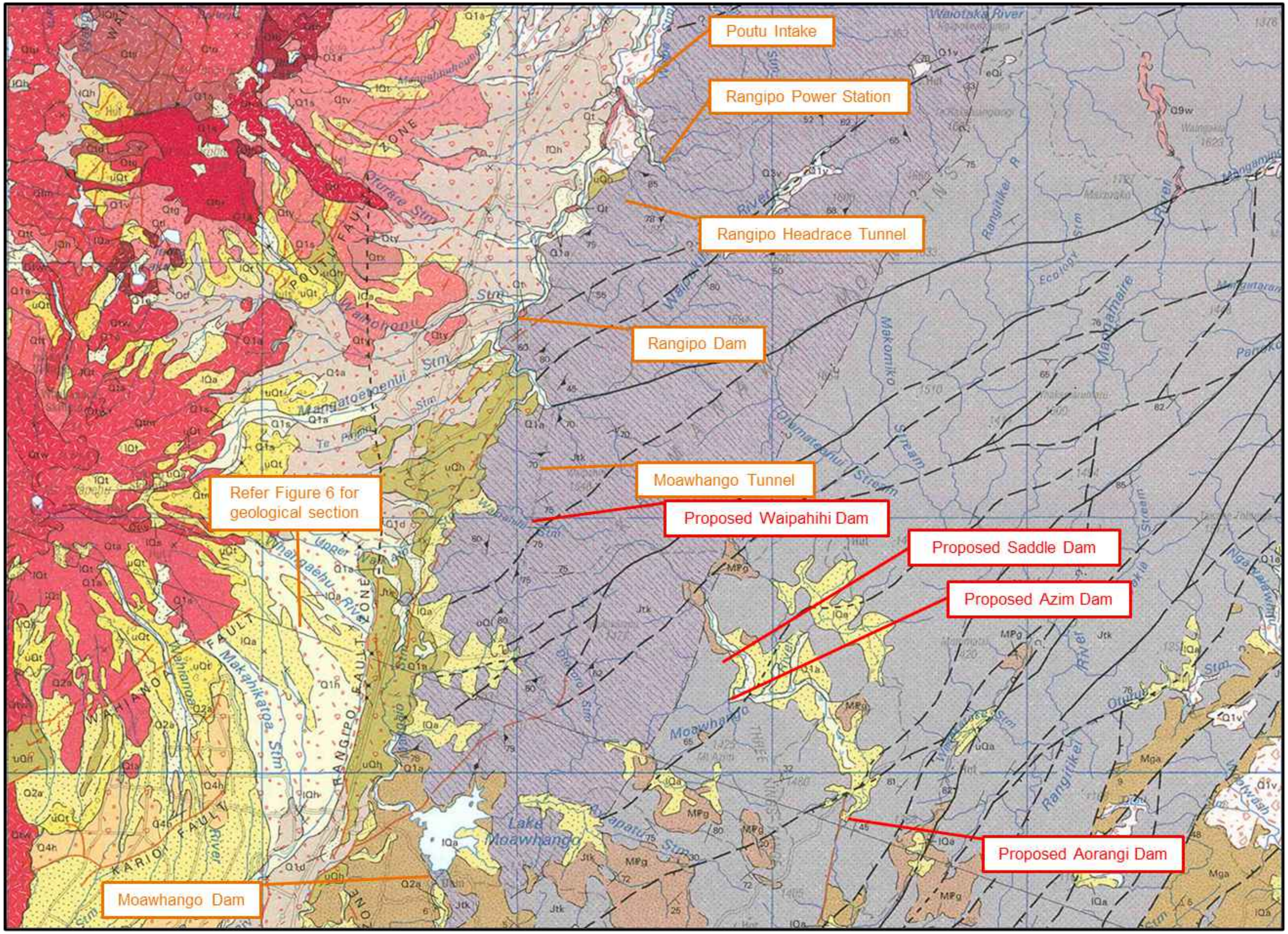


Figure 4 - Published geological map of the Hawkes Bay area (Lee et al. 2011)

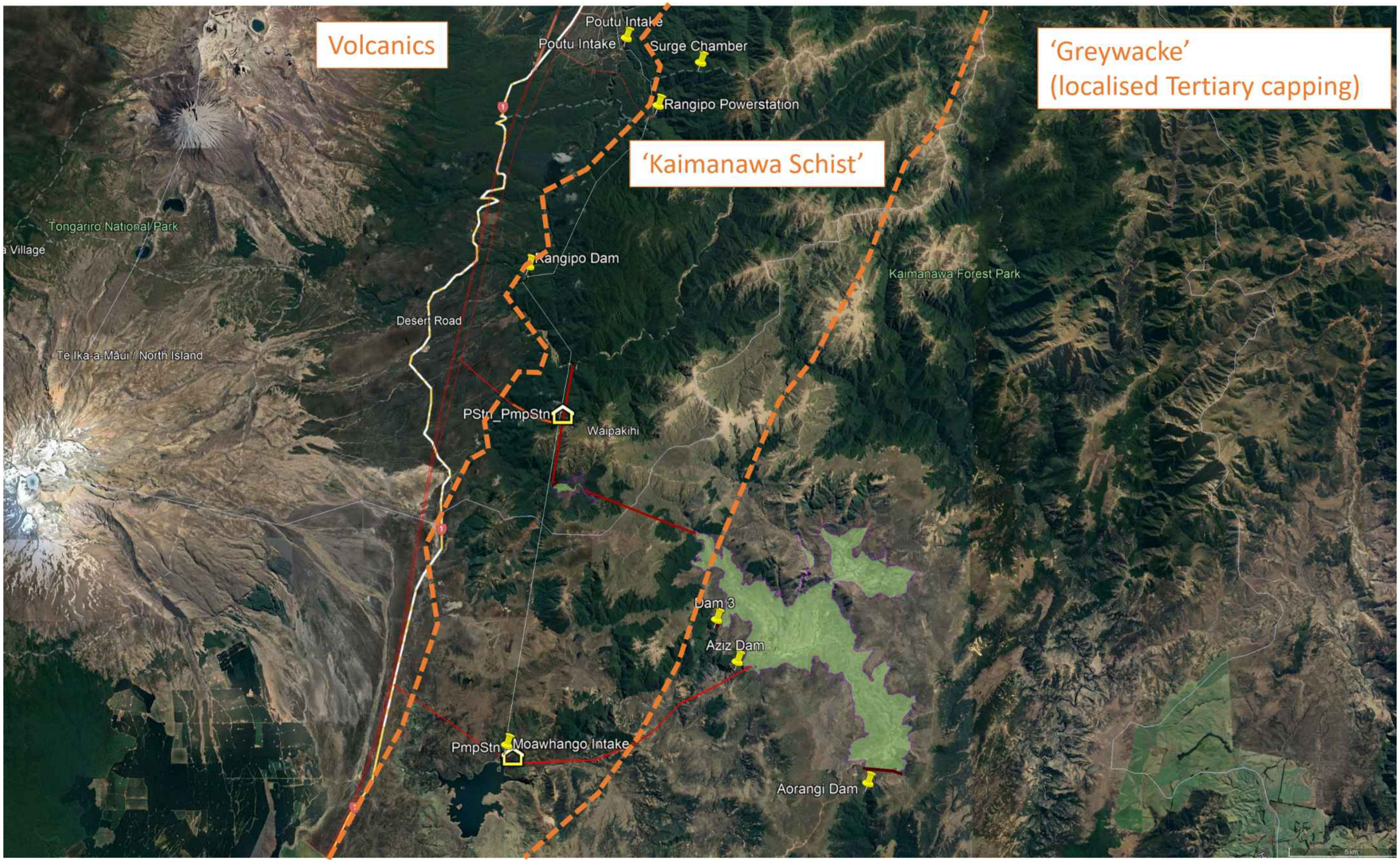


Figure 5 - Simplified bedrock geology for the Site 1

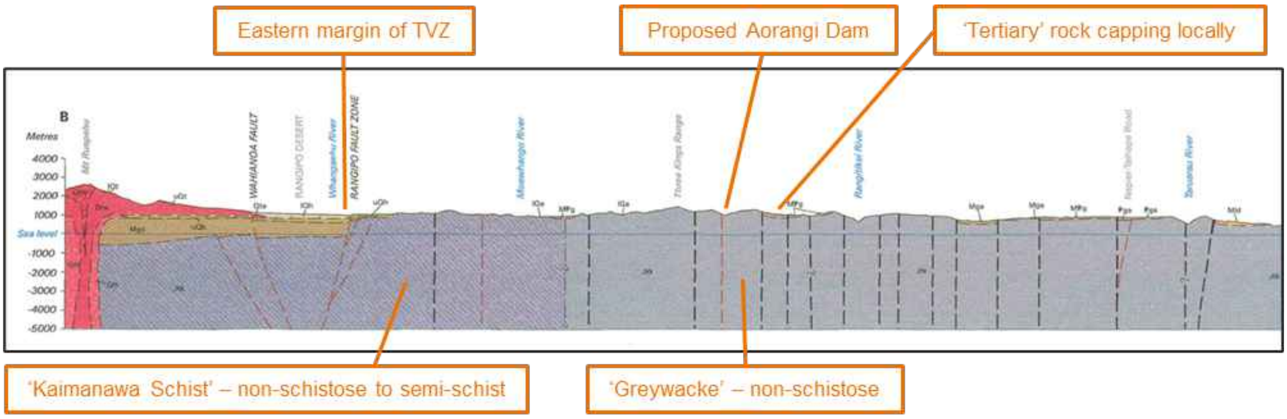


Figure 6 - Geological section through project area (Lee et al. 2011)

The above information shows that the 'greywacke' underlying the site (Jtk) is referred to as the 'Kaweka Terrane', and can be broadly divided into two distinct parts. To the west, the 'Kaimanawa Schist', also referred to as being 'Textural Zone 2A and 2B schistose rocks', and to the east, 'Textural Zone 1, non-schistose greywacke'. Both rocks are generally described as 'Massive, fine to medium-grained quartzofeldspathic sandstone, alternating sandstone and mudstone, minor conglomerate, broken formation, and melange'. The key difference between the two is the higher grade of metamorphism some of the rocks have undergone, which has led to the development of a schistose fabric. Mapped bedding and foliation (schistosity) is variable and is discussed later in this report. It generally strikes from N-S to NE-SW, at dips of more than 75°.

It is noted that the formation is described as containing 'broken formation and melange'. Various definitions of the word 'melange' exist, but the USGS describes it as 'a body of rock characterised by a lack of internal continuity of strata or contacts, and by the inclusion of fragments or blocks of all sizes, both native and exotic, embedded in a fragmental matrix or fine-grained matrix'. These areas of 'melange' are important for the project area and have been identified by previous civil works. They are discussed later in this study.

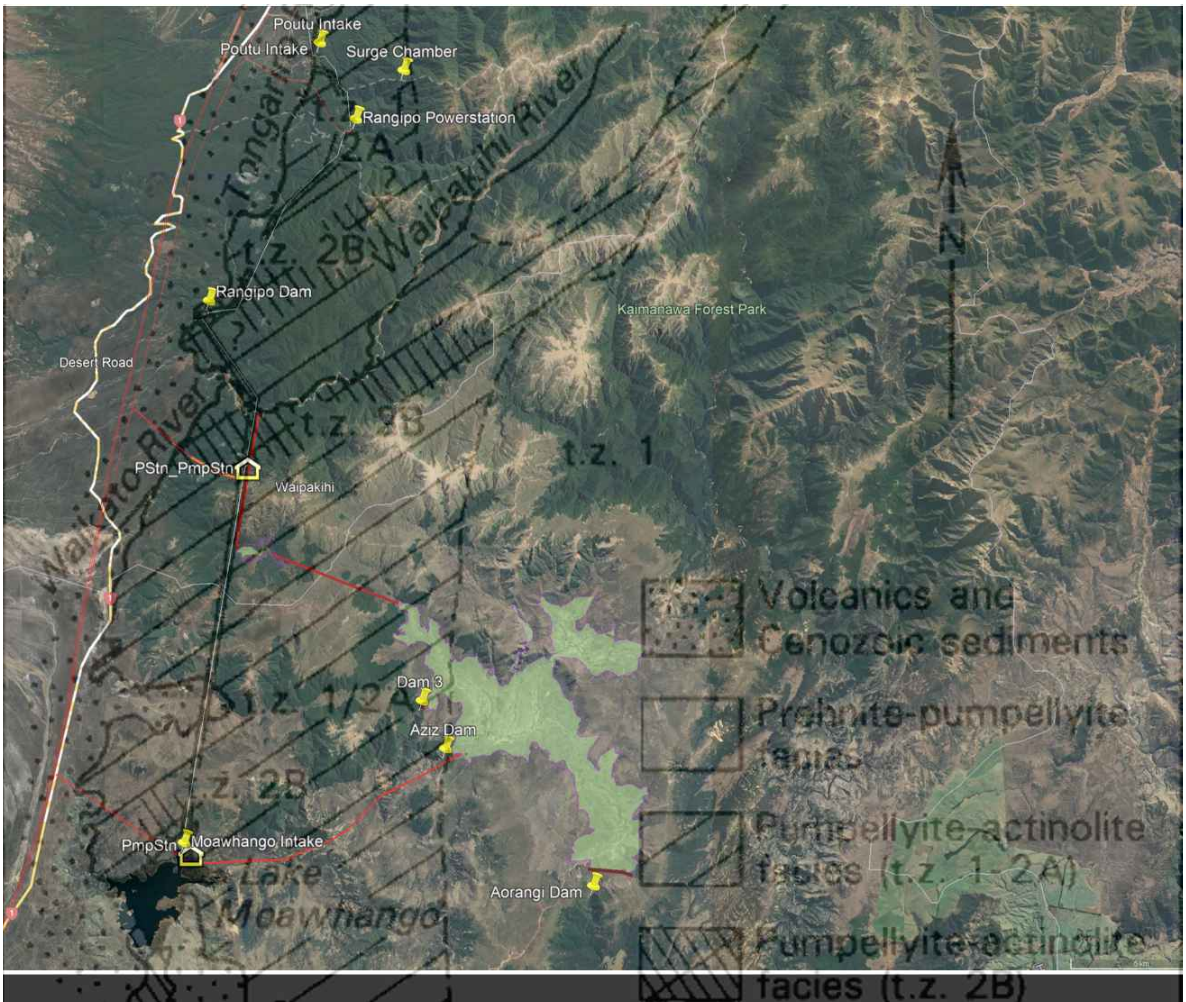
The other key observations from a review of the published geological map are:

- Rocks/deposits associated with the Tongariro Volcanic Centre are not mapped as underlying the immediate project area. Tephra occurrence is unlikely to be shown on the map due to scale and however but may be present in the project area.
- The site is located within the mapped extent of primarily non-welded ignimbrites associated with the Taupo Volcanic center, often referred to as the Taupo Pumice Formation, which also includes some tephra and re-worked deposits. Although not mapped as occurring in the immediate project area, they are expected to be encountered locally overlying older deposits.
- Tertiary-aged rocks are shown as occurring locally overlying the 'greywacke' (Mpg, Mga). These deposits generally increase in occurrence and extent towards the south. The rocks are shown as being associated with the Whangamomona Group which are described as 'Pebbly limestone, cross-bedded sandstone, mudstone, minor conglomerate, and limestone'. It can be seen bedding in the Tertiary rocks is also somewhat variable, but is generally to the SE or S at between 5° and 20.°
- Areas of alluvium are present overlying the rock within and adjacent to some of the larger watercourses. A notable occurrence of this is in the vicinity of the proposed reservoir and associated dams. Two types of alluvium are mapped in the project area:
  - Q1a – described as 'gravel, sand, silt, and mud, forming alluvial terraces' of Holocene-age.
  - IQa – described as 'alluvial fan and colluvial deposits' of Late Pleistocene to Holocene-age.
- Some areas of landslide deposits are mapped in the wider project area delineated as uQl on the published geological map. An example is that mapped in the Manutahi Stream catchment. The mapped areas of landslide deposits do not appear to include the currently proposed infrastructure locations.
- Faulting:
  - The active Rangipo (Desert Road) Fault Zone is shown to the west of the project area, forming the boundary between the greywacke and volcanics of the Tongariro Volcanic Centre. Active faulting, and earthquake hazards in general, are discussed in more detail later in this study report.
  - Several faults mapped as being inactive are mapped beneath the immediate project area. These faults generally strike NE to SW and are therefore parallel with the plate boundary. As these faults are mapped as being 'inactive', they are less important for earthquake hazards and more important for likely subsurface conditions.

In addition to the published geological map of the area, various published papers document the geology of the general project area. Most of this information was sourced from early investigations and construction of the Tongariro Power Scheme. Two papers that provide general geological information of the project area are:

- Beetham & Watters 1985. Geology of Torlesse and Waipapa terrane basement rocks encountered during the Tongariro Power Development project, North Island, New Zealand, New Zealand Journal of Geology and Geophysics, 28:4, 575-594.
- Spörli & Barter 1973. Geological reconnaissance in the torlesse super-group of the kaimanawa ranges along the lower reaches of the Waipakihi River, North Island, New Zealand, Journal of the Royal Society of New Zealand, 3:3, 363-379.

These references are important, as they provide more location-specific geological information for the project area. 0 shows the distribution of metamorphic zones from Beetham & Watters (1985) overlain with the currently proposed scheme arrangement. This information suggests most works would occur in Textural Zones 1 and 2A, or 'non-schistose' greywacke. Localised occurrences of Zone 2B (referred to as semi-schist) are mapped as occurring near Lake Moawhango, the Waipakihi River area. Other occurrences of Zone 2B are mapped further north, outside of the current scheme infrastructure location, such as near the existing Rangipo Dam.



Metamorphic facies	Textural zones: Danseys Pass	Textural zones: Western Kaimanawa Range
Prehnite-pumpellyite	T.z. 1 (nonschistose)	T.z. 1 (nonschistose)
Pumpellyite-actinolite	T.z. 1, 2A, 2B (nonschistose to semischist)	T.z. 1, 2A, minor 2B (nonschistose to semischist)
Greenschist	T.z. 3A, 3B (schist)	Rocks not known in Kaimanawa Range

Figure 7 - Distribution of metamorphic zones in the project area (Beetham & Watters 1985)

Detailed geological mapping completed in the vicinity of the Waipakihi River area by Spörli & Barter (1973) is shown as 0 and 0. This includes mapping of metamorphic textural zones and structural geology mapping.

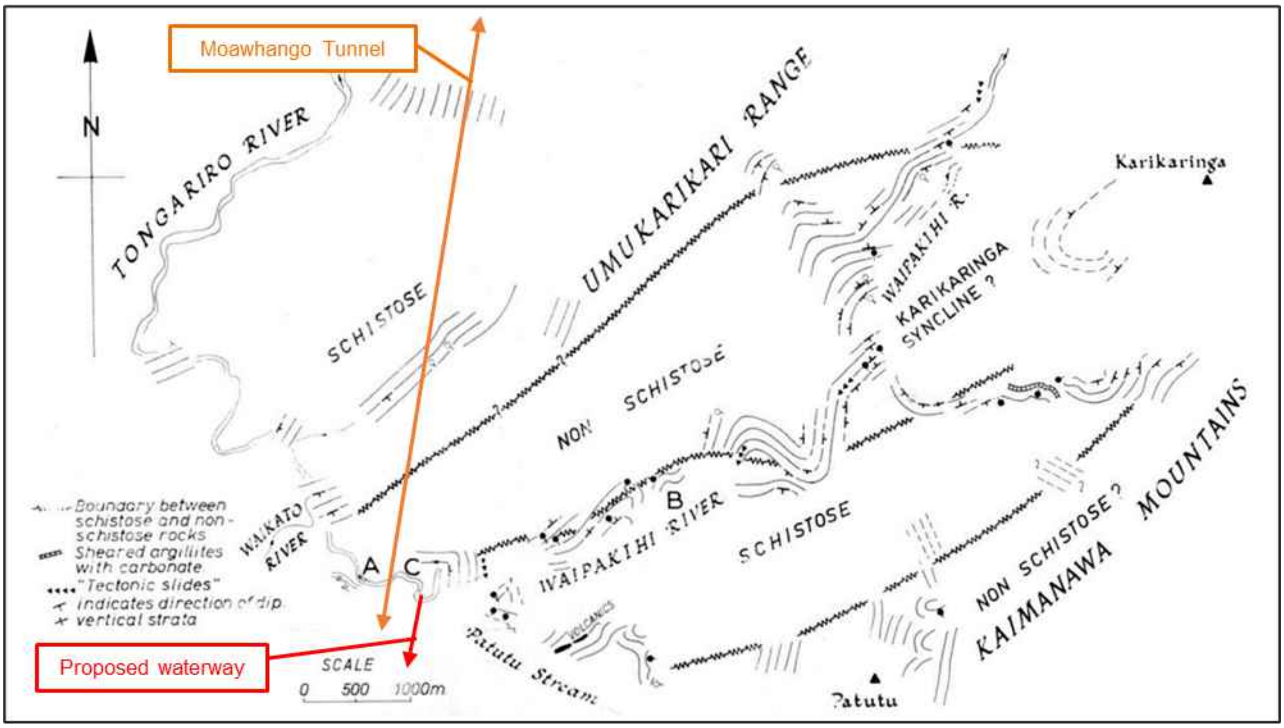


Figure 8 - Distribution of metamorphic zones in Waipakihi River area (Sporli & Barter 1973)

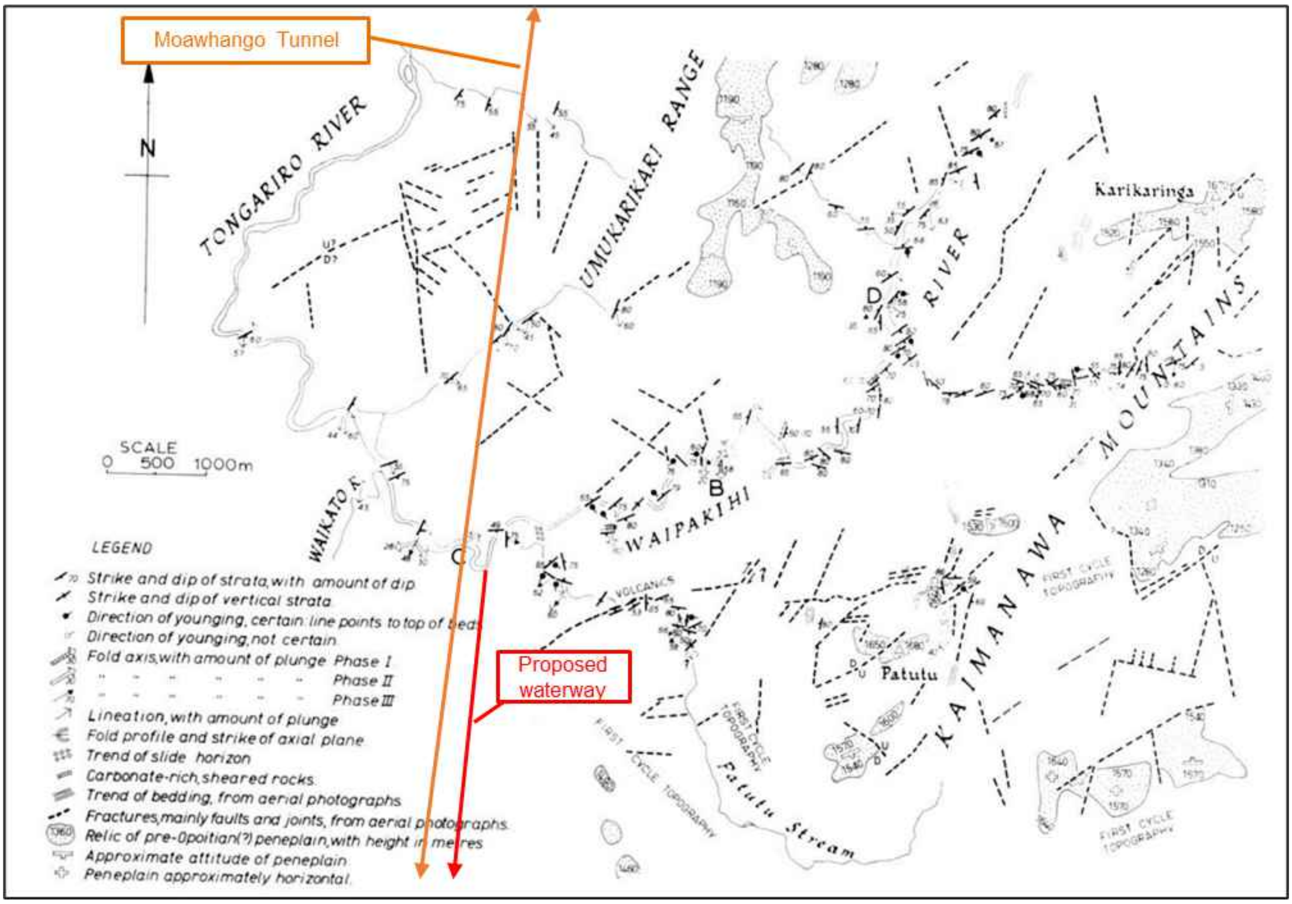


Figure 9 - Structural geology of the Waipakihi River area (Sporli & Barter 1973)

The geological evolution of the Kaweka Terrain is geologically complex. Beetham & Watters (1985) attempted to define the geological history of the rocks and associated geological processes (0). It can be seen the 'greywacke' rocks they have been exposed to two main period of orogenesis, associated with the Rangitata Orogeny (variously aged, but possibly approximately 150 to 100 million years ago) and the Kaikoura Orogeny (possibly 25 million years ago, to present). These periods of orogenesis have resulted in folding, faulting, and metamorphism. This is important for their engineering geological characteristics, which are discussed later in this study.

Main event	Folding	Metamorphism	Faulting
Rangitata Orogeny			
	First phase: cleavage and recumbent folding	Initial development of fissility	
Thrusting and imbrication of accreting sediments at a convergent margin	Second phase: upright folding and boudinage	Localised intense shearing of argillite. Probable development of melange	Dominantly reverse or thrust faulting
	Third phase: wrench folding with steeply dipping axes	Development of lineation	
Kaikoura Orogeny			
Elevation of Kaimanawa block. Volcanism and rifting in Taupo Volcanic Zone	Broad folding between faults. Some small kink folds	Renewed shearing of argillite. Local crushing and formation of gouge zones	? Dominantly transcurrent or oblique. Some rejuvenation of Rangitata Orogeny faults

Figure 10 - Suggested sequence of events in the development of the Torlesse Range (Beetham & Watters 1985)

B.5.4 Geological Hazards

The following subsections summarise publicly available information about geological hazards of relevance to this study. The emphasis has been placed on those geological hazards which could be a significant constraint on design, construction, and operation.

It is expected that the most current information with regards to geological hazards in the project area would be held by Genesis Energy Limited, the owner of the Tongariro Power Scheme, but this is not publicly available.

B.5.4.1 Earthquake Hazards

The definition of an active fault within this study is that used in the New Zealand Active Fault Database which is 'a fault that shows evidence of rupture one or more times in the last 125,000 years and is, therefore, likely to move again in the future'. This is like that presented in NZSOLD DSG (2015).

0 shows active faults contained within the GNS Active Fault Database overlain on the currently proposed scheme arrangement. The figure is approximate only. Minimal information is presented in the database for the mapped active faults, suggesting they are not particularly well studied or characterised.

Key observations from this figure are:

- A zone of active normal faulting runs along the eastern margin of the TVZ, and is defined as the Rangipo (Desert Road) Fault Zone. It is shown as a series of discontinuous fault traces. The fault zone is described as showing activity in the last approximately 12,000 years and to have a Recurrence Interval of less than 2,000 years. It is interpreted to show a slip rate and single-event displacements are not known.
- An active normal fault is mapped along the NW side of the existing Lake Moawhango, extending a distance of around 12 km. Although mapped as active, no further information is presented on its characteristics (such as the age of last rupture, recurrence interval, slip rate, and single event displacements). It is noted that the existing Moawhango Tunnel, part of the Tongariro Power Scheme, crosses this mapped active fault.
- An un-named active normal fault is mapped around 15 km east of Lake Moawhango in the upper part of the Aorangi Stream. This is the location of the proposed Aorangi Dam, required to develop the new reservoir. Although mapped as active, no further information is presented on its characteristics (such as the age of last rupture, recurrence interval, slip rate and single event displacements) other than a mapped trace length of around 5 km. This fault does appear to be evident on aerial imagery (0), although the age of the displaced surfaces is not reliably known. It appears to displace surfaces mapped as IQa, described as 'alluvial fan and colluvial deposits' of Late Pleistocene to Holocene-age. These are shown to have a maximum age of around 70,000 years, meaning the surface rupture has occurred at least in the timeframe. Based upon the trace of the fault, it appears it would be present within the dam footprint of both the upper and lower (gorge) options for the Aorangi Dam which have been considered. It may also extend northwards through the reservoir location.

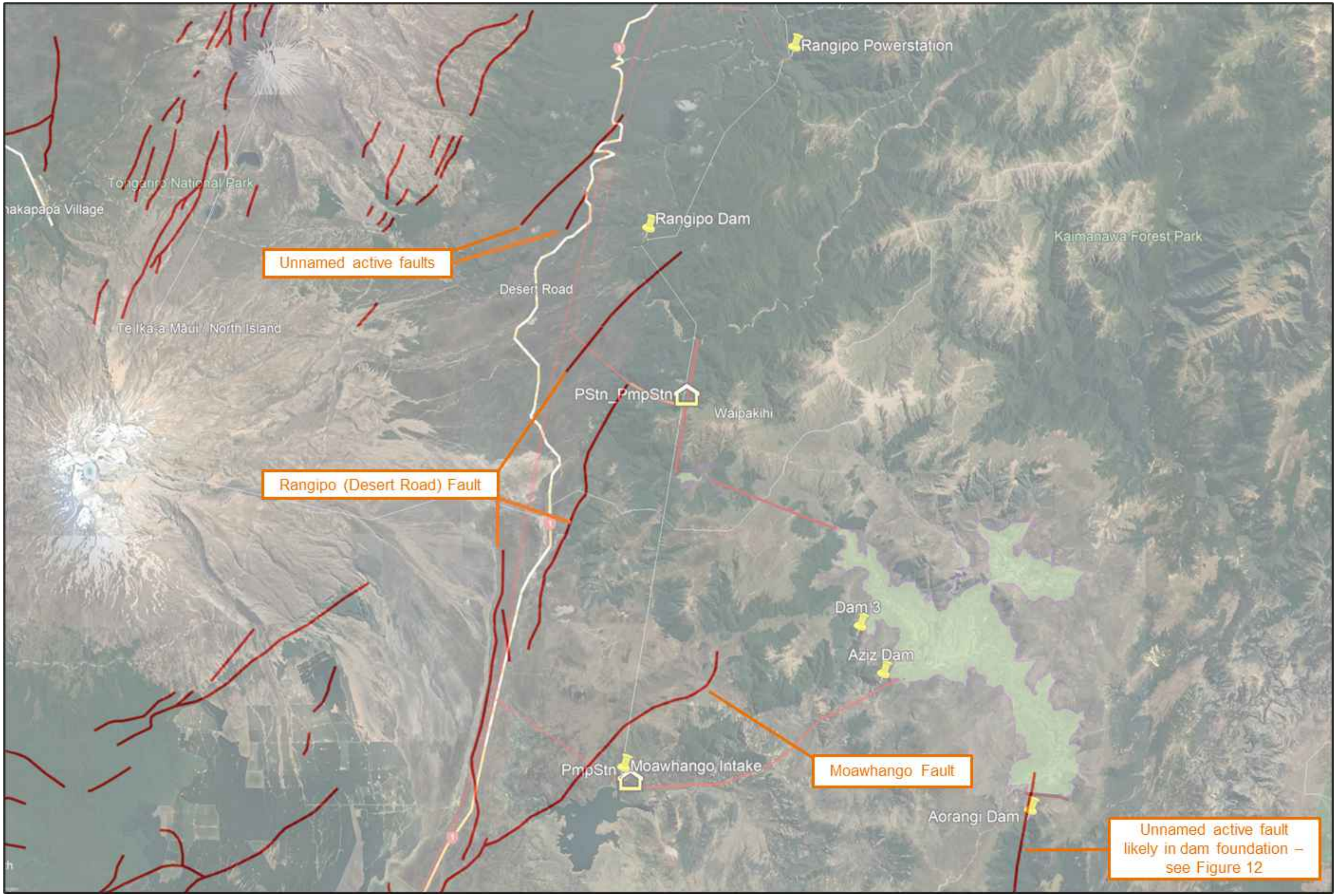


Figure 11 - Approximate location of active faults in the project area (from GNS Active Fault Database)

Figure 12 - Possible active fault trace in proposed Aorangi Dam footprint (note – upper dam option shown)

For most of the scheme infrastructure, active surface faulting does not appear to place a significant constraint on its development. Based upon the work completed, a possible active fault trace may be present within the foundation of the proposed Aorangi Dam (both the upper and lower dam options) and also the reservoir. The absence of available information means the constraint it places on development cannot be reliably assessed at this time. In addition, the Moawhango Fault may have a greater extent than that currently mapped. Further work would be required as part of the next stage of project investigation of the constraints placed by active faulting.

For earthquake shaking hazard, the NZSOLD DSG (2015) design criteria for a High PIC dam can be summarised as:

- Operating Basis Earthquake – 1 in 150 AEP.
- Safety Evaluation Earthquake – 84th percentile level for the Credible Maximum Earthquake (CME) if developed by a deterministic approach and need not exceed the 1 in 10,000 AEP ground motion developed by a probabilistic approach.

It is noted that some owners of high-importance assets, including dams and those which may provide post-disaster services, use higher serviceability limits for their assets than a 1 in 150 AEP. Some use serviceability levels of 1 in 500 AEP for example. This may be applicable to the proposed works.

We have calculated likely seismic design requirements using NZS1170.5 to provide an indication of what may be required. We have assumed Site Class A based upon likely foundation conditions. Horizontal peak ground accelerations calculated are:

- OBE (150 AEP) – 0.18 g.
- SEE (10,000 AEP) – 0.88 g.

Although lower than some other parts of New Zealand, relatively speaking, this still represents a very high seismic hazard. The seismic design criteria will be critical for design, construction, and operation. Defensive design principles will be required to be used. Topographic amplification effects would also need to be considered in the future for some infrastructure. We are not aware of any publicly available information which may provide greater detail than NZS1170.5 at this stage.

We are not aware of any publicly available liquefaction study for the project area.

Based upon the published geological map, most of the infrastructure will be founded on, or in, rock. On this basis, it is non-liquefiable.

Alluvium is mapped within and adjacent to some of the watercourses, including much of the footprint of the proposed reservoir area. It is also possible that Taupo Pumice Alluvium would be present locally across the site also.

It would appear the Waipakihi Dam, Azim Dam and the proposed saddle dam of the upper reservoir would be founded on rock, based upon their 'gorge-like' appearance. Any localised alluvium on the valley floor would be removed. This would be the case for the lower Aorangi Dam location also (i.e. the gorge). The upper Aorangi Dam option, as shown in 0, is underlain by mapped alluvium, and this is likely to be of greater extent (in both plan and depth) than the localised alluvium that may be encountered elsewhere. As the description of the alluvium on the published geological map is very general, it is not possible to say if these materials would be liquefiable. Their description ranges from fine-grained to coarse-grained soils.

It should therefore be assumed any liquefiable soils, if present in foundations, would be removed and would be of a limited extent. This is except for the Upper Aorangi Dam site if assumed for the concept design, where a nominal provision should be made for greater over-excavation (and associated increase in embankment volumes) to remove potentially liquefiable soils.

A further earthquake hazard is that of seiche waves (standing waves in an enclosed body of water). We are not aware of any historical or pre-historical occurrences of significant seiche waves in reservoirs of the central North Island. We are also not aware of any publicly available information with regards to seiche wave hazards in North Island reservoirs.

GNS (2015) completed an assessment of possible seiches in the Mackenzie Basin lakes (South Island). It was concluded that it was not possible to determine likely seiche wave characteristics as there are no reliable established relationships, due to the complexity of factors involved. GNS (2015) lists some case studies from overseas, which indicate seiche waves of up to a few metres. On this basis, any seiche waves which may occur are likely to be accommodated in freeboard allowance for the dam. It is further noted that overtopping seiche waves would need to lead to sufficient erosion. We are not aware of any documented case studies of this occurring, due to the episodic and short duration of any overtopping that would be generated. Hydrodynamic loading due to seiche waves on concrete dams (and gates etc.) would likely be comparable to other design cases considered.

On this basis, earthquake-induced seiche waves are not expected to be a key consideration for scheme development.

B.5.4.2 Slope Instability

Based upon the published geological map, no significant areas of slope instability have been mapped in the immediate project area. We have also reviewed the national landslide database held by GNS. Some landslides in the vicinity of the project area are included in the database, but minimal associated information is presented (such as their landslide type, age, current activity etc). The definition of landslide 'size' isn't readily apparent in the database.

A 'large' landslide is mapped on the northern side of Lake Mowhango (0). It is mapped as a 'landslide feature' comprising 'hummocky ground'. This location is not in the vicinity of proposed infrastructure and is somewhat above existing reservoir FSL. On this basis, any change in the operation of the existing reservoir should not significantly impact the mapped landslide, as it doesn't form the immediate reservoir shoreline. The location is mapped as Tertiary-aged rocks on the published geological map. Bedding is not mapped at the immediate location but may dip to the south at low angles (i.e. out of slope). It does not appear an obvious dipslope failure, however.

Figure 13 - Mapped area of landsliding on the northern side of Lake Moawhango (from GNS)

A further area of landsliding shown in the database in the project area is that on the NE shoreline of the proposed upper reservoir (0). It is mapped as several adjacent 'landslide features' comprising 'hummocky ground', which may be part of a landslide complex. The mapped location is close to the boundary of alluvium and 'greywacke' on the published geological map. Tertiary-aged rocks are not mapped at the location, but possibly may be present. Bedding is not mapped at the immediate location in the greywacke, but the slope is unlikely to be dipslope based upon regional bedding. As minimal information is available for these mapped landslides, further work would be required as part of the next stage of project development to assess their significance for reservoir shoreline stability, under varying loading conditions.

The mapped occurrence of Tertiary-aged rocks around parts of the reservoir shoreline would need specific consideration as part of any future reservoir shoreline stability assessment. Particularly those which may present dislopes or show signs of historic or pre-historic instability.

Figure 14 - Mapped area of landsliding on the shoreline of proposed reservoir (from GNS)

Of less relevance, but worth noting, a 'large' landslide is mapped in the database as forming the right abutment of Rangipo Dam. It is referred to as the 'Barbour Stream' landslide. No further information is presented. The area is mapped as being underlain by greywacke.

We are not aware of any publicly available assessment of slope instability susceptibility in the project area.

Based upon the information sourced as part of this study, there is no current evidence that slope instability would place a significant constraint on design, construction and operation of the works.

B.5.4.3 Volcanic / Geothermal

The project area is located approximately 20 km east of the currently active craters/vents associated with the Tongariro Volcanic Centre. The site is also located a similar distance from the southern margin of the Taupo Volcanic Centre. Consideration of volcanic and geothermal hazards is therefore important.

The main hazard to the site is likely associated with eruption of Mount Ruapehu. 0 shows lava flows from Mount Ruapehu in the last approximately 10,000 years. 0 shows both pyroclastic flows and lahars from Mount Ruapehu, in the last approximately 20,000 years. It can be seen from this information that the hazard from lava domes and flows, pyroclastic flows, and lahars, is essentially restricted to the west of SH1 and the Tongariro River. It is noted that the hazard area largely coincides with the current mapped extent of volcanic deposits on the published geological map shown in 0. It is noted that surface topography is very important for these volcanic hazards, often being constrained to topographic lows associated with river valleys. Significant surface drainage features exist between the volcanic centre and the project area (such as the Tongariro River).

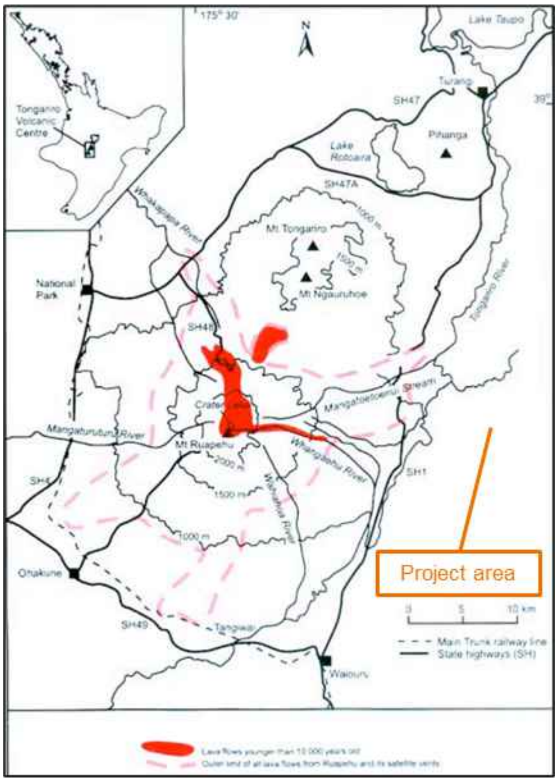


Figure 15 - Lava flows from Mount Ruapehu in the last 10,000 years (Neall et al. 1999)

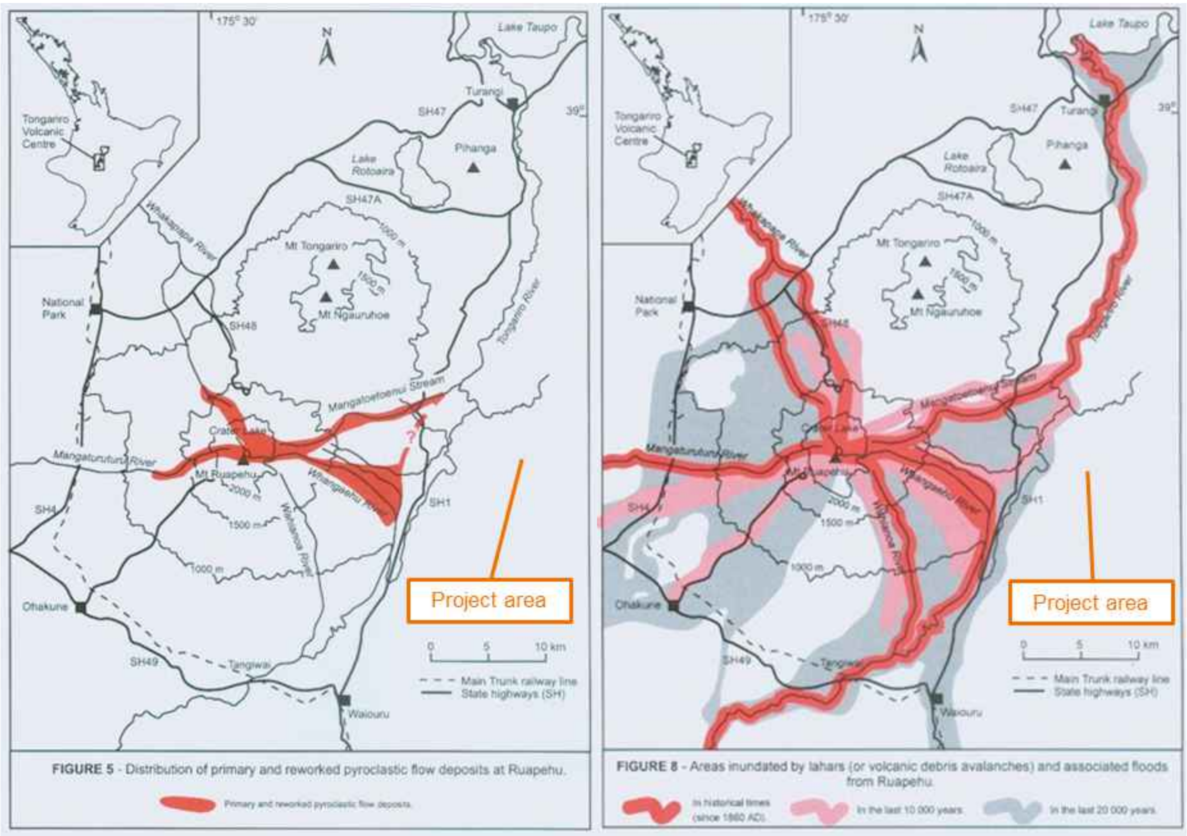


Figure 16 - Pyroclastic flows and lahars from Mount Ruapehu (Neall et al. 1999)

The greatest volcanic hazard is likely to be that associated with tephra. Tephra is often subdivided into ash (fine, less than 2 mm), lapilli (2 to 64 mm), and volcanic bombs/locks (larger than 64 mm). It can be assumed lapilli and volcanic blocks/bombs would not impact the project area based upon their size and the distance of the project area from the eruptive centre (roughly 20 km).

For this reason, ash is the key tephra hazard. Various consequences exist from tephra hazard, one would be ash in water and damage to the mechanical plant (highly abrasive due to shape and composition). It could also impact the availability of water for filling/refilling the reservoir and this may exist for some time following an eruption. The site is located downwind of the volcanic centre, assuming the common prevailing winds (i.e., westerly, north-westerly).

0 shows tephra deposits associated with historical eruptions. The influence of the prevailing winds at the time of the eruption can be seen. Neall et al. (1999) have produced a tephra hazard map for Mount Ruapehu, and this is shown in 0. This shows the hazard associated with larger tephra is restricted to the immediate volcanic centre area. The project area is located within 'Area B', which is likely to receive 10 to 40 mm of tephra during a 'small-magnitude eruption' and '80 to 300 mm' of tephra during a 'large-magnitude eruption'. Obviously, these accumulations are dependent on prevailing winds and the AEP of the different eruptive scenarios is not stated.

Tephra deposits from Mount Tongariro and Mount Ngauruhoe are likely less critical than Mount Ruapehu. This is as they are more likely to have smaller-sized eruptions, they are further away from the project area and when prevailing winds are considered.

A more important source of tephra hazard is the Taupo Volcanic Centre. 0 shows assessed tephra deposits associated with the Taupo Volcanic Centre in the last approximately 22,000 years. It is therefore assumed the largest known eruption, the Oruanui eruption, is not included in this figure. This eruption occurred around 26,500 years ago and around 2 m of tephra may have accumulated at the site in association with this eruption alone. The figure shows around 1.5 m of Tephra associated with the Taupo Volcanic Centre may have accumulated at the project area in the last 22,000 years or so.

