Factual Technical Report

Kings Quarry Groundwater Effects - Numerical Modelling Analysis

KINGS QUARRY LIMITED

WWLA0931 | Rev. 5

26 March 2025

Kings Quarry Groundwater Effects - Numerical Modelling Analysis

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Document history and status

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Rev	Date issued	Issued to	Comments

Executive Summary

Williamson Water & Land Advisory (WWLA) were commissioned by Kings Quarry Limited to provide a groundwater effects analysis to support an application for fast-track consenting application for the expansion of the Kings Quarry site at Pebble Brook Road, Wainui. Kings Quarry has served as a source of high-quality aggregate derived from Albany Conglomerate for over 50 years, though commercial extraction was halted in 1995. The site was purchased by the Semenoff Group in 2017, who have restarted Stage 1 operations and are engaged in further expansion (this application).

This groundwater analysis comprised two primary components:

1. Compiling existing information and developing a conceptual hydrogeological model of the site.

2. Transforming the conceptual model into a numerical groundwater model to be used as a tool for providing the groundwater assessment.

Objectives

The overall objective of the work is to support an Assessment of Environmental Effects (AEE) forming part of a resource consent application. The groundwater effects assessment quantifies the potential effects of quarry excavation on the local groundwater system. This analysis comprises the following:

a) An evaluation of the depth and extent of drawdown resulting from pit excavations;

b) An assessment of neighbouring bore interference effects;

c) An assessment of potential depletion effects on streams and wetlands within and adjacent to the proposed quarry area due to dewatering and drawdown;

d) Estimation of the rate and volume of groundwater seepage into the quarry; and

e) An assessment of predicted groundwater effects relative to Auckland Unitary Plan (AUP) criteria for groundwater diversions.

To achieve these objectives a 3D numerical groundwater model was developed, and documentation of the model's conceptualisation, calibration and scenario simulation are detailed in this report.

Numerical Model Development and Application

The model development comprised the following process:

Model build – The Development of a single layer numerical model was undertaken using AquaVeo's Groundwater Modelling System (GMS) as an interface for the MODFLOW Unstructured Grid (MODFLOW-USG) code developed by the United States Geological Survey (USGS).

The model boundary corresponds to the Waitoki Stream catchment boundary in order to capture all hydrological effects that may result from quarrying at the proposed location. The model was constructed with a single layer representing the geologic material as a bulk unit, with lateral variation in hydraulic conductivity based on geological units.

Surface conditions such as topography and the stream network were incorporated directly into the model, as was subsurface conditions such as geology and associated hydrogeologic properties to represent physical conditions within the study area. The Soil Moisture Water Balance Model (SMWBM) was used to calculate groundwater recharge, incorporating soil permeability and sub-soil drainage to determine recharge. The SMWBM was calibrated to simulate the Kaukapakapa River at Taylors Road, with results indicating that 5.8% of rainfall within the catchment becomes groundwater recharge.

Model calibration - The numerical model was calibrated to two groundwater level measurements, a measurement of drainage at the existing quarry, and estimated baseflow sourced from NZ Rivermaps. Hydraulic conductivity was set equal to the hydraulic testing results provided in PDP (2008), which are shown in **Table E1**.

Table E1. Conductivity of materials within the model area.

Material	Horizontal k (m/day) [m/sec]
Albany Conglomerate	0.01728 [2.0×10^{-7}]
Basalt	0.00864 [1.0×10^{-7}]
Mudstone	0.000864 [1.0×10^{-8}]
Limestone	0.00311 [3.6×10^{-8}]
Turbidite	0.000864 [1.0×10^{-8}]

A satisfactory calibration was achieved where all target data was reasonably simulated by the model and the model was then determined be fit for purpose.

Scenario modelling - The calibrated model was applied to generate predictions for drawdown and associated effects on neighbouring bores, streams, and wetlands. The model was also used to predict the degree of ongoing dewatering that will be required during quarry operations.

The transient model data set (1972-2023) was used for predicting the effects of quarry development, effectively using the quarry excavation scenario as a hypothetical event with the climate and physical conditions otherwise equal to the historic model.

Model Analysis Results - **Table E2** provides a summary of the predicted groundwater effects following the 45-year quarry excavation sequence.

Table E2. Summary of groundwater modelling results.