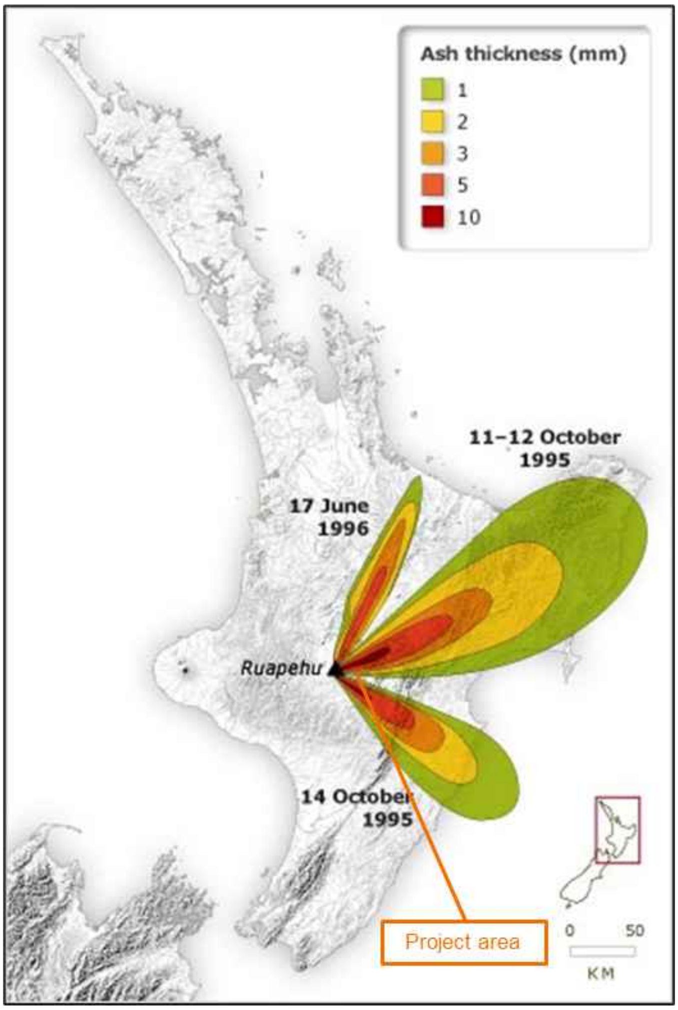


Figure 17 - Tephra deposits associated with recent Mount Ruapehu eruptions (GNS, undated)

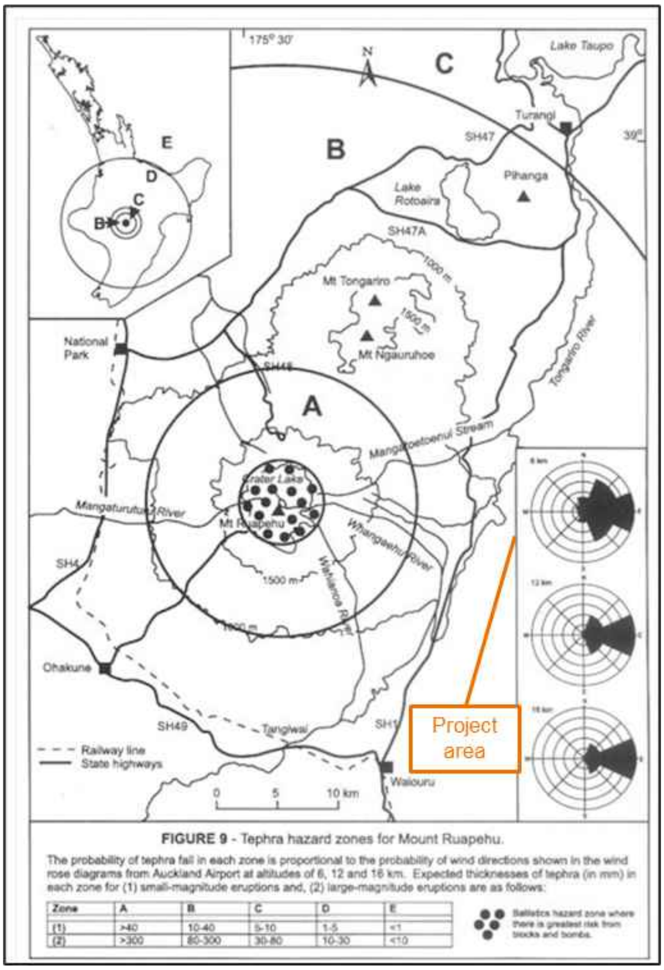


Figure 18 - Tephra hazard for Mount Ruapehu (Neall et al. 1999)

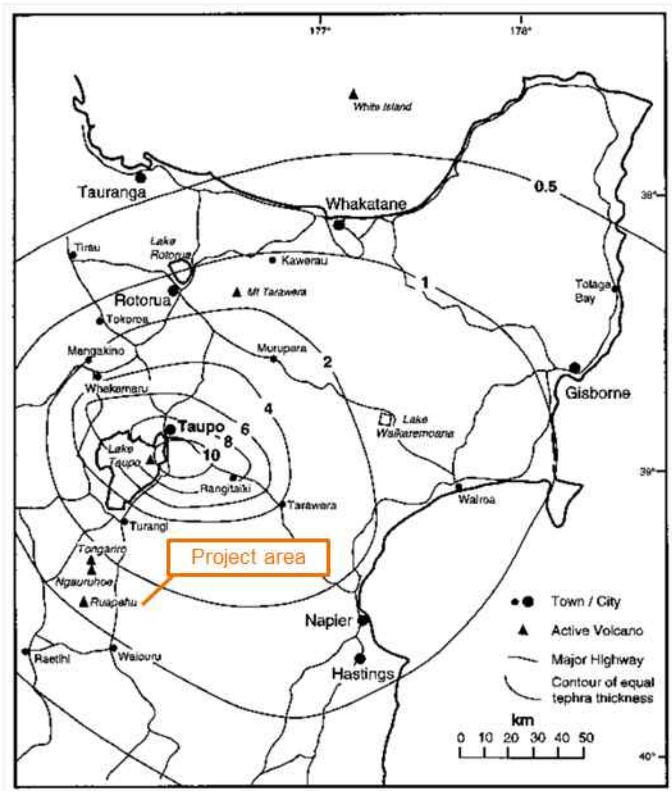
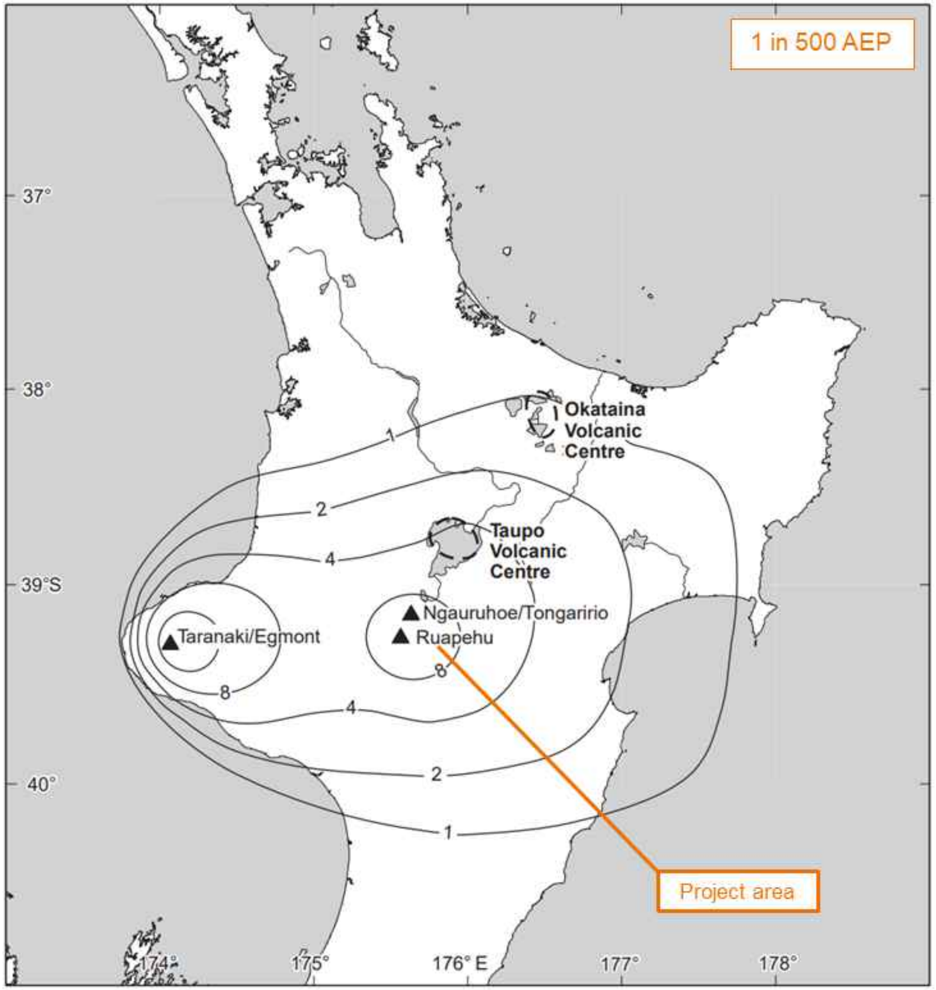


Figure 19 - Tephra deposits from Taupo Volcanic Centre (Frogatt et al. 1999)

Hurst & Smith (2010) completed a probabilistic ash deposition assessment based upon multiple sources, including both the Tongariro Volcanic Centre and the Taupo Volcanic Centre. They produced hazard maps for both 1 in 500 AEP and 1 in 10,000 AEP events, which are shown in 0. This information shows around 8 to 10 mm of ash deposition for a 1 in 500 AEP event and between 64 and 128 mm ash deposition for a 10,000 year event.

In summary, most volcanic hazards are not expected to place a significant constraint on project development. The risk associated with tephra deposits will need to be considered further as part of the next stage of project development.

We are not aware of any publicly available information that indicates any geothermal activity in the immediate project area. Similarly, there is no published or anecdotal information suggesting geothermal activity was encountered during surface and underground works associated with the Tongariro Power Scheme. Considering the site location and proximity to the TVZ, it is possible geothermal activity may be encountered by the construction of the works and further investigation would be required as part of the next stage of project development.



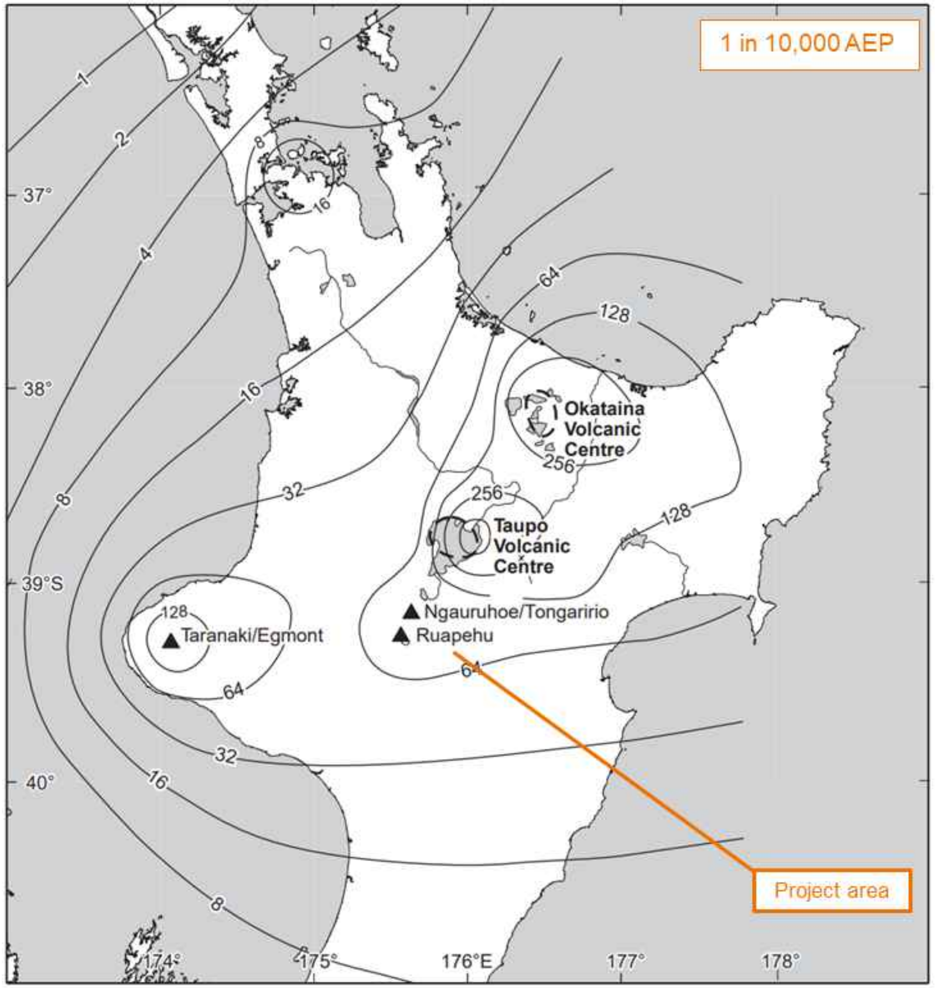


Figure 20 - Probabilistic ash hazard modelling (from Hurst & Smith 2010)

B.5.4.4 Reservoir Water Losses

The location of the proposed upper reservoir is shown in 0, with the published geological map approximately overlain (from lee et al. 2011). This shows the geology of the reservoir area likely comprises:

- Q1a – described as ‘gravel, sand, silt, and mud, forming alluvial terraces’ of Holocene-age.
- IQa – described as ‘alluvial fan and colluvial deposits’ of Late Pleistocene to Holocene-age.
- MPg – Tertiary-aged rocks described as ‘Pebbly limestone, cross-bedded sandstone, mudstone, minor conglomerate, and limestone’.
- Jtk – greywacke described as ‘Massive, fine to medium-grained quartzofeldspathic sandstone, alternating sandstone and mudstone, minor conglomerate, broken formation, and melange’. Noting most of the reservoir would be in the non-schistose greywacke.

In addition, it is possible veneers of tephra and Taupo Pumice Alluvium exist locally.

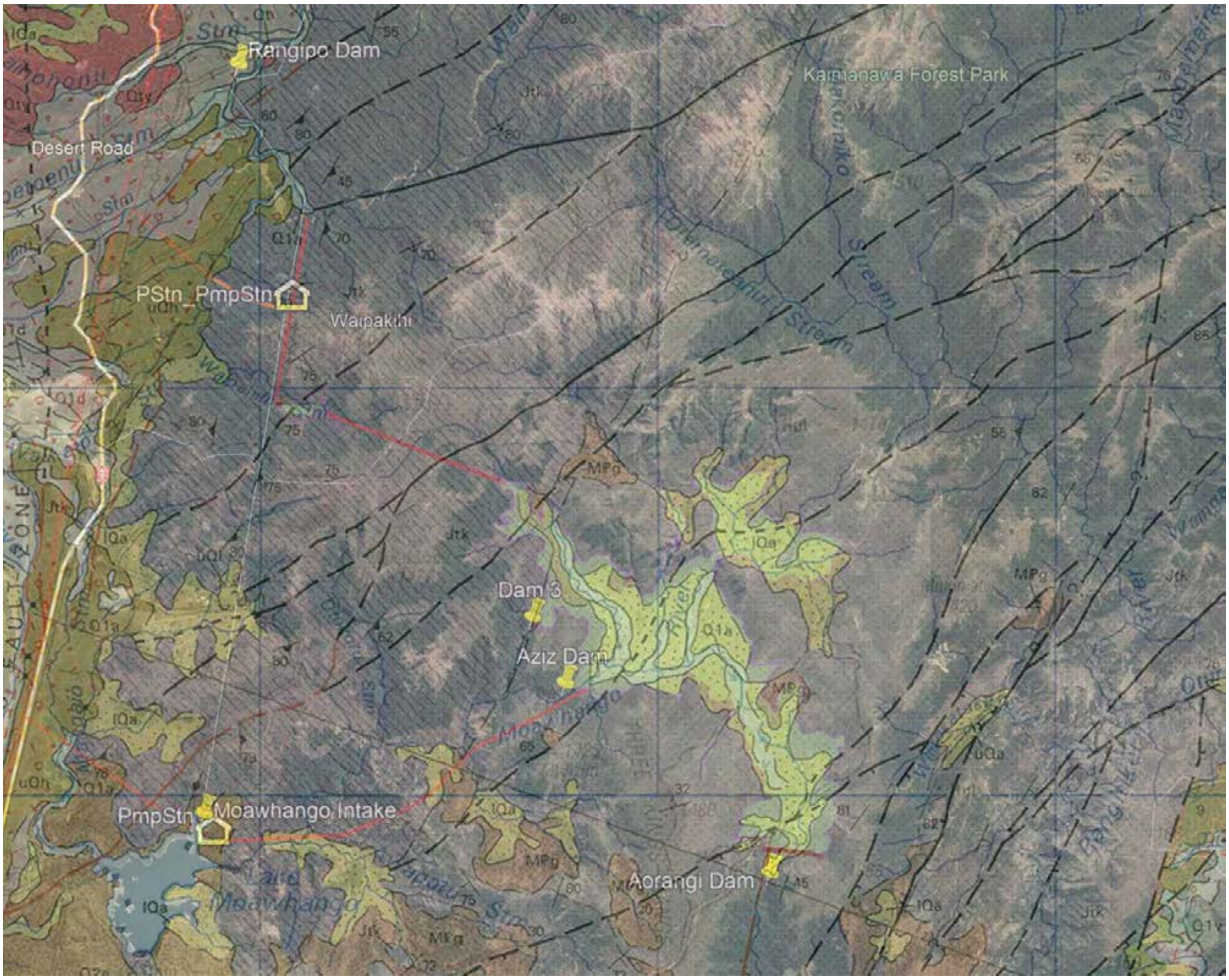


Figure 21 - Geology of the proposed reservoir area (from Lee et al. 2011)

The existing Lake Moawhango provides useful engineering precedence. This has been formed in similar geology to the proposed reservoir, including alluvium, Tertiary-aged rocks, and ‘greywacke’. We are not aware of any issues with significant reservoir water losses.

The Tertiary-aged rocks are described as including carbonate rocks, such as ‘pebbly limestone’ and ‘limestone’. Mapping by Sporli & Barter (1973) also describes ‘carbonate-rich’ rocks associated with the ‘greywacke’. We are not aware of any publicly available information which is suggestive of dissolution landforms within the limestone, which could lead to significant water losses.

The ‘greywacke’ is described as containing ‘broken formation and melange’. We have no information that these coincides with areas of moderate to high permeabilities which may lead to significant water losses from the reservoir, should they occur beneath it (which is not currently known). One of these areas was encountered during the construction of the Tongariro Power Scheme. It is stated in Beetham & Watters (1985) ‘Near the Moawhango dam site, mélange termed autoclastic breccia by Hancox (1975) is exposed along the 500 m of the gorge below the damsite, as well as along the upper dam site gorge which lies along the strike 3 km to the northeast. It thus appears this mélange is at least 500 m thick and extends along strike for at least 4 km'. This unit of mélange is therefore beneath the existing reservoir and was likely exposed in the original Moawhango River channel (i.e. direct connectivity to the reservoir). As mentioned above, we are not aware of any significant water losses from the reservoir.

We are aware that significant groundwater inflows occurred in some underground excavations associated with the Tongariro Power Scheme. One paper we have not been able to source is titled 'Control of heavy water inflows into the Moawhango-Tongariro tunnel'. This description suggests some areas of the greywacke are of 'moderate' to 'high' permeability, and this will be associated with the presence of 'open defects'. The locations and mechanism of inflows, such as if inflows were high volumes and/or pressures, are not currently known.

The topographical map for the reservoir area shows extensive areas mapped as 'swampy ground' (0). This may be suggestive of near-surface low-permeability soils for example. These are the low-lying areas most likely filled with alluvium, and Taupo Pumice Alluvium (in-situ or re-worked).

There is therefore no currently available information suggestive that significant reservoir water losses may occur from the upper reservoir.

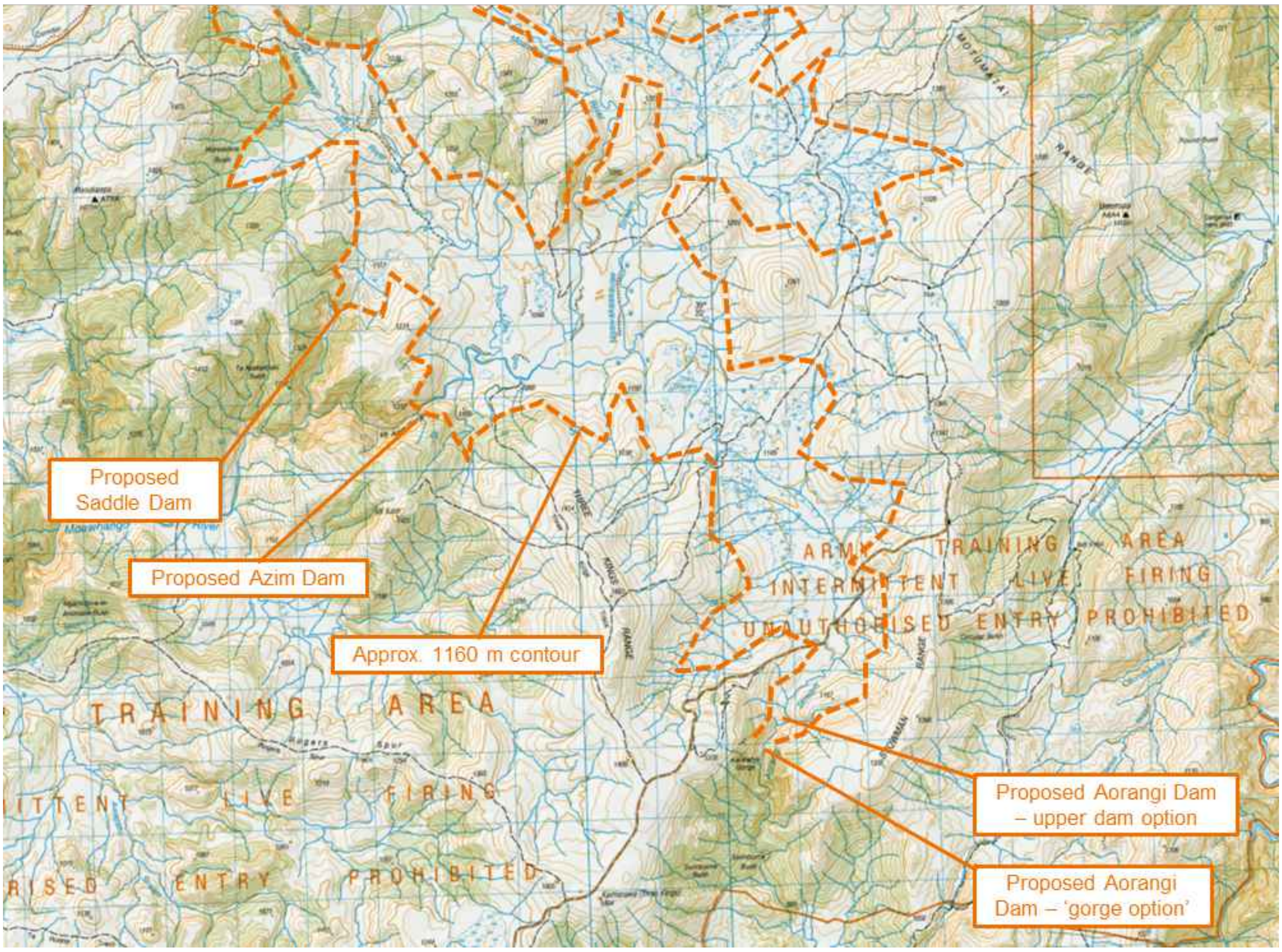


Figure 22 - Topographic map of the proposed reservoir area

The reservoir on the Waipakihi River should be formed on 'greywacke, and therefore similar comments to those presented above apply.

B.5.5 Geological Model

A significant amount of site-specific geological information is available to define a conceptual geological model for the site. For this study, an emphasis has been placed on the information presented in the following two papers:

- Beetham, R.D & Watters, W.A 1985. Geology of Torlesse and Waipapa terrane basement rocks encountered during the Tongariro Power Development project, North Island, New Zealand, New Zealand Journal of Geology and Geophysics, 28:4, 575-594, DOI: 10.1080/00288306.1985.10422534
- Duder, J.N, et al. 1977. Engineering Geology and Foundation Engineering of the Moawhango Arch Dam.

B.6 Site 2 – Taruarau

The following subsections summarise the findings of the geological study for Site 2.

B.6.1 Scheme Description

The scheme description is presented in the main study report.

B.6.2 Available Information

The key references which have been used in this study are similar to those for Site 1, due to their relative proximity:

- Published geological maps:
  - Lee, J.M.; Townsend, D.; Bland, K.; Kamp, P.J.J. (compilers) 2011: Geology of the Hawke's Bay area: scale 1:250,000. Lower Hutt: Institute of Geological & Nuclear Sciences Limited. Institute of Geological & Nuclear Sciences 1:250,000 geological map 8. 86 p. + 1 folded map.
- Geological hazards:
  - Froggatt, P. 1997. Volcanic hazards at Taupo Volcanic Centre. Ministry of Civil Defence. Volcanic hazards information series 7. 26 p.
  - GNS Science Active Fault Database (https://data.gns.cri.nz/af/).
  - GNS Landslide Database (http://data.gns.cri.nz/landslides/).
  - Hurst & Smith 2010. Volcanic ashfall in New Zealand – probabilistic hazard modelling for multiple sources, New Zealand Journal of Geology and Geophysics, 53:1, 1-14.
  - Neall, V.E.; Houghton, B.F.; Cronin, S.J.; Donoghue, S.L.; Hodgson, K.A.; Johnston, D.M.; Lecointre, J.A.; Mitchell, A.R. 1999. Volcanic hazards at Ruapehu Volcano. Wellington: Ministry of Civil Defence. Volcanic hazards information series 8. 30 p.
- Published and unpublished geological papers:
  - Atkins, R.A.E 1976. Rangipo Power Project seismic determination of elastic properties in powerhouse investigation drives. Ministry of Works and Development Central Laboratories Report No. 2-76/2
  - Beetham, R.D & Watters, W.A 1985. Geology of Torlesse and Waipapa terrane basement rocks encountered during the Tongariro Power Development project, North Island, New Zealand, New Zealand Journal of Geology and Geophysics, 28:4, 575-594, DOI: 10.1080/00288306.1985.10422534
  - Bryant, J.M 1977. Rock deformation investigations at Rangipo. Ministry of Works and Development Central Laboratories Report No. 2-77/4
  - Bryant, J.M 1977. Shear strengths of joints in Rangipo rocks. Central Laboratories Report No. 2-77/2
  - Bryant, J.M 1977. Some properties of Kaimanawa Greywacke. Ministry of Works and Development Central Laboratories Report No. 2-77/1
  - Duder, J.N, et al. 1977. Engineering Geology and Foundation Engineering of the Moawhango Arch Dam.
  - Hegan, B.D 1977. Engineering geological aspects of Rangipo underground powerhouse. New Zealand Institute of Engineers. Papers presented to the Symposium on Tunnelling in New Zealand. Hamilton
  - Millar, P.J 1977. The design of Rangipo Underground Powerhouse. Ministry of Works and Development.
  - Prebble, W.M 1983. Investigations in an active volcanic terrain.
  - Spörli, K.B & Barter, T.P 1973. Geological reconnaissance in the Torlesse super-group of the Kaimanawa Ranges along the lower reaches of the Waipakihi River, North Island, New Zealand, Journal of the Royal Society of New Zealand, 3:3, 363-379, DOI: 10.1080/03036758.1973.10421862
  - Spörli, K.B & Bell, A.B 1976. Torlesse mélange and coherent sequences, eastern Ruahine range, North Island, New Zealand, New Zealand Journal of Geology and Geophysics, 19:4, 427-447, DOI: 10.1080/00288306.1976.10423538
  - Williams, J.K 1994. Some aspects of the Cenozoic Geology of the Moawhango River region. Master of Science Thesis, Massy University.

B.6.3 Published Geology

Figure 1shows the project area is in an area defined as 'Eastern greywacke basement rocks' described as being between 300 to 100 million years old.

A more detailed geological map of the project area is shown in Figure 2 (from Lee et al. 2011), which includes the proposed scheme infrastructure. Figure 3 is a geological section of the approximate site location, also from Lee et al. (2011).

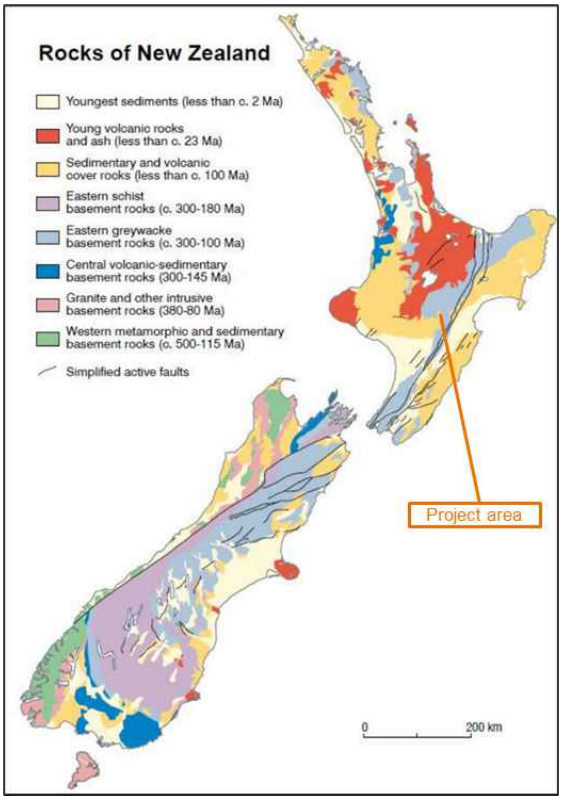


Figure 1 - Simplified geological map of New Zealand (from GNS undated)

The information shows that the 'greywacke' underlying the site (Jtk) is referred to as the 'Kaweka Terrane'. The greywacke is described as 'Massive, fine to medium-grained quartzofeldspathic sandstone, alternating sandstone and mudstone, minor conglomerate, broken formation, and melange'. The greywacke is mapped as comprising metamorphic textural zone 1, defined as 'non-schistose'. Mapped bedding is variable and is discussed later in this report. It generally strikes from N-S to NE-SW, at dips of more than 75°. It is noted that the formation is described as containing 'broken formation and melange'. Various definitions of the word 'melange' exist, but the USGS describes it as 'a body of rock characterised by a lack of internal continuity of strata or contacts, and by the inclusion of fragments or blocks of all sizes, both native and exotic, embedded in a fragmental matrix or fine-grained matrix'.

The basement 'greywacke' is overlain in some places by a capping of Tertiary-aged rocks (sediments). These rocks have been deposited in different depositional basins, including the Eastern Wanganui Basin in the western part of the project area, and the East Coast Basin in the eastern part of the project area. They can be generalised as increasing in extent, both in plan and depth, southwards through the project area. The Tertiary-aged rocks (sediments) belong to several different 'Groups' and 'Formations'. They, therefore, present variable engineering geological characteristics. For example, in some instances, they likely display soil-like characteristics.

The key Tertiary-aged rocks (sediments) are:

- Eastern Wanganui Basin:
  - Whangamomona Group (Mpg, Mga, Pga) - which are described as 'Pebbly limestone, cross-bedded sandstone, mudstone, minor conglomerate, and limestone'.
- East Coast Basin:
  - Blowhard Formation (Mld) – described as 'poorly sorted conglomerate, sandstone, limestone, and minor siltstone'.
  - Pmz – described as 'siltstone, sandstone, and minor shell lenses'.
  - Pmm – described as 'Massive, locally fossiliferous, mudstone, alternating sandstone and mudstone, tephra beds common'.

It can be seen bedding is somewhat variable in the Tertiary-aged rocks (sediments), but is generally to the SW or S at between 5° and 20°. This is except for the Tertiary-aged rocks on the very eastern side of the project area, which dip more to the east and southeast at similar dips. These lie on the eastern side of the range front faults which separate mainly greywacke to the west, and Tertiary-aged rocks to the east.

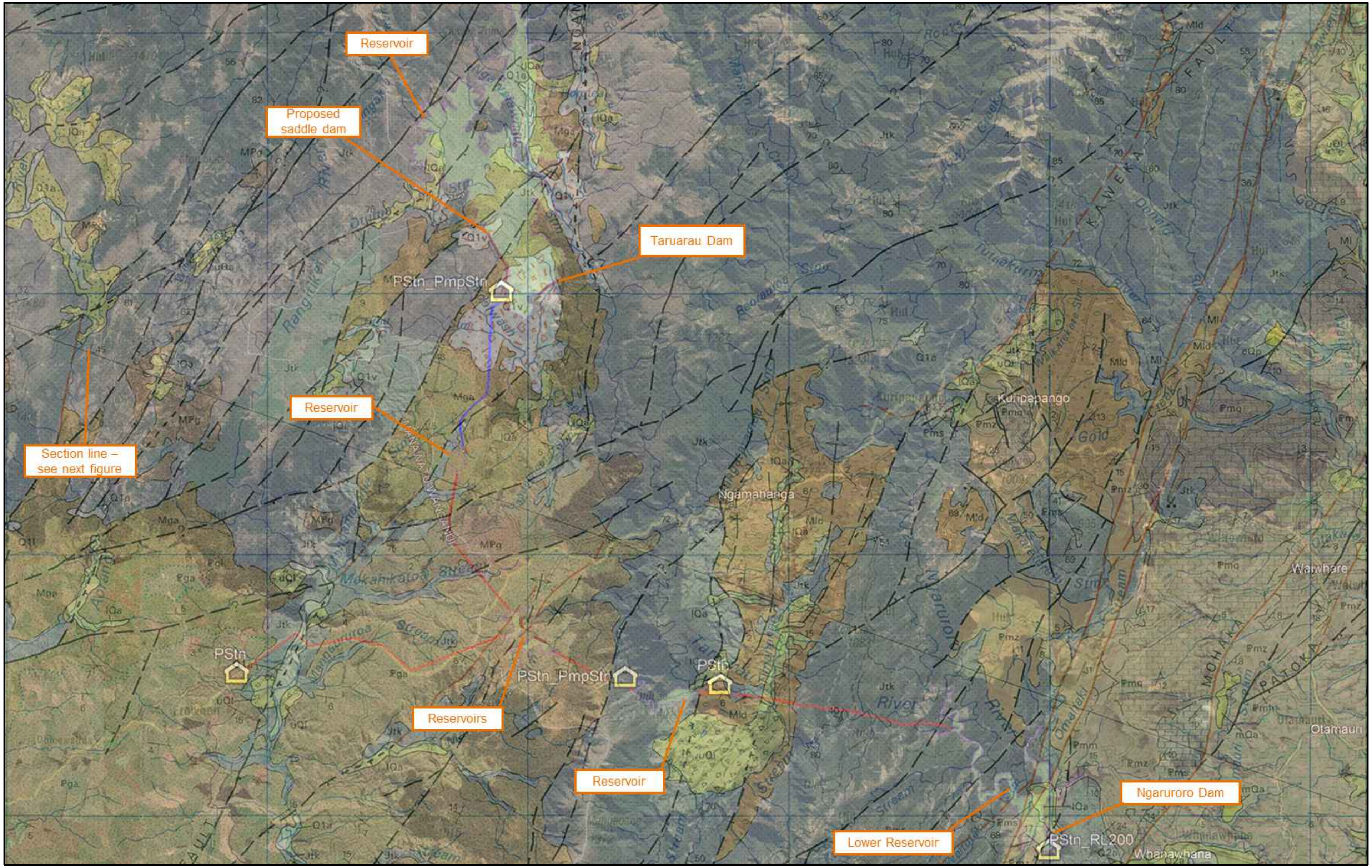


Figure 2 - Published geological map of the Hawkes Bay area with scheme arrangement overlain (Lee et al. 2011

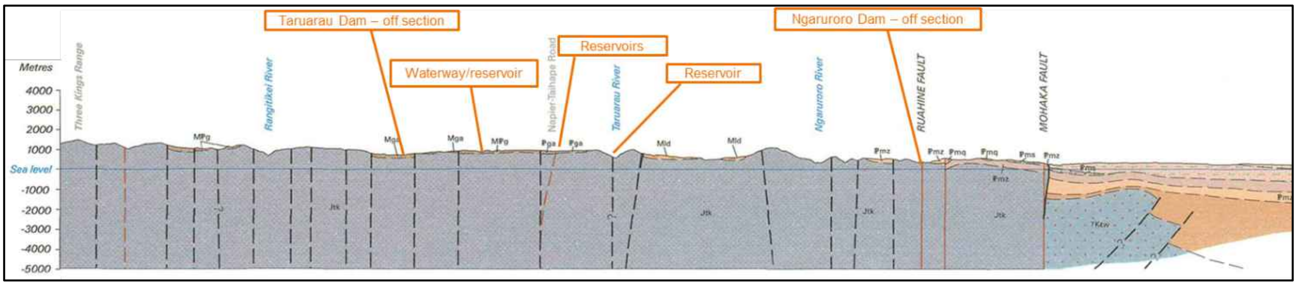


Figure 3 - Geological section through project area (Lee et al. 2011)

The other key observations from a review of the published geological map are:

- Rocks/deposits associated with the Tongariro Volcanic Centre are not mapped as underlying the immediate project area. Tephra occurrence is unlikely to be shown on the map due to scale and however but may be present in the project area.
- The site is located within the mapped extent of primarily non-welded ignimbrites associated with the Taupo Volcanic center, often referred to as the Taupo Pumice Formation (Q1v), which also includes some tephra and re-worked deposits. Although not generally mapped as occurring in the immediate project area, they are expected to be encountered locally overlying older deposits. A notable mapped occurrence is within the footprint of the upper reservoir.
- Areas of alluvium are present overlying the rock within and adjacent to some of the larger watercourses. A notable occurrence of this is in the vicinity of the proposed reservoir and associated dams. Two types of alluvium are mapped in the project area:
  - Q1a – described as 'gravel, sand, silt, and mud, forming alluvial terraces' of Holocene-age.
  - IQa – described as 'alluvial fan and colluvial deposits' of Late Pleistocene to Holocene-age.
- Some areas of landslide deposits are mapped (uQl) in the general project area, often being associated with the mapped occurrence of Tertiary-aged rocks (sediments). These are described as 'poorly to unconsolidated landslide deposits ranging from coherent to broken rock'.
- deposits do not appear to include the currently proposed infrastructure locations.
- Faulting – several active faults are mapped within the project area, these are discussed in more detail later in this study. The faults generally strike N-S to NNE-SSW, consistent with the main structures on the east coast of the North Island.

B.6.4 Geological Hazards

The following subsections summarise publicly available information about geological hazards of relevance to this study. The emphasis has been placed on those geological hazards which could be a significant constraint on design, construction, and operation.

B.6.4.1 Earthquake Hazards

Active faults present a surface rupture hazard for infrastructure located over them (this includes reservoirs and the potential for displacement of the water body i.e. tsunami). Active faults shown in the GNS Science Active Fault Database are shown in Figure 4, relative to the approximate position of the proposed scheme infrastructure. Key observations from this data are:

- Several un-named active faults are mapped as occurring in the western part of the project area. This includes underlying the location of the mapped scheme infrastructure. Although mapped as active, no further information is presented on its characteristics (such as the age of the last surface rupture, recurrence interval, slip rate, and single event displacements). The possible trace of one of these faults is shown as Figure 5, relative to the current location of the scheme infrastructure.
- Several active faults are mapped in the eastern side of the project area. These active faults essentially form the 'rangefront' and define the boundary between more basement rocks to the west (i.e. greywacke) and more Tertiary-aged rocks (sediments) and younger deposits to the east. It is noted some of these active faults are mapped within the lower reservoir (and therefore proximity to the associated infrastructure such as the dam and power station). The key faults are:
  - Makaroro Fault – defined as being a dextral fault, with a Recurrence Interval of between 3,500 and 5,000 years, its age of last surface rupture is dated as Holocene-age (i.e. the last approximately 12,000 years). Slip rate and single event displacement are not specified.
  - Ruahine Fault Zone - defined as being a dextral fault, with a Recurrence Interval of between 2,000 and 3,500 years, its age of last surface rupture is dated as Holocene-age (i.e. the last approximately 12,000 years). Slip

rate is defined as being ‘moderate’ (1 to 5 mm/yr) and single event displacement is not specified. Refer Figure 6 for its possible surface trace in imagery, relative to currently proposed scheme infrastructure.

- Big Hill Fault - defined as being a reverse fault, with a Recurrence Interval of between 5,000 and 10,000 years, its age of last surface rupture is dated as Holocene-age (i.e. the last approximately 12,000 years). Slip rate is defined as being ‘moderate’ (1 to 5 mm/yr) and single event displacement is not specified. Refer to Figure 6 for its possible surface trace in imagery, relative to the currently proposed scheme infrastructure.
- Mohaka Fault - defined as being a dextral fault, with a Recurrence Interval of less than 2,000 years, its age of last surface rupture is dated as ‘millennium’, meaning the last 1,000 years. Slip rate is defined as being ‘moderate’ (1 to 5 mm/yr) and single event displacement is ‘moderate’ (1 to 5 m).

For most of the scheme infrastructure, active surface faulting does not appear to place a significant constraint on its development.

Based on the work completed, active fault traces may be present within the foundation infrastructure at some locations (including reservoirs). Further work would be required as part of the next stage of the project investigation of the constraints placed by active faulting.

For earthquake shaking hazard, the NZSOLD DSG (2015) design criteria for a High PIC dam can be summarised as:

- Operating Basis Earthquake – 1 in 150 AEP.
- Safety Evaluation Earthquake – 84th percentile level for the Credible Maximum Earthquake (CME) if developed by a deterministic approach and need not exceed the 1 in 10,000 AEP ground motion developed by a probabilistic approach.

It is noted that some owners of high-importance assets, including dams and those which may provide post-disaster services, use higher serviceability limits for their assets than a 1 in 150 AEP. Some use serviceability levels of 1 in 500 AEP for example. This may apply to the proposed works.

We have calculated likely seismic design requirements using NZS1170.5 to indicate what may be required. We have assumed Site Class A based upon likely foundation conditions (representative of ‘greywacke’). Horizontal peak ground accelerations calculated are:

- OBE (150 AEP) – 0.18 g.
- SEE (10,000 AEP) – 0.88 g.

Although lower than some other parts of New Zealand, relatively speaking, this still represents a very high seismic hazard. The seismic design criteria will be critical for design, construction, and operation. Defensive design principles will be required to be used. Topographic amplification effects would also need to be considered in the future for some infrastructure. We are not aware of any publicly available information which may provide greater detail than NZS1170.5 at this stage.

We are not aware of any publicly available liquefaction study for the project area. Based on the published geological map, most of the infrastructure will be founded on, or in, rock. On this basis, it is non-liquefiable. Alluvium is generally not shown on the published geological map (nor Taupo Pumice Alluvium), and therefore if it is encountered, it is assumed to be of limited extent and would be removed during construction.

Alluvium is mapped within and adjacent to some of the watercourses, including within the footprint of the proposed upper reservoir area. Although not mapped as occurring, deeper alluvium is likely to be present at the location of the Ngaruroro Dam. The description of the alluvium is very broad, ranging from fine-grained to coarse-grained soils. It is therefore not possible to reliably assess its likely susceptibility to liquefaction. Taupo Pumice Alluvium is also mapped at the location of the upper reservoir and this is likely to be liquefiable. Further work would be required as part of the nest stage of development to more-reliably assess the constraint placed by liquefaction. It should therefore be assumed for concept design that any liquefiable soils, if present in foundations, would be removed and would be of a limited extent. Provision for some excavation (and the associated increase in dam volumes) should be made.

A further earthquake hazard is that of seiche waves (standing waves in an enclosed body of water). We are not aware of any historical or pre-historical occurrences of significant seiche waves in reservoirs of the central North Island. We are also not aware of any publicly available information with regards to seiche wave hazards in North Island reservoirs. GNS (2015) completed an assessment of possible seiches in the Mackenzie Basin lakes (South Island). It was concluded that it was not possible to determine likely seiche wave characteristics as there are no reliable established relationships, due to the complexity of factors involved. GNS (2015) lists some case studies from overseas, which indicate seiche waves of up to a few metres. On this basis, any seiche waves which may occur are likely to be accommodated in freeboard allowance for the dam. It is further noted that overtopping seiche waves would need to lead to sufficient erosion. We are not aware of any documented case studies of this occurring, due to the episodic and short duration of any overtopping that would be generated. Hydrodynamic loading due to seiche waves on concrete dams (and gates etc.) would likely be comparable to other design cases considered. On this basis, earthquake-induced seiche waves are not expected to be a key consideration for scheme development.