Category	Description	Analysis
Environmental	Drawdown	Drawdown outside of the excavation area is limited to 7 m, at a maximum, which occurs directly north of the completed quarry. Drawdown does not extend across the Waitoki Stream to the south of the quarry or across tributaries to the northeast and southwest of the quarry.
	Neighbouring Bore Interference	Three water bores within 2 km of the excavation area were identified. All of these bores are outside of the 0.05 m maximum drawdown contour and are therefore considered to have negligible effects from the proposed excavation.
	Stream Baseflow Depletion	During low flow conditions, when the stream is most sensitive to depletion, the maximum depletion rate is 1.3 L/s, approximately 10% of MALF. Baseflow depletion is limited on account of the quarry design, which stipulates that the base elevation of the quarry does not extend below 44 mAMSL, several meters above the stream bed elevation for the adjacent reach of the Waitoki Stream, to prevent stream dewatering.
	Wetland Conditions	There is one known wetland within the Waitoki Catchment, as shown on the AUP Wetland Management Areas Overlay. This wetland is in a location where drawdown is not predicted to occur, being on the opposite side of the Waitoki River. Therefore, the wetland is not vulnerable to effects from the quarrying.
	Saline Intrusion	The quarry, and extent of drawdown are too far from the coast for saline intrusion to be a concern.
	Land Settlement	Land settlement will not occur in the excavation area. The incompressible Albany Conglomerate and limited drawdown outside of the excavation footprint (maximum 7.0 m) indicate that settlement

Category	Description	Analysis
		is not a concern for the proposed quarry. In addition to the above, there is no vulnerable infrastructure in the area where drawdown is predicted.
Quarry excavation	Pit Seepage	Seepage into the quarry pit will occur when the excavation intersects the water table. There is predicted to be limited groundwater seepage into the quarry (~0.5 L/s) until 40 years into the excavation period when a larger portion of aquifer material is excavated. At this point there is a brief spike to 6.0 L/s, as the excavation level falls below the existing groundwater level. This flow is predicted to rapidly drop to a more consistent rate of 2-2.5 L/s after two to three months of elevated flow.

AUP Chapter E7 Evaluation

Chapter E7 of the AUP, which addresses consenting requirements related to 'Taking, using, damming and diversion of water and drilling', was reviewed in relation to the proposed quarry excavation and its effects on groundwater. From a consenting perspective, the quarry classifies as a groundwater diversion caused by an excavation (refer AUP Table E7.4.1 (A28)), in addition to not meeting permitted activity standards (A20), and is therefore considered a 'Restricted Discretionary' activity, hence a resource consent is required.

The matters of discretion upon which consent will be considered are provided in AUP Section E.7.8. The primary issues related to the proposed quarry expansion are addressed in **Table E3**.

Table E3. Review of AUP matters of discretion related to groundwater diversion (refer to AUP E7.8.1 (6) (a))

AUP E7.8.1 (6) (a) Category		Predicted effect
i	Base flow in rivers and springs	The maximum baseflow depletion predicted for the Waitoki Stream during low flow conditions is 1.3 L/s, amounting to 10.3% of MALF for the stream (**Section 6.2.3**). The minimum flow requirement for the Waitoki Stream is provided in Table 1 of the AUP Appendix 2: River and stream minimum flow and availability. The stream falls under the category of 'Other rivers and streams', hence the default allocation limit is 30% of MALF and the minimum flow requirement is 85% of MALF. The implication is that the level of effects that may result from the proposed quarry expansion are within the allocation limits and associated baseflow reduction envisaged in the AUP criteria and will not violate minimum flow requirements hence no flow mitigation is recommended. It is also noted that this level of baseflow depletion is not predicted to manifest until 40 years into the excavation sequence. Monitoring both upstream and downstream is recommended to be undertaken. Although highly unlikely, if any adverse effect on streamflow or water quality is detected, mitigation measures are proposed as part of the Groundwater Diversion Permit Conditions.
ii	Wetland water levels and flows	There is one wetland within the Waitoki Catchment and it is not affected (**Section 6.2.4**).
iii	Lake levels	Not relevant (no lakes).
iv	Existing groundwater takes	No other groundwater takes are within the area affected by drawdown, therefore there will be no effects on other groundwater users in terms of bore production. The closest bore is at 70 Pebble Brook Road, situated across the Waitoki Stream which constitutes a hydraulic flow barrier except at times of maximum drawdown within the bore (**Section 6.2.2**). Contaminants reaching the bore is considered highly unlikely due to the low bore production rate of 20 m^3/day and the bore being located across the Waitoki Stream. Water quality monitoring in the quarry storage ponds, required under the proposed Water Quality Programme Consent Conditions offered by the Applicant, will serve as an early warning system for any potential bore contamination by triggering immediate testing of the bore if a trigger level breach is detected. If any adverse effect on flow or water quality is detected, mitigation measures are proposed as part of the Groundwater Diversion Permit Conditions.

AUP E7.8.1 (6) (a) Category		Predicted effect
v	Groundwater pressures and saline intrusion	Several nearby bores and piezometers are available to use as potential monitoring sites (refer **Figure 9**). The cone of depression will not extend anywhere close to the coast, hence there will not be any risk of saline intrusion (**Section 6.2.1**).
vi	Ground settlement	In the quarry area the dewatered material will be removed, therefore settlement cannot occur. The surrounding area is comprised of non-compressible Albany Conglomerate and only predicted to have a maximum of 7 m of drawdown which is not enough to cause land settlement in this type of material. In addition, there is no infrastructure in this area to be affected. Land settlement effects are addressed in **Section 6.2.5**.
vii	Surface flooding	The excavation will have a dewatering effect and will not increase flood risk in any area.
viii	Cumulative effects with other groundwater diversions	There are no other groundwater diversions within the area affected by the excavation cone of depression.
ix	Discharge of groundwater containing sediment or contaminants	Addressed in the Erosion and Sediment Control report included with the resource consent application (LDE 2023).
x	Effects on historic heritage sites	Based on a review of the AUP Overlay there are no heritage sites within the Waitoki Catchment. No heritage sites that will be affected.
xi	Terrestrial and freshwater ecosystems and habitat	Ecological effects are being addressed by Bioreasearches Ltd. It is presumed the total baseflow depletion for the entire catchment, generally under 2.0 L/s, will not cause harm to aquatic habitat and is within the allocation limits set in the AUP.

Summary

WWLA has completed a groundwater effects analysis as to support an application for fast-track consenting application for the expansion of the Kings Quarry site. The predicted effects on groundwater and groundwater related features within the Waitoki Catchment are considered to be minor, with no adverse consequences to people or the environment resulting from the proposed quarry excavation.

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1. Introduction

Williamson Water & Land Advisory (WWLA) was commissioned by Kings Quarry Limited to provide a groundwater effects analysis as to support an application for fast-track consenting application for the expansion of the Kings Quarry site. Kings Quarry currently covers an area of approximately 3.4 ha and has served as a source of high quality aggregate derived from Albany Conglomerate for over 50 years, though commercial extraction ceased in 1995 prior to recent efforts to restart operations under the ownership of the Semenoff Group.

This groundwater analysis documented in this report has been undertaken in collaboration with other consultants, in particular Aggretech and CMW Geosciences, also working on quarry design and geotechnical analyses respectively, related to the quarry expansion.

This analysis comprised two primary components:

1. Compiling existing information and developing a conceptual hydrogeological model of the site.

2. Transforming the conceptual model into a numerical groundwater model to be used as a tool for providing the groundwater assessment.

Figure 1 provides an overview, showing the current and proposed quarry extent and the surrounding area.

1.1 Objective and scope

The overall objective of the work is to support an Assessment of Environmental Effects (AEE) forming part of a resource consent application. The groundwater effects assessment quantifies the effects of quarry excavation on the local groundwater system. This analysis comprises the following:

a) Evaluation of the depth and extent of drawdown resulting from pit excavations;
b) Assessment of neighbouring bore interference effects;
c) Assessment of potential depletion effects on streams and wetlands within and adjacent to the proposed quarry area due to dewatering and drawdown;
d) Estimation of the rate and volume of groundwater seepage into the quarry; and
e) An assessment of predicted groundwater effects relative to Auckland Unitary Plan (AUP) criteria for groundwater diversions.

To achieve these objectives a 3D numerical groundwater model was developed, and documentation of the model's conceptualisation, calibration, scenario simulation, and predicted effects of quarry development are the subject of this report.