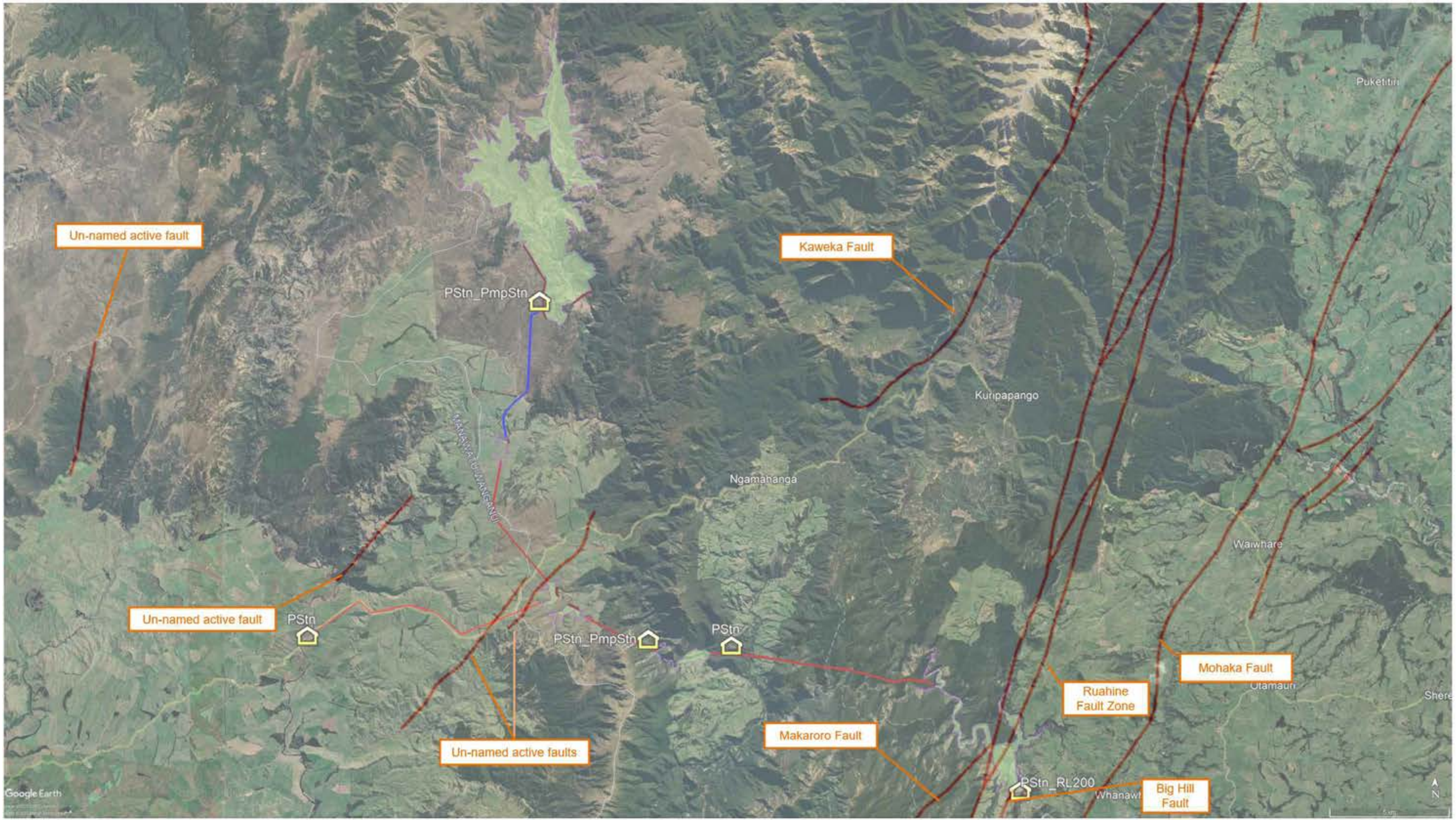


Figure 4 - Approximate location of active faults in the project area (from GNS Active Fault Database)

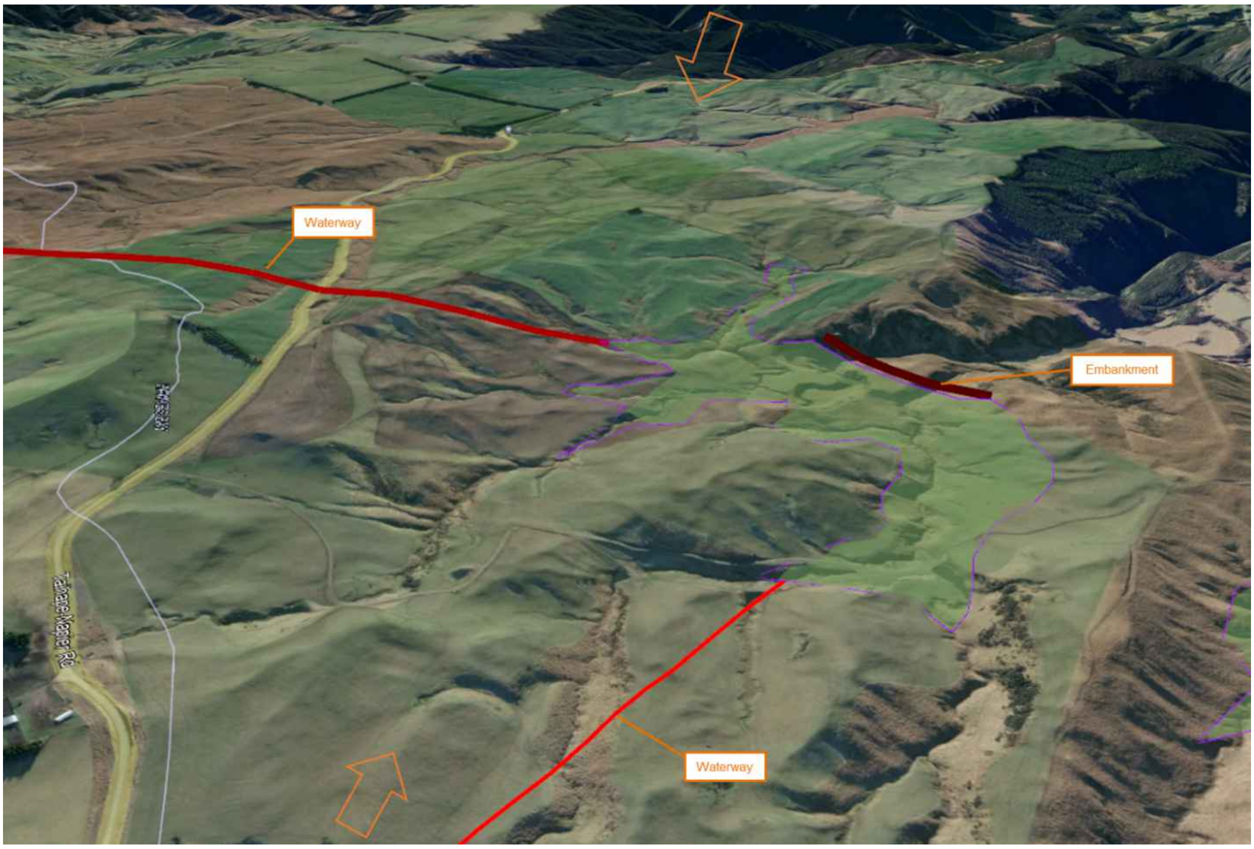


Figure 5 - Possible unnamed active fault trace near reservoir and waterway

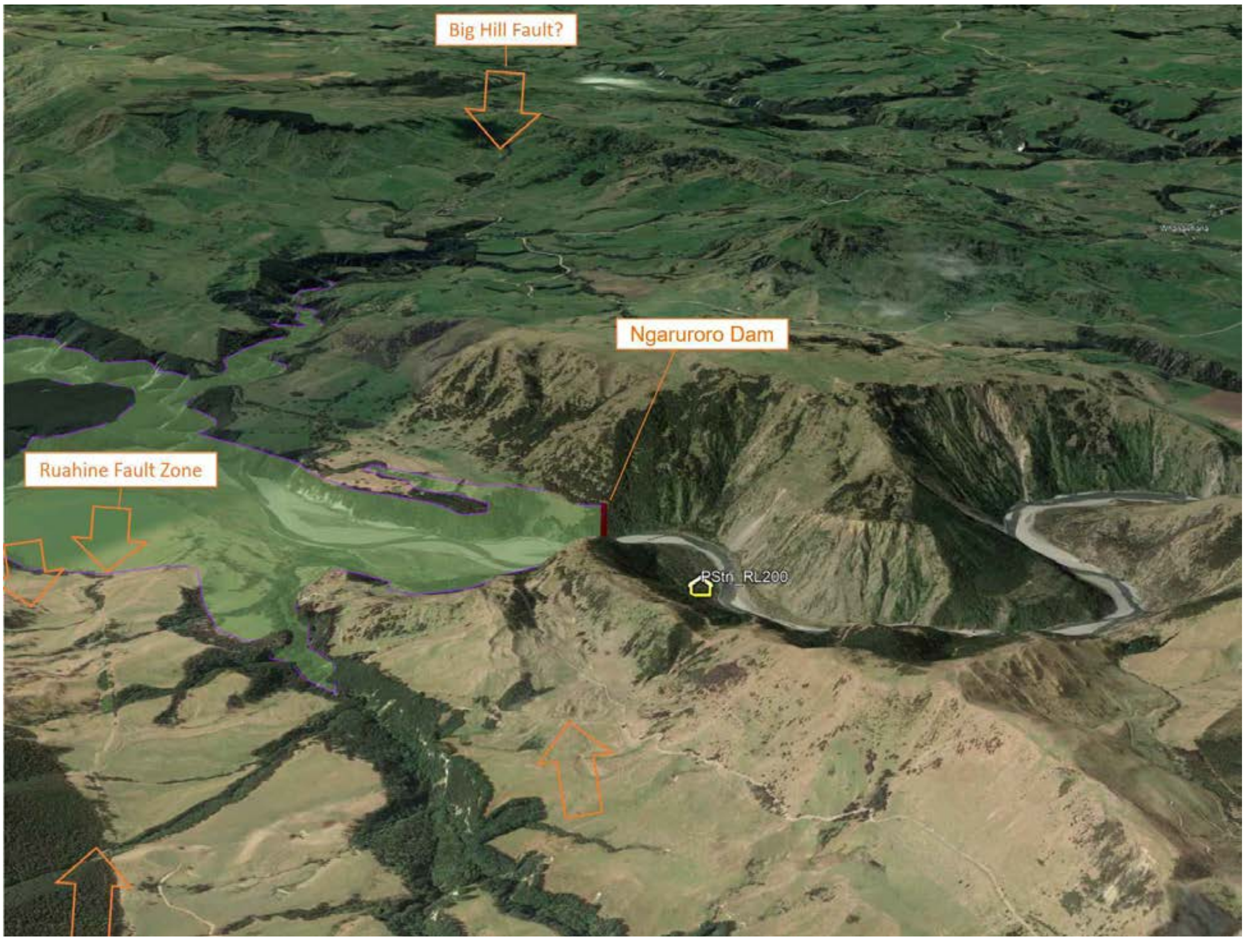


Figure 6 - Possible active fault traces at the location of the proposed Ngaruroro Dam and reservoir

B.6.4.2 Slope Instability

Based on the published geological map, some large areas of slope instability have been mapped in the general project area. These areas of 'landslide deposits' are generally mapped as being Late-Pleistocene to recent in age (i.e. the last approximately 70,000 years). It is noted only 'large' landslides are shown on the published geological map due to scale (i.e. the map is published at a scale of 1:250,000). The majority of the mapped 'landslide deposits' appear to show close associated with the occurrence of 'Tertiary-aged rocks (sediments).

None of the mapped areas of 'landslide deposits' immediately underlie currently proposed scheme infrastructure, including the shoreline of the proposed reservoirs. An example of one of the mapped areas of 'landslide deposits' and its proximity to the site is shown in Figure 7. This appears to be a very-large deep-seated landslide which may be a dipslope, with bedding mapped as being at 6° towards the south. This equates to out of the page for Figure 7. A visual assessment suggests this landslide is likely 'active' or 'dormant'. Although not underlying scheme infrastructure, it highlights the slope instability hazard associated with Tertiary-aged rocks (sediments).

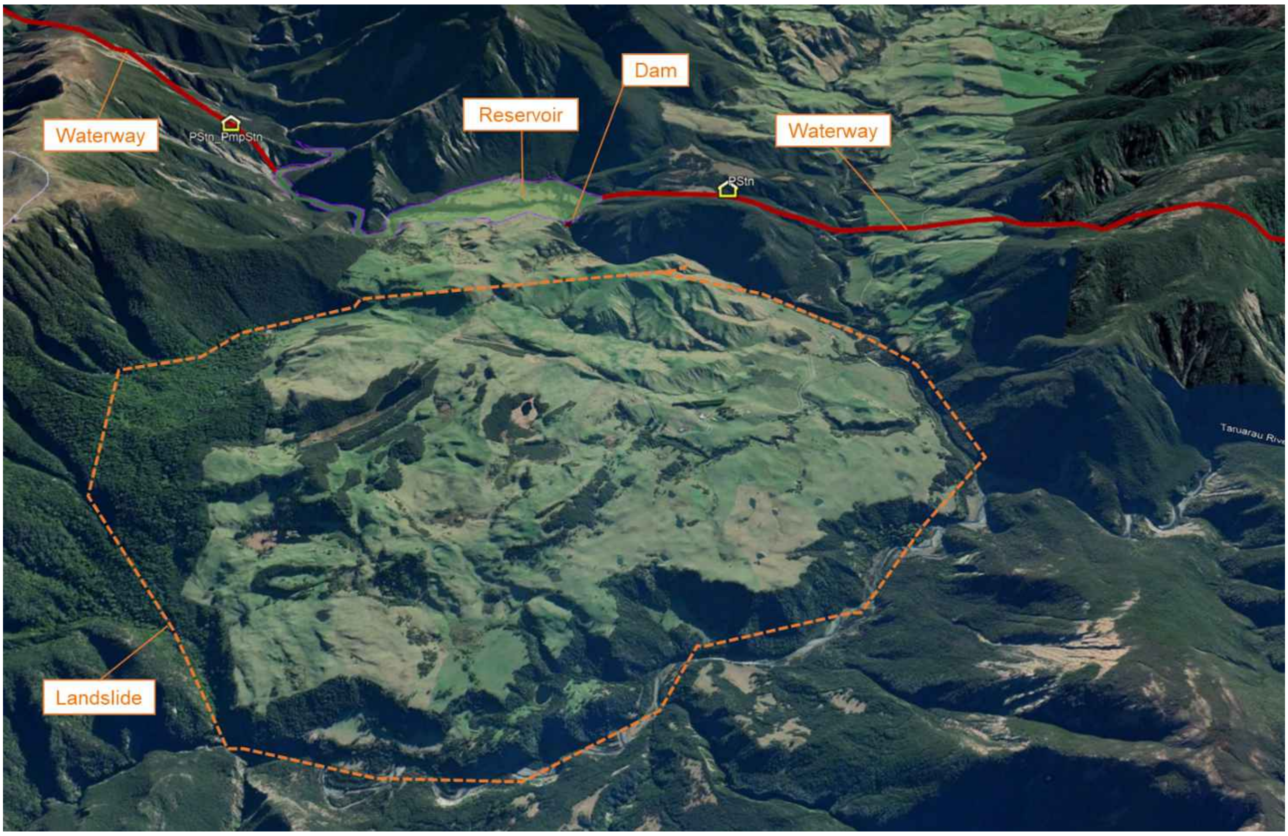


Figure 7 - Example of landsliding in Tertiary-aged rocks

GNS Science maintains a landslide database for New Zealand, and it is noted this is in development and not complete. We have briefly completed a review of the database as part of this study. Many landslides are identified in the general project area in the database. It is noted minimal associated information is presented with the identified landslides in the database (such as their landslide type, age, current activity, etc.). The definition of landslide 'size' isn't readily apparent in the database.

Landslides can be broadly divided into that associated with:

- Tertiary-aged rocks (sediments).
- 'Greywacke'.

Figure 8 provides an example of one location, with the current scheme arrangement at the top of the figure and the GNS landslide database for the area shown at the bottom of the figure. This section of the project area is mapped as being underlain by Tertiary-aged rocks. It can be seen several landslides are mapped near the scheme infrastructure, although not directly underlying it. Figure 9 provides an oblique view of this area, with one of the mapped landslides highlighted. This landslide has been highlighted as visual evidence suggests it is currently 'active'. This further highlights the slope instability hazard in the general project area.

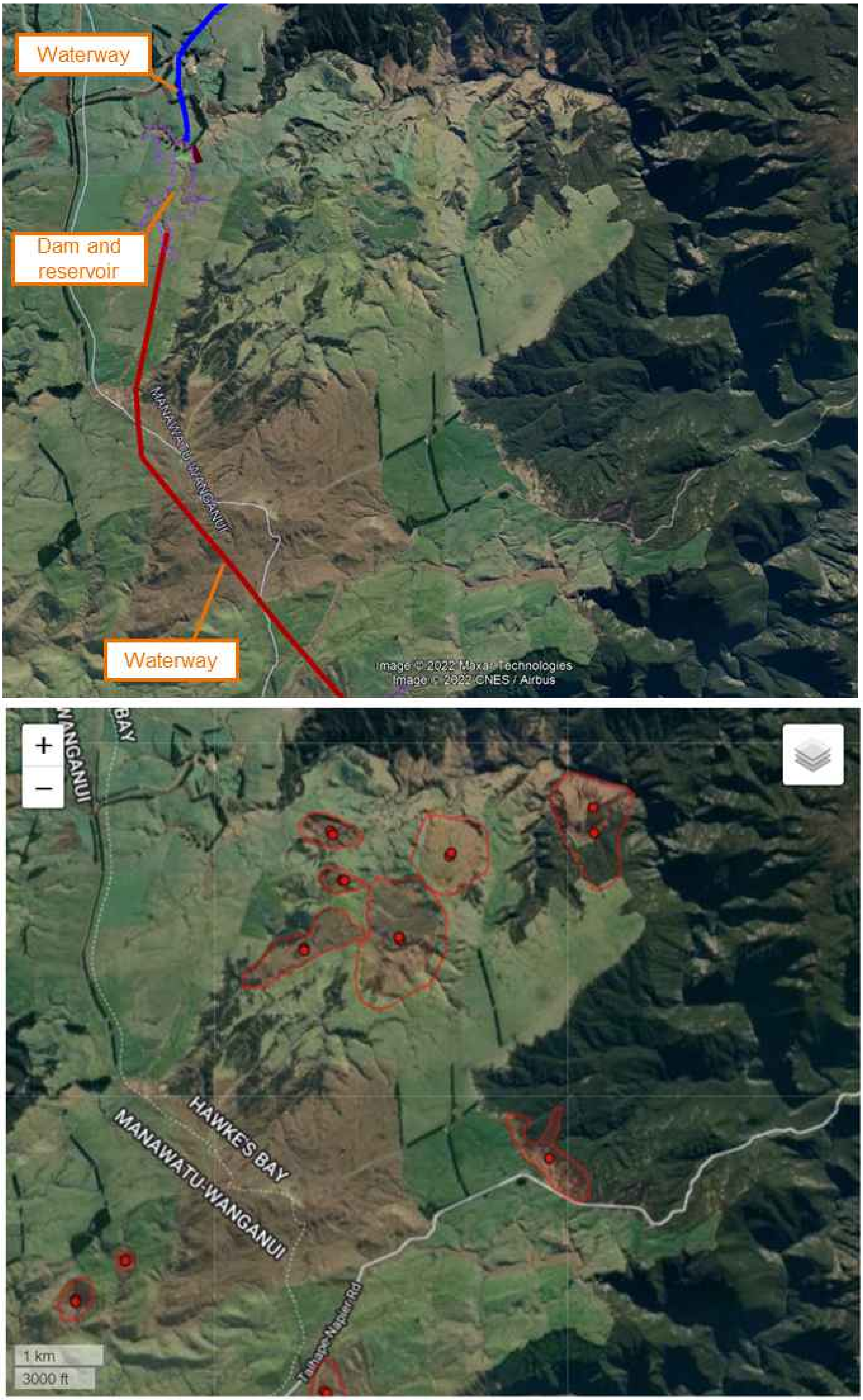


Figure 8 - Example of landsliding contained in GNS Science landslide database in Tertiary-aged rocks

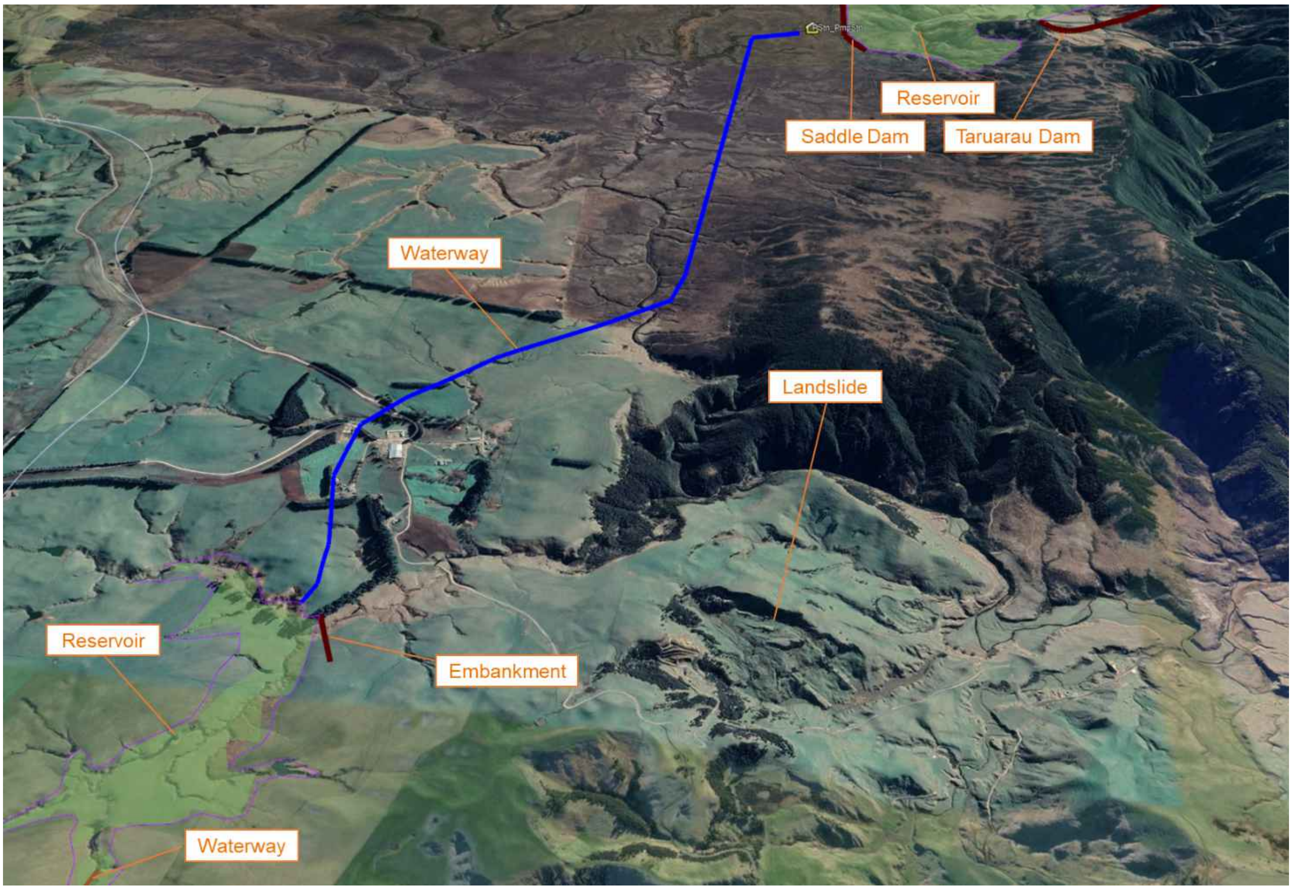


Figure 9 - Example of landsliding in Tertiary-aged rocks

Figure 10 provides an example of landslides shown in the GNS Science landslide database in areas underlain by 'greywacke'. The areas underlain by greywacke can be approximated as the forested areas in the image. Again, minimal information is contained within the database in regards to these mapped landslides. This figure shows the susceptibility of the steep greywacke slopes to landsliding, and that this would be an important consideration for abutment and reservoir shoreline stability for any of the reservoirs developed in 'greywacke' terrain.

We are not aware of any regional landslide hazard assessment, such as susceptibility mapping, that is publicly available.

No fatal flaw due to landslide hazard has been identified as part of this study, as the hazard is not sufficiently well defined by the information available. It is also assumed some flexibility would exist for scheme infrastructure positioning. Further work is required as part of the next stage of project development to better define landslide hazards. The information available does suggest however that slope instability is likely to be a key consideration for scheme design, construction and operation.

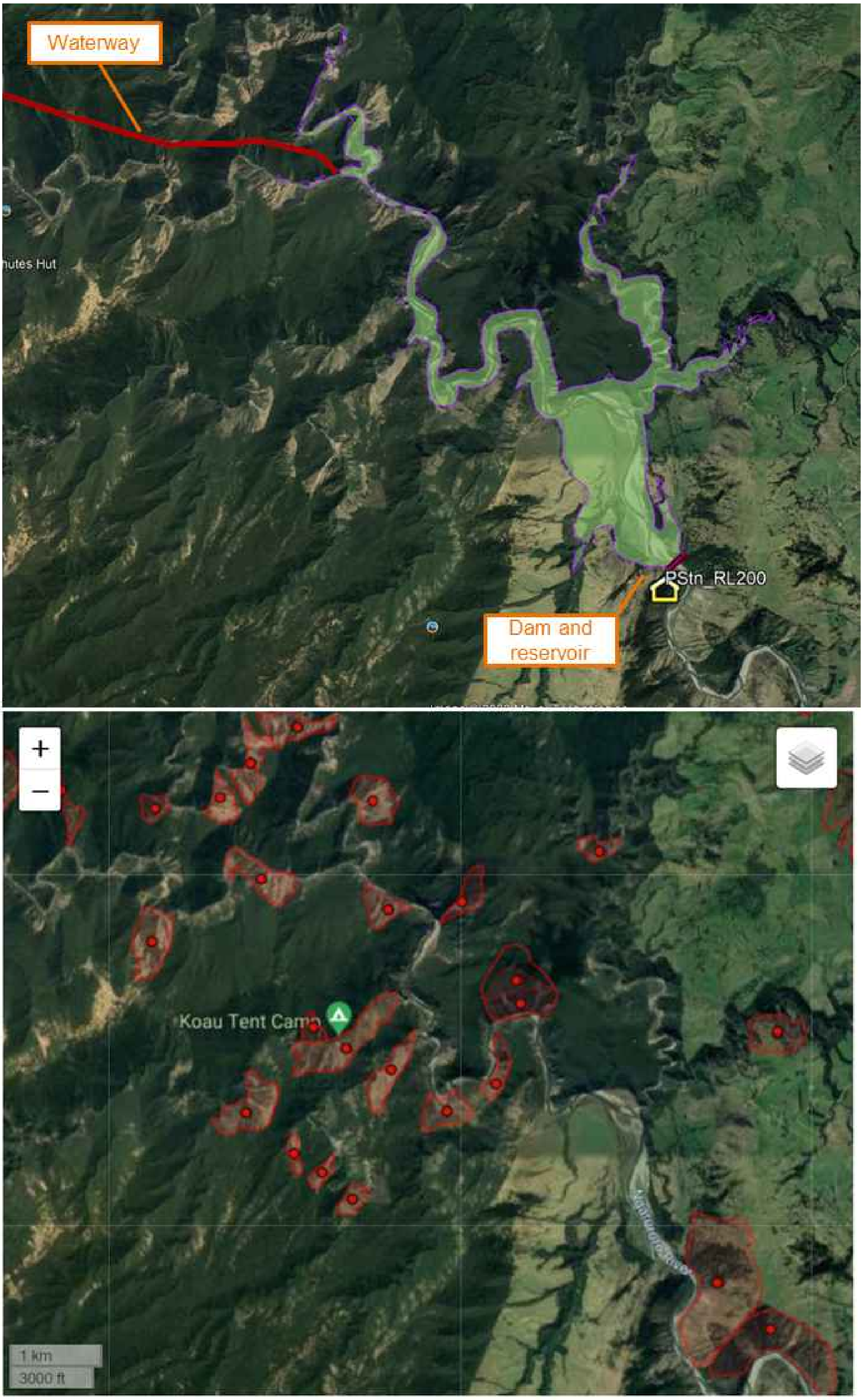


Figure 10 - Example of landsliding contained in GNS Science landslide database in 'greywacke'

B.6.4.3 Volcanic / Geothermal

The project area is somewhat removed from both the Tongariro Volcanic Centre and Taupo Volcanic Centre, being more than approximately 50 km distance at its closest point. For this reason, volcanic hazards are considered to not place significant constraints on scheme design, construction, and operation. These hazards include those associated with lava domes/flows, lahars, pyroclastic flows etc. Refer to Site 1 for hazard maps associated with these types of volcanic hazard.

The greatest volcanic hazard is likely to be that associated with tephra. Tephra is often subdivided into ash (fine, less than 2 mm), lapilli (2 to 64 mm), and volcanic bombs/locks (larger than 64 mm). It can be assumed lapilli and volcanic blocks/bombs would not impact the project area based upon their size and the distance of the project area from the eruptive centre (roughly 50 km). For this reason, ash is the key tephra hazard. Various consequences exist due to tephra hazard, one would be ash in water and damage to the mechanical plant (highly abrasive due to shape and composition). It could also impact the availability of water for filling/refilling the reservoir and this may exist for some time following an eruption. The site is located downwind of the volcanic centre, assuming the common prevailing winds (i.e., westerly, north-westerly).

Tephra deposits from Mount Tongariro and Mount Ngauruhoe are likely less critical than Mount Ruapehu. This is because they are more likely to have smaller-sized eruptions, they are further away from the project area and when prevailing winds are considered. The Taupo Volcanic Centre is a further important source of ash that required consideration.

Figure 11 shows tephra deposits associated with historical eruptions of Mount Ruapehu. The influence of the prevailing winds at the time of the eruption can be seen. This suggests up to 5 mm of ash associated with the 14 October 1995 eruption may have accumulated on parts of the site.

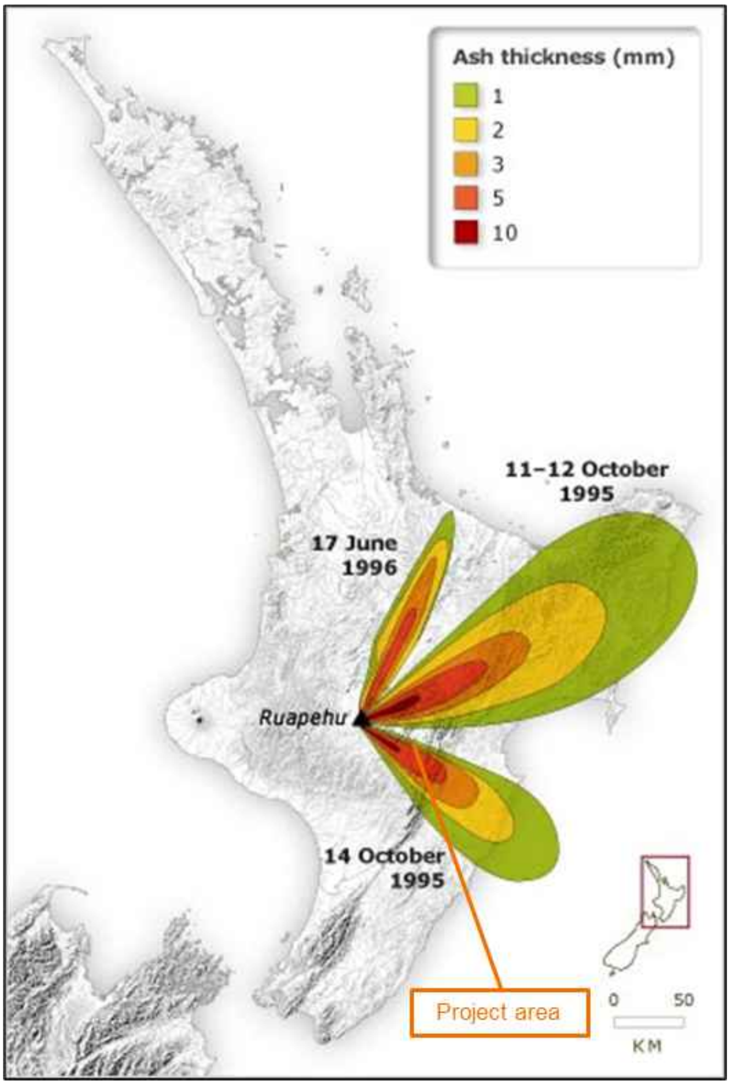


Figure 11 - Tephra deposits associated with recent Mount Ruapehu eruptions (GNS, undated)

Neall et al. (1999) have produced a tephra hazard map for Mount Ruapehu, and this is shown in Figure 12. This shows the hazard associated with larger tephra is restricted to the immediate volcanic centre area. The project area is located within ‘Area c’, which is likely to receive 5 to 10 mm of tephra during a ‘small-magnitude eruption’ and ’30 to 80 mm’ of tephra during a ‘large-magnitude eruption’. These accumulations are dependent on prevailing winds and the AEP of the different eruptive scenarios is not stated.

A more important source of tephra hazard is the Taupo Volcanic Centre. Figure 13 shows assessed tephra deposits associated with the Taupo Volcanic Centre in the last approximately 22,000 years. It is therefore assumed the largest known eruption, the Oruanui eruption, is not included in this figure. This eruption occurred around 26,500 years ago and around 2 m of tephra may have accumulated at the site in association with this eruption alone. The figure shows around 1 to 2 m of tephra associated with the Taupo Volcanic Centre may have accumulated at the project area in the last 22,000 years or so.

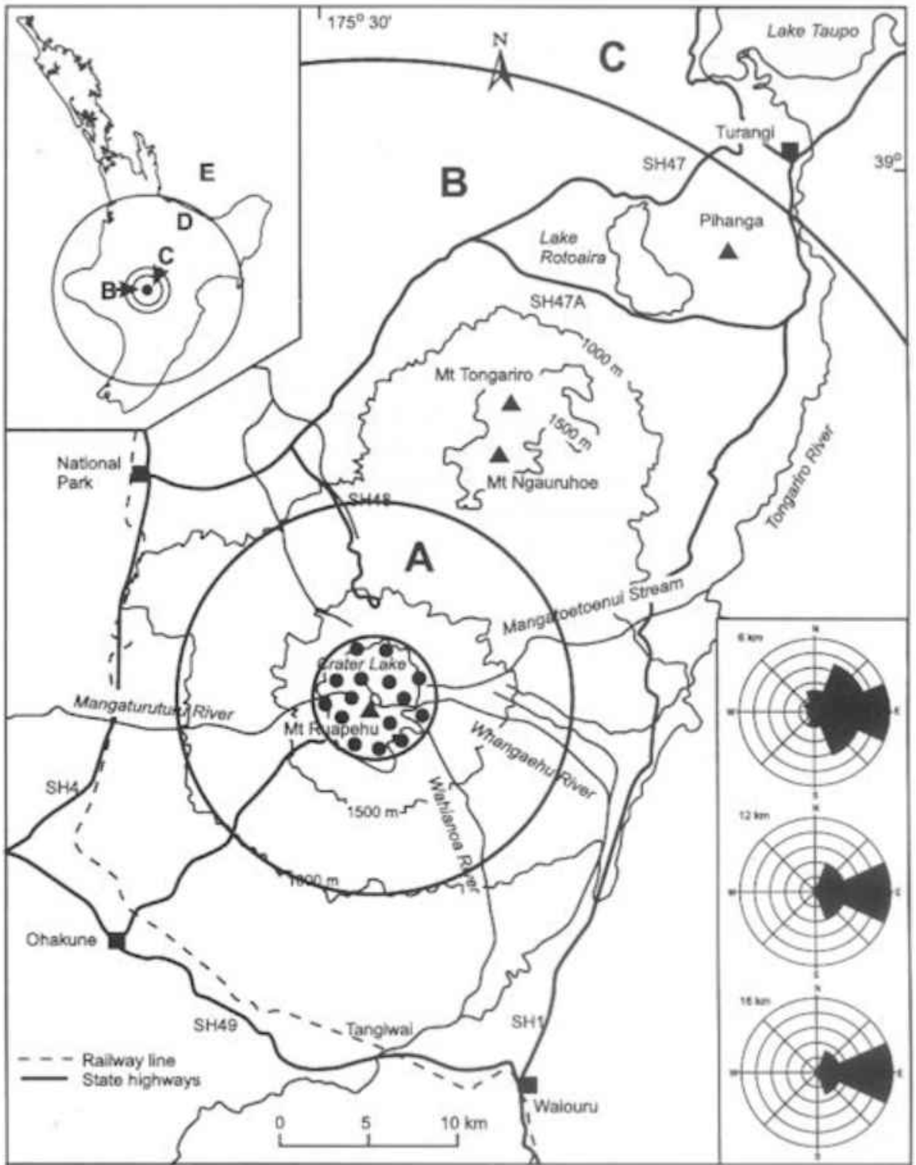


FIGURE 9 - Tephra hazard zones for Mount Ruapehu.

The probability of tephra fall in each zone is proportional to the probability of wind directions shown in the wind rose diagrams from Auckland Airport at altitudes of 6, 12 and 16 km. Expected thicknesses of tephra (in mm) in each zone for (1) small-magnitude eruptions and, (2) large-magnitude eruptions are as follows:

Zone	A	B	C	D	E
(1)	>40	10-40	5-10	1-5	<1
(2)	>300	80-300	30-80	10-30	<10

Ballistics hazard zone where there is greatest risk from blocks and bombs.

Figure 12 - Tephra hazard for Mount Ruapehu (Neall et al. 1999)

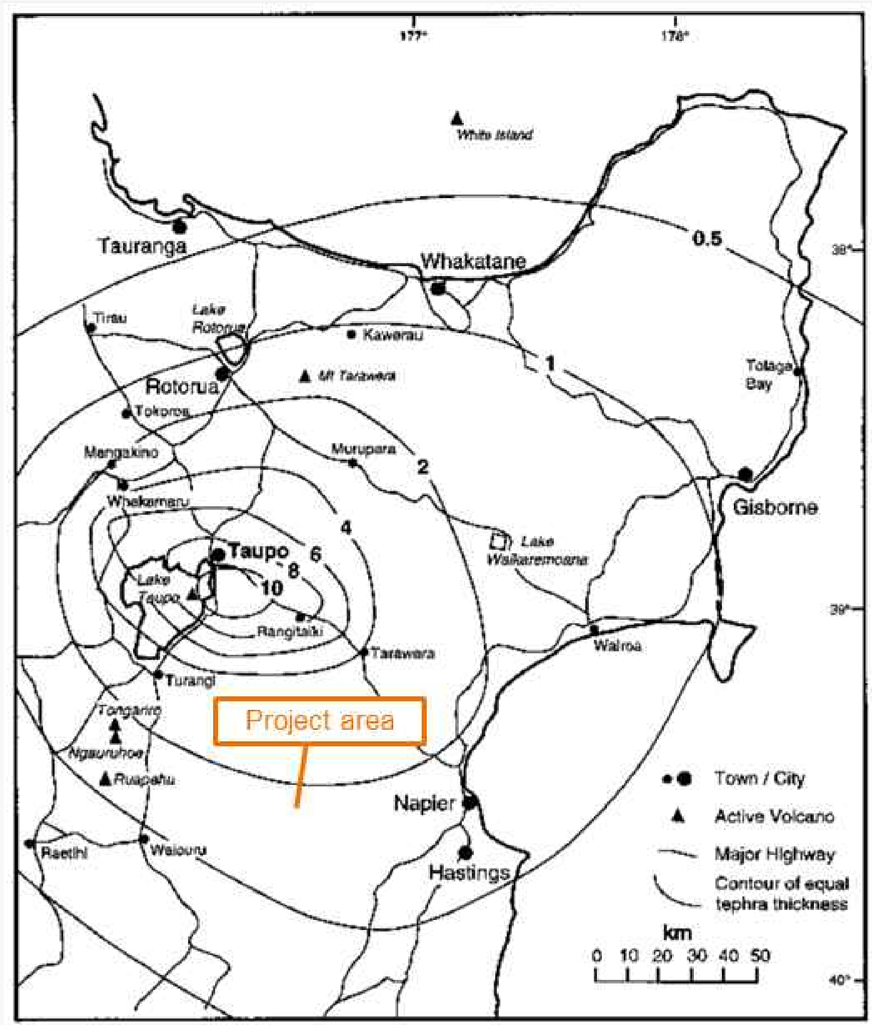
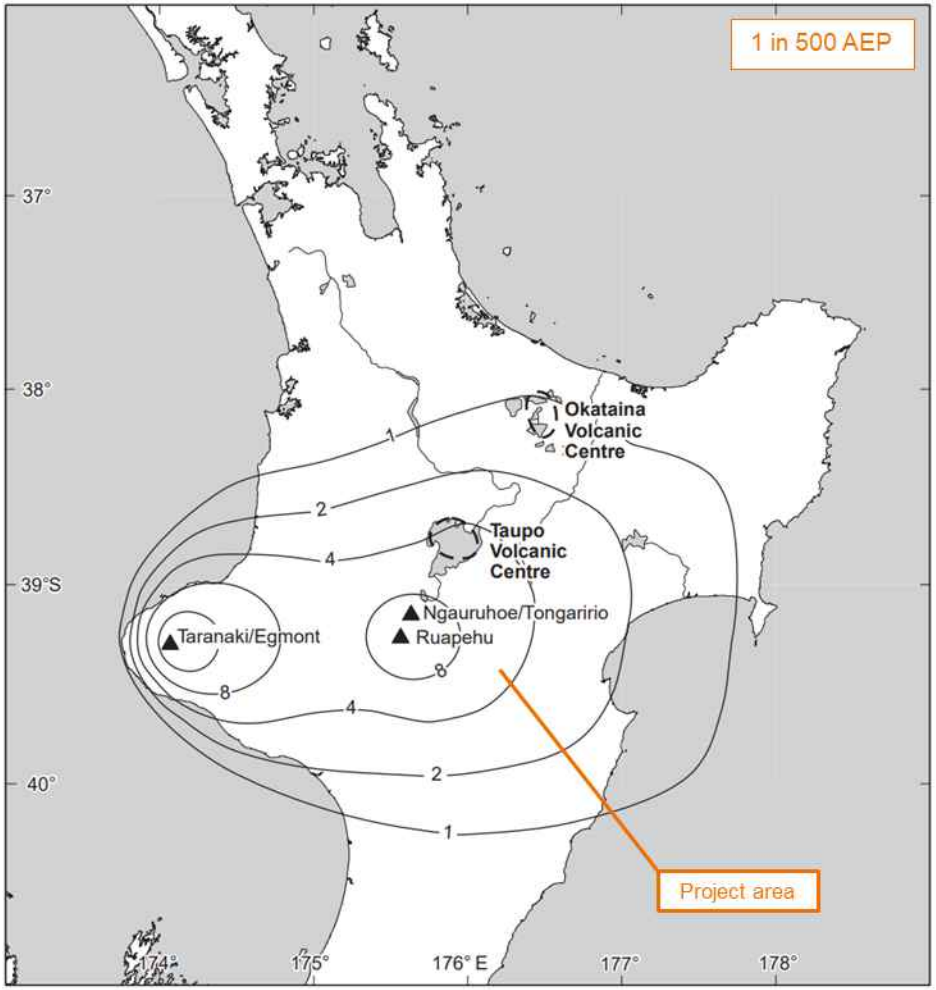


Figure 13 - Tephra deposits from Taupo Volcanic Centre (Frogatt et al. 1999)

Hurst & Smith (2010) completed a probabilistic ash deposition assessment based upon multiple sources, including both the Tongariro Volcanic Centre and the Taupo Volcanic Centre. They produced hazard maps for both 1 in 500 AEP and 1 in 10,000 AEP events, which are shown in Figure 14. This information shows around 4 to 8 mm of ash deposition for a 1 in 500 AEP event and between 32 and 64 mm ash deposition for a 10,000 year event.

In summary, most volcanic hazards are not expected to place a significant constraint on project development. The risk associated with tephra (ash) deposits will need to be considered further as part of the next stage of project development.



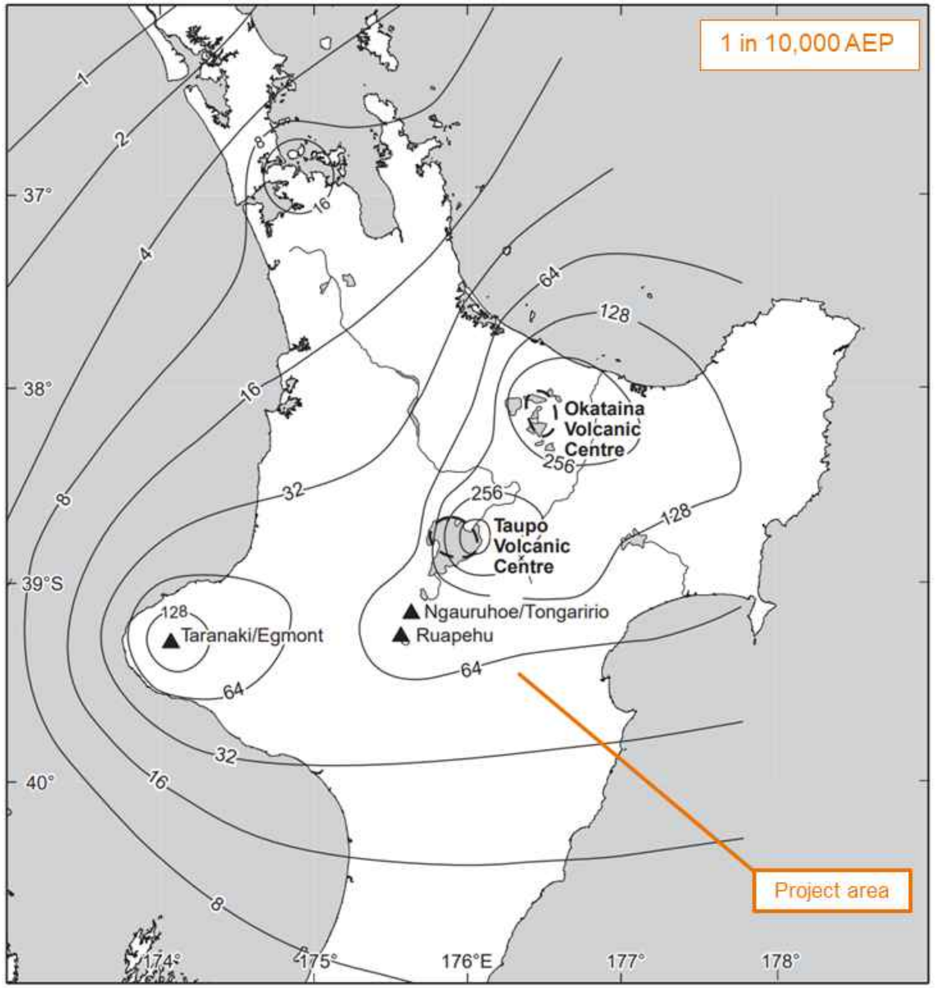


Figure 14 - Probabilistic ash hazard modelling (from Hurst & Smith 2010)

Publicly available information does show the presence of some geothermal activity in the general project area. A hot spring is mapped near to the scheme, as shown in Figure 15. The hot springs are assumed to occur in the river, and is located downstream of the current dam and reservoir location. Importantly, the waterways at this location are tunnelled and there may be potential for encountering geothermal activity within underground excavations (water, gas, etc.). The location of the hot spring roughly corresponds to two mapped inactive faults, which control the presence of the Tertiary-aged rocks locally at this location. It is assumed the hot springs may be associated with the mapped fault.

The extent of geothermal activity in the project area is not reliably known. It is therefore not known what constraint this may place on scheme design, construction, and operation. For concept design, it should be assumed no significant constraint exists. It would be expected mapped inactive faults and other major geological structures such as these, would be the locations where geothermal activity may be encountered in underground excavations.

Figure 15 - Location of Waipiropiro Hot Springs

B.6.4.4 Reservoir Water Losses

Several reservoirs are to be developed as part of the currently proposed scheme arrangement. These are summarised below, together with a summary of the published geology for the approximate reservoir area.

- Taruarau Dam (i.e. upper reservoir):
  - Alluvium in valley floor.
  - Taupo Pumice Alluvium in valley floor (and possible veneer of ash at all elevations).
  - Tertiary-aged rocks.
  - 'Greywacke'.
- Smaller reservoirs (x 3) providing regulation:
  - Alluvium in valley floor.
  - Taupo Pumice Alluvium (and possible veneer of ash).
  - Tertiary-aged rocks.
- Lower Taruarau Dam:
  - Alluvium in valley floor.
  - 'Greywacke'.

- Ngaruroro Dam (i.e. lower reservoir):
  - Alluvium in valley floor.
  - Taupo Pumice Alluvium (and possible veneer of ash).
  - Tertiary-aged rocks.
  - 'Greywacke'.

The existing Lake Moawhango provides useful engineering precedence. This has been formed in similar geology to the proposed reservoir, including alluvium, Tertiary-aged rocks, and 'greywacke'. We are not aware of any issues with significant reservoir water losses.

The Tertiary-aged rocks shown on the published geological map are mapped as containing some carbonate rocks. We are not aware of any publicly available information which is suggestive of dissolution landforms within the carbonate rocks of these Tertiary-aged rocks, which could lead to significant water losses. A brief review of imagery did not identify any obvious dissolution landforms in the reservoir areas.

Some Tertiary-aged rocks are associated with dissolution landforms. These limestones do not appear to occur in the immediate project area but are mapped in proximity to the site, such as near the lower reservoir. Figure 16 (from Kenny & Hayward 2010) shows notable occurrences of limestone displaying dissolution features, and it can be seen none are mapped in the immediate project area (but the scale of the map should also be considered).

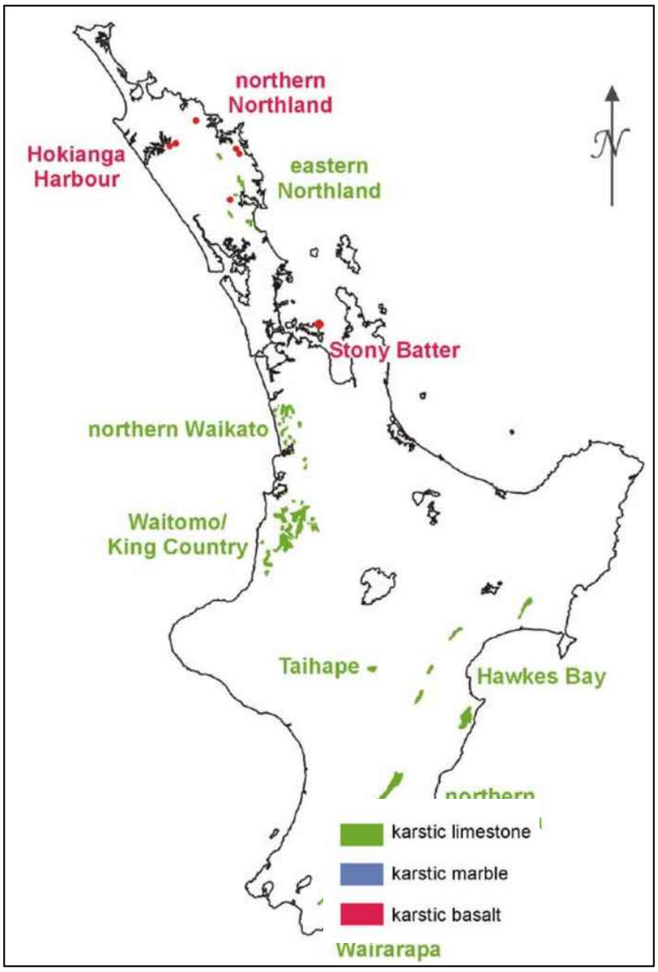


Figure 16 - Major karst landforms in New Zealand (from Kenny & Hayward 2010)

Kenny & Hayward (2010) specifically list several areas within Hawkes Bay which contain notable karstic landforms. These are:

- Blowhard Range karst
- Mangaone Cave, Nuhaka
- Maraetotara joint-related gorges and natural bridge
- Maraetotara Plateau karst
- Mt Kahuranaki sinkholes

- Te Reinga Cave System, Wairoa
- Te Waka #1 Cave, Te Pohue
- Whakapunake cuesta karst, Te Reinga/Tiniroto.

We have attempted to locate these karst landforms, with their possible positions shown in Figure . None of these locations appear to be in the immediate project area.

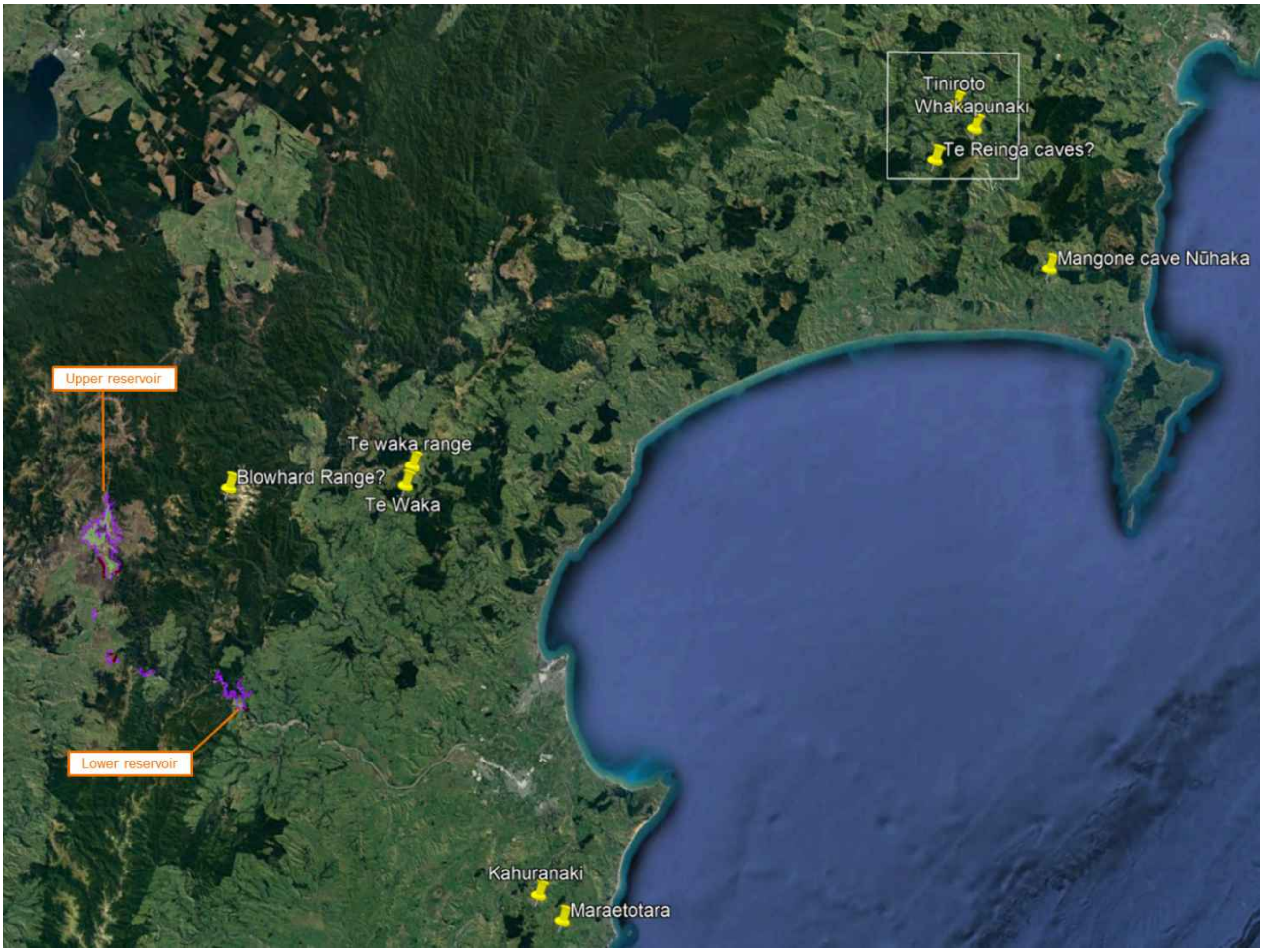


Figure 17 - Major karst landforms in Hawkes Bay (referenced in Kenny & Hayward 2010)

The Tertiary-aged rocks (sediments) generally speaking, contain a variety of rock types, but overall are expected to be of low permeability.

The 'greywacke' is described as containing 'broken formation and melange'. We have no information that these coincides with areas of moderate to high permeabilities which may lead to significant water losses from the reservoir, should they occur beneath it (which is not currently known). One of these areas was encountered during the construction of the Tongariro Power Scheme. It is stated in Beetham & Watters (1985) 'Near the Moawhango dam site, mélange termed autoclastic breccia by Hancox (1975) is exposed along the 500 m of the gorge below the damsite, as well as along the upper dam site gorge which lies along the strike 3 km to the northeast. It thus appears this mélange is at least 500 m thick and extends along strike for at least 4 km'. This unit of mélange is therefore beneath the existing reservoir and was likely exposed in the original Moawhango River channel (i.e. direct connectivity to the reservoir). As mentioned above, we are not aware of any significant water losses from the reservoir.

We are aware that significant groundwater inflows occurred in some underground excavations associated with the Tongariro Power Scheme. One paper we have not been able to source is titled 'Control of heavy water inflows into the Moawhango-Tongariro tunnel'. This description suggests some areas of the greywacke are of 'moderate' to 'high' permeability, and this will be associated with the presence of 'open defects'. The locations and mechanism of inflows, such as if inflows were high volumes and/or pressures, are not currently known.

Both the upper and low reservoirs may be associated with deeper alluvium. This may include undifferentiated alluvium, but also Taupo Pumice Alluvium. Both may contain coarse-grained soils of moderate to high permeability. At depth, these soils are expected to be underlain by Tertiary-aged rocks (sediments) and/or 'greywacke'. For this reason, significant water losses would not be expected. For the upper reservoir, it is possible veneers of ash may exist, which would be of low-permeability and therefore help to reduce any water losses.

Figure is a topographic map of the upper reservoir location. It can be seen some of the reservoir areas and its surrounds are mapped as 'swampy ground'. There also appears to be permeant surface water features, such as Lake Horotea. This information is further suggestive of near-surface low-permeability soils and that reservoir losses from the proposed reservoir may not be significant.

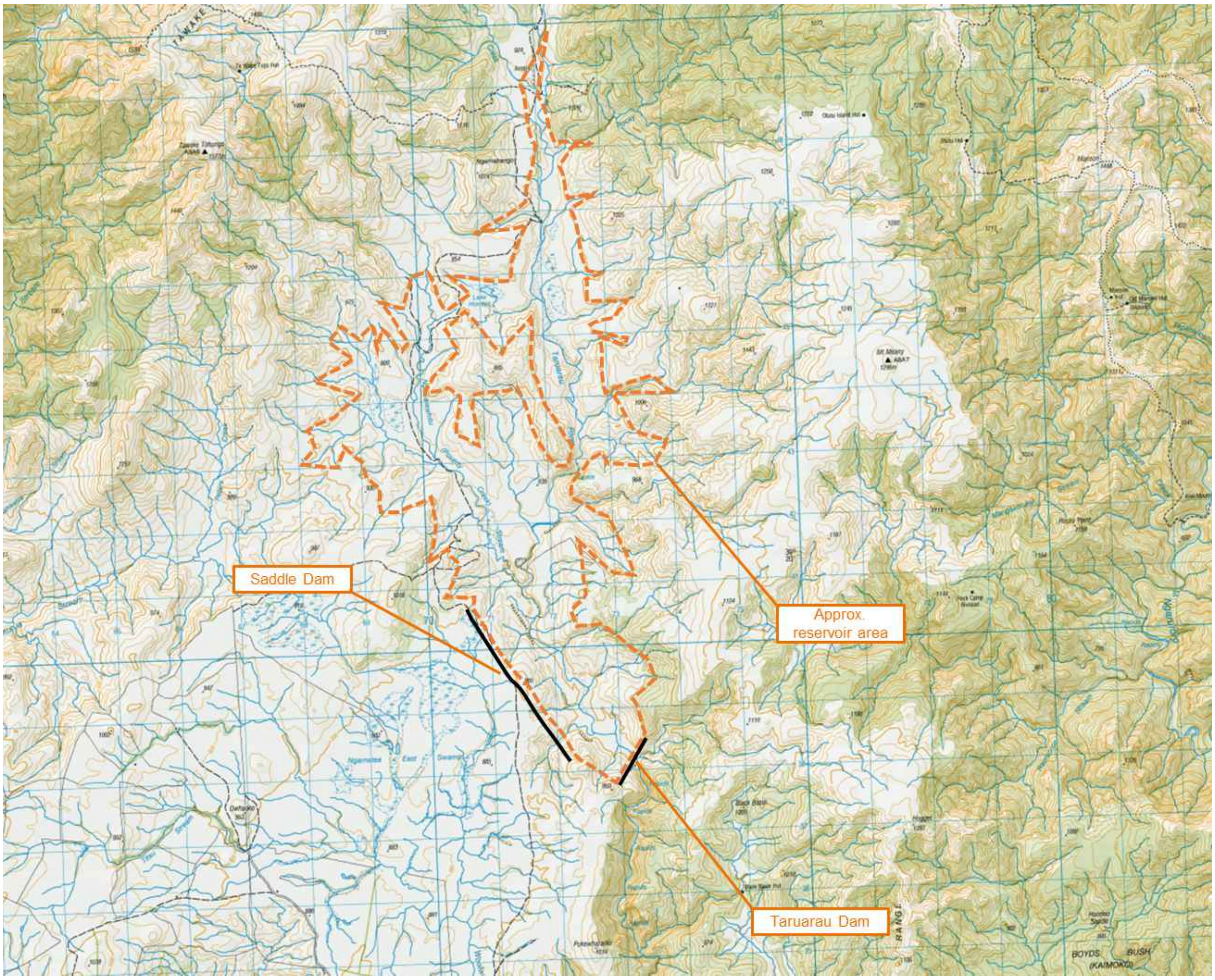


Figure 18 - Topographic map of upper reservoir area

B.6.5 Geological Model

Much of the information presented for Site 1 with regards to the characteristics of 'greywacke' ais also applicable to Site 2. The key difference being the higher metamorphic textural zones are not present for Site 2 (i.e. Zones 2A to 2B) and therefore all the 'greywacke' is 'non-schistose'.

B.6.5.1 Surface Conditions

The Upper Taruarau Dam and the Lower Taruarau Dam are expected to be constructed on 'greywacke'. It is noted that the currently shown location of the Upper Taruarau Dam likely comprises Tertiary-aged rocks overlying 'greywacke' and it is assumed the dam location would be relocated approximately 1 km downstream into the 'greywacke' gorge. Any soils or Tertiary-aged rocks present locally, would be removed.

The engineering geological precedence of the existing Moawhango Dam is applicable to these dams. This dam was constructed in similar ground conditions. The characteristics and considerations for surface excavations in 'greywacke' are therefore as described for Option 1.

The remainder of the dam locations, and much of the surface waterways, will be underlain by much more variable founding conditions. They will be constructed primarily within Tertiary-aged rocks. The extent of these rocks in plan and depth likely means their excavation is uneconomic and will therefore form the foundation for dams and other surface infrastructure. There is much less dam and hydropower engineering precedence of major dam and hydropower works in Tertiary-aged rocks (sediments).

The Tertiary-aged rocks do posses some undesirable characteristics and these will make the design and construction of scheme infrastructure more challenging than that in 'greywacke'. Examples include the potential for bearing/deformability issues under induced loads, slaking/deterioration on exposure, potential erodibility and/or dispersivity issues, and the general construction difficulties of working in these materials (loss of strength of silts on excavation/disturbance, fine-grained soils of varying plasticity, etc).

In addition, undifferentiated alluvium and Taupo Pumice Alluvium may be encountered by surface works and locally may extend to depths of several metres. These deposits are inherently variably and present challenges where they are encountered within the foundation. This would include bearing/deformability issues under induced loads, potential liquefaction susceptibility, sensitive materials, etc. At this stage, for simplicity, it is assumed these materials would be excavated and removed from foundations where present.

B.6.5.2 Subsurface Conditions

Underground excavations are expected to largely be in 'greywacke'. The Tongariro Power Scheme provides significant engineering precedence of similar underground excavations in similar conditions. The characteristics and considerations for underground excavations in 'greywacke' are as described for Option 1.

There is the potential that Tertiary-aged rocks may be encountered locally within underground excavations, such as near tunnel portals or in areas of lower ground cover. It is noted that the southern end of the existing Moawhango Tunnel was constructed in similar conditions to this and therefore it provides precedence. No specific challenges associated with the Tertiary-rocks in underground excavations is documented in publicly available information for the scheme.

B.6.5.3 Construction Materials

All the dams required are currently assumed to be Roller Compacted Concrete (RCC). For this reason, the main construction material required would be concrete aggregate.

The 'greywacke' which underlies the site, either at the surface or depth, is the main likely source of concrete aggregate. The 'massive sandstone association' described by Beetham & Watters (1985) would likely be suitable for the production of concrete aggregate via processing. It is described as 'occurring in beds from 2 m, to 100 m or more, and may locally be 1 km thick'. It is judged unlikely to have any durability and reactivity issues in RCC. There is engineering precedence in using this material for a variety of aggregates throughout New Zealand. We are not aware of any performance issues.

The other key lithologies described by Beetham & Watters (1985) include 'massive argillite association', 'alternating sandstone/argillite association', 'thin bed association' and 'mélange'. It should be currently assumed suitable RCC concrete aggregate cannot be produced from these materials due to potential durability issues associated with the argillite and the difficulty of this being interbedded with the sandstone and processing.

It should be assumed therefore that an onsite quarry (or quarries) can be developed near the site, within the 'massive sandstone association', and this can be processed to produce suitable RCC aggregate. Limited overburden (i.e. soil, Tertiary-rocks, weathered rock) can be assumed at a quarry site.

A significant amount of 'greywacke' would be excavated as part of underground excavations. Selected material from the excavations could be used to provide concrete aggregate. Beetham & Watters (1985) do not state how much of the 'greywacke' comprises the 'massive sandstone association'. They do state around 50% of the rock comprises the 'alternating sandstone/argillite association'. On this basis, it could be assumed 25% of excavated rock from underground excavations could be re-used and processed to produce RCC aggregate.

It should be further assumed:

- Excavated materials from surface excavations would not be suitable for re-use as concrete aggregate (such as alluvium).
- Tertiary-aged rocks are unlikely to yield suitable concrete aggregate (due to potential durability issues).
- Volcanic rocks are unlikely to yield suitable concrete aggregate (due to potential durability and reactivity issues).

Should only approximately 25% of tunnel spoil be suitable for re-use with processing to produce concrete aggregate, a significant volume of material will require disposal. This will be added to by unsuitables excavated from the surface foundations.

Should embankment dams be considered as an alternative, it can also be assumed required construction materials can be sourced in proximity to the sites. Greywacke could be used as rockfill, and filter and drainage material can likely be processed from the higher-quality greywacke aggregates. Rip rap could be sourced from a quarry also. Tertiary-aged rocks could be used for the core of an earthfill dam and also as a source as earthfill for the dam shoulders if required for a zoned earthfill. There is some precedence of using Tertiary-aged materials for dam engineering, which includes mine sites (i.e. coal mines in Tertiary-aged rocks).

B.6.6 Summary

The key findings of this geological study of Site 2 can be summarised as:

- No geological fatal flaws have been identified based upon the currently available information.
- Less site-specific information is available for this option when compared to Options 1 and 3.
- The design, construction, and operation of the Tongariro Power Scheme provides an engineering geological precedence of the feasibility of the proposed option for where 'greywacke' will be encountered. This includes the development of both surface and underground works.
- Less engineering precedence exists for the development of surface and underground works associated with dam and hydropower engineering projects in the Tertiary-aged rocks (sediments). Other civil engineering precedence may exist, such as those associated with transport infrastructure or wind energy. Their engineering geological characteristics do present some engineering geological considerations which require further evaluation as part of the next stage of project development.

B.6.7 Next Steps

Recommendations for the next stage of geological study should the proposed option proceed to the next stage of project development are:

- The sourcing and review of relevant pre-existing site-specific geological information which is privately held. This would include:
  - For 'greywacke', that related to the design, construction, and operation of the Tongariro Power Scheme.
  - For the Tertiary-aged rocks, any precedence which can be found for dam and hydropower engineering, or other major civil works such as transport infrastructure or wind energy.
- Development of geological study objectives and scope of works as required for the stage of project development as recommended by ICOLD (2005) and ANCOLD (2020).

Further work could be completed to further advance the conceptual geological model based upon other available references, but this is not possible at this time due to project timeframes. This would include geological sections at the dam sites, along the proposed waterway alignments, and material characterization based upon the available in-situ and laboratory test data.

Beetham & Watters (1985) summarise the characteristics of the 'greywacke' as follows based upon it being encountered during the Tongariro Power Scheme:

- *The basement rocks of the western part of the Kaimanawa Range were included by Sporli (1978) in the Torlesse terrane. They are generally similar in petrography and chemistry to Torlesse rocks from other parts of New Zealand, but because of their greater degree of induration and slightly higher metamorphic grade they were mapped as distinct from the Torlesse rocks making up the Kaweka Range immediately east of the Kaimanawa Range and given a tentative Permian-Triassic age (Grindley 1960).*
- *A major dilemma encountered during the mapping of the excavations is posed by the widespread occurrence of broken rocks of differing types. It is possible that the whole sequence examined is in the form of a great melange in which some units of normally interbedded sandstone/siltstone/argillite may be very large irregular discoid bodies (phacoids) in a megabreccia.*
- *Some units may be more clearly termed melange in the strict sense because of the presence of fragments of exotic rock, particularly chert. Elsewhere, for units formed by disruption of interbedded sandstone and argillite, the term broken formation is appropriate.*
- *We have followed Sporli (1978) in using the term melange in a broad sense " ... to denote indurated rocks, mainly greywackes, but with a well-developed argillite matrix and commonly, but not necessarily, including lenses of spilite, chert, and limestone." Nevertheless, the terms broken formation or autoclastic breccia may be more appropriate for particular occurrences of clearly heterogeneous rock.*
- *The main lithological associations recognised are described below:*
  - *Massive sandstone association:*
    - *Grey fine to medium-grained quartzofeldspathic sandstone units range in thickness from 2 m to 100 m or more and may locally be up to 1 km thick (W. M. Prebble pers. comm.). In general, the beds appear to be nongraded, poorly sorted, and structureless, but locally a few poorly defined laminae of finer-grained or carbonaceous sediment are present. Sporli & Barter (1973, p. 365) recorded recrystallised ellipsoidal carbonate concretions in a few places.*
  - *Massive argillite association:*
    - *This consists of dark-grey to black mudstone units ranging in thickness from 2 m to 100 m, or more locally.*
    - *Some units are massive and relatively unjointed, but many have been incipiently sheared and are now fissile.*
    - *Of the latter, some may formerly have contained sandstone, siltstone, chert, or possibly limestone beds which were later disrupted because of ductile flow of the enclosing argillite, and they now have the form of isolated boudins and blebs. These composite units are included in melange (see below).*
  - *Alternating sandstone/argillite association:*
    - *This is estimated to form about 50% of the total sequence. The beds vary widely in thickness between limits of about 100 mm and 2 m, thicker beds falling within the massive associations and thinner ones within the thin-bedded association.*
    - *The argillite is generally fissile, and the sandstone is structureless, although it is quartz veined in many places.*
    - *In the tunnels, it was not possible to link all individual beds from one side to the other, a distance no greater than 10 m. In part, this is due to the offsetting of beds by faulting and shearing, and to the apparent lack of continuity of individual beds.*
    - *An explanation for this lack (of continuity?) was provided during the excavation of the Rangipo underground powerhouse, where a large three-dimensional view of the rock mass became clear as the excavation progressed. The sandstone there was found to consist of phacoids, with dimensions up to 5 X 10 X 15 m. The argillite separates and appears to flow around, a disrupted assemblage of these bodies, for which the term "megabreccia" was used.*
  - *Thin-bedded association:*
    - *This is one in which sandstone predominates over argillite and where the beds are commonly 50 mm thick or less. It makes up a relatively minor proportion of the total sequence.*
    - *In the tunnels, the beds appear to have retained some of their sedimentary characteristics, although drillcores show that in many places they underwent ductile deformation before complete lithification of the rock.*
  - *Melange:*
    - *We have used the term melange for argillite-rich units in which a predominantly fine-grained sheared matrix encloses sandstone and locally other rocks such as chert, siltstone, and limestone. In many places,*

these are streaked out to form lensoid or less-regular bodies up to 100 mm across, although many are less than this. Some larger inclusions are exposed in the walls of tunnels and in the Rangipo powerhouse.

  - *Near the Moawhango dam site, melange, termed autoclastic breccia by Hancox (1975), is exposed along the 500 m length of the gorge below the dam site, as well as along the upper damsite gorge which lies along the strike 3 km to the northeast. It thus appears likely that this unit of melange is at least 500 m thick and extends along the strike for a minimum distance of 4 km.*
  - *From inspection of drillcores, the argillite: sandstone content lies between 50:50 and 80:20%. The sandstone phacoids are aligned about 035-040° and dip southeast between 4SO and 80°. The argillite matrix is massive in places, but elsewhere has a marked fissility with the same attitude as the enclosed phacoids. Clasts within the Moawhango area melange include sandstone, some with laminated bedding, argillite, chert, and separate fragments of breccia, indicating at least two phases of disruption of the original rocks.*
  - *Logging of the Rangipo tailrace tunnel showed that such melange is widespread there, too, with the units logged having a combined thickness of at least 1.5 km, a northeast strike, and a variable southeast dip.*

- *Minor lithologies:*

  - *Small amounts of altered basalt and jasper were found at two places in the Moawhango-Tongariro tunnel (Hegan 1980).*
  - *Sporli & Barter (1973) reported minor lenticular bodies of highly altered igneous rocks in Patutu Stream.*
  - *Pebble conglomerate boulders from Waipakihi River point to the existence of conglomerate in the valley catchment (Sporli & Barter 1973, p. 364), but it was not found in any of the excavations or investigations.*
  - *Limestone, though generally very rare in the Torlesse sequence, was found as a lozenge-shaped clast about 100 mm long forming part of melange in Waihaha Stream.*
  - *Quartz veining is widespread throughout the basement rocks; vein widths range from < 1 mm to l 00 mm. The most common mineral is quartz, but others recorded, some of which are locally abundant, are albite, calcite, muscovite, chlorite and other metamorphic minerals, such as zeolite.*

- *Metamorphism:*

  - *In the western part of the Kaimanawa Range, the sandstone shows pervasive very low-grade metamorphism, most of the rocks belonging to the lower grade part of the pumpellyite-actinolite facies. Most samples of sandstone examined are metagreywackes falling between the prehnite-disappearance and K-feldspar-disappearance isograds*
  - *In fabric, the rocks range from textural zone l to 2A (Bishop 1972), but the widespread shearing associated with the occurrences of melange helps to confuse and complicate isotect mapping.*
  - *Schistose (lineated) rocks belonging to textural zone 2B appear to be confined to small areas in the northern part of the range (Sporli & Barter 1973) and in the south between the southern end of the Moawhango-Tongariro tunnel and the Moawhango dam site.*
  - *Many rocks show a tendency to form platy fragments on fracture, although this is more noticeable in the finer-grained horizons. Much of the fissility characterising many argillites was probably localised by late metamorphic and post-metamorphic shearing.*
  - *The higher grade, textural zone 2B rock, is marked by a pronounced steeply dipping lineation, but are virtually non-foliated, although they tend to form platy fragments on hammering.*

- *Structure:*

  - *Defects:*

    - *Although sharp argillite-sandstone contacts are relatively common, many probably do not represent true bedding, as the argillite and sandstone commonly show signs of ductile deformation, the first stage in the development of broken formation.*
    - *Nevertheless, if the ductile deformation has not proceeded to the stage of completion, chaotic disruption of the original beds, the argillite-sandstone contacts are still likely to be representative of the attitude of bedding.*
    - *True bedding is relatively rare and confined mainly to the thinly interbedded units and a few silty or carbonaceous layers in some massive sandstone units, or silty beds in argillite units.*
    - *Bedding is not a prominent rock-mass defect, and the rock breaks readily across the bedding planes.*
    - *However, incipient transposition of bedding by fissility is apparent in many places, and the rock mass fractures more readily along the foliation. Fissility in some units is closely developed in linear bands with relatively massive rock between. In many places, particularly faulting and shearing have enhanced the development of fissility and formed slickensiding along the surfaces.*
    - *The rock mass is commonly well jointed, up to three joint sets being present. In areas where fissility is well developed, the rock mass has very low or zero tensile strength across the fissility, and poor interlocking between individual pieces of the rock mass, a feature which tends to promote uneven overbreak and to control the shape of underground excavations.*
    - *Sporli & Barter (1973) recorded fissility crosscutting bedding in part of the Waipakihi River area. This was not found in the tunnels or elsewhere in the western Kaimanawa Range, where the dominant orientation of bedding and fissility is between north and northeast, with a steep dip to the southeast.*

        - *Some localized departures from this dominant trend are caused by post-metamorphic crumpling and open folding adjacent to major fault zones.*
    - *Folding:*
        - *The Kaimanawa basement rocks are complexly folded, but the restricted outcrop and lack of marker beds generally preclude the recognition of folds of a greater scale than mesoscopic.*
        - *Both surface and underground geological work during construction gave little further information on folding, other than that the structural trends logged in the tunnels are remarkably uniform.*
    - *Faulting:*
        - *Some of the major structural features studied are the ramifying zones of rock mechanically disturbed by faulting. They vary in attitude and spacing, range in thickness from a few millimetres to a hundred metres or more, and in many localities are the most continuous structural features present.*
        - *During logging they were classed as crush, shear, or shatter zones according to the degree and type of mechanical disintegration and alteration of the rock fragments.*
        - *Correlation of surface lineaments with fault zones encountered underground was good and showed that every lineament detected from aerial photographs is a fault zone, although fewer faults were detected on the surface or on photographs than were visible underground.*
        - *From tunnel logging, minor fault zones up to 200 mm thick are found, on average, every few metres, medium fault zones up to 2 m thick (though generally thinner) every 100 m, and at least one major fault zone, wider than 2 m, every kilometre.*
        - *Post-metamorphic, low angle reverse faults logged in the Rangipo tailrace tunnel are consistent with a southeast-northwest compressional stress regime.*

B.5.5.1 Surface Conditions

Most of the surface works, such as the dams required dams, will be constructed on 'greywacke'. For this reason, the design, construction, and operation of the existing Moawhango Dam provides useful engineering geological precedence.

Key information presented in Duder et al. (1977) can be summarised as (refer Figure 23 to Figure 26):

- Geology:
    - Early investigations were aimed at the siting of a thin concrete arch dam in the narrowest part of the gorge immediately downstream from the present site.
    - However, mapping of the surface geology combined with subsurface investigations demonstrated that the gorge was unsuitable for a thin arch dam. The discovery of extensive rock defects at this site indicated that the foundation pressures from a thin arch dam might have resulted in excessive movements in the abutments.
    - The main structural trends in the greywackes (bedding, foliation, crush and shear zones, etc.) strike generally north to north-east with steep dips east or west.
    - At the dam site, the greywacke basement is in places overlain by a thin (1-3 m) cover of Tertiary sediments. The unconformable contact is well exposed in the dam excavation and along the top of the gorge walls. Here the water-eroded greywacke surface is overlain by sands and pebble conglomerates with sparse marine fossils and poorly cemented, brown sandstones containing occasional thin (25-50 mm) carbonaceous layers
    - Overlying the Tertiary sediments, and in some areas resting directly on greywacke, is a blanket of soft, weathered, brown andesitic ash overlain by sandy Taupo pumice. The ash mantle varies in thickness from about 1.5 to 7 m or more and is present in all areas except on the steeper slopes in the gorge.
    - Collectively the ash and the Tertiary sediments were considered as overburden, which, together with the weathered mantle of shattered, near-surface greywacke, were removed during excavation of the dam foundations.
    - Initial investigations at the site involved mapping of the surface outcrops, which was restricted by the extensive cover of pumice, ash, and Tertiary sediments.
    - Consideration was given to further subsurface investigations, but the stripping of the dam abutments was preferred. This proved to be a wise decision because it was not until the excavations were completed and the foundations fully exposed that the continuity and implications of the major zones of weakness were fully appreciated. Additional subsurface investigations could not have provided this information.
- Excavation:
    - Some 53,000 m3 of overburden and weathered greywacke were excavated for the dam foundations at a cost of about $340,000.
    - In accordance with the designers' specifications, excavation continued so that the base of the dam would be founded in "sound" rock, with the upstream toe generally keyed a minimum of 3.0 m below rock level, and the downstream toe keyed 1.5 m into rock. "Sound" rock was, in most cases, very hard, unweathered to slightly weathered and iron-stained.
    - Koehring 505 "Skoopers" were used to excavate the overlying ash and softer Tertiary rocks, and the weathered greywacke was ripped with D8 and D9 bulldozers.
    - Blasting was limited to trimming of the scarcement* batters (benches at foundation level at the heel of the dam)), and of localised areas that could not be ripped, especially in the river section.

- In general, overbreak was minimal and although in some places loose joint blocks had to be removed, the profile of the excavation was relatively smooth.
- Because of variable rock conditions that were not revealed by the investigation drilling, the east bank excavation was finished about 3.0 m below the proposed design levels, whereas the west bank was completed approximately as planned.

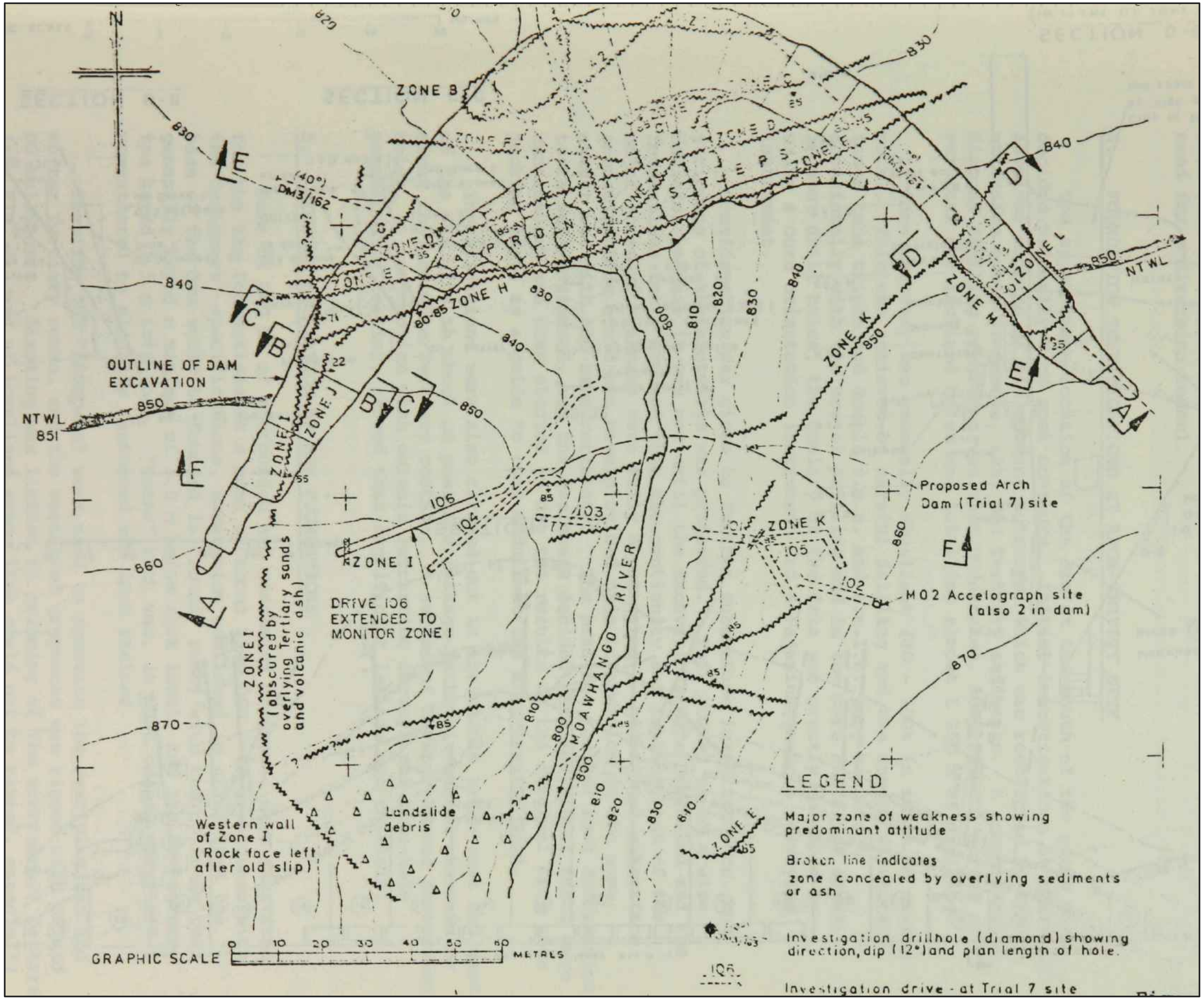


Figure 23 - Foundation plan of existing Moawhango Dam (from Duder et al. 1976)

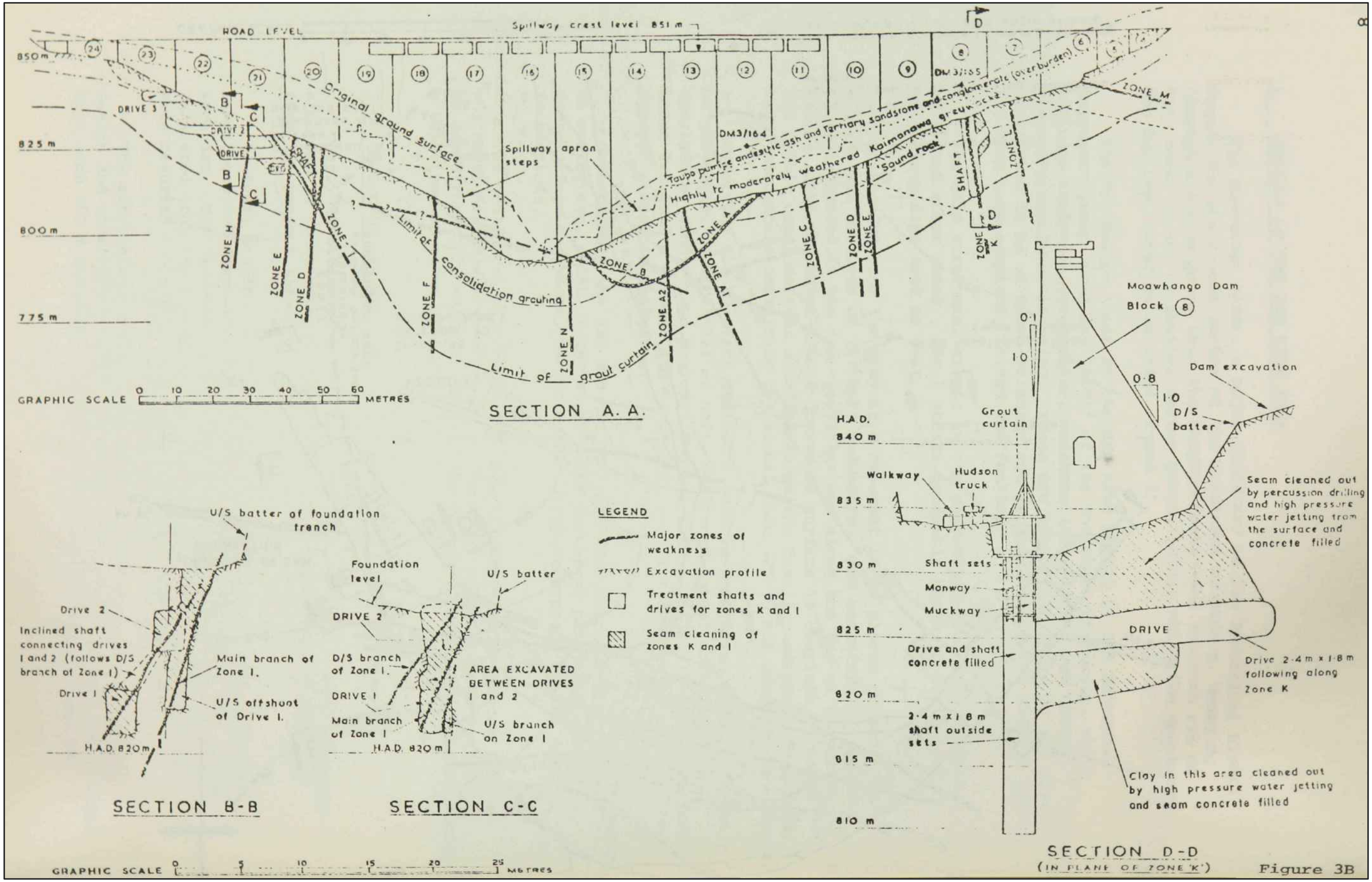


Figure 24 - Foundation elevation of existing Moawhango Dam (from Duder et al. 1976)

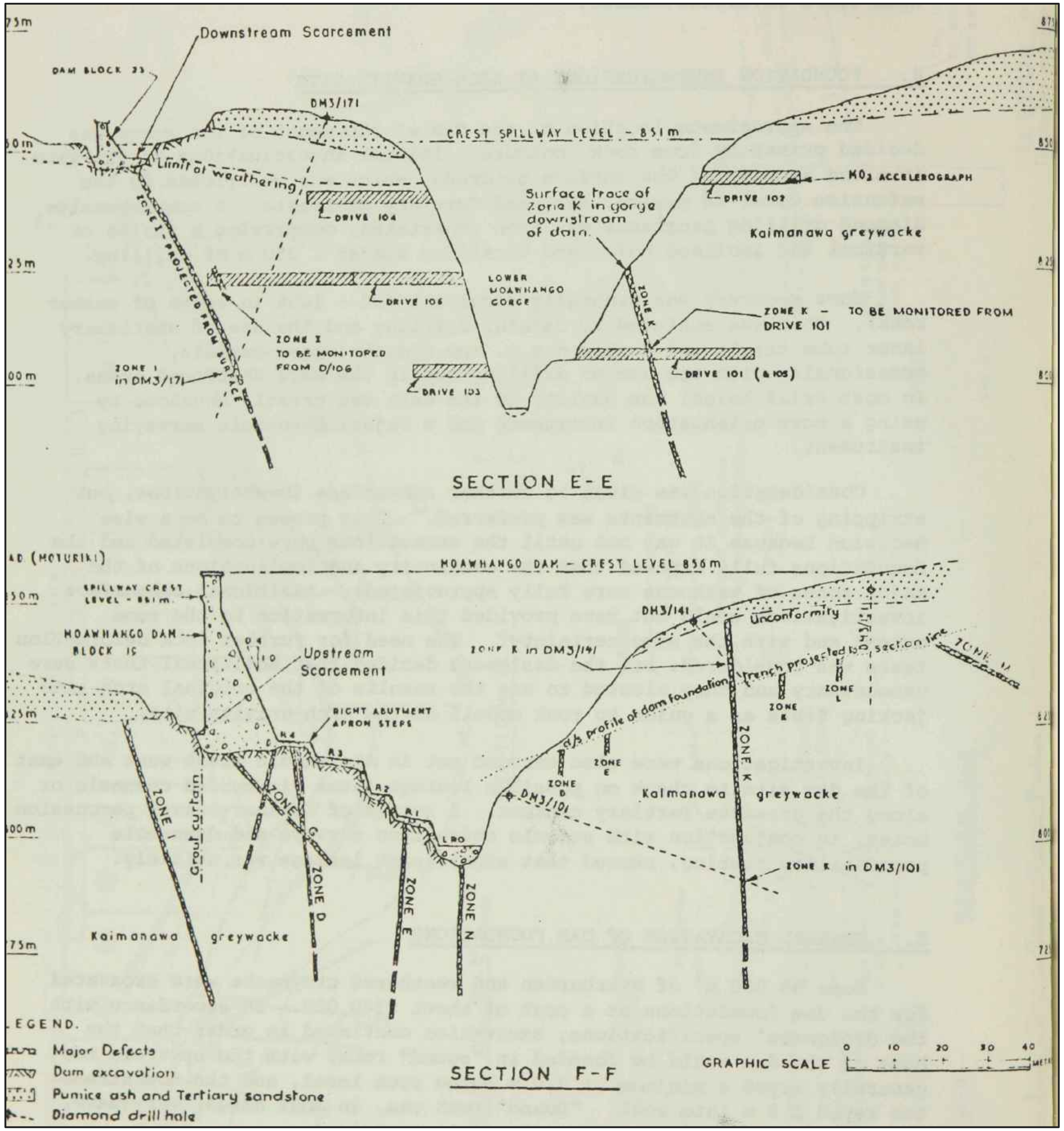


Figure 25 - Foundation sections of existing Moawhango Dam (from Duder et al. 1976)

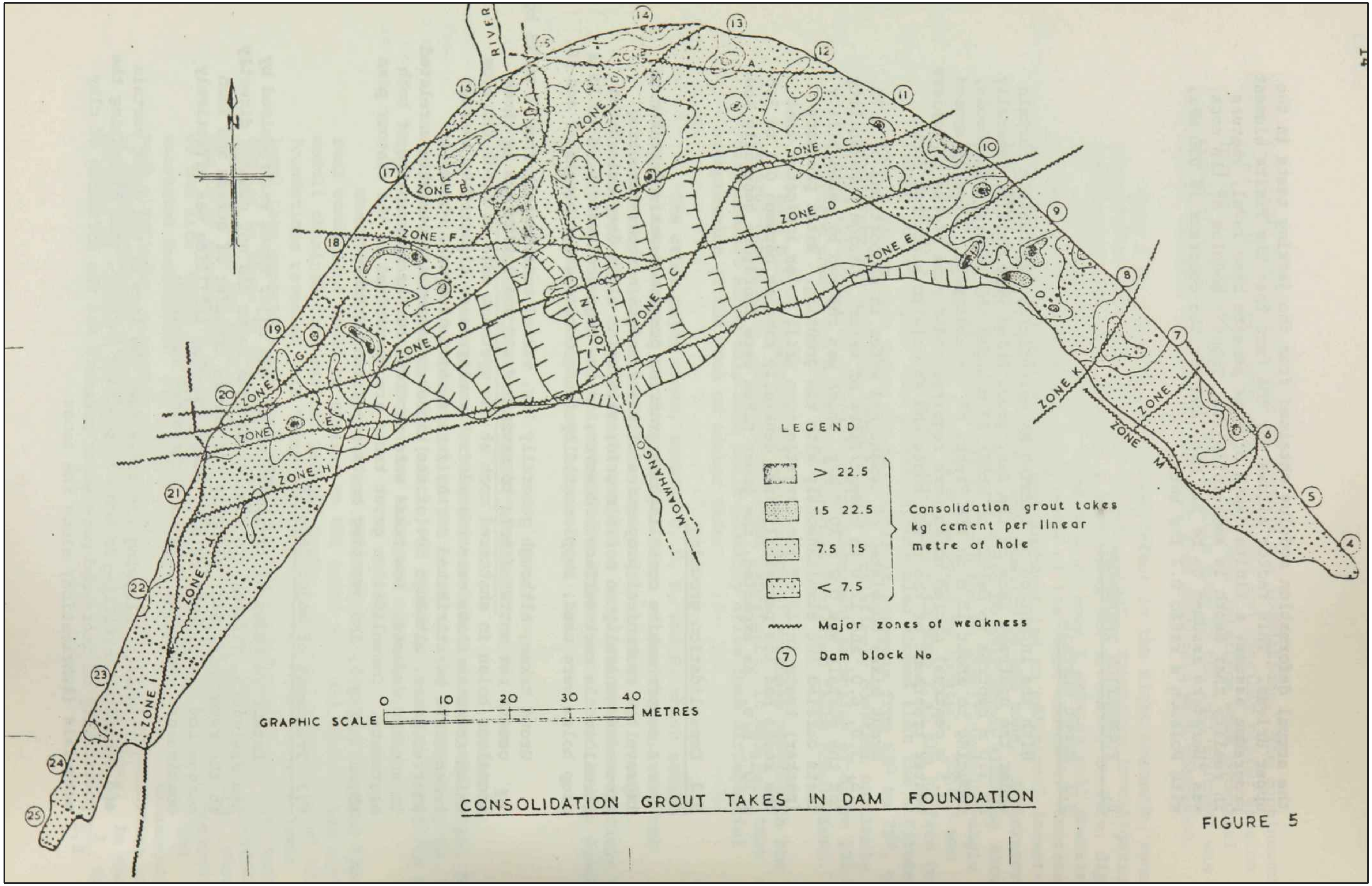


Figure 26 - Consolidation grouting of existing Moawhango Dam (from Duder et al. 1976)

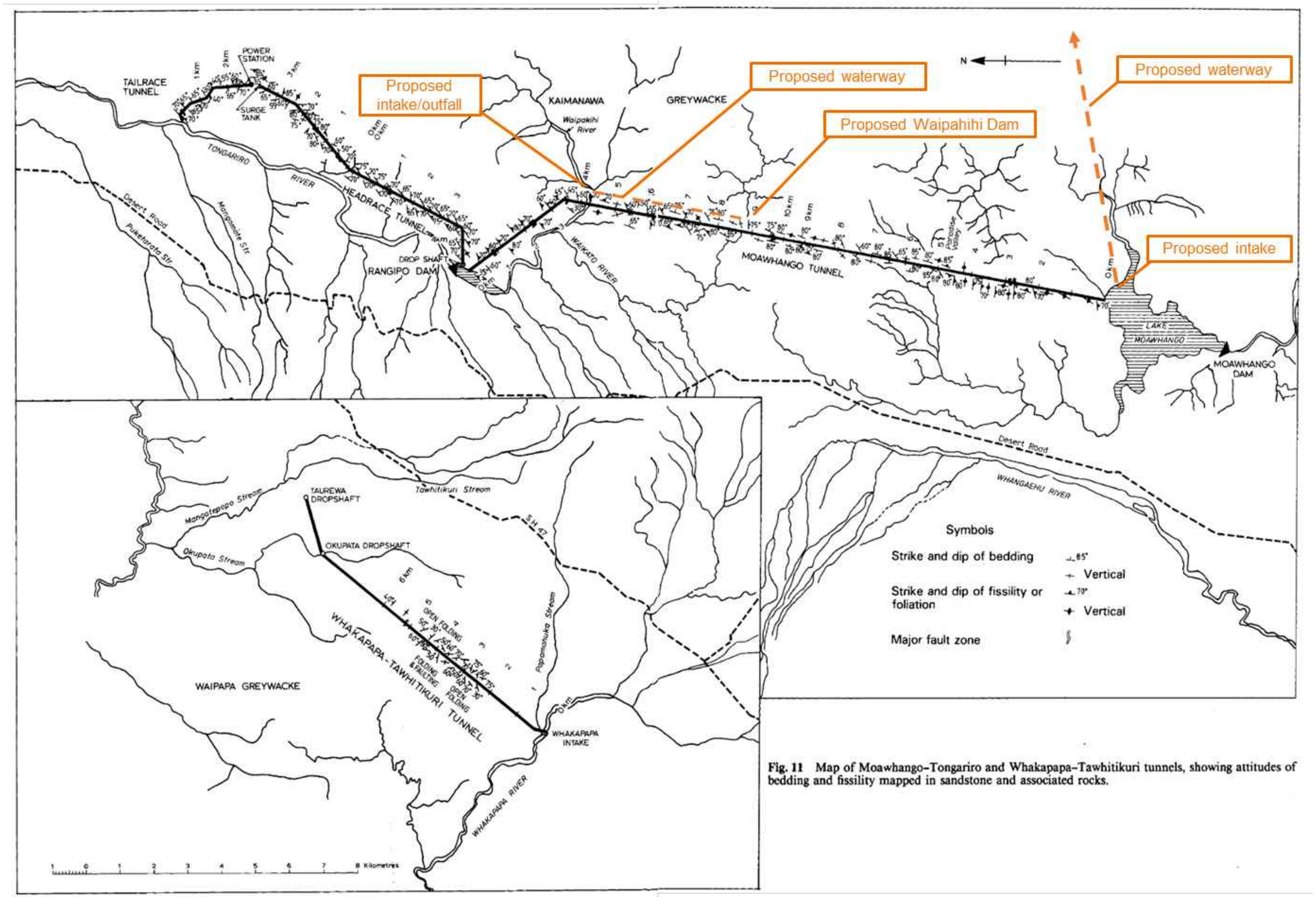


Figure 27 - Attitude of bedding and 'fissility' mapped in Tongariro Power Scheme tunnels (from Beetham & Watters 1985)

- Defects:
  - Like most New Zealand "greywacke", the Moawhango rocks are closely jointed and shattered
  - Minor defects such as bedding planes, foliation (fissility), and joint surfaces, occasionally with clay coatings, caused only minor problems such as overbreak and batter instability in a few areas.
  - Joints are the most common rock defect at the dam site, and despite the closely spaced, apparently irregular blocky jointing, statistical treatment enabled four joint sets to be defined (Hancox 1975).
  - Major rock defects such as clay gouge, crush, and shatter and shear zones, varying in thickness from about 20 mm to 600 mm, have been formed by mechanical disintegration during faulting, and were defined according to the soil properties of the materials comprising the zones.
    - In shatter zones, the rock has been reduced to small angular fragments (10 - 15 mm) with minor amounts of sandy clay and rare clay seams.
    - Zones of sub-parallel, Slickensided, closely spaced fracture planes forming platy or wedge-shaped rock slivers were designated shear zones.
    - Crush zones are well-defined sub-planar zones, with angular rock fragments down to sand size in a matrix of plastic, silty clay; many contain seams of soft, plastic clay gouge with minor angular rock fragments up to 10 mm diameter.
    - These defects are invariably intimately associated, forming a continuous spectrum of fault-zone materials grading into one another without clearly defined boundaries.
  - Many of the zones are sub-vertical features, parallel to steep joints, bedding, and foliation, and striking north to north-east with dips of 85- 90° east, suggesting that faulting occurred along pre-existing planes of weakness. Evidence of relative displacement was only rarely found, so, to avoid the implications of the term "fault", descriptive terms based on varying clay content and rock particle size were used, as defined above.
  - Detailed mapping of the dam foundations enabled the most prominent and continuous defects to be identified and investigated so that their effects on the stability of the site could be assessed. Seventeen major defects were located, two of these, zones K and I, were serious weaknesses requiring extensive remedial treatment under the dam.
- Grout curtain:
  - With the intention of forming an essentially impermeable curtain under the upstream face of the dam, grout holes were drilled generally at 3.0 m centres to depths of about 33 m under the central dam blocks, reducing to about 15 m on the flanks of the abutments. Closely spaced (1.5 m centres) angled holes were required under some blocks to achieve better treatment of the crush zones and associated shattered rock.
  - Grout mixes consisted of cement and water in proportions of 0.75, 1.5, 3.0, 6.0, and 12.0 kg cement/litre of water. Design permeability for the curtain was 0.2 x I0-6 m/s which was checked by permeability tests carried out simultaneously with the grouting.
  - Water pressure (packer) tests in 12 of the investigation drill holes indicated that the rocks had low permeabilities, generally ranging between 0.1 to 3.5 x IO-6 m/s. As expected, the grout takes were therefore generally low.
- Consolidation grouting:
  - A comprehensive consolidation grouting programme was undertaken to improve the mechanical properties of the foundation rock. Grouting proceeded generally on a 6.0 m grid, with holes 6.0 m deep orientated normal to the rock surface. However, in the region of zone B, 6 to 15 m deep holes were used, supplemented by fan grouting under blocks 17 and 18.
  - Grout takes, although generally low, varied considerably from 7 to 13 kg of cement per metre of hole to maxima of 400 and 1,170 kg/m in three anomalous holes in shattered rock at the upstream edge of block 11, from which artesian flows were recorded.
  - In many cases higher than average takes could be attributed to the intersection of crush, shear, or shatter zones, although 30% of the higher takes were unrelated to surface defects.
  - Low takes were recorded on the upper parts of both abutments.
- Foundation treatment:
  - Extensive remedial treatment of the two major zones were required by the designers, firstly to ensure that the zones did not connect directly to the reservoir, and secondly to ensure transfer of stress and load across the zones, particularly where the clay infilling was effectively continuous.
  - Remedial treatment therefore required:
    - Shafts following the zones down the line of the grout curtain and concrete backfilling to achieve positive cut-off, thus minimising the possibility of increased pore water pressure and the softening of clay materials (lubrication) along the zones.
    - The removal of clay and crushed rock for an average depth of some 13 m under the base of the dam with the excavations backfilled with concrete and contact grouted, the primary objectives being to transmit

thrust across the zones and to minimise the possibility of differential deflection of rock masses under the dam.