1.2 Project Overview

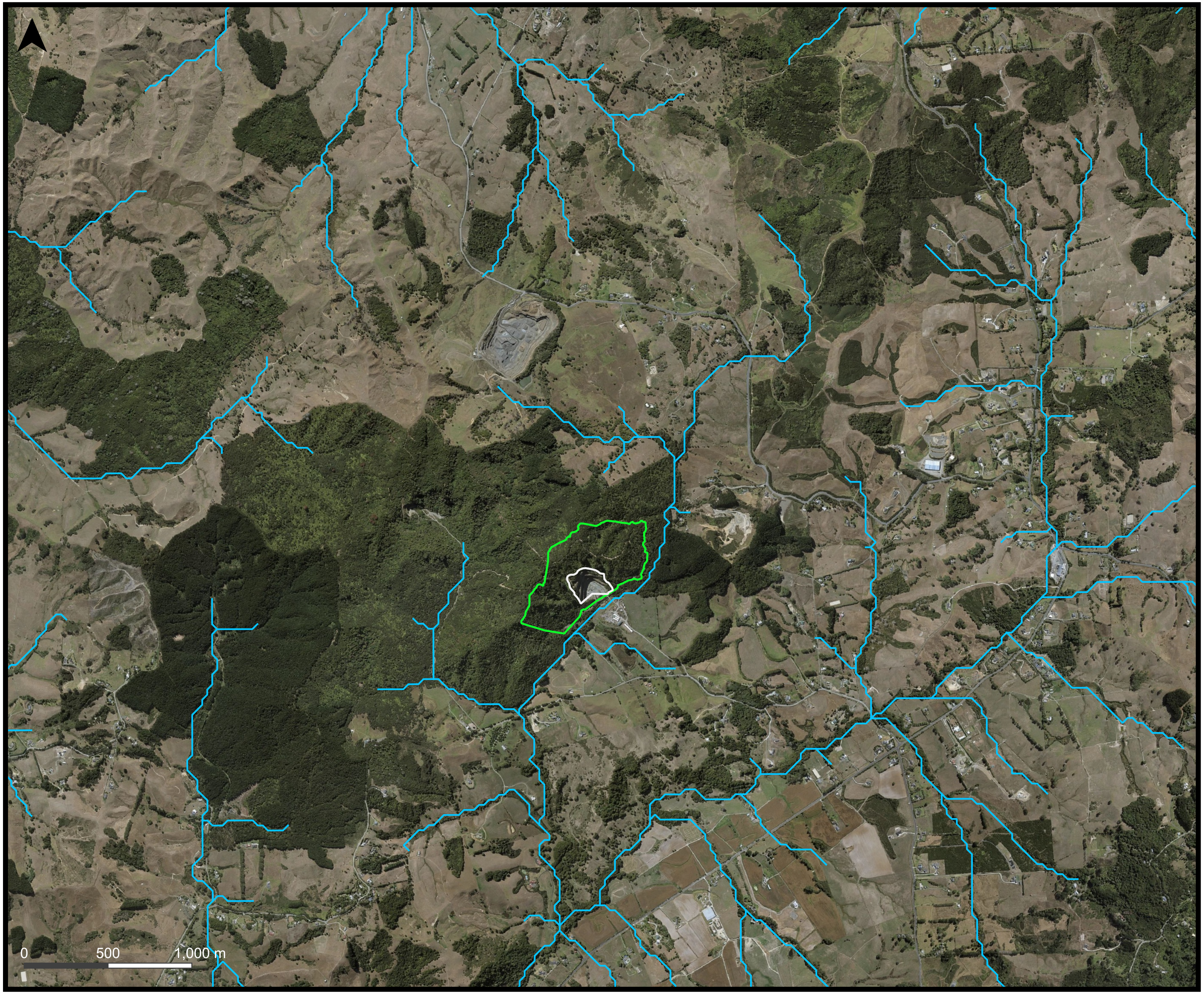
The proposal covers 45 years of quarry development. Site A comprises a cut/fill operation, where overburden material will be deposited following an initial excavation period. Site B comprises the primary quarry pit where excavation will be carried out after the fill site is established, beginning in year 6 and continuing through the duration of quarry operations, with the quarry expanding to approximately 29 ha in area after the full excavation period is complete.