  - For all other major zones "dental" treatment only was required to prevent localised stress concentrations and possible migration of fines into the dam underdrains. This consisted of localised high pressure jetting and minor trenching excavation to a maximum depth of 1 m to remove clay, crushed rock and associated shattered material, followed by backfilling with concrete.

- Foundation drainage - A series of drainage holes were drilled to half the vertical depth of the grout curtain in order to relieve hydrostatic pressures under the dam downstream of the grout curtain. The depths and angles of the holes were specified to intercept the main crush zones.

On this basis, the following can be assumed for the concept design of the dams:

- Average excavation depth of 7.5 m to a suitable foundation – removal of alluvium, Tertiary-aged rock (sediments), and any weathered 'greywacke'. Adequate bearing/deformability for a concrete dam will typically be achieved at this depth.
- Soils will be diggable. Tertiary-aged rocks will diggable to rippable. 'Greywacke' will be rippable. Excavated materials not suitable for re-use.
- Foundation will not degrade/slake on exposure.
- Provision for dental concrete, seam treatment and slush grouting. Provision should be made for a reasonable amount of surface preparation
- Allowance for grout curtain, consolidation grouting and foundation drainage. Typical 'rules of thumb' for concrete gravity dams can be used.
- Foundation strength does not control sliding stability of the dam.
- Bedding is very steeply inclined (more than 70), so is unlikely to be critical for abutment or dam foundation stability.
- 'Greywacke' should be assumed as being erodible and therefore protection/dissipation required for spillway flows near the dam.
- Permanent slopes in soil should be formed at around 2H:1V. permanent slopes in rock ('greywacke') should be formed at less than 55° and this assumes no kinematically feasible failure mechanisms. Measures may be required to prevent long-term slaking/degradation of argillite rock.

B.5.5.2 Subsurface Conditions

All the underground excavations will be constructed in 'greywacke'. The Tongariro Power Scheme provides significant engineering precedence of similar underground excavations in similar conditions.

For underground excavations, it can be assumed:

- The varying metamorphic textural zones do not significantly change tunnelling conditions (i.e. the semi-schist does not possess a distinct fabric).
- Bedding, and the 'fissility' where present, is at dips of more than 50°. Drive of excavations will occur both perpendicular and approximately parallel to the strike of bedding. No allowance is therefore required for high-unfavourable orientation of the primary defect set.
- No allowance needs to be made for either high or low in-situ stress related conditions in the excavations.
- It would be expected most of the 'greywacke' would comprise 'very poor' conditions as per the Q system (Barton 1974). Better tunnelling conditions would only occur in the 'massive sandstone association', if encountered.
- From tunnel logging of the Tongariro Power Scheme, minor fault zones up to 200 mm thick are found, on average, every few metres, medium fault zones up to 2 m thick (though generally thinner) every 100 m, and at least one major fault zone, wider than 2 m, every kilometre. The published geological map shows the underground excavations will intersect several mapped 'inactive faults'. Ground conditions would equate to 'extremely poor' to 'exceptionally poor' in accordance with the Q system (Barton 1974). An arbitrary allowance should be made for their occurrence (i.e. 25% of underground excavations are within these classes of rock).
- The argillite when exposed in the tunnel does not significantly slake/deteriorate on excavation.
- Provision should be made for the management of high groundwater flows into excavations. Provision should include a nominal allowance for very high inflows at three locations in the underground excavations, which may require pre-treatment (drainage, grouting etc.). No special requirements are needed for disposal of tunnel groundwater, other than sedimentation.
- Selected excavated materials from the tunnels will be suitable for re-use, refer below.
- The remainder of tunnel spoil will require disposal. No provision should be made at this stage for special requirements for tunnel spoil disposal (such as those associated with Acid Mine Drainage or similar).
- No provision should be made for the intersection of geothermal activity at this stage (be it water, gas etc.).
- No active faults are to be intersected by underground excavations and therefore no special considerations exist.

B.5.5.3 Construction Materials

All of the dams required are currently assumed to be Roller Compacted Concrete (RCC). For this reason, the main construction material required would be concrete aggregate.

The 'greywacke' which underlies the site is the main likely source of concrete aggregate. The 'massive sandstone association' described by Beetham & Watters (1985) would likely be suitable for production of concrete aggregate via processing. It is described as 'occurring in beds from 2 m, to 100 m or more, and may locally be 1 km thick'. It is judged unlikely to have any durability and reactivity issues in RCC. There is engineering precedence of using this material for a variety of aggregates throughout New Zealand. We are not aware of any performance issues.

The other key lithologies described by Beetham & Watters (1985) include 'massive argillite association', 'alternating sandstone/argillite association', 'thin bed association' and 'mélange'. It should be currently assumed suitable RCC concrete aggregate cannot be produced from these materials due to potential durability issues associated with the argillite and the difficulty of this being interbedded with the sandstone and processing.

It should therefore be currently assumed that an onsite quarry can be developed in close proximity to the site, within the 'massive sandstone association', and this can be processed to produce suitable RCC aggregate. Limited overburden (i.e. soil, Tertiary-rocks, weathered rock) can be assumed at a quarry site.

A significant amount of 'greywacke' would be excavated as part of underground excavations. Selected material from the excavations could be used to provide concrete aggregate. Beetham & Watters (1985) do not state how much of the 'greywacke' comprises the 'massive sandstone association'. They do state around 50% of the rock comprises the 'alternating sandstone/argillite association'. On this basis, it could be assumed 25% of excavated rock from underground excavations could be re-used and processed to produce RCC aggregate.

It should be further assumed:

- Excavated materials from surface excavations would not be suitable for re-use as concrete aggregate (such as alluvium).
- Tertiary-aged rocks are unlikely to yield suitable concrete aggregate (due to potential durability issues).
- Volcanic rocks are unlikely to yield suitable concrete aggregate (due to potential durability and reactivity issues).
- The description of some rocks being 'semi-schistose' and with pervasive shearing, may mean they possess a distinct fabric and make breakdown on processing, transport and compaction.

Should only approximately 25% of tunnel spoil be suitable for re-use with processing to produce concrete aggregate, a significant volume of material will require disposal.

B.5.6 Summary

The key findings of this geological study of Site 1 can be summarised as:

- No geological fatal flaws have been identified based upon the currently available information.
- The design, construction, and operation of the Tongariro Power Scheme provides significant engineering geological precedence of the feasibility of the proposed works. This includes the development of both surface and underground works.

B.5.7 Next Steps

Recommendations for the next step of geological studies should this site proceed to a subsequent stage of development are:

- The sourcing and review of relevant pre-existing site-specific geological information which is privately held. This would include that related to the design, construction, and operation of the Tongariro Power Scheme. In particular, that associated with the Eastern Diversion and Rangipo Power Station.
- Development of geological study objectives and scope of works as required for the stage of project development as recommended by ICOLD (2005) and ANCOLD (2020).

Documents - 310103739

B.7 Site 3 – Pukaki

The following subsections summarise the findings of the geological study for Site 3.

B.7.1 Scheme Description

The scheme description is presented in the main study report.

B.7.2 Available Information

The key references which have been used in this study are:

- Published geological maps:
  - Barrell et al. 2011. Glacial geomorphology of the central South Island, New Zealand. GNS Science Monograph 27.
  - Cox et al. 2007. Geology of the Aoraki Area GNS, 1:250,000 Geological Map 15.
- Published and unpublished geological papers:
  - Barrell & Read 2013. The deglaciation of Lake Pukaki, South Island, New Zealand—a review, New Zealand Journal of Geology and Geophysics, 57:1, 86-101.
  - Cooksey 2008. Hydrogeology of the Mackenzie Basin. University of Canterbury, Department of Geological Sciences, Master of Science Thesis.
- Geological hazards:
  - Geotech 2008. Earthquake hazard assessment for Waimate, Mackenzie, and part Waitaki Districts. Environment Canterbury Report Number: U08/18.
  - Golder 2016. Mackenzie Lakes, Landslide Tsunami Investigation, Report for Environment Canterbury.
  - GNS 2007. Update Probabilistic seismic hazard assessment for the Canterbury region, Environment Canterbury Report No. U06/6.
  - GNS 2008. Update Probabilistic seismic hazard assessment for the Canterbury region: addendum report, Environment Canterbury Report No. U06/6/2.
  - GNS 2010. Assessment of active faults and folds in the Mackenzie District, South Canterbury, GNS Science Report 2010/040, Environment Canterbury Report No. R10/25.
  - GNS 2015 Tsunami and seiche hazard scoping study for Lakes Tekapo, Pukaki, Ohau, Alexandrina and Ruataniwha. GNS Science Report number 2014/227, Environment Canterbury Report Number R15/39.
- Site-specific information:
  - Read 1976. Upper Waitaki Power Development Scheme, Pukaki Lake Control, Engineering Geological Completion Report. New Zealand Geological Survey, Engineering Geology Section, Department of Scientific and Industrial Research.

A key reference on which this study has been based is that by Read (1976). The report provides site-specific geological information from the design and construction of the existing Pukaki Dam. 0 (from Read 1976) shows the arrangement of Pukaki Dam and key terms which have been used in this study when referencing the existing Pukaki Dam. 0 (from Read 1976) shows subsurface investigation completed as part of the design and construction of Pukaki Dam. In addition to the investigations show, the exposed foundations for the key structures were also geologically mapped. For these reasons, anticipated geological materials and their characteristics are relatively well known.

The design, construction, and operation of the existing Pukaki Dam provides useful engineering precedence for the study. As does the Upper Waitaki Power Scheme in general, as the geological materials are similar throughout.

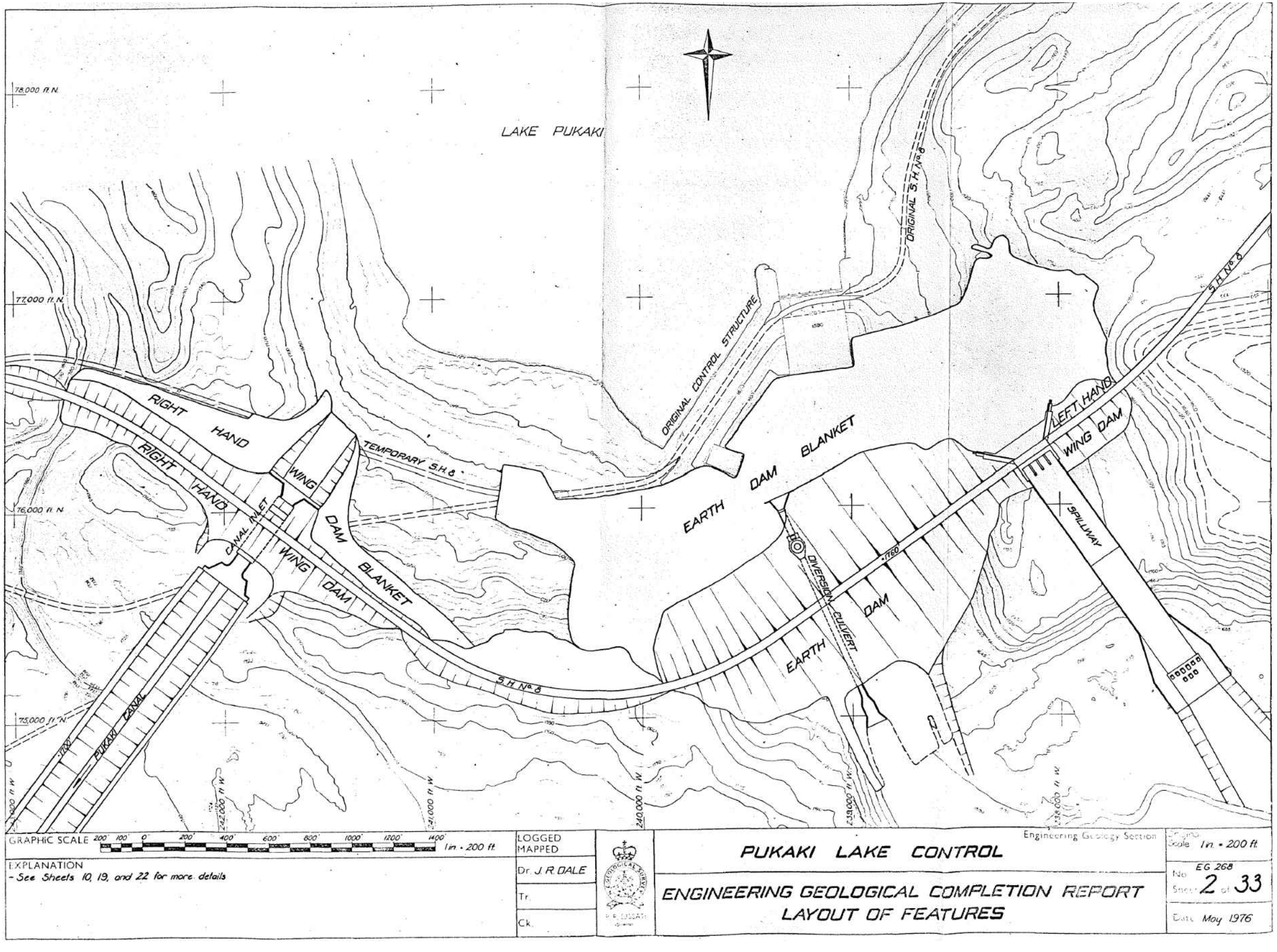


Figure 1 - Arrangement of the existing Pukaki Dam (from Read 1976)

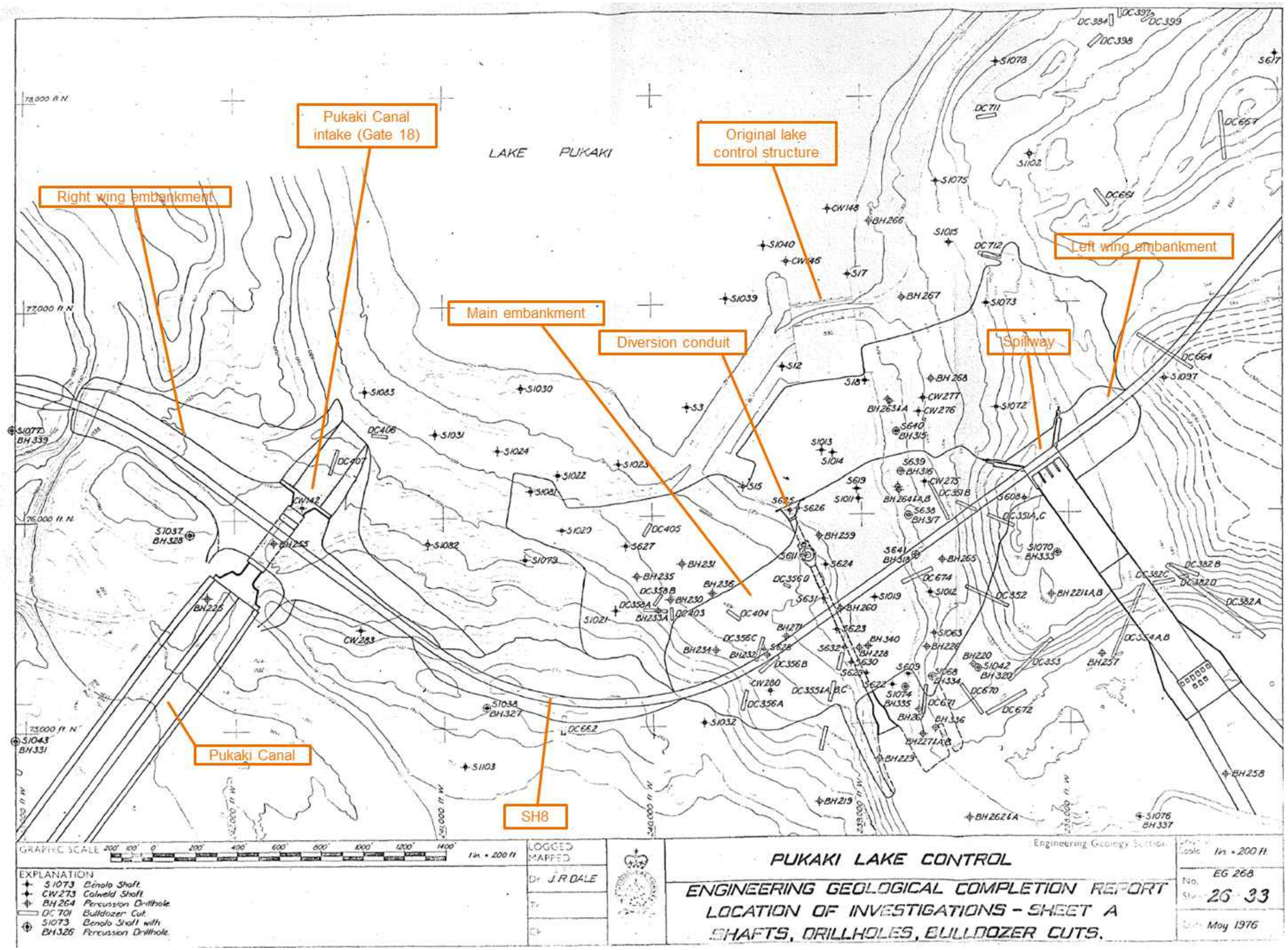


Figure 2 - Geological investigations from the design and construction of the existing Pukaki Dam (from Read 1976)

B.7.3 Published Geology

Lake Pukaki is located within the Mackenzie Basin, an intermonate basin located within the central part of the South Island (0). The origins of the basin are believed to be associated with the development of the current plate boundary through New Zealand (i.e. the Alpine Fault) around 23 million years ago. Originally transcurrent, the boundary is judged to have become more convergent approximately 10 to 5 million years ago, leading to associated uplift and formation of the Southern Alps. Although the plate movement was largely Concentrated along the Alpine Fault, deformation also occurred along other structures and resulted in the development of fault-controlled basin and ranges. The Mackenzie Basin is one of the largest of these fault-controlled basins.

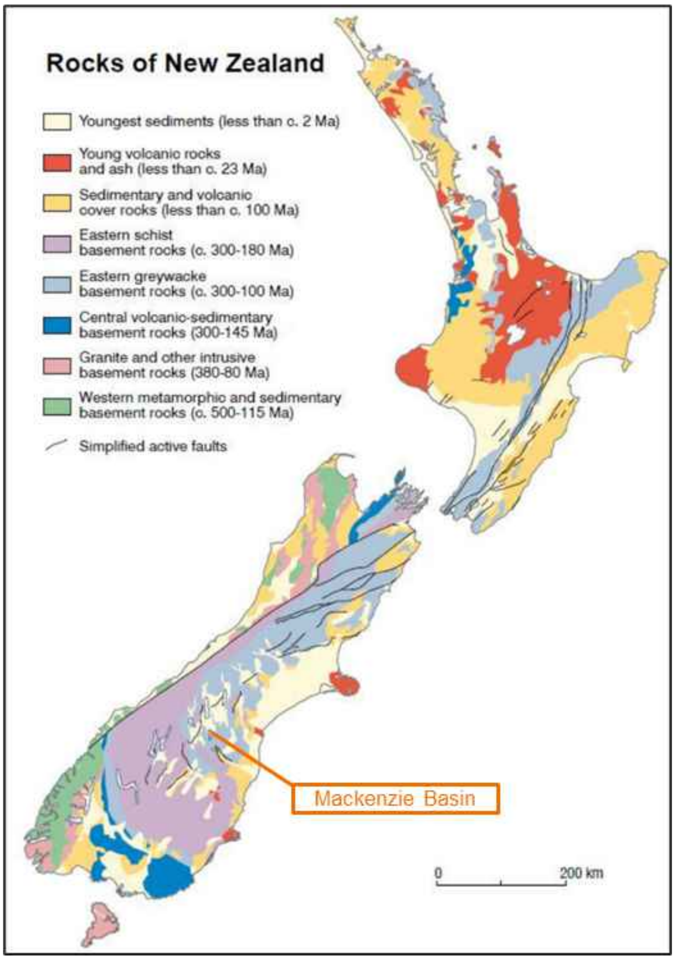


Figure 3 - Simplified geological map of New Zealand (from GNS undated)

The Mackenzie Basin has subsequently been infilled with sediments derived from the uplifted areas surrounding it. The bedrock surrounding all sides of the basin, and at depth beneath it, comprises the Raikaia Terrane, often referred to as 'greywacke'. The depth of bedrock beneath the Pukaki Dam location is not reliably known. It was not intersected in any investigations or by construction for the existing dam. Based upon geophysical surveys, the depth to bedrock beneath the Mackenzie Basin is interpreted to be between 300 and 1,000 m below ground level typically (Cooksey 2008). At its deepest point, bedrock may be up to 2000 m below ground level in the basin (Cooksey 2008).

Reference is made to 0 and 0 for published geological maps of the Lake Pukaki area. 0 provides a correlation of the varying soils and their ages, together with the formation names associated with the different periods of glaciation.

From this, it can be seen that the immediate reservoir shoreline, including the existing Pukaki Dam area, are mapped to be underlain by varying glacial (i.e. 'till', 'moraine'), fluvioglacial (i.e. 'outwash'), and alluvial soils ranging in age from approximately Late Otiran (45,000 years) to recent. The soils reflect varying glacial conditions from the Late Otiran times to the end of the last major glaciation, around 12,000 years ago. The two key periods of glaciation during this time are known as the Mount John and Tekapo Formations. It is noted deposits associated with older glaciations occur in Mackenzie Basin (i.e. Early Otiran and earlier), but are not directly relevant to this study.

Post-glacial alluvium has subsequently been deposited, and continues to be deposited, within and adjacent to watercourses, which includes the Pukaki River at the dam site and Tasman River at the head of Lake Pukaki.

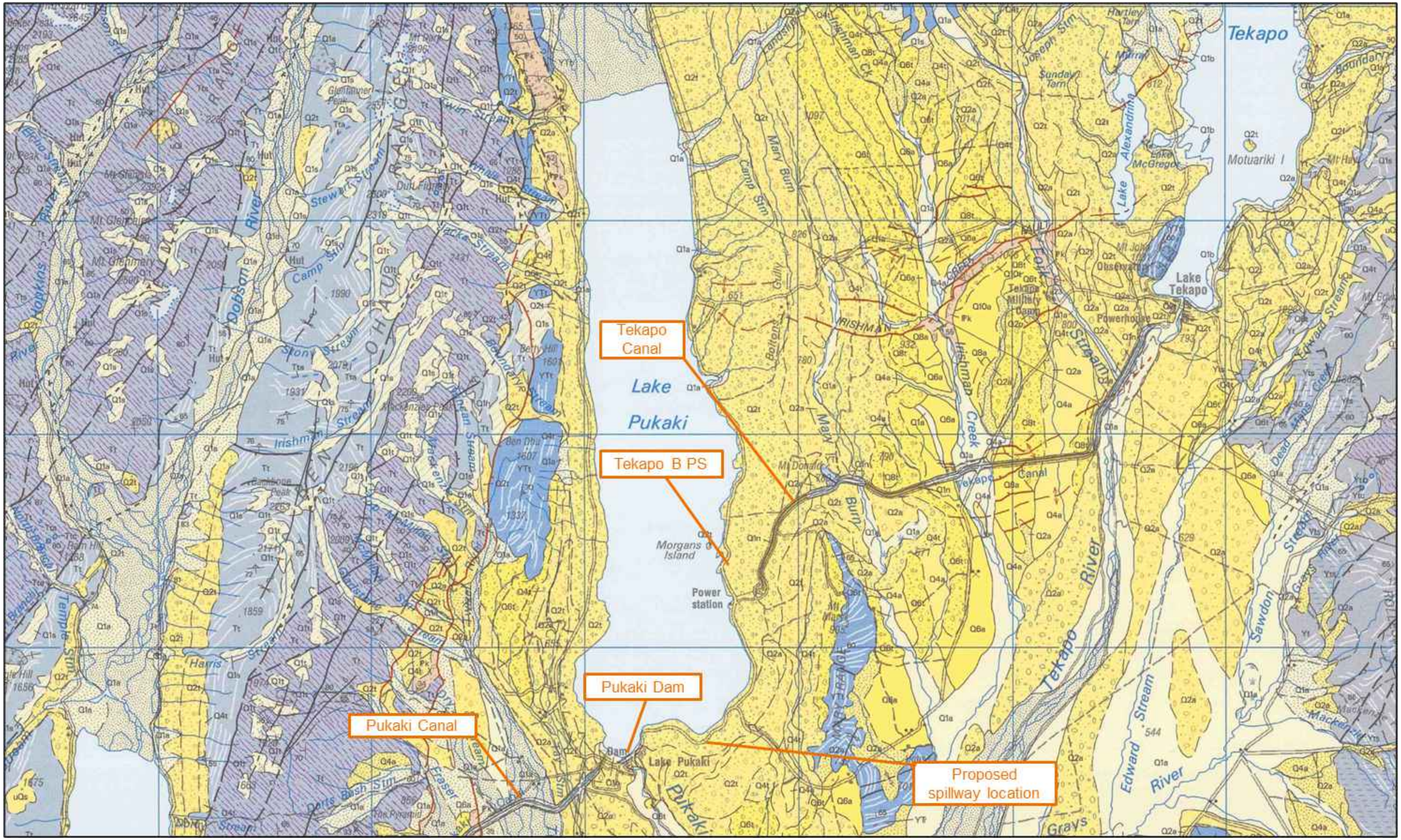
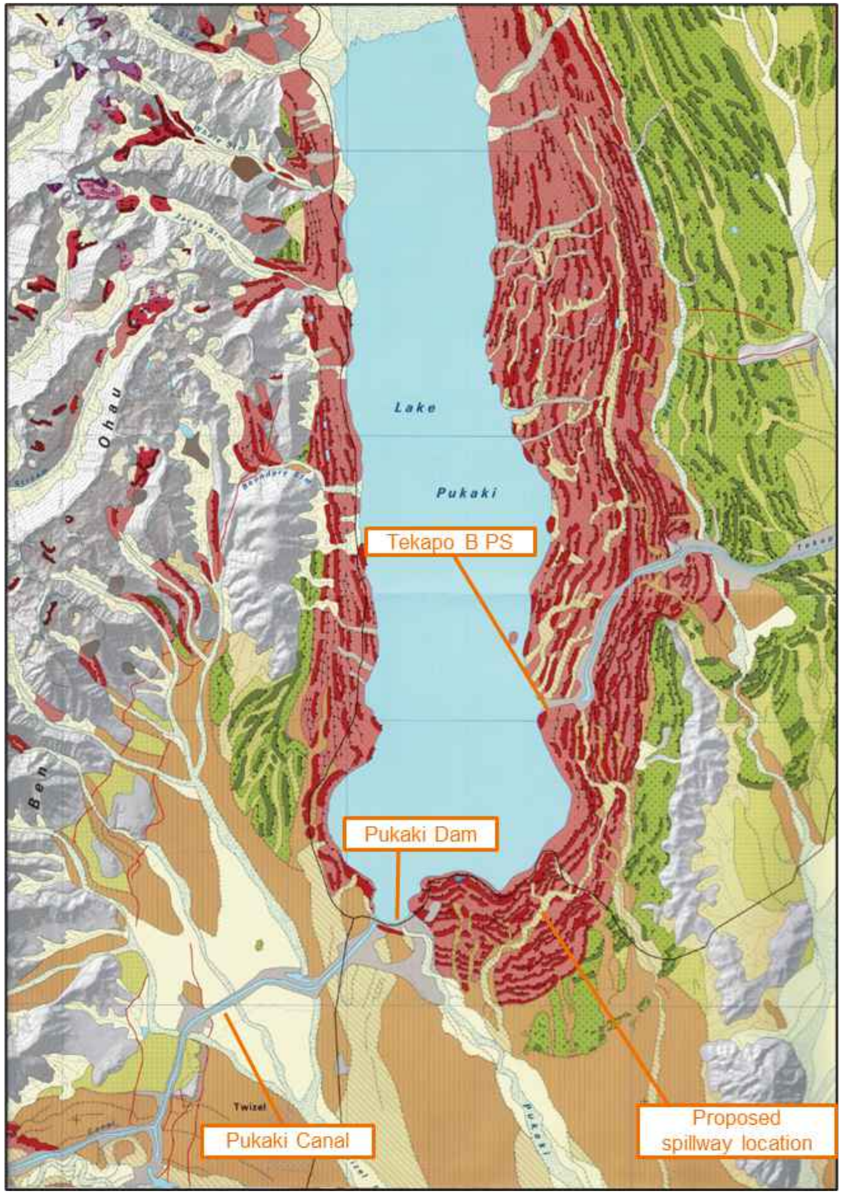


Figure 4 - Published geological map of the Lake Pukaki area (from Cox et al. 2007)



Westland[1]	Waimakariri[2]	Rakaia[3]	Canterbury Plains[4]	Lake Heron-Arrowsmith Range[5]	Rangitata - Clearwater[6]	Mackenzie basin[7]	This map moraine/outwash MIS
	Barker	Whitcombe		Arrowsmith			Latest Holocene
Nine Mile	O'Malley	Lyell	Springston	Younger Marquee Older Marquee		Ben Ohau	1 Holocene
Waiho	Arthur's Pass	Meins Knob Reischek Jagged Stm		Wildman		Birch Hill	Late-glacial
Moana (M6) Larrikins (M4b-M5)	McGrath Poulter Blackwater	Lake Stream Acheron Bayfield Tui Creek	(St Bernard) Burnham (Windwhistle)	Lake Heron Johnstone Stm Emily	Two Thumbs Spider Lakes Hakatere Trinity Hill	Tekapo Mt John	2, 3 Latest Late Otiran Late Otiran
Loopline Waimea Tansey Cockeye	Otarama Woodstock Avoca	Woodlands Hororata	Woodlands Hororata	Dogs Hill Pyramid	Dogs Hill Pyramid	Balmoral Wolds	4, 6, 8, 10 Early Otiran and older

Figure 5 - Published geological map of the Lake Pukaki area (from Barrell et al. 2011)

Oborn (1961)		Speight (1963)	McGregor (1967)	Gair (1967), Oborn (1978)[a]		Cox & Barrell (2007)[b]	
Formation	Member	Landform association	Formation	Formation	Member	Map unit	Formation/Member
		Birch Hill	Birch Hill	Birch Hill		Q1t (red pattern)	Birch Hill
Tekapo	Till	Pukaki		Tekapo	Till	Q2t (grey pattern)	Tekapo/till
	Outwash				Outwash	Q2a (grey pattern)	Tekapo/outwash
Mt John	Till			Mt John	Till	Q2t (red pattern)	Mt John/till
	Outwash				Outwash	Q2a (red pattern)	Mt John/outwash
Balmoral	Till	Maryburn		Balmoral	Till	Q4t/Q6t	Balmoral/till
	Outwash				Outwash	Q4a/Q6a	Balmoral/outwash
		Stevenson		Wolds	Till	Q8t	Wolds/till
					Outwash	Q8a	Wolds/outwash

[a]Gair's (1967) map text uses McGregor's (1967) formation name 'Birch Hill', which is identified on the map by the code 'sd'. Oborn (1978) referred to this unit as 'Sibbalds Formation' (presumably after Sibbalds Island, a remnant mound of moraine in the Godley valley of the Lake Tekapo catchment), suggesting that 'Sibbalds' was the intended formational term in keeping with the approach of naming the Late Pleistocene formations of the Mackenzie basin from the Tekapo area. We surmise that Oborn (1978) did not agree with Gair's (1967) late-stage adoption of McGregor's (1967) terminology.
[b]The formation names are in the digital (vector) map data, but are not stated on the published map or in the accompanying text. The number in each map unit code is an indicative correlation to a Marine Isotope Stage chronozone number.

Figure 6 - Correlation of glacial and fluvioglacial deposits in the Lake Pukaki area (from Barrell & Read 2013)

Brief reference is also made to the published geology of the following locations, for which works are required as part of the proposed option, that are underlain by the same geological materials introduced above:

- Proposed spillway location.
- Right abutment location.
- Tekapo B Power Station.

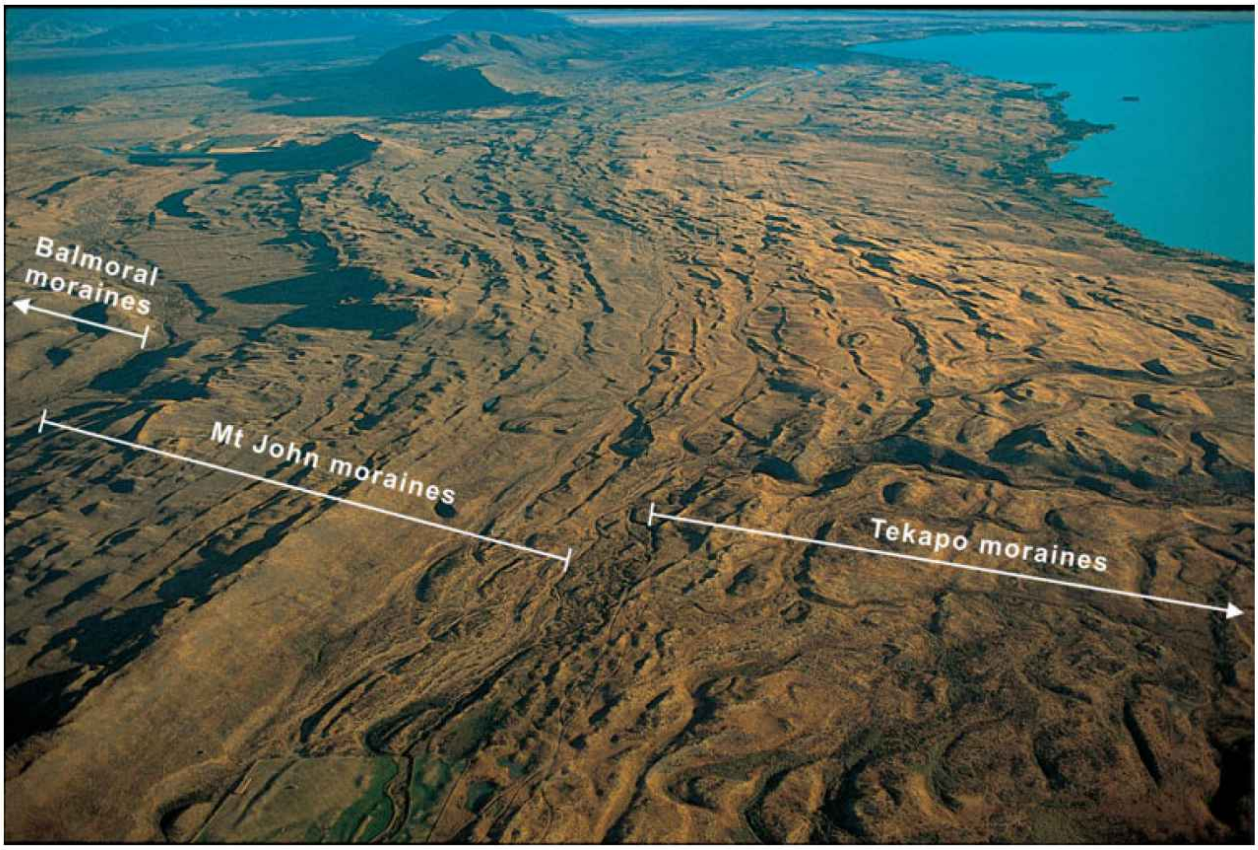


Figure 7 - Various aged glacial till on the eastern side of Lake Pukaki (from Barrell & Read 2013)

B.7.4 Geological Hazards

The following subsections summarise publicly available information about geological hazards of relevance to this study. The emphasis has been placed on those geological hazards which could be a significant constraint on design, construction, and operation.

B.7.4.1 Earthquake Hazards

The definition of an active fault within this study is that used in the New Zealand Active Fault Database which is 'a fault that shows evidence of rupture one or more times in the last 125,000 years and is therefore likely to move again in the future'. This is similar to that presented in NZSOLD DSG (2015).

Known active faults in the Mackenzie Basin are shown on 0 (from GNS 2010). Their characteristics are detailed further in 0.

Significant investigation of the location, activity, and displacement characteristics of faults within the Mackenzie Basin was completed as part of the Upper Waitaki Power Scheme development. It would be considered one of the better characterised locations within New Zealand and on this basis, the information would not be expected to change significantly in the future (such as the identification of previously unidentified 'active' faults or significant change in their assessed level of activity or rupture characteristics).

It can be seen from 0 (from GNS 2010) that no known active faults are located within or near the foundation of infrastructure as currently proposed for this option.

In addition to surface fault rupture within the foundation of infrastructure, a further hazard is a potential for surface fault rupture beneath the reservoir, leading to a tsunami. It can be seen from 0 that no known active faults are mapped beneath Lake Pukaki. Obviously, the knowledge of surface fault traces beneath the lake is limited due to its presence (as a natural lake was present prior to dam construction, although smaller in area).

It can be seen that the Ostler Fault if extended along strike, does not intersect Lake Pukaki. Traces associated with the Irishman Creek Fault Zone are mapped on the eastern side of Lake Pukaki. Although mapped as 'active' further east, they are mapped as being 'possibly' active at the intersection with the reservoir shoreline. It is judged likely these traces may extend along strike beneath Lake Pukaki. These are shown as being 'folds', specifically anticlines. It is assumed these are underlain by a 'blind fault' at depth, however.

GNS (2015) calculated the following possible tsunami heights due to surface rupture beneath some reservoirs of the Upper Waitaki Power Scheme:

- *A 4.7 m fault offset (≈ 3.3 m vertical displacement) on the Ostler Fault beneath Lake Ruataniwha could produce wave heights of at least 3 m in Lake Ruataniwha.*
- *A 2.7 m fault offset (≈ 1.9 m vertical displacement) on the Irishman Creek Fault zone could produce wave heights of at least 2 m on Lake Alexandrina. Warping across the active fold at the southern end of Lake Alexandrina may also produce a tsunami but the likely size, and the possibility of synchronicity with rupture of the fault trace in northern Lake Alexandrina cannot be assessed.*
- *Fault offsets of 2.7 m (≈ 1.9 m vertical displacement) on an extension of the Irishman Creek Fault Zone into Lake Tekapo could produce wave heights of at least 2 m on Lake Tekapo. If there is an extension of the Coal River/Forest Creek Faults into Lake Tekapo the fault offset of 3.5 m (≈ 3 m vertical displacement) could produce wave heights of at least 3 m, however, we emphasise these are likely to be maximum heights as the offset at the fault tips in the lake are likely to be less than 3.5 m (which is the modelled average for the whole fault plane).*

It can be seen that tsunami heights of around 2 m were calculated for the Irishman Creek Fault Zone beneath Lake Alexandrina and Lake Tekapo. Similar values could be assumed if the fault zone extends beneath Lake Pukaki. Tsunami waves of this magnitude would likely be accommodated within conventional freeboard allowance for dam design as required by the NZSOLD DSG (2015).

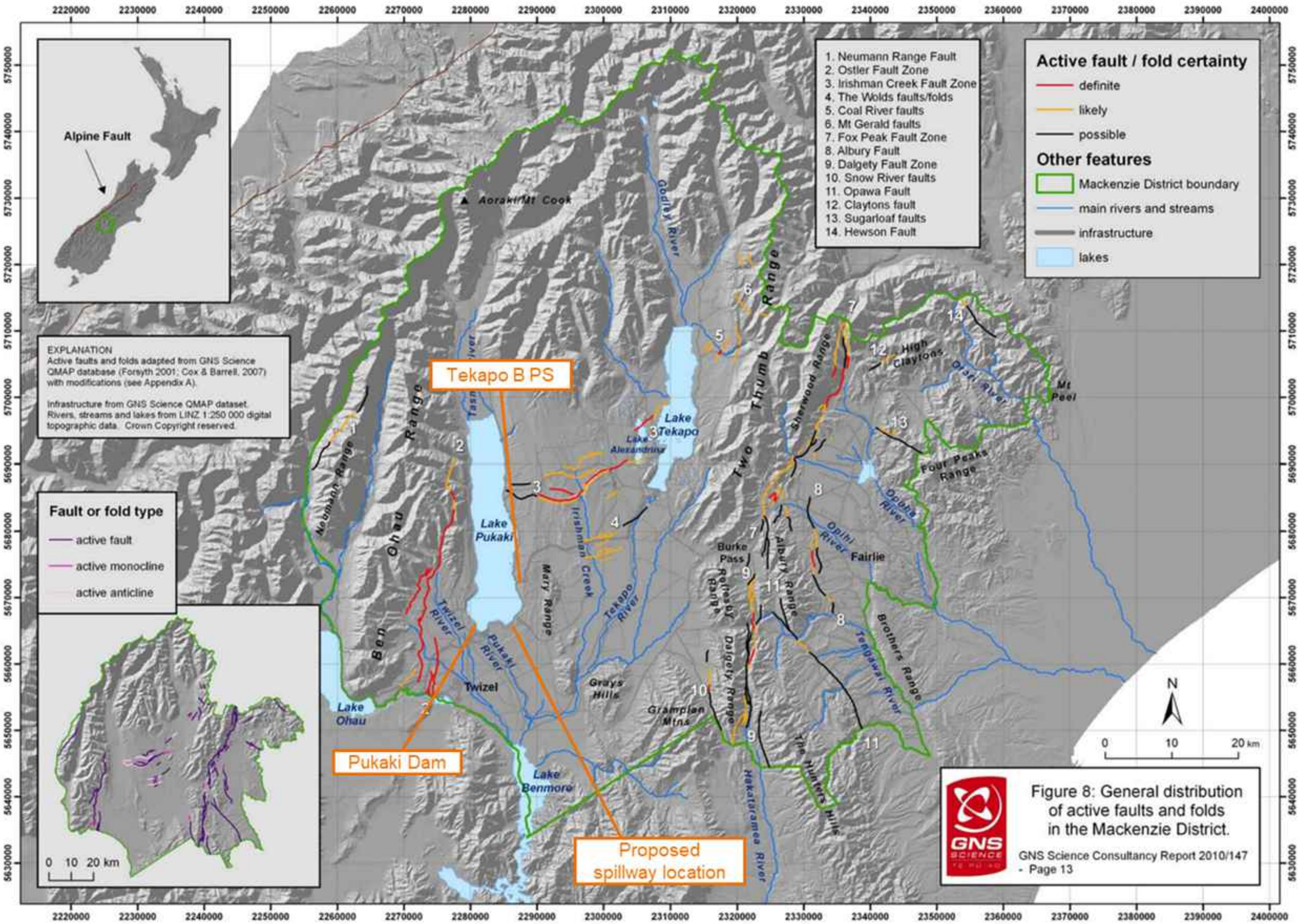


Figure 8 - Active faults and folds in the Mackenzie District (from GNS 2010)

Name	Observed characteristics	References	Deformation estimates						
Lower case last term (e.g. fault) = informal name. Upper case = name previously published	Geologic evidence	Most comprehensive published information on fault/fold activity	Basis of estimates	Estimated age of deformed landform (years before present)	Estimated vertical deformation of landform (m)	Calculated average vertical slip rate (mm/yr)	Implied long-term average recurrence interval (RI - years) of deformation event, assuming 2 m vertical deformation per event*	Nominal 67% uncertainty in RI (years) **	Implied range of RI Classes (following Kerr et al. 2003)
1. Neumann Range fault	Likely fault offsetting ice-smoothed topography.	Cox & Barrell 2007	airphoto interpretation; regional geologic mapping	18,000	5	0.3	7,200	4,824	II-V
2. Ostler Fault Zone***	Definite and likely faults and monoclines.	Read 1984; Blick et al. 1989; Van Dissen et al. 1993; Cox & Barrell 2007; Amos et al. 2010 in press	field inspection and surveying; regional geologic mapping; airphoto interpretation	18,000	20	1.1	3,000	990	II-III
3. Irishman Creek Fault Zone	Definite and likely faults and monoclines.	Speight 1963; Cox & Barrell 2007; Amos et al. 2007; Upton & Osterberg 2007	field inspection; airphoto interpretation; regional geologic mapping	18,000	10	0.6	3,600	2,412	I-IV
4. The Wolds faults/folds	Likely faults and monoclines deforming moraines and outwash terraces older than the last ice age.	Cox & Barrell 2007	airphoto interpretation; field inspection; regional geologic mapping	140,000	10	0.07	28,000	18,760	IV-VI
5. Coal River faults	Definite and likely faults and monoclines. Fault offset of river gravel exposed in Coal River.	Cox & Barrell 2007	airphoto interpretation; field inspection	18,000	5	0.3	7,200	4,824	II-V
6. Mt Gerald faults	Likely faults offsetting ice-smoothed topography.	Cox & Barrell 2007	airphoto interpretation	18,000	5	0.3	7,200	4,824	II-V
7. Fox Peak Fault Zone	Definite, likely and possible faults and monoclines.	Beanland 1987; Cutten 1990; Upton et al. 2004; Cox & Barrell 2007	airphoto interpretation; field inspection; regional geologic mapping	18,000	10	0.6	3,600	2,412	I-IV
8. Albury Fault	Definite, likely and possible faults/monoclines. Fault offset of stream gravel exposed near School Road.	Cox & Barrell 2007	airphoto interpretation; field inspection; regional geologic mapping	140,000	13	0.1	21,538	14,431	V-VI
9. Dalgety Fault Zone	Definite, likely faults/folds, with possible extentions along faults mapped in bedrock.	Forsyth 2001; Cox & Barrell 2007	airphoto interpretation; field inspection; regional geologic mapping	18,000	5	0.3	7,200	4,824	II-V
10. Snow River faults	Definite fault offsetting stream terraces. Possible extensions on mapped faults in bedrock.	Cox & Barrell 2007	airphoto interpretation; regional geologic mapping	18,000	5	0.3	7,200	4,824	II-V
11. Opawa Fault	Likely fault offsetting hill slopes. Possible extensions along mapped faults in bedrock.	Cox & Barrell 2007	airphoto interpretation; field inspection; regional geologic mapping	65,000	5	0.1	26,000	17,420	IV-VI
12. Claytons fault	Likely fault offsetting hill slopes. Possible extensions along mapped faults in bedrock.	Cox & Barrell 2007	airphoto interpretation; regional geologic mapping	18,000	5	0.3	7,200	4,824	II-V
13. Sugarloaf faults	Likely faults that appear to have offset alluvial fans. Possible extensions along mapped faults in bedrock.	Cox & Barrell 2007	airphoto interpretation; regional geologic mapping	18,000	5	0.3	7,200	4,824	II-V
14. Hewson Fault	Likely fault offsetting hill slopes over a mapped fault in bedrock.	Oliver & Keene 1990; Cox & Barrell 2007	airphoto interpretation; field inspection; regional geologic mapping	18,000	5	0.3	7,200	4,824	II-V

NOTES

* Deformation of 2 m per event is arbitrarily assumed, for the purpose of placing these features in the context of the Kerr et al. (2003) RI classification. See text for further discussion

** In order to highlight the arbitrarily assumed deformation value, a nominal error of plus/minus two-thirds of the RI value (~67%) is applied

*** Ostler Fault Zone recurrence is based on detailed investigations by Van Dissen et al. 1993. A RI of 3,000 years and 33% uncertainty are arbitrarily applied

RI Class definitions

I ≤2000 years
II >2000 years to ≤3500 years
III >3500 years to ≤5000 years
IV >5000 years to ≤10,000 years
V >10,000 years to ≤20,000 years
VI >20,000 years to ≤125,000 years

Figure 9 - Characteristics of active faults and folds in the Mackenzie District (from GNS 2010)

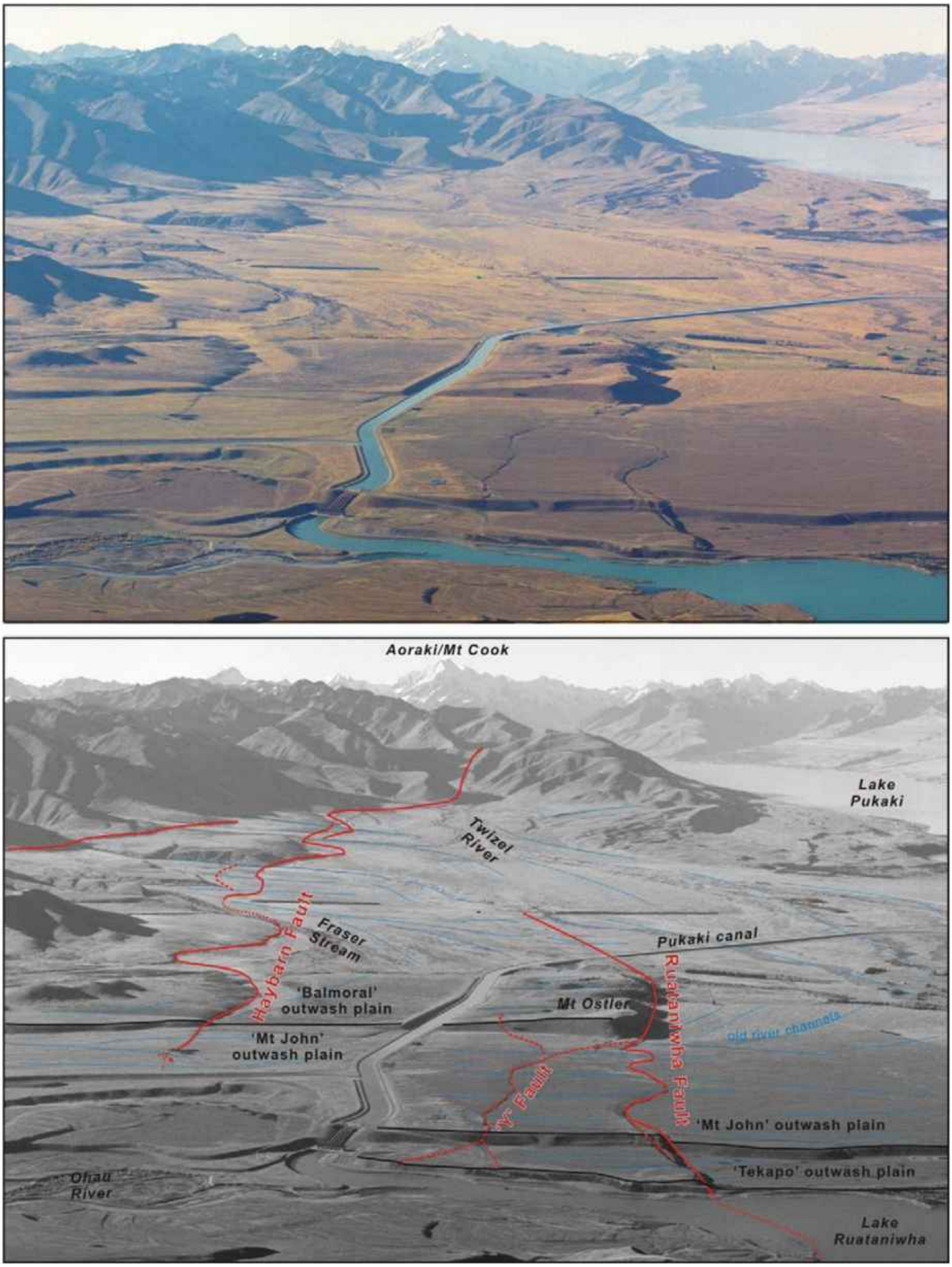


Figure 10 - Appearance of the Ostler Fault Zone which crosses Pukaki Canal downstream of Pukaki Dam (from Barrell & Read 2013)

For earthquake shaking hazard, the NZSOLD DSG (2015) design criteria for a High PIC dam can be summarized as:

- Operating Basis Earthquake – 1 in 150 AEP.
- Safety Evaluation Earthquake – 84th percentile level for the Credible Maximum Earthquake (CME) if developed by a deterministic approach, and need not exceed the 1 in 10,000 AEP ground motion developed by a probabilistic approach.

It is noted that some owners of high-importance assets or those which serve a post-disaster function, including dams and hydropower facilities, use higher serviceability limits than 1 in 150 AEP for their assets. Some use serviceability of 1 in 500 AEP. This may be applicable to the proposed works.

It is understood Meridian Energy Limited has completed a site-specific Probabilistic Seismic Hazard Assessment (PSHA) for the Upper Waitaki Power Scheme and this is the basis they use for assessing earthquake shaking hazards to their assets. We understand that this PSHA has been recently updated and therefore represents the latest and most reliable information on seismic hazards in the Mackenzie Basin. This PSHA is not publicly available.

Seismic hazard for expected horizontal peak ground accelerations (pga) at varying return periods were calculated for the Canterbury region by GNS (2007). Site Class C is assumed. Vertical accelerations can be assumed to be approximately 0.66 of horizontal accelerations. The results of their assessment for Twizel are shown in 0.

Twizel

	PGA	MW	0.08	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.50	0.75	1.00	1.50	2.00	3.00
20yrs	0.07	0.05	0.10	0.12	0.14	0.16	0.15	0.15	0.14	0.13	0.11	0.06	0.04	0.02	0.02	0.01
50yrs	0.13	0.10	0.21	0.25	0.29	0.33	0.31	0.30	0.27	0.25	0.21	0.12	0.07	0.05	0.04	0.02
75yrs	0.16	0.13	0.26	0.32	0.37	0.42	0.40	0.38	0.35	0.32	0.27	0.16	0.10	0.06	0.05	0.03
200yrs	0.26	0.22	0.47	0.57	0.65	0.73	0.67	0.63	0.58	0.54	0.46	0.29	0.19	0.13	0.10	0.06
475yrs	0.36	0.31	0.71	0.88	0.97	1.07	0.96	0.88	0.80	0.74	0.63	0.42	0.28	0.21	0.15	0.11
1000yrs	0.48	0.40	0.99	1.23	1.32	1.43	1.25	1.12	1.01	0.92	0.79	0.54	0.37	0.28	0.21	0.15
2000yrs	0.62	0.52	1.35	1.71	1.78	1.90	1.61	1.40	1.25	1.13	0.97	0.66	0.46	0.35	0.26	0.20
5000yrs	0.86	0.75	1.93	2.52	2.59	2.69	2.20	1.84	1.62	1.44	1.25	0.84	0.61	0.46	0.34	0.27
10000yrs	1.07	0.97	2.45	3.25	3.38	3.52	2.72	2.20	1.93	1.71	1.50	1.00	0.74	0.55	0.41	0.33
20000yrs	1.28	1.19	3.00	4.09	4.29	4.50	3.39	2.68	2.28	1.97	1.76	1.18	0.86	0.65	0.49	0.40

MMI 50yrs=6-7; 150yrs=7-8; 475yrs=8-9; 1000yrs=8-9

Figure 11 - Seismic hazard for Twizel for various return periods (from GNS 2008)

We have calculated likely seismic design requirements using NZS1170.5. We have assumed Site Class D based upon the foundation conditions described in Read (1976). The Ostler Fault is not listed as an active fault requiring specific consideration. Horizontal peak ground accelerations calculated are:

- OBE (150 AEP) – 0.18 g.
- SEE (10,000 AEP) – 0.9 g.

Although lower than some other parts of New Zealand, relatively speaking, this still represents a very high seismic hazard. The seismic design criteria will be critical for design, construction, and operation. Defensive design principles will be required to be used (such as relatively flat upstream and downstream slopes, wider sloping core, well-designed and constructed filters etc.).

A regional assessment of earthquake-induced liquefaction is presented in Geotech (2008) and is represented as 0. The glacial and fluvioglacial deposits are categorised as being of 'very low liquefaction potential'. Post-glacial alluvium is of 'low liquefaction potential'. This would be judged generally consistent with observations related to the 2010 Canterbury Earthquake and 2016 Kaikoura Earthquake.

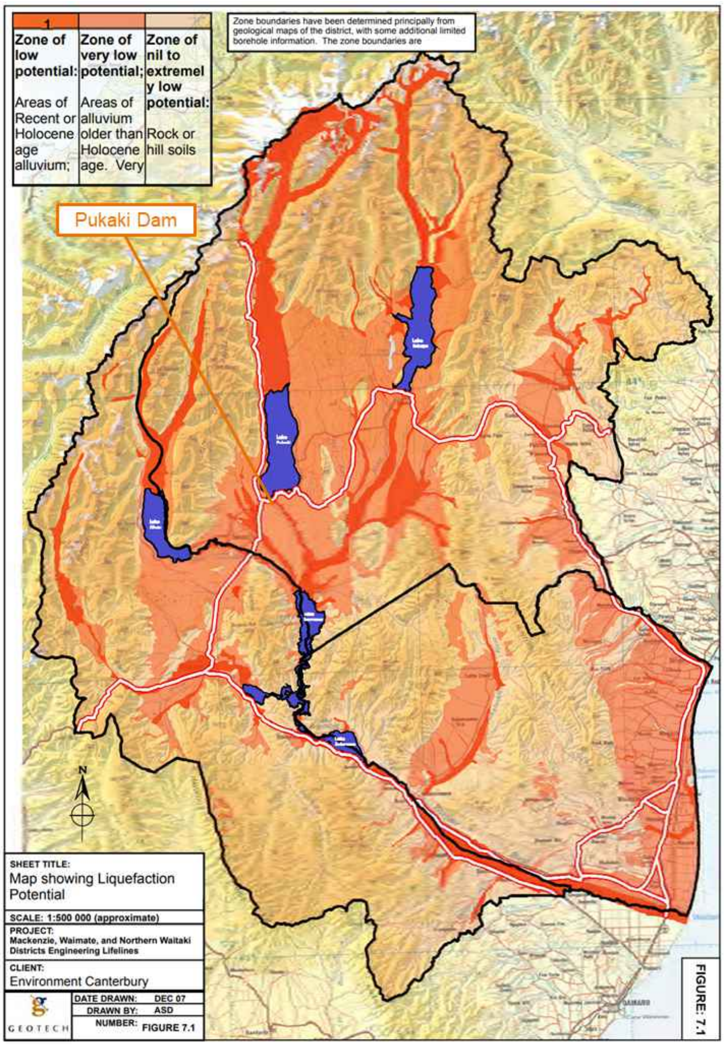


Figure 12 - Regional liquefaction susceptibility map (from Geotech 2008)

Some site-specific information relating to the liquefaction potential of foundation materials is available in Read (1976). This is discussed in more detail below, but in summary:

- Likely liquefaction susceptible soils in the foundation of the existing Pukaki Dam appear to have largely been removed during construction. Other than this excavation, no other liquefaction mitigation measures appear to have been employed, suggesting the foundation was considered non-liquefiable.
- Some soils remain locally in the foundation which may have some liquefaction susceptibility, but often these are of limited extent and have some fines content. This includes the ‘Fancy Sands’.
- The geologically older glacial and fluvioglacial soils within the foundation have been subsequently overridden by the Tekapo Advance.
- The groundwater level is stated as being ‘at least 100 feet below Lake Pukaki’ immediately following construction (it is assumed this is below bed level). Current levels are not known. But it appears the upper approximately 30 meters or so of the foundation is above regional groundwater level.

It is therefore unlikely that earthquake-induced liquefaction of the foundation (and any associated effects) would be a key design consideration. It can also be assumed existing embankment materials would be non-liquefiable. Reservoir sediments would require separate consideration for their likely earthquake performance, which would be expected to be predominantly fine-grained soils of low density/consistency.

A further earthquake hazard is that of seiche waves (standing waves in an enclosed body of water). GNS (2015) completed an assessment of possible seiches in the Mackenzie Basin lakes. It was concluded that it was not possible to determine likely seiche wave characteristics as there are no reliable established relationships, due to the complexity of factors involved. It was stated no known seiche waves have been observed and therefore the lakes may be of ‘low susceptibility’. GNS (2015) lists some case studies, which indicate waves of up to a few metres. On this basis, any seiche waves which may occur are likely to be accommodated in freeboard allowance for the dam.

It is further noted that overtopping seiche waves would need to lead to sufficient erosion to fail the dam. We are not aware of any documented case studies of this occurring, due to episodic and short duration of any overtopping that would be generated. The downstream shoulder of the dam is unlikely to be highly erodible also, assuming it is constructed from outwash gravel.

B.7.4.2 Slope Instability Hazards

Key slope instability hazards are:

- Slope instability at infrastructure locations.
- Slope instability of the reservoir shoreline – which could generate an impulse wave, block or partial blockage the reservoir (upstream flooding, loss of water for generation) and increased sedimentation. Noting that the raised FSL by approximately 30 m would further inundate reservoir shoreline slopes. This would almost exclusively comprise soil slopes, formed from glacial and fluvioglacial deposits.

Figure 13 - Example of slopes on the western side of Lake Pukaki, with obvious soils at lower levels and 'greywacke' at higher levels (from Barrell & Read 2013)

Figure 14 - Example of the slopes on the eastern side of Lake Pukaki, with obvious soils comprising outwash in channels amongst moraine (till) ridges (from Barrell & Read 2013)

We are not aware of any significant historical slope instability at key infrastructure locations or of the reservoir shoreline. This includes the approximately 60 years of operation of the existing assets.

It can be seen from Cox et al (2007) and Barrell et al. (2011) that no significant landslides deposits are mapped around the immediate shoreline of the current or proposed raised Lake Pukaki shoreline.

Geotech (2008) undertook a regional assessment of slope instability hazards. Earthquake shaking was considered the most likely triggering mechanism for larger landslides, and their susceptibility map is shown in 0. It appears to be primarily based upon the underlying geology, which of course, has a link to topography. The Pukaki Dam and the majority of the reservoir shoreline were assessed as being of 'low to very low hazard from earthquake-induced instability even under strong earthquake shaking'. The steeper glacial deposits adjacent to the western shoreline of Lake Pukaki were assessed as 'some hazard from earthquake-induced slope instability, but only affecting relatively small areas within the zone, even under string earthquake shaking'.

It can be seen the areas of bedrock above the western shoreline of Lake Pukaki, which would lie above the raised shoreline of the lake, were assessed as 'significant hazard from earthquake-induced slope instability underate moderate to strong earthquake shaking'. These slopes are formed from 'greywacke'. 0 from Geotech (2008) shows the location of 'pre-historic rock avalanches' in the region. It can be seen that several are mapped in bedrock within the Lake Pukaki catchment, although none are mapped in bedrock above the western shoreline of Lake Pukaki. This figure supports 0 , as earthquake shaking is one of the key triggers of 'rock avalanches' in the Southern Alps. Significant reactivation of the identified existing rock avalanches is unlikely, considering their age (several thousand years old, have been exposed to many large earthquakes over this time). Any future rock avalanches are most likely to be first-time landslides.

Geotech (2008) does not specifically detail any occurrences of significant historic or active slope instability in the Lake Pukaki area. For this reason, it is assumed they did not identify any, as these would likely be areas of higher hazard.

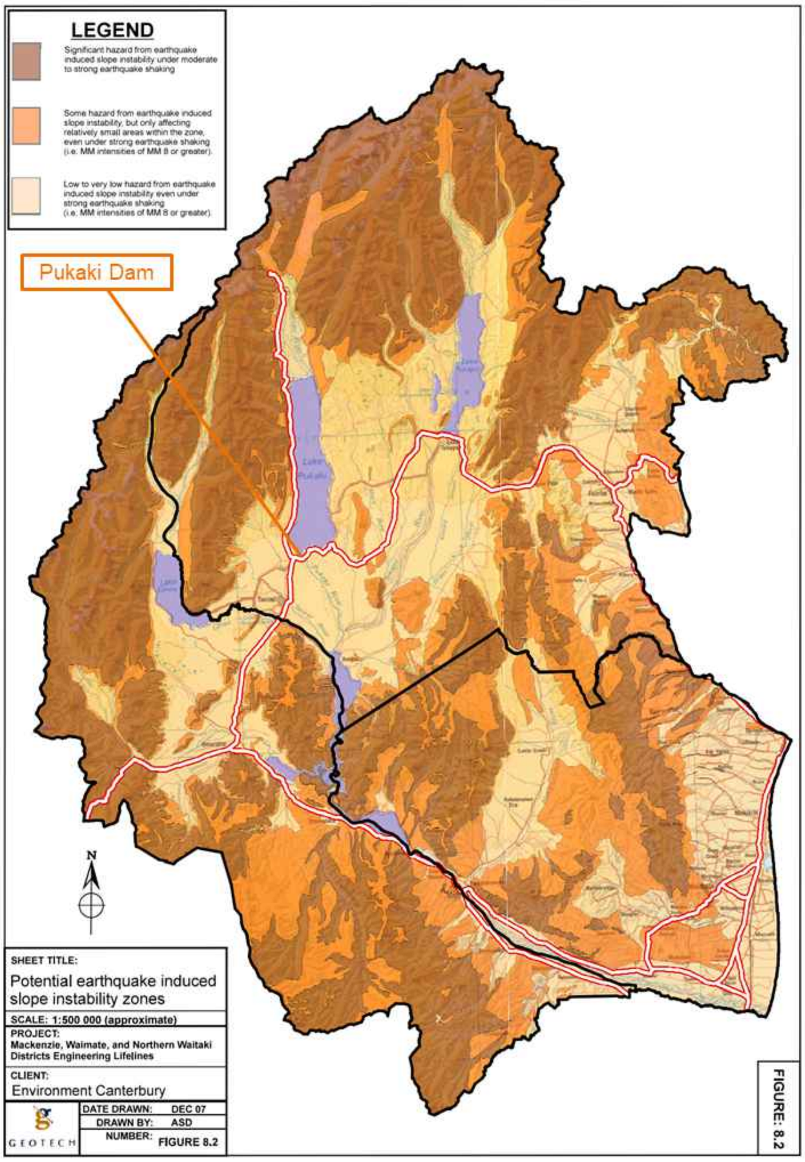
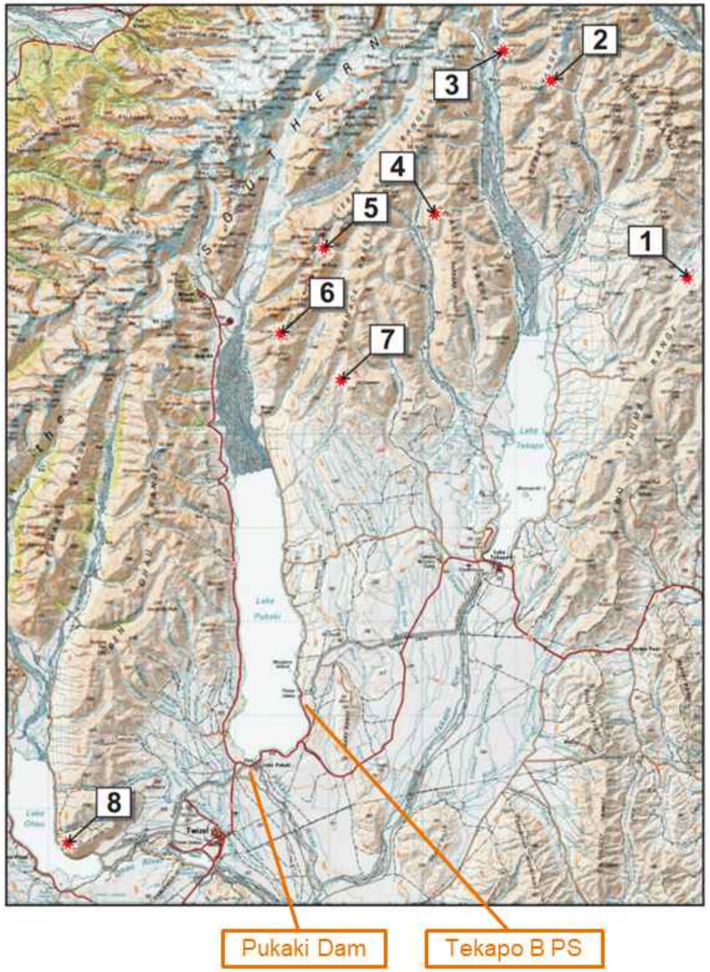


Figure 15 - Regional seismically induced slope instability susceptibility (from Geotech 2008)

GNS (2015) also completed a slope instability assessment of the Lake Pukaki shoreline, as part of the assessment for landslide susceptibility and possibility landslide generated impulse (tsunami) waves. Their assessment was also focused on earthquake-induced landsliding. Their susceptibility map is shown in 0.

Key conclusions from a review of this assessment are:

- The majority of the reservoir shoreline, including the Pukaki Dam area, is mapped as 'low' susceptibility, defined as slopes less than 25°.
- The immediate reservoir shoreline, where cliffs have formed, is mapped as being of 'moderate' susceptibility, being described as slopes of 25°.
- Sections of the western shoreline of Lake Pukaki, in the glacial deposits, is also mapped as /moderate susceptibility'.
- GNS mapped several current, historical and pre-historical landslides in the vicinity of the NW shoreline of the existing lake. These represent soil slope failures, of relatively limited volume. A single failure is also mapped in the SE corner of the lake, near Tekapo B Power Station.
- Several active fans are present and enter Lake Tekapo.



SCALE:
1 : 75,000 @ A3 (approximate)

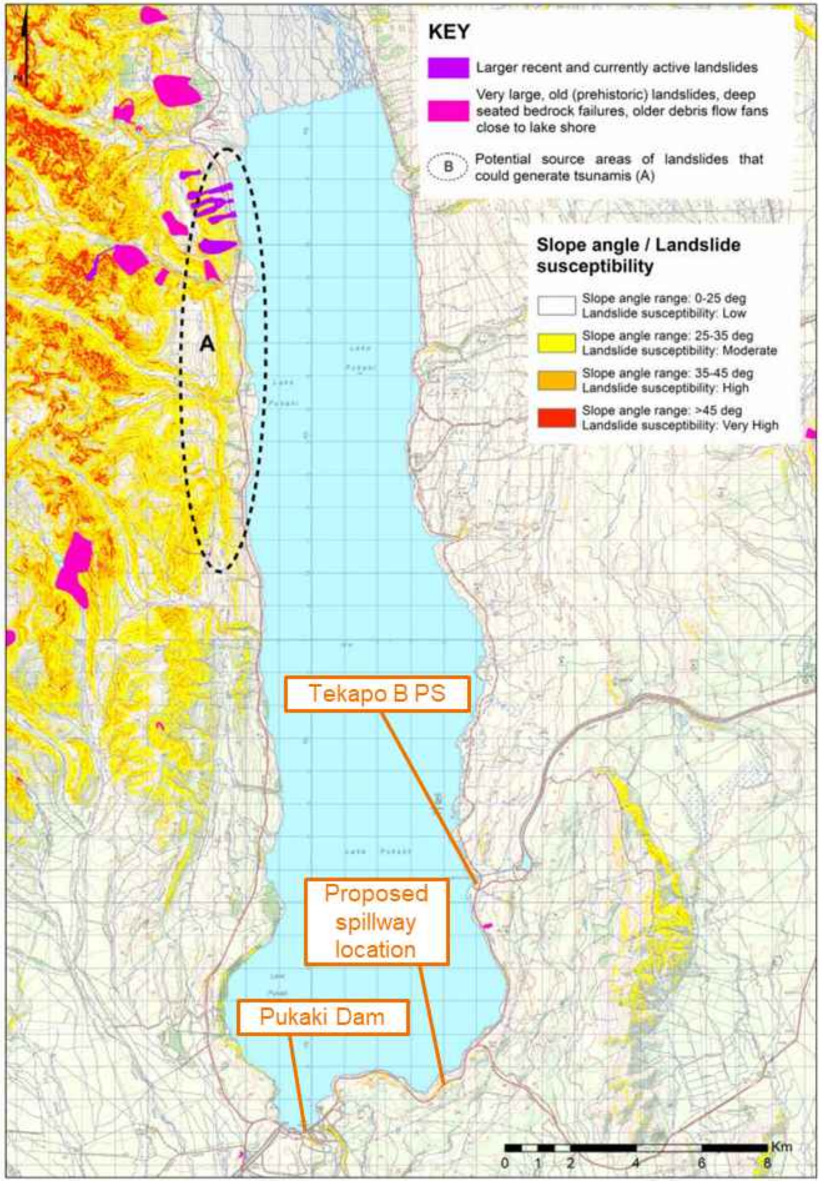
Number	Locality/Name	Area (hectares)	Volume (millions of m³)	Age	Dating method
1	Rangitata River (Bush Stream)	330	99 ±10	1370BC ±880	Weathering rind (not recalculated)
2	Macauley River (Tindill Stream)	138	27 ±3	8460BC ±120	Weathering rind (not recalculated)
3	Godley River	84	21 ±3	1700BC ±440	Weathering rind (not recalculated)
4	Cass River	36	3.6 ±0.4	1200BC ±310	Weathering rind (not recalculated)
5	Jollie River	23	4.6 ±0.5	2750BC ±710	Weathering rind (not recalculated)
6	Jollie River (Arthurs Point)	110	77 ±5	1700BC ±440	Weathering rind (not recalculated)
7	Landslip Creek	N/A	N/A	N/A	
8	Ben Ohau	N/A	N/A	N/A	

NOTE: Rock avalanches 1 - 6 from Whitehouse (1983) with original weathering rind age estimates, not recalculated by the method of McSaveney (1992).
Rock avalanches 7 & 8 recognised during field reconnaissance for this project.
There are likely to be many more that remain unrecognised.

The hazard maps contained in this report are regional in scope and detail, and should not be considered as a substitute for site-specific investigations and/or geotechnical engineering assesments for any project. Qualified and experienced practitioners should assess the site-specific hazard potential, including the potential for damage, at a more detailed scale.

PROJECT:	Mackenzie, Waimate, & Waitaki District Lifelines
CLIENT:	Environment Canterbury Andtimaru District Council
DATE DRAWN:	**03/03/08**
DRAWN BY:	**ASD**
CHECKED BY:	**MDY**
SHEET TITLE:	Prehistoric Rock Avalanches recognised in Mackenzie, Waimate, and North Waitaki Districts
SCALE:	**1:75,000 APPROX**
GEOTECH	**FIGURE 8.1**

Figure 16 - Regional global slope instability occurrences (from Geotech 2008)



Earthquake-induced Landslide Susceptibility	Slope Range and failure %[1]	Typical Slope Types and Rock Types [2]
1 – Low	0-25° (~10 %)	Few failures, several low-angle dip slope slides in Tertiary sandstone, mudstone, and limestone. More failures likely on steep gravel banks and terrace edges along rivers etc.
2 - Moderate	26-35° (~ 30 %)	Dip slope failures in Tertiary rocks (as above); steeper slopes in hard rocks (greywacke, schist, granite etc.).
3 - High	36-45° (~40 %)	Steep dip slopes, cliffs, escarpments, and gorges in Tertiary sedimentary rocks; both dip and scarp slopes in hard rocks (greywacke, schist, granites etc.) especially in steep glaciated areas and alpine terrain. Also source and scarp areas of pre-existing landslides on slopes[3].
4 - Very High	> 45° (~20 %)	

Notes:

1. Slope ranges and failure percentages based on historical NZ earthquake-induced landslide data (Hancox et al. 2002).
2. The slope failure percentages and descriptions apply mainly to natural slopes and do not take into account the many smaller falls and slides that occur on steep unsupported road cuts and excavations during strong earthquakes.
3. Many pre-existing landslides have significant potential for reactivation by strong earthquake shaking (MM8-10), mainly due to their very steep, oversteepened head scarps, and in this model are assigned high to very high susceptibility.

Potential source area	Location	Slope morphology and existing landslides
A	West side of lake from Twin Stream to Jacks Stream	Area of steep and very steep slopes; 6 mapped landslides and many large active gullies
A3	Twin Stream	Area of moderately steep to steep slopes; 1 Large active landslide mapped; Several large active gullies and scree slopes adjacent to Twin Stream; potential for debris flows?
A2	Whale Stream	Large areas of very steep and extremely steep slopes surrounding Whale Stream; Several large active gullies and scree slopes; potential for debris flows? Active fan at the mouth of Whale Stream.
A1	Jacks Stream	Areas of very steep and extremely steep slopes surrounding Jacks Stream; Several large active gullies and scree slopes; potential for debris flows?

Figure 17 - Lake Pukaki shoreline slope instability assessment (from GNS 2015)

Figure 18 - Lake Pukaki shoreline slope instability assessment, area of steeper shoreline slopes (from GNS 2015)

Other general comments with regards to shoreline instability are:

- The Tertiary Sediments that outcrop in the NW corner of Lake Pukaki dip towards the west, which is into the slope (scarp slope). This is favourable for stability.
- The mapped bedding in greywacke which forms the higher elevation areas along the western shoreline of Lake Pukaki also generally dip towards the west (i.e. into the slope).
- Schist rocks, which are susceptible to slope instability and is well documented around the shorelines of some New Zealand hydroelectric lakes, are not present in near the site.
- The filling of Pukaki Dam provides useful precedence of lake filling effects on reservoir shoreline slopes, with no significant instability documented.
- Operation of Lake Pukaki over the last 40 years provide some precedence of the influence on changing reservoir levels on slopes. No significant slope instability has been reported with falling or rising lake levels. The characteristics of the glacial and fluvioglacial deposits do not make them particularly susceptible, as for example, they are coarse-grained soils and not susceptible to rapid drawdown.
- Regional groundwater levels reported by Read (1976) in the soils surrounding the shoreline are estimated as being 30 m or so below ground level. No direct connectivity between the lake and regional groundwater is suggested by Read (1976).

Based upon the balance of information, reservoir shoreline instability is unlikely to be a significant consideration for scheme design, construction and operation. Localised instability of slopes can be expected during lake fill and operation, but these are likely to be of limited volume and therefore unlikely to pose a significant hazard.

For the same reason, landslide-generated impulse waves are also not judged a key consideration. Any displacements waves created by more localised instability would be expected to be accommodated within the conventional freeboard allowance for the dam.

A further slope instability hazard raised by GNS (2015) is that of an impulse wave generated by a collapse of the Tasman River delta. GNS states insufficient information was available to assess the hazard. No further publicly available information is available to further assess this hazard. GNS estimated the delta was approximately 30 m high, with an average slope angle of around 5°.

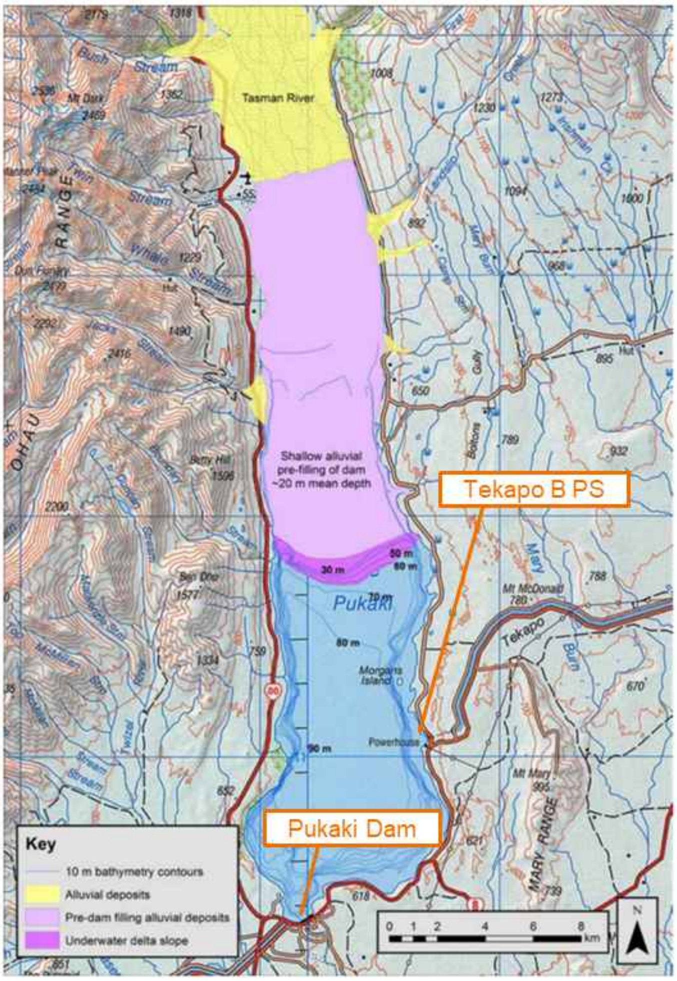


Figure 19 - Location of main deltas in and around Lake Pukaki (from GNS 2015)

B.7.5 Volcanic / Geothermal Hazards

Volcanic and/or geothermal hazards are not a key consideration for development. There is no publicly available information that references their occurrence in the vicinity of the site.

B.7.6 Reservoir Water Losses

The key geological water loss consideration for a raised Lake Pukaki is the presence of primarily glacial, fluvioglacial, and alluvial deposits within the reservoir area. Some of these are coarse-grained soils that may have moderate to high permeability.

A natural lake was present at the location of Lake Pukaki prior to construction of the original lake control structure in the 1950s. Construction of the original lake control structure, and subsequently Pukaki Dam in the 1970s, provide useful precedence of possible reservoir water losses. The current FSL of Pukaki Dam is EL 530.7 m. We are not aware of any significant water losses from the reservoir, which covers a period of approximately 60 years of operation.

It is noted in Read (1976) that:

- *'Macdonald (1966) using resistivity soundings determined that the water table was 100 to 200 feet below river level…'.*
- *'As part of the earth dam instrumentation six pneumatic piezometers and 20 seal open standpipe observation wells are being installed to monitor the groundwater table which is now recognised at being at a level of at least 100 feet below Lake Pukaki, suggesting it is perched'.*
- *'The water table did not rise in sympathy with the first period of lake raising early in 1976. Lake raising commenced on the 23 January 1976 and came up to 20 feet above the normal maximum storage for the original structure, but there was not sympathetic rise in the water table.'*

- *'Lake Pukaki, at least at its southern end, is perched, and surrounded by the lateral and terminal moraine from the Tekapo Advance. It is not known if the water table is recharged from the lake'.*
- *'The thickness of the natural blanket forming the present lake has not been determined with any degree of accuracy. A sparker survey, however, did not indicate large 'windows' of gravel.*
- *'Thin areas of the natural blanket near the Pukaki Lake control (i.e., Pukaki Dam) have been or will be covered and significant leakage in the zone above the water table is not expected in the immediate vicinity of the dam'.*
- *'Above the present lake level the natural blanket is non-existent in places and the Mount John Outwash gavel is exposed in several places along the western shoreline'.*

It is noted no further piezometer monitoring data is publicly available since Read (1976) and the data on which the report is based is very limited (i.e. commencement of lake fill only). The inference in Read (1976) is that Lake Pukaki is 'perched', and has limited connectivity to regional groundwater, which is at depth.

Based upon Barrell et al. (2013), as shown in 0, the majority of the reservoir shoreline comprise Till (Mount John and Tekapo). These are the same materials used for the core of the existing dam and therefore could be expected to be of moderate to low permeability. Some occurrences do occur along the western shoreline and at the head of the current Lake Pukaki where post-glacial alluvium does occur. These are likely to be coarse-grained soils of relatively higher permeability than the till. On balance, reservoir losses would not be expected to be significant, but would require further consideration as part of future stages of development. They would need to be considered in combination with other potential methods of water losses (such as evaporation).

Barrell & Read (2013) speculate that Lake Pukaki may have formerly extended greater than that currently. If this is the case, some lower permeability lake deposits may be present, which would limit possible reservoir losses.

B.7.7 Geological Model

B.7.7.1 Foundation Conditions

Anticipated foundations conditions have been assessed based upon the information presented within Read (1976). In that report, foundations conditions for the existing Pukaki Dam are subdivided into three areas:

- Main embankment – which includes the diversion conduit area.
- Right hand wing dam – which includes the Pukaki Canal intake (i.e. Gate 18).
- Left hand wing dam and spillway.