1.3 Report Structure

The report comprises descriptions of:

- Environmental Conditions (**Section 2**);
- Conceptual Hydrogeological Model (**Section 3**);

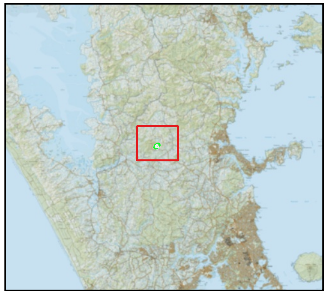
- Model Development (**Section 4**);
- Model Calibration (**Section 5**);
- Predictive Simulations and Results (**Section 6**);
- Auckland Unitary Plan (AUP) Chapter E7 Assessment (**Section 7**); and
- Conclusions (**Section 8**).



Map Title:
Overview of study area

Project:
Kings Quarry Groundwater Model

Client:
Semenoff Group Ltd.



Legend

- **Rivers/streams**
- **Existing Quarry**
- **Proposed quarry**

Data Provenance
Aerial imagery and land parcels from Land Information New Zealand

Drawn by: J Scherberg
01/11/2023

Layout Name
Fig 1 - King Quarry Overview

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Figure 1.

2. Environmental Conditions

The environmental conditions within and around the Kings Quarry site including climate, topography, drainage, soil, geological and hydrogeological characterisations are described in the following sections. Collectively, this data has been used to develop a conceptual model of the surface water hydrological characteristics, which is important in understanding of the sub-soil drainage and hence groundwater recharge characteristics for the study area.

The following sections describe the methodology of developing this conceptual understanding and translation of site physical characteristics into parameterisation of the Soil Moisture Water Balance Model (SMWBM), which is a daily catchment water balance accounting tool. The SMWBM was used to calculate catchment water balance components including interception loss, surface runoff, soil evaporation and groundwater recharge, with the key focus for this aspect of the project on the groundwater recharge component. Details of the setup and parameterisation of the SMWBM are provided in **Appendix A**.

2.1 Climate

Rainfall data from 1972-2020 was obtained from the closest NIWA Virtual Climate Station Network (VCSN) – Station 21795 to the Kings Quarry site. The VCSN network provides climate data interpolated on a 5 km grid across New Zealand, however the data is not available past November 2020. Rainfall data after November 2020 was sourced from the Warkworth EWS Station available through Cliflo (https://cliflo.niwa.co.nz/). A statistical evaluation was undertaken to determine that rainfall measured at the Warkworth station was the closest match to the VCSN data set.

A summary of a composite data set comprised of the VCSN and Warkworth rainfall data is presented in a box-whisker plot in **Figure 2**, showing monthly average rainfall and PET from the recorded data. The boxes represent the 25^{th} to 50^{th}, and 50^{th} to 75^{th} percentile ranges and the whiskers represent the most extreme years.

The data set shows that median rainfall is relatively consistent throughout the year, with peak average rainfall occurring in July, which has a median rainfall of 113 mm, and a typical range of 70 to 173 mm per month. Minimum average rainfall typically occurs in the peak summer months (January, February), with February median rainfall being 52 mm. PET peaks in summer, recording averages of ~ 140 mm per day in January, and minimum PET typically occurs in June with an average of ~ 19 mm per day.

Figure 3 shows monthly rainfall and cumulative departure from average rainfall. Cumulative departure shows the long term rainfall trend, specifically that a wet period occurred during the mid-1970s with relatively stable conditions through the mid-1990s, following by a prolonged dry period peaked in 2021 and ended abruptly with the heavy rainfall that has occurred in 2023. This pattern of climate data is reflected in this study as the climate data was used to estimate streamflow and groundwater recharge, as detailed in **Section 4.3** and **Section 5** of this report.