Geological plans and sections for these three areas are presented in 0 to 0. Read (1976) simplifies the foundation conditions as '*The outlet to Lake Pukaki (i.e. the dam site) is located at the snout of glaciers which advanced to that point between 17,000 and 14,000 years before present. These advances have resulted in complex site geology in which lower permeability glacial till and pro-glacial lake deposits overlie higher permeability ice contact and fluvioglacial outwash deposits'.*

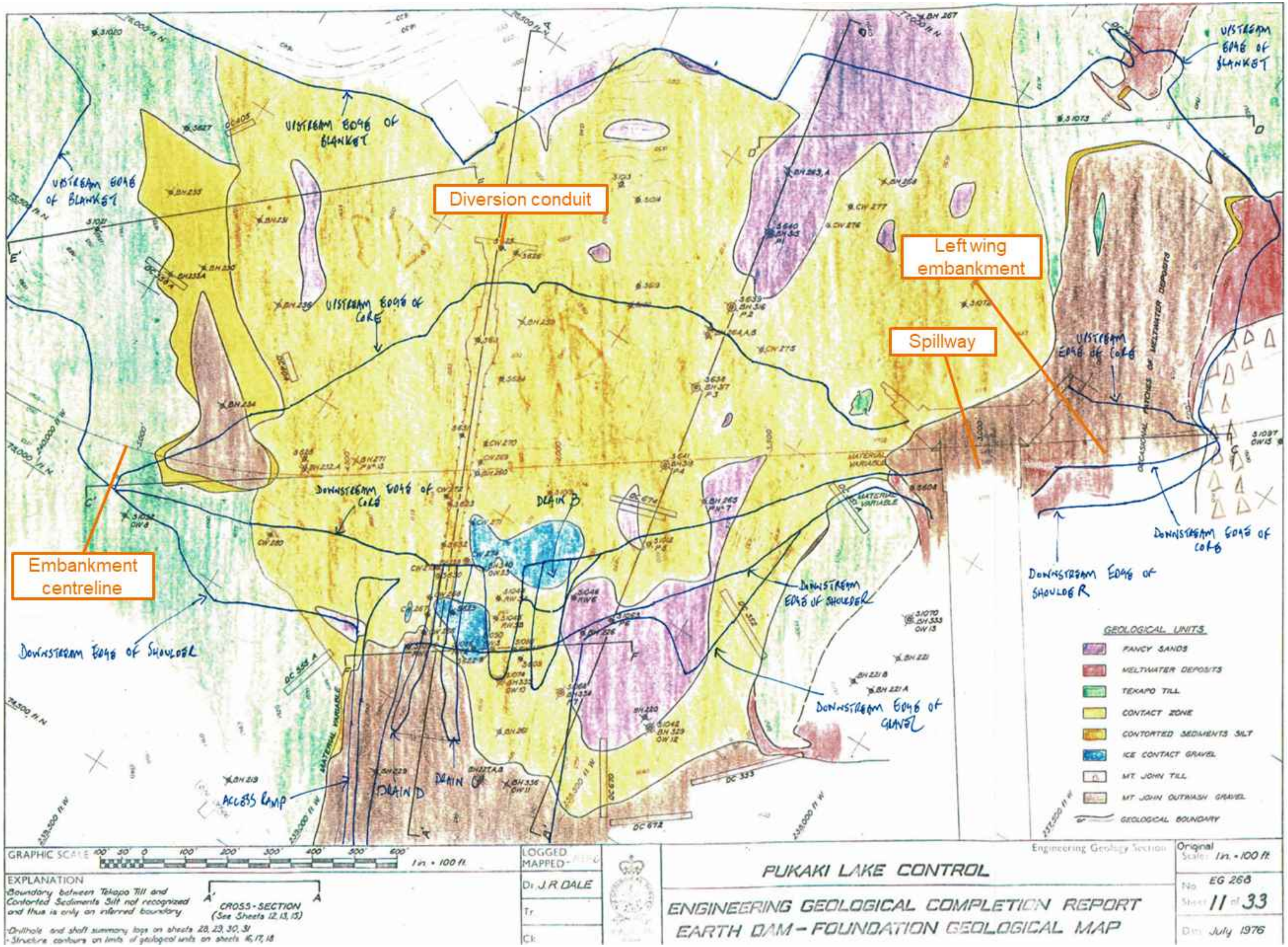


Figure 20 - Geological plan of the main embankment (from Read 1976)

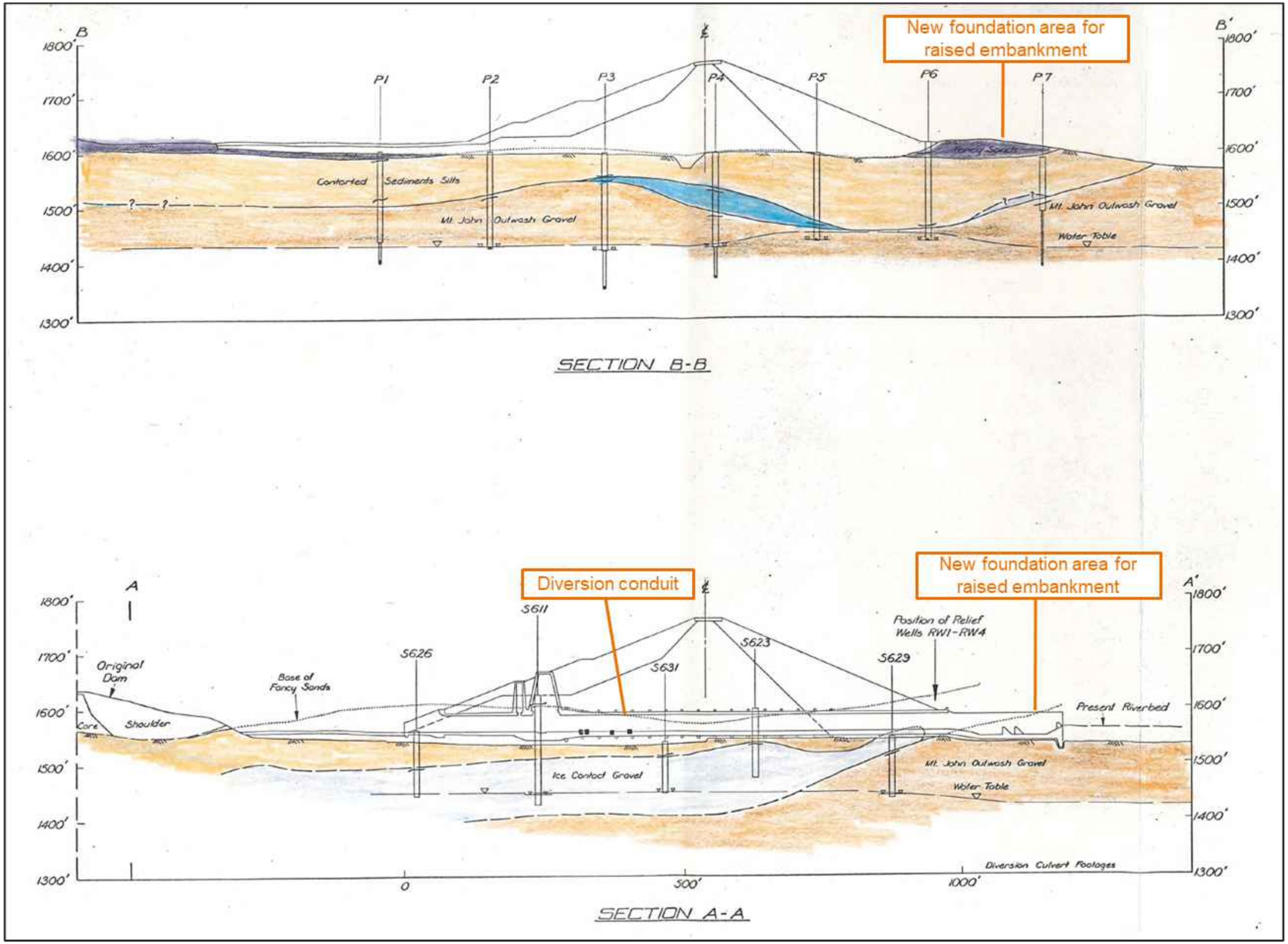


Figure 21 - Geological sections of the main embankment (from Read 1976)

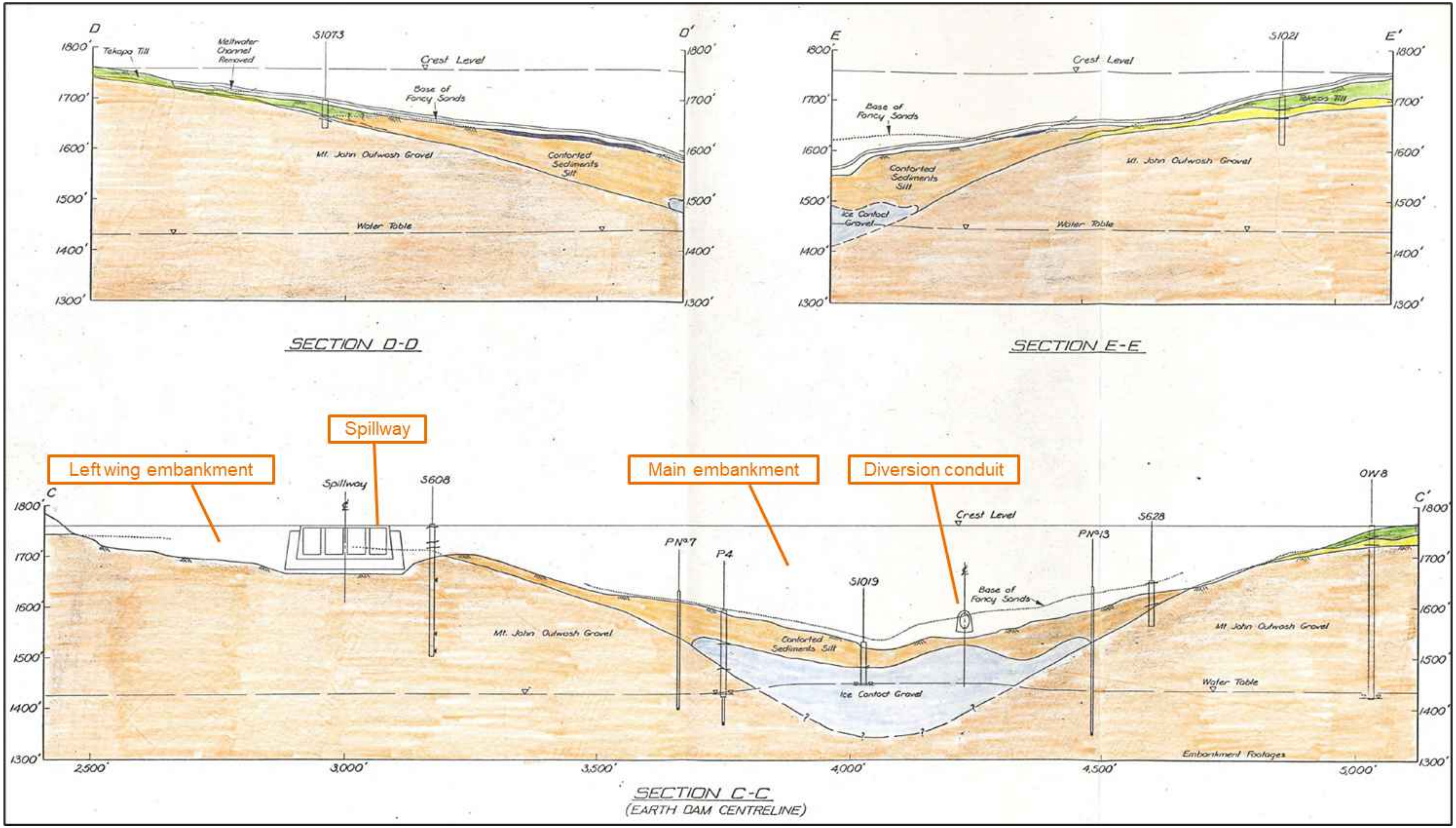


Figure 22 - Geological sections of the main embankment (from Read 1976)

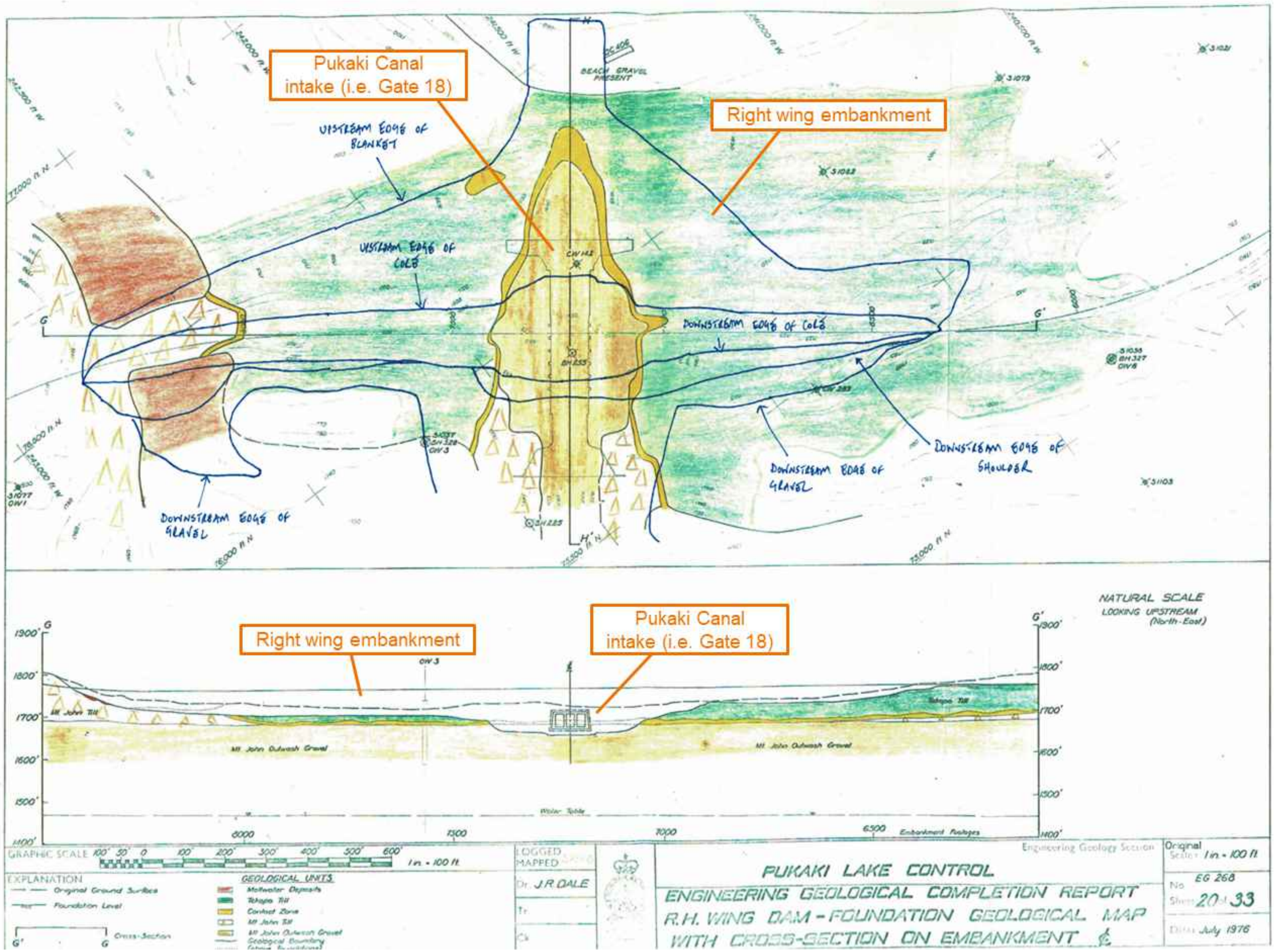


Figure 23 - Geological plan and section of the right wing embankment (from Read 1976)

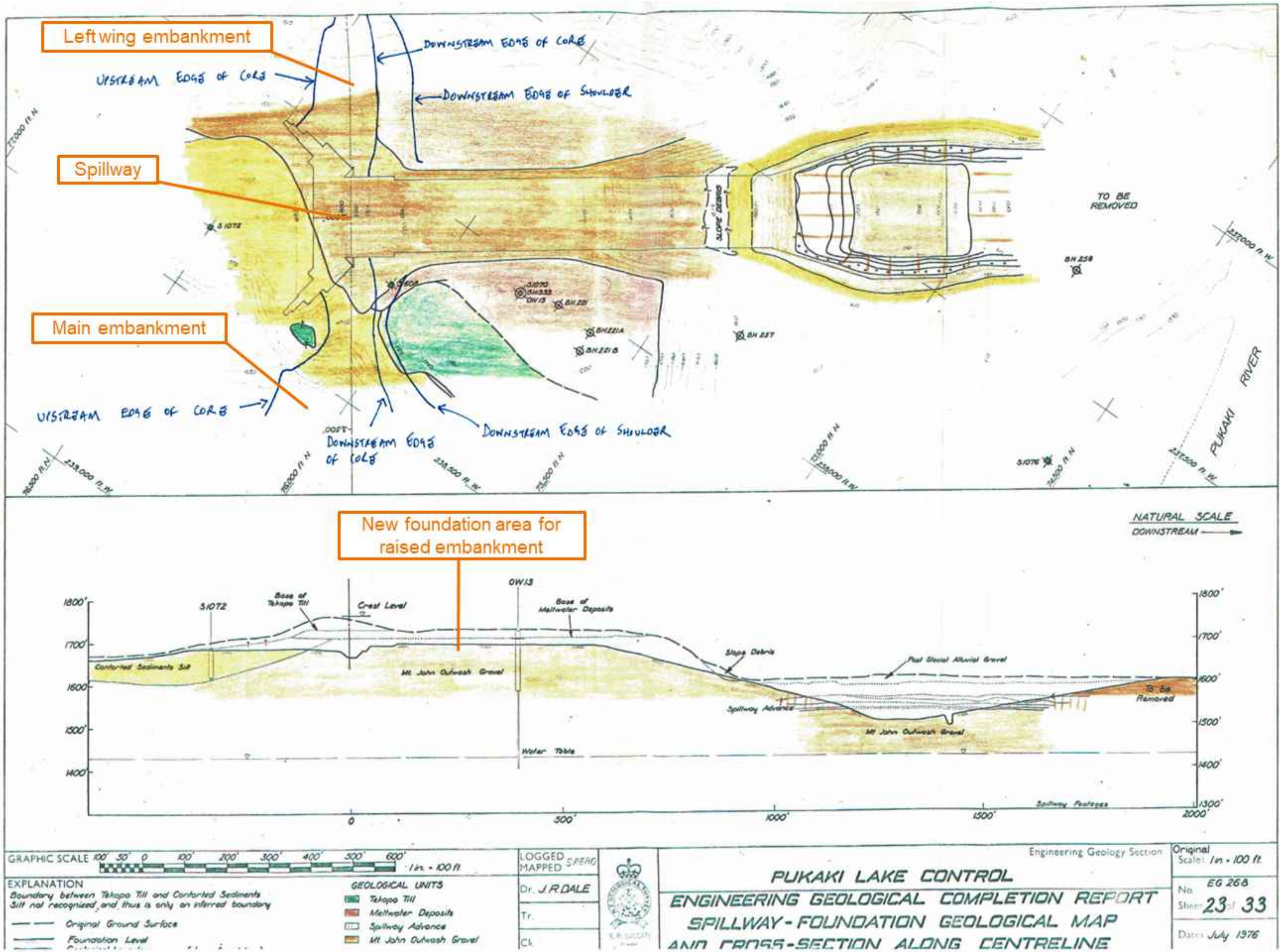


Figure 24 - Geological plan and section of the left wing embankment and existing spillway (from Read 1976)

The key geological units encountered during the construction of Pukaki Dam are summarised in 0. They are listed from oldest (bottom) to youngest (top).

Speight 1942	Read 1976	Hart 1996[a]	Mager & Fitzsimons 2007		Evans et al. 2013[b]		This paper	
Stratigraphic units	Stratigraphic units	Stratigraphic unit	Formation/ Member	Facies association	Formation	Member (lithofacies)	Formation	Member or *Bed*[c]
Lake-beach deposits	Beach Gravel						Not assigned	*Beach Gravel*
	Fancy Sands (including Rough Gravel and Pukaki Pug)							*Pukaki Pug* *Rough Gravel* *Fancy Sands (ss)*
not described	Meltwater Deposits, Tekapo Outwash Gravel	*not described*	Tekapo/ Outwash	*not described*	Tekapo Allo- formation	?Waitaki (LF7)	Tekapo	Tekapo Outwash
'Moraine' and 'Silts', etc'	Tekapo Till	Pukaki Diamicton	Tekapo/ Moraine	four (A–D)		Twizel (LF4-6) Pukaki (LF1-3)		Tekapo Till
	Contorted Sediments Silt[d]	*not described*		*not described*				
	Ice Contact Gravel						Mt John	Mt John Till
River Gravels	Mt John Outwash Gravel	*not described*	Mt John	*not described*	Mt John Allo- formation	?Twizel (LF5) ?Waitaki (LF7)		Mt John Outwash

[a]Hart (1996) described four lithofacies that were referred to collectively as Pukaki Diamicton.
[b]It is unclear whether Evans et al. (2013) intended the member terms to apply to just their Tekapo 'Alloformation' or to their Mt John 'Alloformation' as well.
[c]Fancy Sands (ss) here refers in a strict sense (ss) to the well-stratified fine sand/silty clay component of the general unit defined by Read (1976).
[d]The only exposure of Contorted Sediments Silt remaining after dam construction is in the western river bank just downstream of Pukaki Dam (Figs 5, 6), where Read (1976) distinguished between Tekapo Till and Contorted Sediments Silt, while Evans et al. (2013) identified a single unit of diamicton dominated by materials of their LF3 (i.e. Pukaki Member), but sufficiently deformed to warrant a classification of LF4 (i.e. Twizel Member). Hart (1996) and Mager & Fitzsimons (2007) did not describe this exposure.

Figure 25 - Correlation of glacial and fluvioglacial deposits at Pukaki Dam (from Barrell & Read 2013)

As documented by Read (1976), the general sequence of development of the Pukaki Dam foundation materials can be summarised as (from oldest to youngest):

1. Formation of a thick (>100 m) deposit of 'Mount John Outwash Gravel'. Within this unit on the eastern side of the outlet between 10 and 20 m below Pukaki River level, temporarily exposed in the excavation for the spillway stilling basin, is ice-contact gravel and till attributed to the 'Spillway Advance'.
2. Subsequent erosion by glacier activity of a trough into the 'Mount John Outwash Gravel' at about the location of the Lake Pukaki outlet (diversion conduit), probably during multiple episodes of ice advance/retreat that deposited the 'Mount John Till' within the Mount John moraine complex that extends as much as 4 km further downstream of the dam.
3. After the last retreat of ice from the Mount John moraines, the trough in the vicinity of the lake outlet was filled first by subaqueous/subglacial coarse-grained gravel deposits ('Ice Contact Gravel)', as much as 30–40 m thick, and then by as much as 50 m of bedded proglacial lake sediments.
4. Readvance of ice with accompanying glaciotectonic deformation of the proglacial lake sediments producing the 'Contorted Sediments Silt'. These proglacial lake sediments were partly reworked and mixed with other materials to form 'Tekapo Till', of which the Tekapo terminal moraine is constructed:
    a. The observation that the 'Tekapo Till' onlaps alluvial surfaces at a level similar to that of the Mount John outwash plain suggests that there was no substantial fluvial downcutting following the last Mount John ice retreat.
    b. As a consequence, 'Tekapo Outwash Gravel' and associated 'Meltwater Deposits' are considered to form little more than a veneer over the 'Mt John Outwash Gravel'.
5. As the ice retreated from the terminal moraine leaving a recessional drape of Tekapo Till, a proglacial lake began to form. Near the lake outlet subaqueous, often well-bedded, sands and silts ('Fancy Sands (ss)') were deposited within the newly ice-evacuated trough.
6. Near the eastern side of the dam site area was a deposit of angular bouldery gravel, as much as c. 15 m thick, referred to as 'Rough Gravel' by Read (1976), resting on the bedded sands. The 'Rough Gravel' represents the highest part of the Fancy Sands unit at that location. Similar material was commonly found elsewhere in the dam site area, directly underlying 'Pukaki Pug'. The texture and stratigraphic position of the 'Rough Gravel', particularly where it overlies the lacustrine well-bedded 'Fancy Sands (ss)', suggests deposition from melting icebergs.
7. With the enlargement of the water body, still-water sedimentation of suspended silt-clay produced the 'Pukaki Pug', while veneers of 'Beach Gravel' were deposited at the lake margin at its post-glacial highstand of c. 25 m above its 'natural' level.
8. Incision of the Pukaki River and associated lowering of the lake level, accompanied by formation of a drape of Beach Gravel deposits on the shoreline.

As can be seen in 0 to 0, the key geological units can be summarised as:

- Main embankment – the primary geological unit the embankment is founded on is the Contorted Silt Sediments. Most of the other geological units were exposed locally within the foundation.
- Right hand wing dam – is primarily founded on the Tekapo Till and Mount John Till, with the section near the Pukaki Canal outlet (Gate 18) founded on the Mount John Outwash.

- Left hand wing dam and spillway – primarily founded on the Mount John Outwash, with some occurrence of the Contorted Silt Sediments at the upstream end. Varying deposits associated with the 'Spillway Advance' occur in the vicinity of the stilling basin, which is associated with the Mount John Outwash and Till.

For the proposed downstream dam raise, it can be seen from 0 to 0 that the expected subsurface conditions at the new foundation location are expected to be similar to those encountered during the construction of the existing dam. It would be expected most of the above-described units would be encountered, although some only locally. It appears the majority of the new raised section of embankment foundation would be formed from the Mount John Outwash, Mount John Till, and the Tekapo Till. The Fancy Sands, Meltwater Deposits and Ice Contact Gravel would be locally encountered, as would deposits associated with the Spillway Advance. The more downstream location for the new foundation of the raised embankment means likely more simple geology.

The key characteristics of important materials as described by Read (1976) are provided below, from youngest to oldest. It is noted descriptive terms are somewhat different from those used today (NZGS 2005). Important differences are the grain-size classification for coarse-grained soils and the descriptive terms used for the 'minor' soil fraction. These are highlighted in 0.

- *Fancy Sands:*
  - *Pukaki Pug – blue, soft, highly plastic silty clay existing at or above its liquid limit.*
  - *Rough Gravel – located at the base of the Pukaki Pug, a grey angular gravel-cobble-boulder mixture, with rare silt/clay.*
  - *Fancy Sands:*
    - *Grey, light yellow or blue, laminated to medium interbedded fine sand, silt, clayey silt and silty clay. More sandy near right abutment. The clay portions are generally soft when freshly exposed, existing near or above its liquid limit.*
    - *Layers or beds of gravel and medium sand occur throughout the pug.*
- *Meltwater Deposits – subhorizontal faintly bedded or homogeneous boulder, cobbly, fine to coarse gravel with rare or very rare silt. Commonly contains boulders up to 10 feet in size, and thin lenses of silt can also be present.*
- *Contact Gravel – lies between the Tekapo Till and the Mount John Outwash, usually at elevations above 1650 feet. The material is normally a grey faintly bedded (usually subhorizontal) fine to coarse gravel, with some sand, rare boulders, and rare to very rare silt. Boulders up to 4 feet form a large proportion of the material.*
- *Tekapo Till – similar to the Contorted Sediments Silt, but with higher coarse-fraction:*
  - *Bedding is usually not present, but where it is, is often contorted..*
  - *The material is generally a grey, fine to coarse gravel, with some or rare silt, rare sand and rare cobbles.*
  - *Pockets and lenses of silt, sandy gravel and sand are present and give the material a not dissimilar appearance to the Ice Contact Gravel.*
- *Contorted Silt Sediments:*
  - *Light yellow to yellowish grey silty fine to coarse sand or sandy silt, and varies from laminated to thickly bedded fine to fine medium sand interbedded with silt to a homogeneous sandy silt/silty fine to medium sand with rare gravel and cobbles.*
  - *Clean sandy gravels with very rare silt layers or lenses are present in a few places.*
  - *Bedding where developed has a wide variety of attitudes and is heavily contorted, and sheared as a result of deformation by the overriding of the Tekapo ice.*
  - *The material usually becomes more variable near the contact with the Mount John Outwash, with boulders and lenses or layers of sandy gravel becoming common.*
- *Ice Contact Gravel:*
  - *Wide variety of materials deposited in a complex environment.*
  - *The dominant material is a grey variably-bedded or homogeneous fine to coarse gravel with some cobbles, very rare boulders and rare to very rare silt.*
  - *The variations include beds, pockets or lenses of light yellow silt, fine or fine to coarse sand, gravelly sandy silt, open gravel, rougher horizons and clean horizons.*
- *Mount John Till:*
  - *Light yellow or greyish yellow homogeneous silty sandy gravel with rare cobbles and very rare boulders.*
  - *Occasional lenses of sandy gravel with rare or very rare silt were present throughout.*
- *Spillway Advance:*
  - *These are considered part of the Mount John Outwash and are exposed in the spillway stilling basin area only.*
  - *There is a sequence of ice contact gravel, till, ice contact gravel, and pro-glacial silt. The characteristics of which are similar to those described above.*
- *Mount John Outwash:*
  - *Typically a grey, subhorizontal, faintly bedded, well graded, fine to coarse gravel with some sand and cobbles and rare silt/clay.*
  - *Variations typically seen in aggradation alluvial deposits are often seen, such as open gravel works, lag deposits, fill and scour features, and cross channelling.*

- *The silt/clay is normally at or above it liquid limit and is though to have been deposited after the gravel by clay-laden water. It can vary in content* from approximately 7%, to virtually none-existent. Fine content appears to decrease upwards.

A. MAIN PARAGRAPH i) Colour ii) Structure iii) Weathering iv) SOIL NAME (with unified soil symbol)	eg Grey, sub-horizontally bedded, moderately weathered SANDY fine GRAVEL with very rare silt/clay. (GW/ch)
B. ADDITIONAL INFORMATION (in set paragraph below A) i) Moisture content ii) Strength term iii) Grading iv) Qualifications of particle size fractions v) Additional in situ structures	—dry; compact; well graded; sand, fine to coarse; silt/clay, plastic; occasional sand lenses (sp).

a) Standard Sequence of Terms

TERM	% OF SOIL MASS	EXAMPLE
with very rare.....	< 5	with very rare silt
with rare.....	5 - 12	with rare silt
with some.....	12 - 20	with some silt
(.....)y	20 - 50	SILTY
.....and.....	approx 35 - 50	SILT and SAND
.....	dominant constituent	SILT
occasional common interbedded	Terms of relative abundance only.	

b) Definition of Proportional Terms

N.B. When silt and clay form <20% of total soil mass, their individual proportions are generally not estimated, eg SANDY fine to coarse GRAVEL with some silt/clay.

TERM	SIZE RANGE (mm)	GRAPHIC SYMBOLS
Clay	< 0.002	
Silt	0.002 - 0.06	
Sand	0.06 - 2.0	
Gravel	2.0 - 75.0	
Cobbles	75.0 - 300.0	
Boulders	> 300.0	

c) Particle Size Definitions (with graphic symbols)

Figure 26 - Descriptive terms used during original investigation and construction (from Read 1976)

Figure 27 - Annotated image showing key geological units (modified from Barrell & Read 2013)

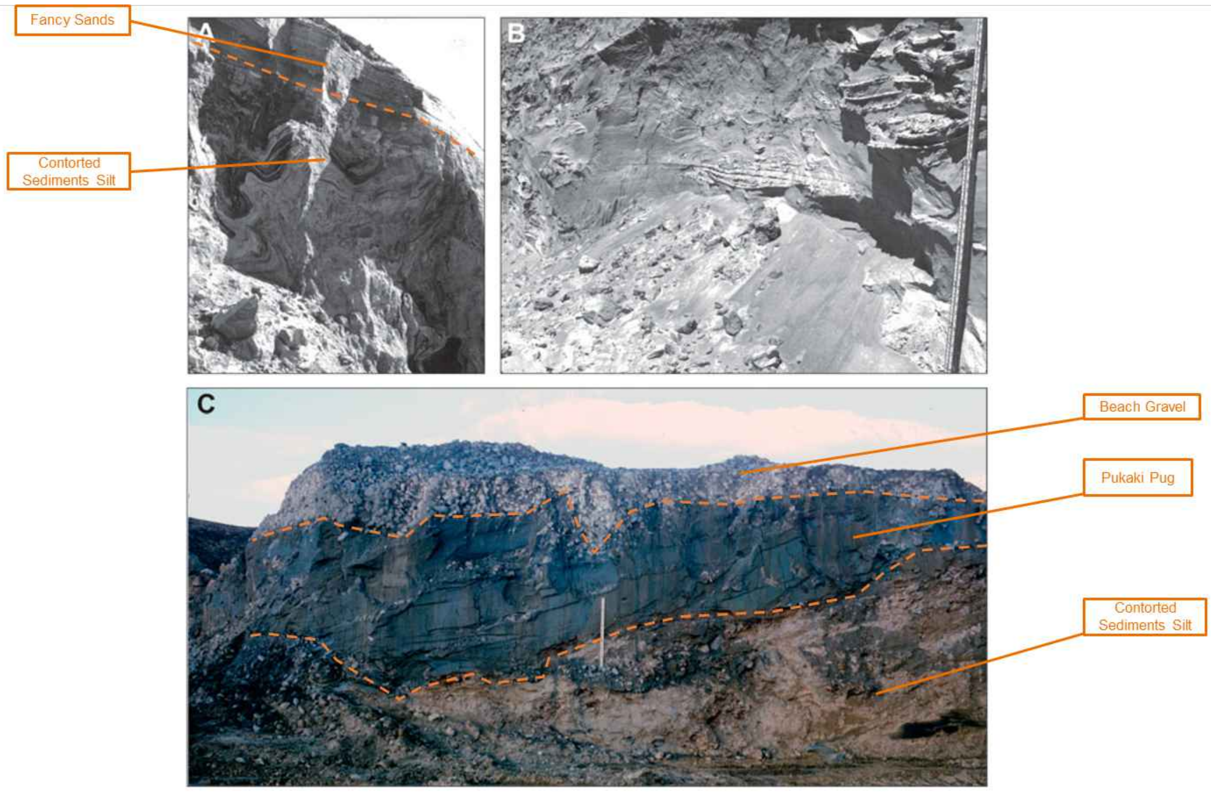


Figure 7 Images of geological units from the Pukaki Dam excavations. **A**, Contorted Sediments Silt, overlain by well-bedded Fancy Sands (ss) (photograph 11 of Read 1976). The exposure is 4.5 m high. **B**, Fancy Sands (ss) (photograph 15 of Read 1976). The scale at right is c. 8 feet long (2.4 m). **C**, Pukaki Pug (massive material) resting directly on Contorted Sediments Silt, and overlain by Beach Gravel (photograph 16 of Read 1976). The wood sample (NZ-1651) was collected from this location, from approximately the middle of the Pukaki Pug layer. Staff is 5 feet (c. 1.5 m) long.

Figure 28 - Annotated image showing key geological units (modified from Barrell & Read 2013)

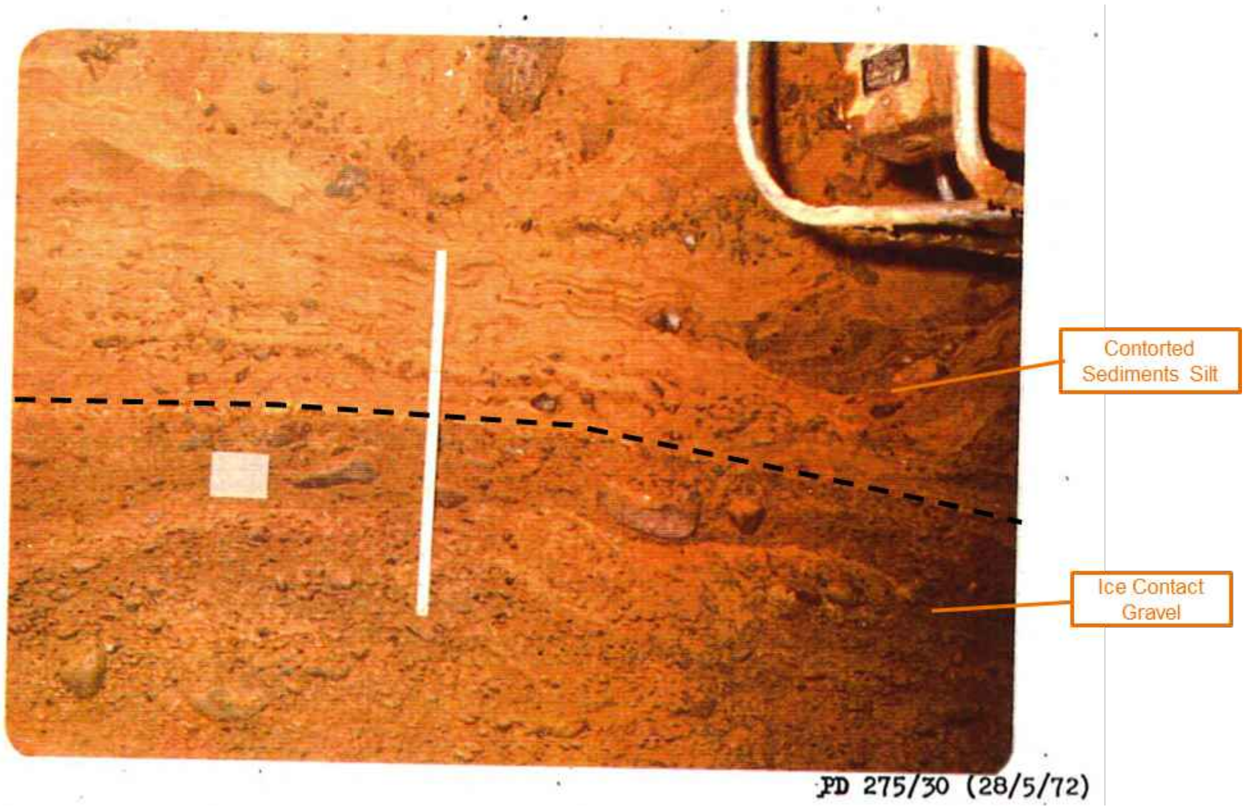
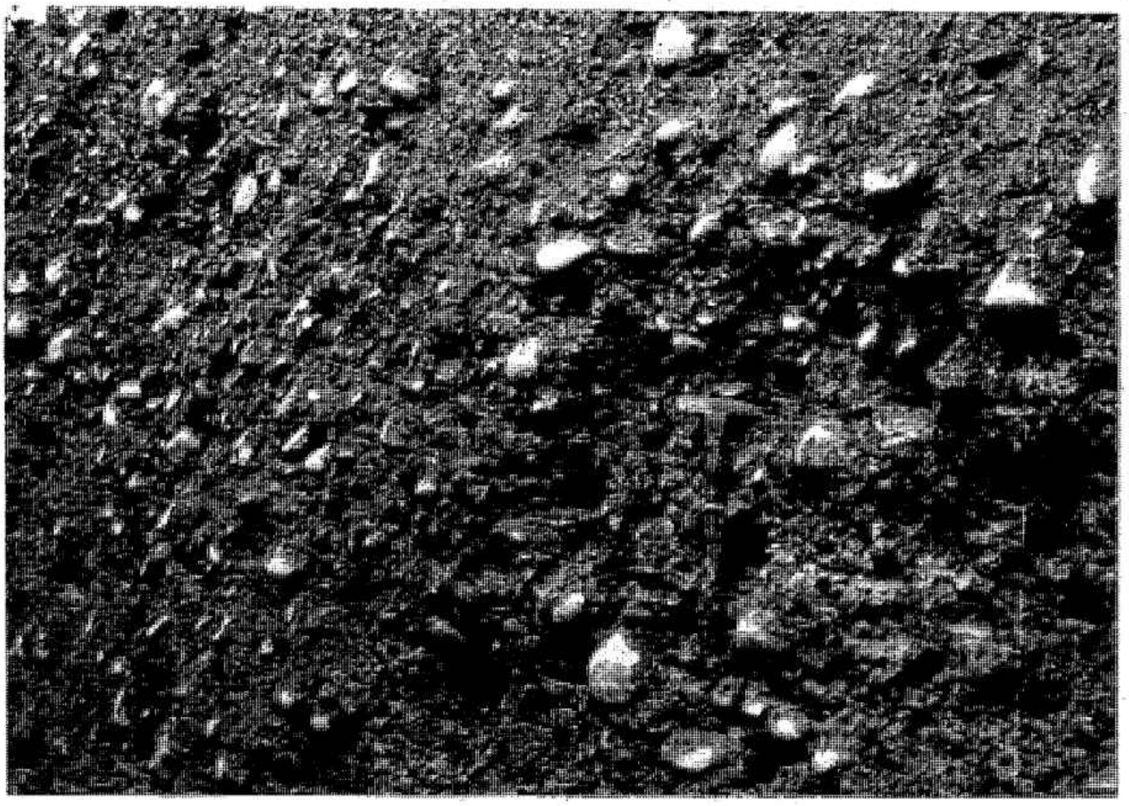


Figure 29 - Typical appearance of Ice Contact Gravel (from Read 1976)

PD518/7 (25/7/73)

Figure 30 - Typical appearance of meltwater deposits near spillway (from Read 1976)



PD220/5 (18/8/72)

Figure 31 - Typical appearance of Mount John Outwash (from Read 1976)

In addition to the above, for concept design it can be assumed:

- No pre-existing deficiencies in the existing embankment exist. We are not aware of any significant dam safety upgrades proposed.
- No significant further settlement of the existing embankment fill would occur under newly placed fill. We are not aware of any significant settlement in the existing embankment since construction.
- A similar founding level to the existing dam for the downstream raise.
- The foundation has adequate bearing and deformability characteristics, with no special design measures required. Noting that much of the existing embankment is founded on the 'Contorted Sediment Silt'. We are not aware of any significant observed settlement of the existing embankment since construction.
- Some nominal allowance for over-excavation of undesirable materials should be made, as encountered. This would include removal of the 'Fancy Sands' and undesirable materials associated with the 'Spillway Advance'.
- Filter protection of the foundation will be required for the prevention of IE. A filter blanket should be assumed, noting
- No modifications are required to the existing 'cutoff', which is currently achieved by a combination of the upstream blanket and the core cutoff trench.
- No further measures are required to control foundation groundwater pressures, noting pressure relief wells were installed at the diversion culvert location during original construction. We are not aware of any post-construction performance/observations which suggest otherwise.
- The foundation of the raised dam can be assumed as non-liquefiable. This is on the assumption the Fancy Sands and other potentially liquefiable materials were largely removed from the foundation of the existing dam, and would be removed from the foundation of the downstream raise (if encountered). They are locally present in the foundation however
- Excavations for the new foundation of the raised dam can be assumed to be dry. Allowance should be made for groundwater inflows into the excavations in the vicinity of the diversion culvert and spillway stilling basin area.

Read (1976) states 'The description of problems arising during foundation treatment and the details are not covered in this report'. It is not known what this alludes to.

As part of the proposed works, the existing spillway would be removed and replaced with a new spillway approximately 4 km east of Pukaki Dam. The location is shown in 0. Anticipated subsurface conditions are generally as described above for Pukaki Dam. Because of its location (both in plan and elevation), it is expected the subsurface conditions would be somewhat less complex than those at Pukaki Dam, with less soils associated with glacial-lake, and no soils associated with the 'Spillway Advance'.

No geological information from the construction of the existing Pukaki Dam is available for the proposed spillway location. Reference to 0 and 0 suggests the spillway excavation and foundation conditions would comprise Mount John Till and Tekapo Till, overlying the Mount John Outwash at depth. Their characteristics would be as described above for those encountered at Pukaki Dam.

The spillway is proposed to comprise an approach channel, a concrete control structure, a concrete-lined spillway chute and stilling basin as the energy dissipator. Downstream of the dissipator, water would pass down the existing channel and return to the Pukaki River around 4.5 km downstream of the existing dam. The proposed works are judged geologically feasible, with key considerations being:

- Founding on the control structure on a soil foundation – associated considerations for bearing and deformability, foundation internal erosion, foundation seepage and uplift on the structure.
- Energy dissipation for spillway flows – noting the spillway chute and dissipator will be founded on a soil foundation. Key considerations for these structures are similar to those described above, in addition to erodibility of materials and the potential for headcutting beneath structures. Noting headcutting leading to loss of reservoir storage would be judged unlikely in a single spillway event due to the distances involved, elevations etc.
- Excavation stability and associated remedial works for long-term stability.

The existing Pukaki Dam (and the Upper Waitaki Power Scheme in general) provides similar useful precedence with regards to the feasibility of the proposed spillway works, such as deep excavations and founding of concrete structures on soil.

The proposed works also requires modifications to the existing Tekapo B Power Station (eastern shoreline of Lake Pukaki) and a new Pukaki Canal intake (i.e. Gate 18) at the right abutment of the dam. The geological conditions at these locations are also as described above for Pukaki Dam.

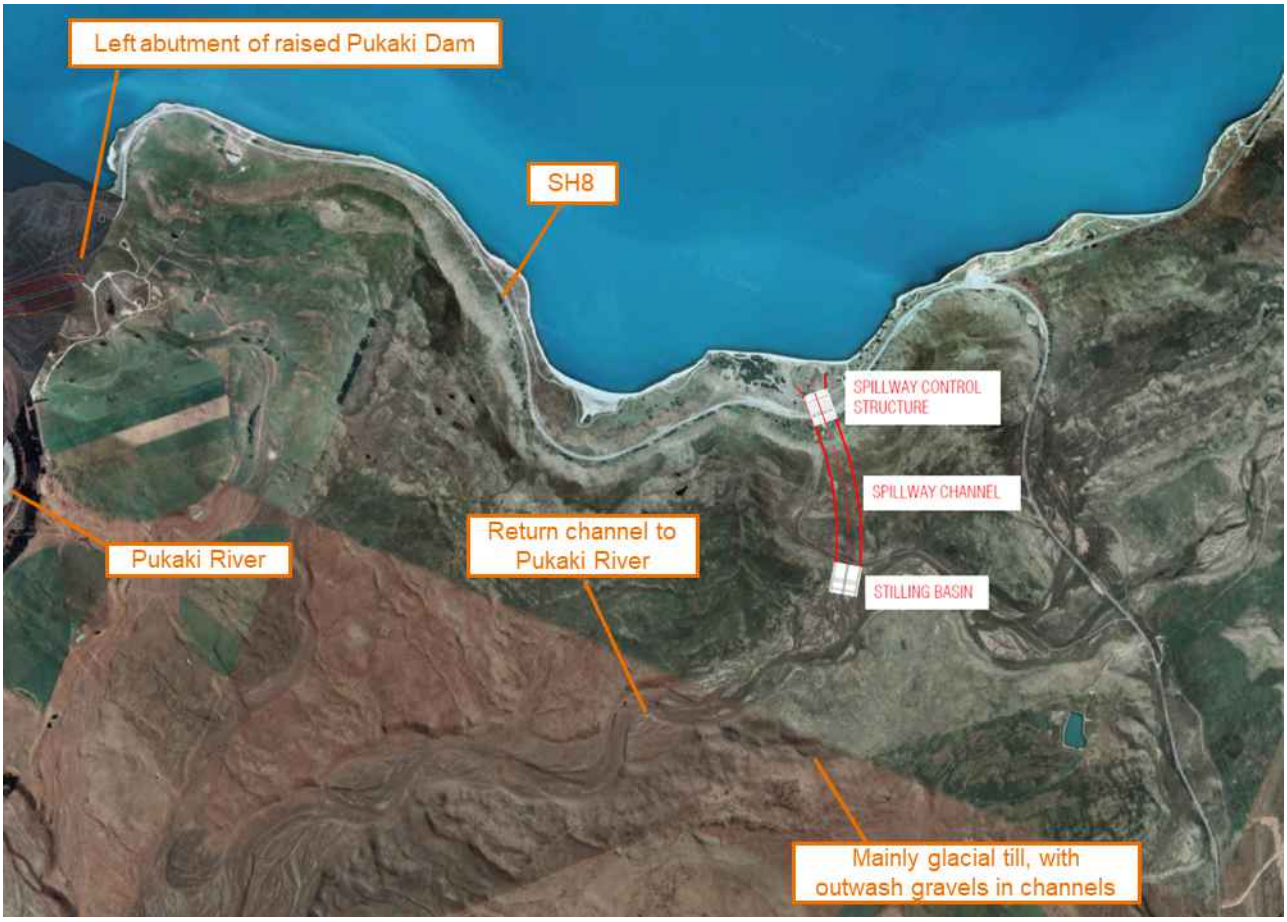


Figure 32 - Location of the proposed spillway at the left abutment of the existing dam

B.7.7.2 Construction Materials

The zonation of the existing Pukaki Dam, together with mean gradings of the different zones, are shown in 0. The dam comprises a relatively conventional zoned earthfill embankment.

It is noted that the numbering of the material zones is not consistent with modern nomenclature and in this study, we have adopted that shown in Fell et al. (2015), as shown in 0. It is noted that not all of the listed zones apply to Pukaki Dam.

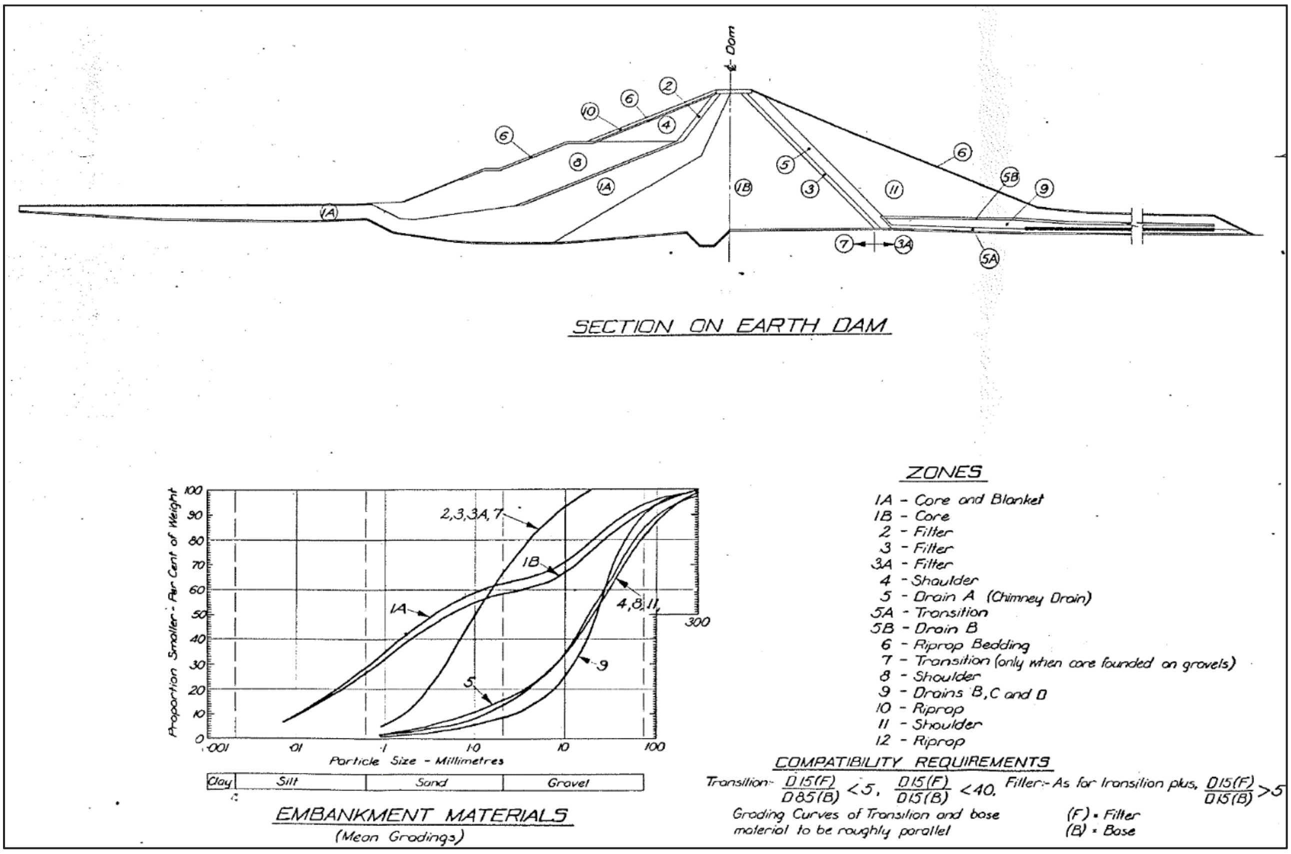


Figure 33 - Zonation of existing Pukaki Dam and mean gradings of zones (from Read 1976)

Zone	Description	Function
1	Earthfill ("core")	Controls seepage through the dam
2A	Fine filter (or filter drain)	(a) Controls erosion of Zone 1 by seepage water, (b) Controls erosion of the dam foundation (where used as horizontal drain), (c) Controls buildup of pore pressure in downstream face when used as vertical drain
2B	Coarse filter (or filter drain)	(a) Controls erosion of Zone 2A into rockfill, (b) Discharge seepage water collected in vertical or horizontal drain
2C	(i) Upstream filter (ii) Filter under rip rap	Controls erosion of Zone 1 into rockfill upstream of dam core Controls erosion of Zone 1 through rip rap
2D	Fine cushion layer	Provides uniform support for concrete face; limit leakage in the event of the concrete face cracking or joints opening
2E	Coarse cushion layer	Provides uniform layer support for concrete face. Prevents erosion of Zone 2D into rockfill in the event of leakage in the face
1–3	Earth-rockfill	Provides stability and has some ability to control erosion
3A	Rockfill	Provides stability, commonly free draining to allow discharge of seepage through and under the dam. Prevents erosion of Zone 2B into coarse rockfill
3B	Coarse rockfill	Provides stability, commonly free draining to allow discharge of seepage through and under the dam
4	Rip rap	Controls erosion of the upstream face by wave action, and may be used to control erosion of the downstream toe from backwater flows from spillways

Figure 34 - Embankment dam zone description and function (from Fell et al.2015)

The borrow sites used during the original construction of Pukaki Dam are shown in 0 (from Read 1976). This can be simplified as:

- Zone 1 (i.e. core) – this comprises 'processed cohesionless till'. The primary borrow was located on the left abutment of the dam and appears to be located within the Mount John Till. It appears two other minor borrows were used for core material, both of which appear to have been in the younger Tekapo Till.