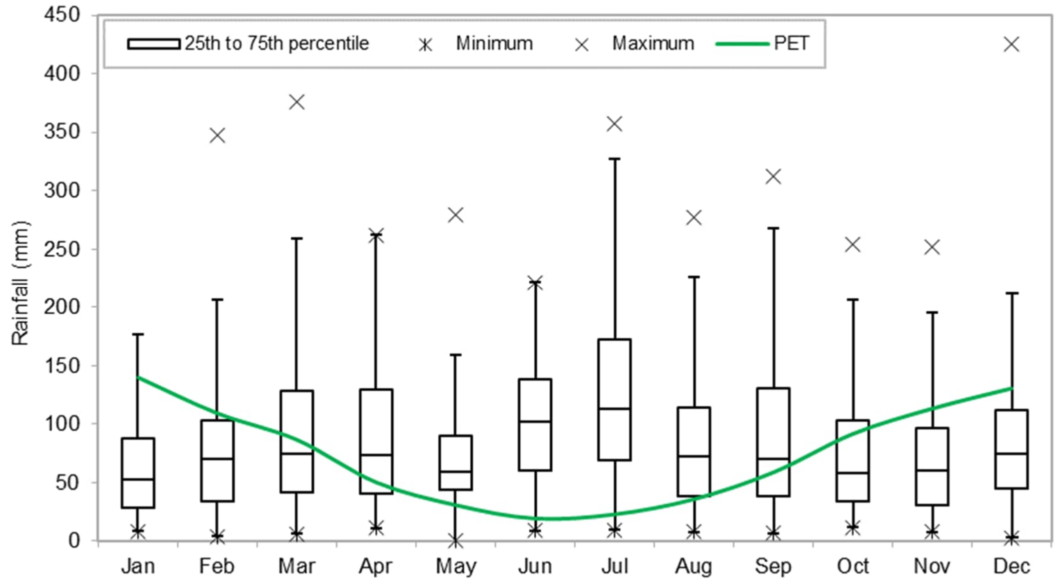


Figure 2. Monthly rainfall (box-whisker plot) and potential evaporation.

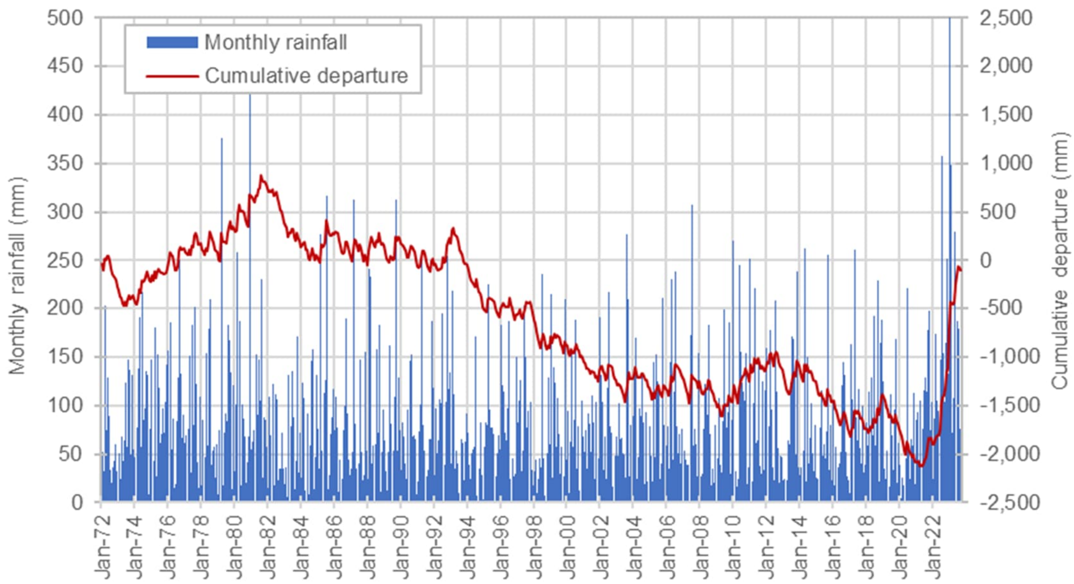
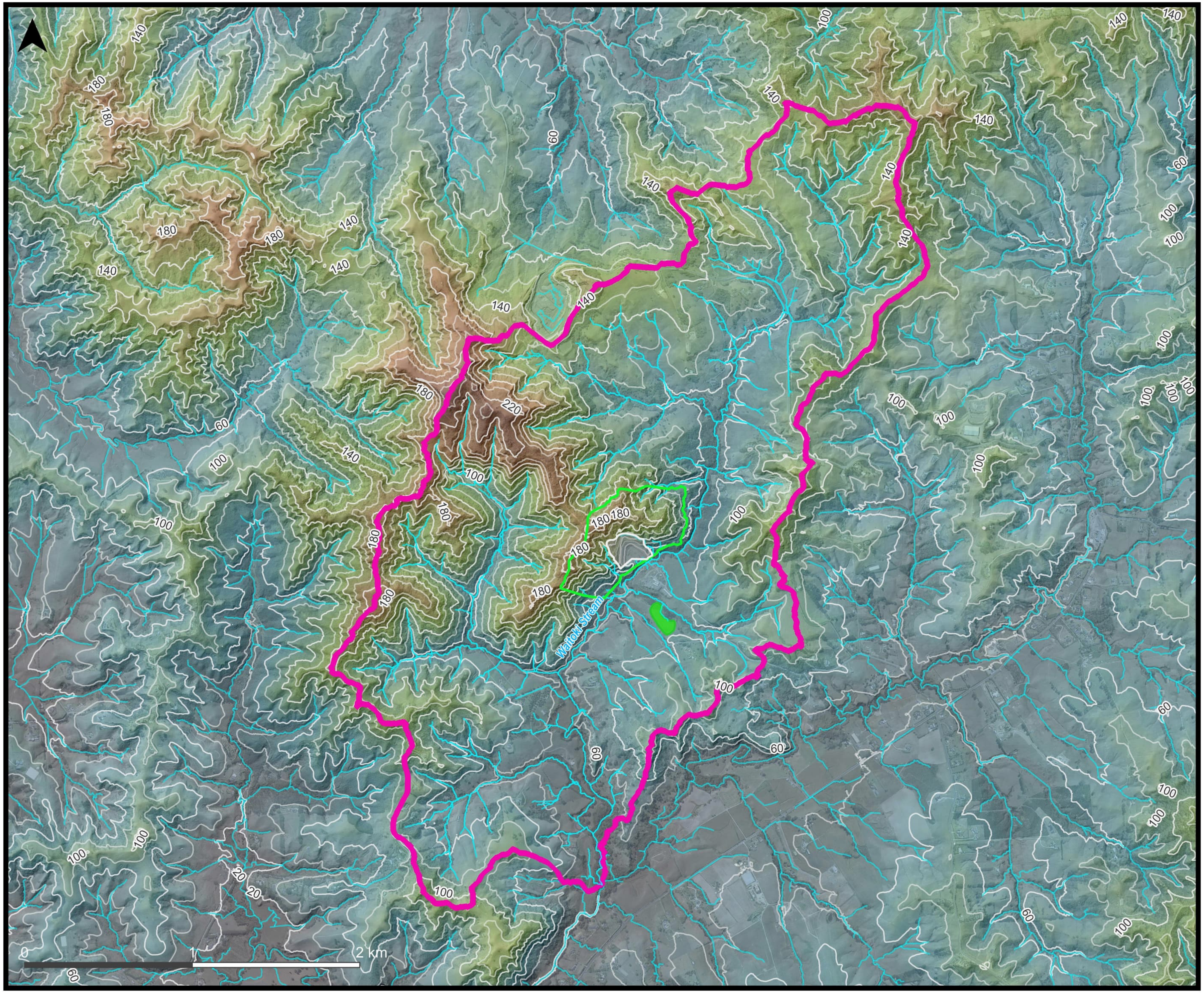