- Zones 2 (filters/transition) and 3 (shoulder) – these appear to have been obtained from 'outwash and post-glacial alluvial gravel'. Based upon available information, the main borrow appears to have been located within the Mount John Outwash, with some post-glacial alluvium from or immediately adjacent to the Pukaki River. It appears some younger Tekapo Outwash may have been present in the western side of the borrow.

The source of Zone 4 (rip rap) and concrete aggregate is not explicitly stated in Read (1976). It is assumed the over-size screened off during the processing of the above materials would have been used (based upon its assessed shape in available images). It can be assumed the concrete aggregate was sourced from the same borrow as the Zones 2 and 3 materials.

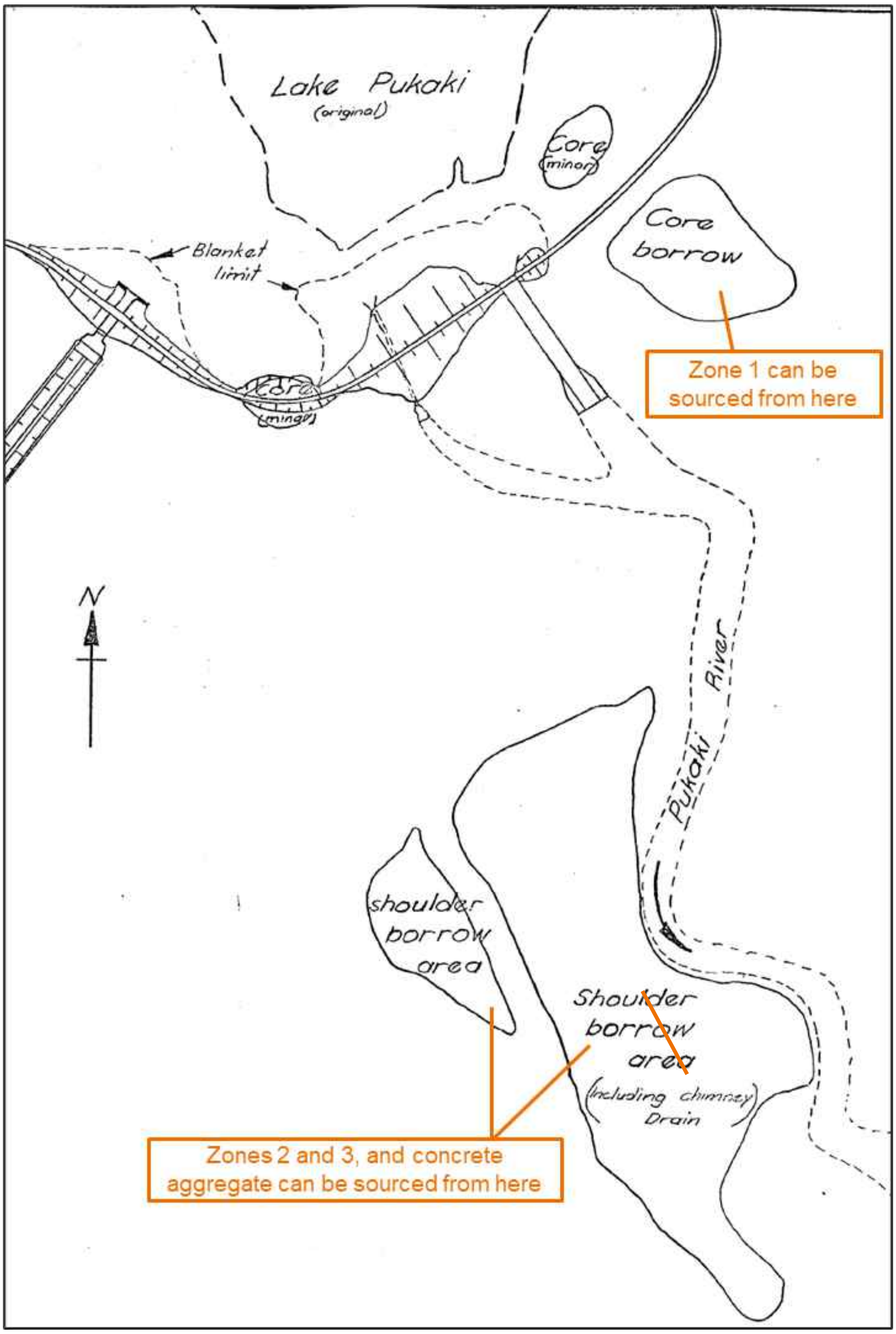


Figure 35 - Location of borrow sites used during construction (from Read 1976)

Key comments presented in Read (1976) with regards to construction materials are:

- *All hauls at Pukaki were relatively short, often requiring only three to four machines for an efficient spread, However these short hauls combined with the rough conditions (large boulders existed in the bulk of Pukaki materials required the use of a relatively large number of 280 to 400 H.P tractors (DB and D9 size).*

- *Initially two spreads of scrapers and two spreads of dumpwagons were used on excavation. Once placement commenced plant numbers were increased to provide up to fourteen 24 cu yd scrapers and twenty three 20 cu yd dumpwagons in the peak season. At the peak ten 380 H.P and sixteen 280 H.P tractors were used.*
- *Forty five per cent of the core material used was processed by a large screen (the 'wobbler') fed with glacial till by up to two 10 cu yd loaders. The remainder was produced by rockraking and mixing till on special stockpiles. Zone 1A material was mainly from the screen (plus 4 inclusive removed) and Zone 1B material was mainly from stockpiles (plus 4 inch removed).*
- *The core placement operation was on shift with the shoulder placement on day-work. All core was placed by scrapers and the bulk of the shoulder by dumpwagons. Peak daily placement rate was 27,000 cu yds.*

For concept design, re-use of the existing borrows can be assumed, all of which are still accessible (except for a minor borrow located beneath the existing embankment). This would likely require their significant extension from their current footprint (both in plan and with depth), due to the volume of materials required. Similar construction methods to those used during the original construction can be assumed for excavation, processing, transport and compaction. Sufficient volumes of materials appear to exist at the previously used borrow locations, assuming they can be extended from their current extent.

Several other options for material sources exist within proximity to the dam, should re-use of the existing borrow locations not be feasible for other reasons (such as land ownership, environmental, cultural & heritage etc).

It is also noted:

- Some materials would be won from the new spillway excavation (approximately 10% of required materials for embankment construction) and this excavation would yield both till and outwash, which could be used to provide Zone 1, and Zones 2 and 3 materials, respectively. These are the same geological materials used for construction of the existing dam, and so their feasibility for use is demonstrated.
- Limited materials for construction would be sourced from the proposed dam excavation. This is as the excavation will largely be the removal of unsuitables (if encountered). On this basis, no construction materials should be assumed to be won from foundation excavations.

Should quarried rip rap be required, instead of screened over-size materials from soils, the closest available location a quarry could be established would be approximately 10 km east of the dam site (greywacke).

B.7.8 Summary

The key findings of this geological study of Site 3 can be summarised as:

- No geological fatal flaws have been identified based upon the currently available information.
- The design, construction, and operation of the Upper Waitaki Power Scheme provide significant engineering geological precedence of the feasibility of the proposed works. This includes the existing Pukaki Dam (foundation conditions, dam materials and design, and reservoir watertightness).

B.7.9 Next Steps

Recommendations for the next step of geological studies should the proposed works proceed to a subsequent stage of development are:

- The sourcing and review of relevant pre-existing site-specific geological information which is privately held. This would include that related to the design, construction, and operation of the Upper Waitaki Power Scheme.
- Development of geological study objectives and scope of works as required for the stage of project development as recommended by ICOLD (2005) and ANCOLD (2020).

Appendix C Detailed Cost Estimates

Appendix C Cost Estimates

With regard to the requirement to develop budget estimates for the costs of construction, the Consultant warrants only that they will exercise the reasonable skill, care and diligence of a Consulting Engineer in the preparation of their professional opinion of those costs. The Client acknowledges that the Consultant has no control over costs of labour, materials, competitive bidding environments and procedures, unidentified field conditions, financial and/or market conditions, or other factors likely to affect the probable cost of the works, all of which are and will unavoidably remain in a state of change. The Client agrees that the Consultant cannot and does not make any warranty, promise, guarantee, or representation, either express or implied, that proposals, bids, project construction costs, or cost of operation or maintenance will not vary substantially from its good faith cost estimate.

C.1 Estimation of Quantities

C.1.1 Dams

Dam volumes were obtained through modelling in AutoCAD Civil 3D using publicly available topographical data. For all dams an excavation depth of 5m across the dam footprint and a 5 m freeboard was assumed. Dams were assumed to be RCC with 10 m wide crests and 0.1:1 upstream slopes and 0.8:1 (h:v) downstream slopes. Central ogee spillways were assumed with capacity to accommodate a small flood flow with 5m high piers. Allowance was made for a larger flow at one dam at Site 2. This dam has a gated rather than free overflow spillway. Smaller costs associated with the dams included allowance for grout curtains and structural concrete for spillways. Grout curtains were assumed to have 1.5m spacing at depths of 0.75 the height to Full Supply Level. Grouting lengths were derived from a CAD long section through the proposed dam.

C.1.2 Hydro-mechanical equipment (gates, embedded parts, hoists)

For Site 3, the quantities were estimated from a high-level design by a mechanical engineer.
Site 1 and 2 used empirical formulas by Erbisti from the book *Design of Hydraulic Gates 2nd Edition* (Erbisti, 2014) to estimate weight of steel for gates and screens. Erbisti developed formulas to determine the weight of various types of gates based on the nominal gate dimensions and the head. The formulas were derived from characteristics of 266 gates.

C.1.3 Conveyance

Penstocks were sized to achieve the same velocity as the incoming tunnel. Where site or powerhouse configuration did not dictate the length, lengths of 400 m were assumed.

Tunnel lengths were derived from Google Earth or AutoCAD Civil 3D.

C.1.4 Powerhouse

Excavations of underground powerhouses followed the geometry of the powerhouse. The powerhouses' sizing is based on the M&E sizing and scaled from a parametric model. For surface powerhouses, excavations were modelled in AutoCAD Civil3D (for Site 3). Excavation slopes of 1.5:1 (h:v) were assumed.

For Sites 1 and 2, the concrete of the main powerhouse structure was based on empirical formulas by Gordon published in the *Canadian Journal of Civil Engineering* (J.L. Gordon, 1983). The formulas were derived from statistics associated with 93 hydropower developments. It estimates concrete by considering rated output, number of units, rated head and runner diameter. It should be noted that these formulas are more accurate in estimating volumes for surface powerhouses.

Superstructure steel for surface powerhouses at Site 1 and 2 were also estimated from empirical formulas by Gordon. These formulas are based on statistics of 12 hydropower plants. The weight of steel is calculated by considering crane capacity (based on generator rating and turbine-generator synchronous speed), number of units and runner diameter.

For Site 3, the structures were designed to a high level by a structural engineer and designed quantities (concrete, structural steel, and architectural treatments) extracted from the design.

C.1.5 Powerhouse Equipment

Preliminary selection of turbine generation plant speed, setting and rating were made using the TurbnPro software package, based on anticipated head and flow details for each site.

Net head was typically assumed to be 98% of gross head, and turbines were selected to operate across the full level range of the associated reservoir.

Turbine settings below tail water level, and consequently unit speed selections, were established based on the likely powerhouse type (surface or underground).

C.1.6 Transmission

Approximate routes were identified on GoogleEarth to estimate transmission line lengths.

C.1.7 Switchyards

Switchyards associated with underground generating facilities have been assumed to be GIS type with all others being AIS type.

One circuit breaker bay was assigned to each generating unit, one for each transmission circuit, plus one bus coupler.

C.1.8 Access Roads

Approximate routes were plotted in AutoCAD (Site 3) and GoogleEarth (Site 1 and 2) to estimate road lengths. 8 m road widths were assumed for sealed roads and 6 m for gravel roads.

C.2 Unit Prices Adopted

Unit rates for construction activities have been developed using a combination of built-up rates and complete rates for similar types of works. These rates have been reviewed with MBIE's technical specialist and minor amendments made based on comments provided.

C.2.1 Contractor's Margin and Risk

Contractor's margins have been allowed at 12% of the construction cost and this is considered to be in line with margins for other large-scale projects in New Zealand.

An allowance of 5% for contractor's risk has been made and this is considered to be a general risk allowance that would likely be included in any contractor's estimate. It is not project contingency held by the Principal which is considered separately in the estimates.

C.2.2 Preliminaries

Preliminary and general items such as site establishment and supervision have been applied as a percentage of construction cost. An allowance of 25% has been made for this along with a further allowance of 10% for the construction of worker camps and facilities.

An allowance of 2% has been made to cover contractor's design that may be required for minor construction items.

C.2.3 Earthworks and Civils

Simplified rates have been developed for earthworks and civils activities based on a combination of first principles build-ups for specific tasks and general industry rates.

For earthworks rates have been developed based on the likely plant and labour requirements for any given activity to establish a unit rate for the work which is combined with appropriate unit rates for materials. For consistency similar rates have been used across all of the proposed sites and amended as required to reflect the particular method of construction and location.

Earthworks rates allow for using large plant and equipment and take into account efficiencies expected in large scale projects. Allowances have also been made for additional works such as blasting and where appropriate this has been included in the rate.

In general rates for civils construction items such as reinforced concrete works have been based on unit rates for similar works and rates are inclusive of all plant, labour and material costs. Different rates have been developed depending on the complexity and location of the works. This includes separate allowances for mass concrete compared to reinforced concrete as well as higher rates for underground structures that may have higher reinforcing content and more complex formwork.

For steelwork rates have been developed to reflect the complexity of the fabrication requirements. Rates have generally been prepared based on current fabrication rates for similar items. The rates range from simple fabrication such as steelwork for buildings to complex fabrication involving mechanical related items such as lifting arrangements or complex moving parts.

The following general rates have been adopted for Earthworks and Civils items:

Item	Rate(s)	Assumptions
Excavation in Rock	$33.00 per m^3	This includes blasting of up to 75% of the rock and ripping 25%.
Excavation in other than rock	$17.00 per m^3	This is for general excavation in rippable / diggable material The built-up cost has been compared to similar rates for which the average is $16.50 per m^3
Reinforced concrete	$2500 - $3500 per m^3	This rate includes all materials, formwork, reinforcement, placement and finishing. The range of rates allows for the various types of construction with the higher rate being used for all underground structures.
Mass concrete	$600 per m^3	This rate includes all materials, placement and finishing.
Structural steel	$6.00 – $9.00 per kg	This rate has been used for all simple structural steel such as buildings and simple structures.
Complex fabrication	$16.50 per kg	This rate has been used for complex fabrication that is likely to require moving parts, bearings, lifting or rigging devices or other mechanical moving parts. The rate has been used for primarily for items such as gates.

C.2.4 Dams

At Sites 1 and 2 RCC placement rates have been developed based on the likely plant and labour requirements to establish a unit rate for the work which is combined with appropriate unit rates for fill materials. Material costs for RCC are provided on an estimated cost per cubic metre basis, since there has not been sufficient time to determine the cost of quarrying, processing, mixing and delivering the material to each individual location.

For consistency similar rates have been used across all of the proposed sites and amended as required to reflect the particular method of construction and location.

For Site 3 placement rates have been developed in a similar way to Sites 1 and 2 with minor changed to reflect the different construction method. Material rates have also been reduced to reflect the reduce requirement for extensive processing. These differences in construction material, method and rates have a significant impact on the overall cost of Site 3.

The following general rates have been adopted for dam construction:

Item	Rate(s)	Assumptions
Roller compacted concrete dams	$184.67 per m^3	This includes the manufacture of concrete and delivery to site at $173 per m^3 and placement at $11.67 per m^3 . Rates have been developed from first principles and checked against similar projects. The range of cost for roller compacted concrete across these projects is $128.00 to $215.00 per m^3.
Rock fill or earth dams	$60.52 per m^3	This rate includes the quarrying, processing and supply of suitable material for earth dams. Rates have been developed from first principles and compared to a range of rates for large scale earthworks projects. The average rate for these comparison projects is $56.00 per m^3.

C.2.5 Tunnels

The tunnelling rates have been developed on a cubic metre of excavation basis and this has been used to establish linear metre rates for varying diameters of tunnel from 3 m to 10 m.

Tunnelling rates have been adjusted to provide rates for lined and unlined tunnels. The rates do not consider the range of possible lining types, but the rate is considered sufficient to meet a range of options, including steel.

Adjustments have been made to the tunnelling rates to take into consideration the high plant and mobilization cost that varies depending on the size of the tunnel. These rates have been checked against other tunnel projects of similar type and scale. Checks have been based on the bare tunnelling costs.

The following general rates have been adopted for tunnel construction:

Item	Rate(s)	Assumptions
3 m diameter tunnels	Lined $8,340 per m Unlined $6,255 per m	Long tunnel lengths have been developed based on using tunnel boring machines. Rates have been developed based on a range of similar size projects that have been carried out in New Zealand in the last 10 years.
4 m to 8 m diameter tunnels	Lined $13,345 to $35,587 per m Unlined $10,009 to $26,690 per m	Long tunnel lengths have been developed based on using tunnel boring machines. Rates have been interpolated based on the rates for large diameter tunnels and compared to similar size tunnel projects where information is available.
10 m diameter tunnels and larger	Lined $46,338 per m Unlined $34,753 per m	Long tunnel lengths have been developed based on using tunnel boring machines. Rates have been developed from first principles and compared to similar large projects for reference.

C.2.6 Roads and access

Rates for general access roads and state highway have been developed using similar linear metre and square metre rates from similar projects. Unless specifically quantified an allowance has been made for bridges and retaining structures over 10% of the total length.

C.2.7 Powerhouse Equipment

Stantec maintains an up-to date detailed database of actual project awards, bid results, and detailed estimates. Stantec applies adjustment factors for unit size, speed and head, escalates older data to today's price, and adjusts for quantity of units in order to establish a cost estimate for budgetary purposes.
The scope for supply for the Water to Wire Pricing baseline starts at the turbine shut off valve (Main Inlet Valve) and ends at the High Voltage (HV) bushing of the main unit transformer as the HV interconnect varies widely project to project.

The following items are assumed to be included in the water to wire costs:

- Turbine shut off valve (Main Inlet Valve)
- Pump-Turbine and governor including embedded parts
- Motor-Generator and exciter, plus SFC starting
- Controls and protection
- UPS & batteries
- LV & MW switchgear, including MV buswork
- HV transformer & HV disconnect
- Electrical Balance of Plant (BoP), including earthing
- Mechanical Balance of Plant (BoP), including HVAC, cooling water, sumps, oil conditioning etc.
- Basic machine shop
- Powerhouse crane and lifts
- Transportation, installation & commissioning

The estimates are based on a fair market price for the equipment, based on Stantec's standard trend line for typical market conditions with only pre-qualified top tier Western bidders from international sourcing. This is typically the budget Stantec recommends for planning purposes and can be explained as the average of the 3 lowest bidders using FIDIC or comparable or equitable contract terms.

At this time market conditions based on recent bids is showing M&E equipment above our estimates. However, market conditions can, and do, change significantly and rapidly depending on geopolitical conditions and how these fare on the global market. Other influencing factors also play recognisable impacts such as commodities prices i.e. copper, taxes, exchange rates etc. and need to be fully considered at the time of tender.

C.2.8 Transmission

Very little transmission line construction has been undertaken in New Zealand over the past decades. The most recent significant construction was the Whakamaru to Brownhills 400 kV double circuit line constructed by Transpower & completed circa 2013. This line was constructed to 400 kV standards but is operated at 220 kV. The line is approximately 190km long.

According to Transpower applications to the Commerce Commission the total cost of the transmission line was NZ$398.8M. Considering the actual applicable costs and original profit margin the anticipated outturn in 2013 dollars would have been $1.8M/km.

Assuming 3% per annum escalation over the intervening period would give an indicative 2022 cost of $2.35 M/km. From our experience 400 kV lines cost in the region of 30% more to construct than a 220 kV line and therefore a current cost for 220 kV of $1.8 M/km would apply.

This cost has been compared against other overseas sources:

The Australian AEMO has published cost estimates for grid upgrade projects to enable renewable generation. For 275 kV lines a typical cost is AU$2.7 M/km. However, this cost includes the substations at each end. Our experience is that construction costs in Australia are significantly higher than in New Zealand.

For projects in Asia Stantec have recently costed transmission lines using a rate of US$800,000/km for double circuit 345 kV lines. This would equate to about NZ$1M/km for a 220 kV line. The costs in NZ will be much higher than Asia .

On balance a cost of NZ$1.8M per km of new build double circuit line has been assumed. For single circuit lines a cost 70% of that for double circuit has been adopted.

C.2.9 Switchyards

Switchyards have been costed on the basis of NZ$1.5M per circuit breaker bay for an air insulated (AIS) site and NZ$3.0M per circuit breaker for a gas insulated (GIS) site.

C.3 Site 1 Cost Breakdown

Item	Description	Base Estimate ($M)	P50 Contingency ($M)	
1	**Client Internal Cost**	**$360.5**	**$108.2**	
1.1	Consent management	$101.6	$30.5	30%
1.2	Design Delivery	$101.6	$30.5	30%
1.4	Operations support	$50.8	$15.2	30%
1.5	Construction Delivery Team	$101.6	$30.5	30%
1.6	Commissioning	$5.1	$1.5	30%
2	**Client's Design**	**$558.6**	**$167.6**	
2.1	Concept Design and basis of design	$50.8	$15.2	30%
2.2	Preliminary Design	$152.4	$45.7	30%
2.3	Detailed Design or Principal's Requirements	$304.7	$91.4	30%
2.4	Construction and Commissioning support	$50.8	$15.2	30%
3	**Consent preparation**	**$114.3**	**$34.3**	
3.1	Consent Application	$50.8	$15.2	30%
3.2	External specialist consultants	$63.5	$19.0	30%
4	**Site Investigations**	**$152.3**	**$45.7**	
4.1	Geotechnical Reports (GIR / GFR / GBR)	$50.8	$15.2	30%
4.2	Geotechnical Investigations (Boreholes /PSI /DSI)	$25.4	$7.6	30%
4.3	Contamination Investigation	$25.4	$7.6	30%
4.4	Survey (Topo etc)	$25.4	$7.6	30%
4.5	Other investigations (Potholing)	$25.4	$7.6	30%
5	**Property & Utilities**	**$12.7**	**$3.8**	
5.1	Property Purchase (Private, Council Owned, AMA, NZTA, AT, Forestry, Kiwi rail, Treaty land, Marine Work)	-	-	30%
5.2	Land Owner Agreement	-	-	30%
5.3	Legal Costs	$12.7	$3.8	30%
5.4	Utilities (Vector/Counties Power Connection Costs, Healthy Waters)	-	-	30%
6	**Project Specific Insurances**	**$76.2**	**$22.9**	
6.1	Project Specific Insurances	$76.2	$22.9	30%
7	**Construction**	**$5,077.9**	**$1,448.7**	
7.1	Construction Monitoring (Consultants)	$58.7	$17.6	30%
7.2	Commissioning	$5.0	$1.5	30%
7.3	Transmission and Substations	$23.4	$7.0	30%
7.5	Pumping and Generation M&E	$321.0	$96.3	30%
7.6	Civil Construction	$4,669.8	$1,326.3	28%
7.6.1	Contractor's Margin (17%)	$500.3	$125.1	25%
7.6.2	Contractor's Risk (5%)	$198.5	$49.6	25%
7.6.3	Preliminary and General (25%)	$794.2	$198.5	25%
7.6.4	Civils Design	$62.3	$18.7	30%
7.6.5	Site Establishment and Disestablishment	$605.1	$181.5	30%

7.6.6	Dam and Spillways (storage) - Subtotal	$959.3		
7.6.6.1	Gravity dam (RCC) (Aorangi Stream)	$626.7	$188.0	30%
7.6.6.2	Gravity dam (RCC) (Azim Gorge)	$150.3	$45.1	30%
7.6.6.3	Gravity dam (RCC) (Saddle)	$43.1	$12.9	30%
7.6.6.4	Gravity dam (RCC) (Waipahihi headpond)	$71.2	$21.4	30%
7.6.6.5	Concrete weir (Waipakihi weir)	$18.8	$5.6	30%
7.6.6.6	Raised Poutu Dam (Waipakihi weir)	$10.0	$3.0	30%
7.6.6.7	Hydro-mechanical (gates, embedded parts, hoists)	$39.3	$11.8	30%
7.6.7	Tunnels - Subtotal	$990.8		
7.6.7.1	Low Pressure Tunnels	$564.3	$169.3	30%
7.6.7.2	Tailraces	$399.8	$120.0	30%
7.6.7.3	Steel penstock	$26.7	$8.0	30%
7.6.8	Powerhouse/pumpstation (Needles) - Subtotal	$199.2		
7.6.8.1	Civil works	$199.2	$59.8	30%
7.6.9	Powerhouse Upgrade (Rangipo)	$87.5	$26.2	30%
7.6.10	Canal (raise of existing)	$82.7	$24.8	30%
7.6.11	Access Roads	$189.8	$56.9	30%
8	**Project Base Estimate (1+2+3+4+5+6+7)**	**$6,352.40**		
9	**Contingency** (Assessed/Analysed)	**(1+2+3+4+5+6+7)**	**$1,831.10**	
10	**Total Project Expected Estimate**	**(8+9)**	**$8,183.50**	
11	**Funding Risk**	**50%**	**$4,091.70**	
12	**90th Percentile Estimate**	**(10+11)**	**$12,275.20**	

C.4 Site 2 Cost Breakdown

Item	Description	Base Estimate ($M)	P50 Contingency ($M)	
1	**Client Internal Cost**	**$389.8**	**$116.9**	
1.1	Consent management	$109.8	$32.9	30%
1.2	Design Delivery	$109.8	$32.9	30%
1.4	Operations support	$54.9	$16.5	30%
1.5	Construction Delivery Team	$109.8	$32.9	30%
1.6	Commissioning	$5.5	$1.6	30%
2	**Client's Design**	**$603.9**	**$181.2**	
2.1	Concept Design and basis of design	$54.9	$16.5	30%
2.2	Preliminary Design	$164.7	$49.4	30%
2.3	Detailed Design or Principal's Requirements	$329.4	$98.8	30%
2.4	Construction and Commissioning support	$54.9	$16.5	30%
3	**Consent preparation**	**$123.5**	**$37.1**	
3.1	Consent Application	$54.9	$16.5	30%
3.2	External specialist consultants	$68.6	$20.6	30%
4	**Site Investigations**	**$164.7**	**$49.4**	
4.1	Geotechnical Reports (GIR / GFR / GBR)	$54.9	$16.5	30%
4.2	Geotechnical Investigations (Boreholes /PSI /DSI)	$27.4	$8.2	30%
4.3	Contamination Investigation	$27.4	$8.2	30%
4.4	Survey (Topo etc)	$27.4	$8.2	30%
4.5	Other investigations (Potholing)	$27.4	$8.2	30%
5	**Property & Utilities**	$13.7	$4.1	
5.1	Property Purchase (Private, Council Owned, AMA, NZTA, AT, Forestry, Kiwi rail, Treaty land, Marine Work)	-	-	30%
5.2	Land Owner Agreement	-	-	30%
5.3	Legal Costs	$13.7	$4.1	30%
5.4	Utilities (Vector/Counties Power Connection Costs, Healthy Waters)	-	-	30%
6	**Project Specific Insurances**	$82.3	$24.7	
6.1	Project Specific Insurances	$82.3	$24.7	30%
7	**Construction**	$5,489.9	$1,570.6	
7.1	Construction Monitoring (Consultants)	$59.8	$17.9	30%
7.2	Commissioning	$5.4	$1.6	30%
7.3	Transmission and Substations	$180.0	$54.0	30%
7.5	Pumping and Generation M&E	$466.0	$139.8	30%
7.6	Civil Construction	$4,778.7	$1,357.2	28%
7.6.1	Contractor's Margin (17%)	$512.0	$128.0	25%
7.6.2	Contractor's Risk (5%)	$203.2	$50.8	25%
7.6.3	Preliminary and General (25%)	$812.7	$203.2	25%
7.6.4	Civils Design	$63.7	$19.1	30%
7.6.5	Site Establishment and Disestablishment	$829.0	$248.7	30%

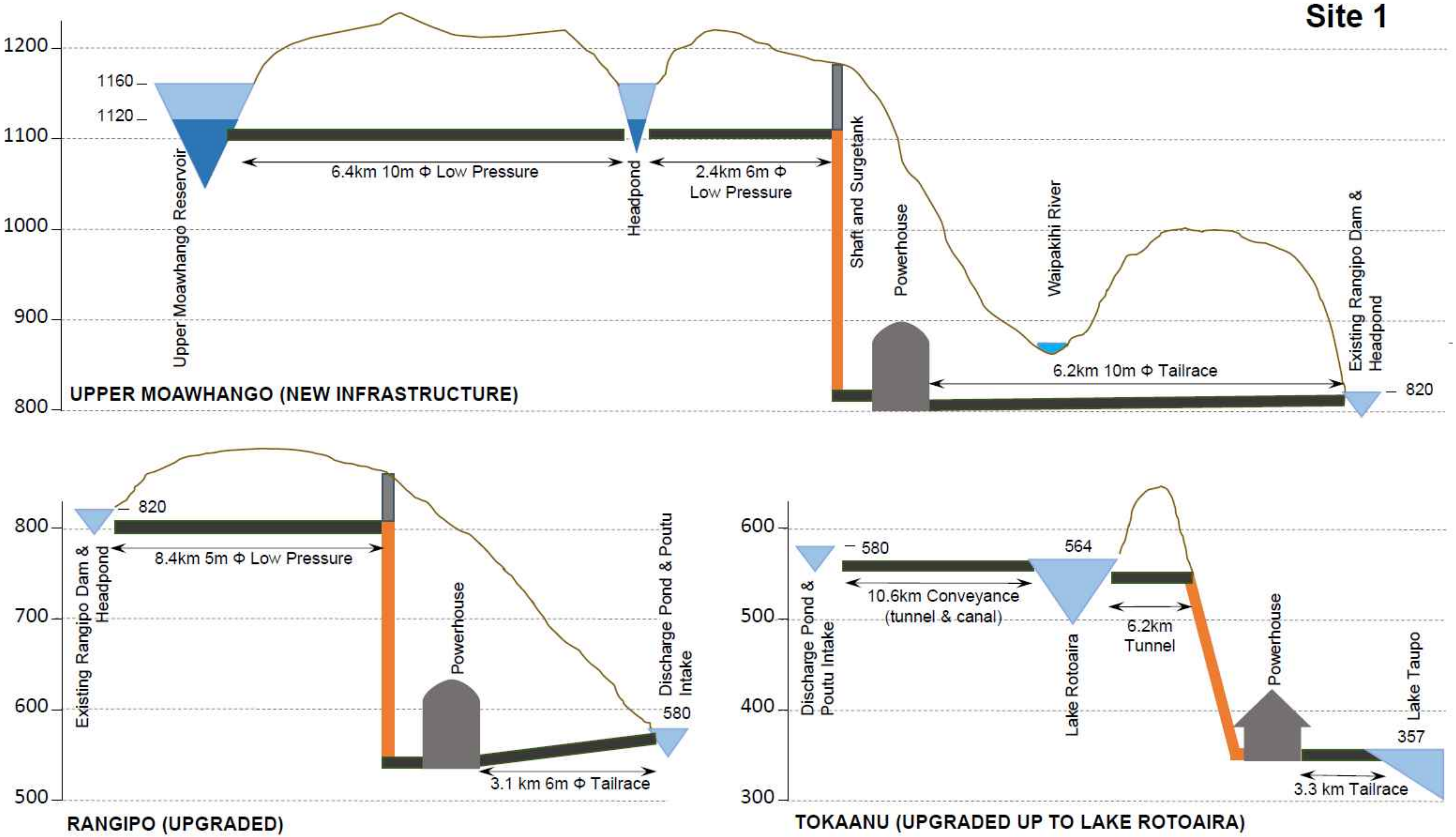
7.6.6	Dam and Spillways (storage) - Subtotal	$1,367.4		
7.6.6.1	Gravity dam (RCC) (Dam 1 Taruarau)	$390.5	$117.1	30%
7.6.6.2	Gravity dam (RCC) (Saddle Dam 1)	$609.7	$182.9	30%
7.6.6.3	Gravity dam (RCC) (Saddle Dam 2)	$63.7	$19.1	30%
7.6.6.4	Gravity dam (RCC) (Buffer Reservoir)	$10.3	$3.1	30%
7.6.6.5	Gravity dam (RCC) (Blowfly Gully Headpond Reservoir Dam 1)	$26.6	$8.0	30%
7.6.6.6	Gravity dam (RCC) (Blowfly Gully Headpond Reservoir Dam 2)	$43.6	$13.1	30%
7.6.6.7	Gravity dam (RCC) (Downstream dam of Power station 2)	$27.6	$8.3	30%
7.6.6.8	Gravity dam (RCC) (Power station 4 dam)	$155.4	$46.6	30%
7.6.6.9	Hydro-mechanical (gates, embedded parts, hoists)	$40.1	$12.0	30%
7.6.7	Tunnels - Subtotal	$262.1		
7.6.7.1	High Pressure Tunnels	$200.7	$60.2	30%
7.6.7.2	Low Pressure Tunnels	$38.1	$11.4	30%
7.6.7.3	Steel penstock	$23.4	$7.0	30%
7.6.8	Powerhouse 1 - Subtotal	$18.8		
7.6.8.1	Civil works	$18.8	$5.6	30%
7.6.8.2	Pumps			30%
7.6.9	Powerhouse/pumpstation 2 (silo type) - Subtotal	$78.6		
7.6.9.1	Civil works	$78.6	$23.6	30%
7.6.9.2	Pumps			30%
7.6.10	Powerhouse/pumpstation 3 (underground) - Subtotal	$429.2		
7.6.10.1	Civil works	$429.2	$128.7	30%
7.6.11	Powerhouse 4 – Subtotal	$12.5		
7.6.11.1	Civil works	$12.5	$3.8	30%
7.6.12	Canals	$24.0	$7.2	30%
7.6.13	Other conveyance	$13.7	$4.1	30%
7.6.14	Access Roads	$151.7	$45.5	30%
8	**Project Base Estimate (1+2+3+4+5+6+7)**	**$6,867.80**		
9	**Contingency** (Assessed/Analysed)	**(1+2+3+4+5+6+7)**	**$1,984.00**	
10	**Total Project Expected Estimate**	**(8+9)**	**$8,851.80**	
11	**Funding Risk**	**50%**	**$4,425.90**	
12	**90th Percentile Estimate**	**(10+11)**	**$13,277.70**	

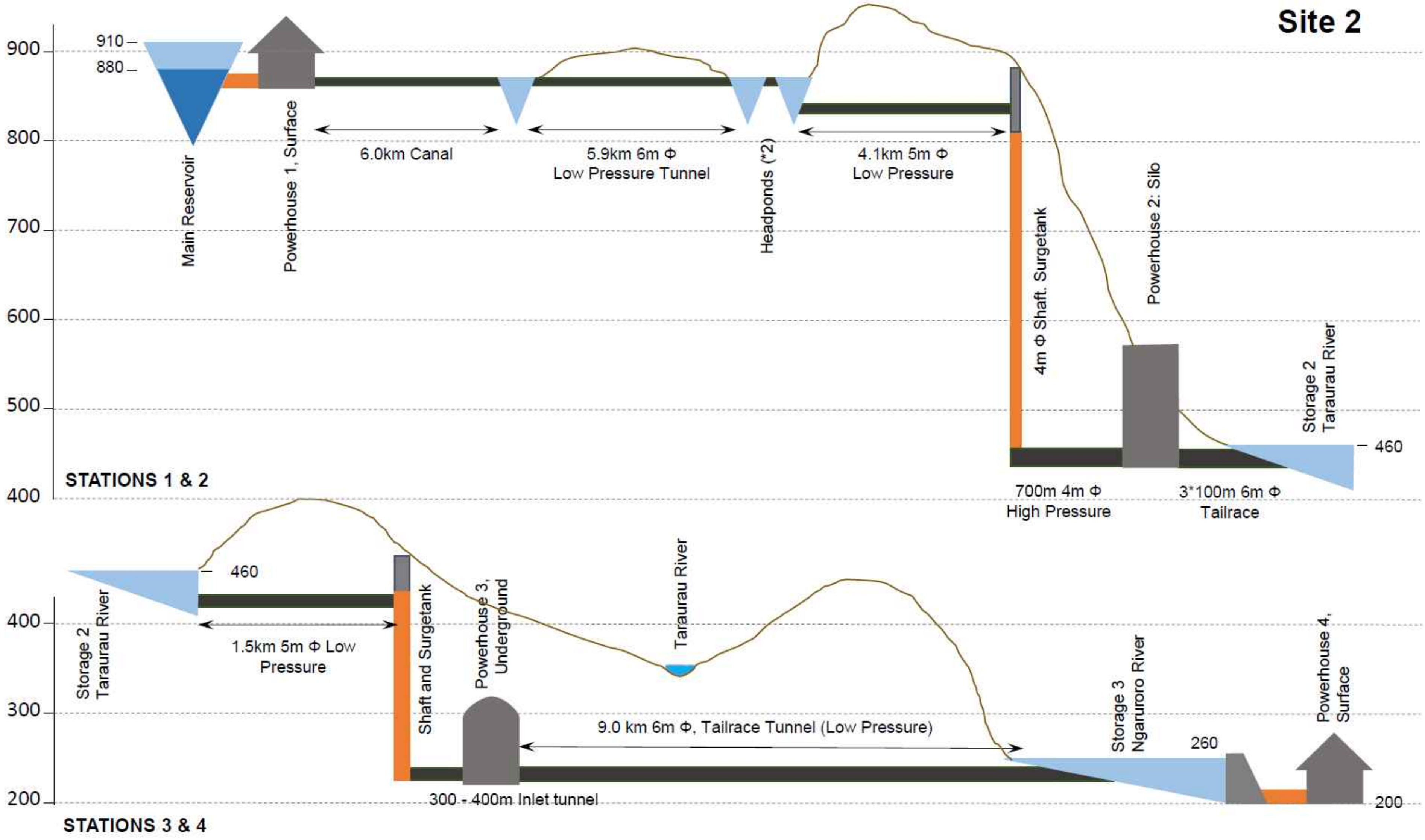
C.5 Site 3 Cost Breakdown

Item	Description	Base Estimate ($M)	P50 Contingency ($M)	
1	**Client Internal Cost**	**$378.9**	**$113.7**	
1.1	Consent management	$106.7	$32.0	30%
1.2	Design Delivery	$106.7	$32.0	30%
1.4	Operations support	$53.4	$16.0	30%
1.5	Construction Delivery Team	$106.7	$32.0	30%
1.6	Commissioning	$5.3	$1.6	30%
2	**Client's Design**	**$587.0**	**$176.1**	
2.1	Concept Design and basis of design	$53.4	$16.0	30%
2.2	Preliminary Design	$160.1	$48.0	30%
2.3	Detailed Design or Principal's Requirements	$320.2	$96.1	30%
2.4	Construction and Commissioning support	$53.4	$16.0	30%
3	**Consent preparation**	**$120.1**	**$36.0**	
3.1	Consent Application	$53.4	$16.0	30%
3.2	External specialist consultants	$66.7	$20.0	30%
4	**Site Investigations**	**$160.1**	**$48.0**	
4.1	Geotechnical Reports (GIR / GFR / GBR)	$53.4	$16.0	30%
4.2	Geotechnical Investigations (Boreholes /PSI /DSI)	$26.7	$8.0	30%
4.3	Contamination Investigation	$26.7	$8.0	30%
4.4	Survey (Topo etc)	$26.7	$8.0	30%
4.5	Other investigations (Potholing)	$26.7	$8.0	30%
5	**Property & Utilities**	**$13.3**	**$4.0**	
5.1	Property Purchase (Private, Council Owned, AMA, NZTA, AT, Forestry, Kiwi rail, Treaty land, Marine Work)	-	-	30%
5.2	Land Owner Agreement	-	-	30%
5.3	Legal Costs	$13.3	$4.0	30%
5.4	Utilities (Vector/Counties Power Connection Costs, Healthy Waters)	-	-	30%
6	**Project Specific Insurances**	**$80.0**	**$24.0**	
6.1	Project Specific Insurances	$80.0	$24.0	30%
7	**Construction**	**$5,336.6**	**$1,462.0**	
7.1	Construction Monitoring (Consultants)	$62.0	$18.6	30%
7.2	Commissioning	$5.3	$1.6	30%
7.3	Transmission and Substations	$9.0	$2.7	30%
7.5	Pumping and Generation M&E	$259.4	$77.8	30%
7.6	Civil Construction	$5,001.0	$1,361.3	27%
7.6.1	Contractor's Margin (17%)	$535.8	$134.0	25%
7.6.2	Contractor's Risk (5%)	$212.6	$53.2	25%
7.6.3	Preliminary and General (25%)	$850.5	$212.6	25%
7.6.4	Civils Design	$66.7	$20.0	30%
7.6.5	Site Establishment and Disestablishment	$882.9	$264.9	30%
7.6.6	Dam and Spillways (storage) - Subtotal	$1,595.3		

7.6.6.1	New Diversion Tunnels	$409.8	$122.9	30%
7.6.6.2	New Canal Inlet Gate Structure	$320.7	$96.2	30%
7.6.6.3	Earth dam	$664.6	$166.2	25%
7.6.6.4	Spillway	$200.2	$60.1	30%
7.6.7	Powerplant 1 (Pukaki) - Subtotal	$176.1		
7.6.7.1	Intake Structure	$90.9	$27.3	30%
7.6.7.2	Penstocks (3 off)	$21.4	$6.4	30%
7.6.7.3	Powerhouse	$55.0	$16.5	30%
7.6.7.4	Tailrace	$8.8	$2.7	30%
7.6.8	Powerplant 2 (Tekapo) - Subtotal	$151.6		
7.6.8.1	Penstocks (2 off)	$50.1	$15.0	30%
7.6.8.2	Powerhouse	$101.4	$30.4	30%
7.6.9	Roading - Subtotal	$529.5		
7.6.9.1	State Highway 80	$272.0	$68.0	25%
7.6.9.2	State Highway 8 Realignment	$243.9	$61.0	25%
7.6.9.3	Tekapo B Access Road	$13.6	$4.1	30%
8	**Project Base Estimate (1+2+3+4+5+6+7)**	**$6,676.10**		
9	**Contingency** (Assessed/Analysed)	**(1+2+3+4+5+6+7)**	**$1,863.80**	
10	**Total Project Expected Estimate**	**(8+9)**	**$8,539.90**	
11	**Funding Risk**	**50%**	**$4,270.00**	
12	**90th Percentile Estimate**	**(10+11)**	**$12,809.90**	

Appendix D Site 1 and 2 Long Sections


Site 1
1200
1100
1000
900
800
1160
1120
Upper Moawhango Reservoir
6.4km 10m Φ Low Pressure
Headpond
2.4km 6m Φ Low Pressure
Shaft and Surgetank
Powerhouse
Waipakihi River
Existing Rangipo Dam & Headpond
820
6.2km 10m Φ Tailrace
UPPER MOAWHANGO (NEW INFRASTRUCTURE)
800
700
600
500
820
Existing Rangipo Dam & Headpond
8.4km 5m Φ Low Pressure
Powerhouse
Discharge Pond & Poutu Intake
580
3.1 km 6m Φ Tailrace
RANGIPO (UPGRADED)
600
500
400
300
580
Discharge Pond & Poutu Intake
10.6km Conveyance (tunnel & canal)
564
Lake Rotoaira
6.2km Tunnel
Powerhouse
Lake Taupo
357
3.3 km Tailrace
TOKAANU (UPGRADED UP TO LAKE ROTOAIRA)


Site 2
STATIONS 1 & 2
900
800
700
600
500
400
910
880
Main Reservoir
Powerhouse 1, Surface
6.0km Canal
5.9km 6m Φ
Low Pressure Tunnel
Headponds (*2)
4.1km 5m Φ
Low Pressure
4m Φ Shaft. Surgetank
Powerhouse 2: Silo
Storage 2
Tararau River
460
700m 4m Φ
High Pressure
3*100m 6m Φ
Tailrace
460
Storage 2
Tararau River
1.5km 5m Φ Low
Pressure
Shaft and Surgetank
Powerhouse 3,
Underground
Tararau River
9.0 km 6m Φ, Tailrace Tunnel (Low Pressure)
Storage 3
Ngaruroro River
260
Powerhouse 4,
Surface
200
300 - 400m Inlet tunnel
400
300
200
STATIONS 3 & 4

CREATING COMMUNITIES

Communities are fundamental. Whether around the corner or across the globe, they provide a foundation, a sense of belonging. That's why at Stantec, we always **design with community in mind**.

We care about the communities we serve—because they're our communities too. We're designers, engineers, scientists, and project managers, innovating together at the intersection of community, creativity, and client relationships. Balancing these priorities results in projects that advance the quality of life in communities across the globe.

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