Figure 3. Monthly rainfall (1972-2023) and cumulative departure monthly total rainfall from an average month.

2.2 Topography and Drainage

Kings Quarry is situated within the Waitoki Stream catchment, which is part of the Kaukapakapa River Watershed. The topography comprises generally steep terrain with an average slope of 17 degrees and elevation ranging from 20 to 250 m above mean sea level (mAMSL) across the catchment area. The highest portion of the catchment is the ridge line to the northwest of the existing quarry. Drainage is toward the south-southwest.

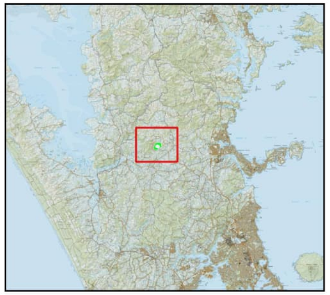
Topography within the Waitoki Catchment is depicted in **Figure 4**.



Map Title:
Study area topography and catchment

Project:
Kings Quarry Groundwater Model

Client:
Semenoff Group Ltd.



Legend

- **Waitoki Catchment (Model boundary)**
- **Existing quarry**
- **Proposed quarry**
- **Streams / rivers**
- **Elevation contours (mAMSL)**
- **Wetland**

Elevation (mAMSL)
250
4.9

Data Provenance
Aerial imagery and land parcels from Land Information New Zealand

Drawn by: J Scherberg
01/11/2023

Layout Name
Waitoki Catchment

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Figure 4.

2.3 Wetlands

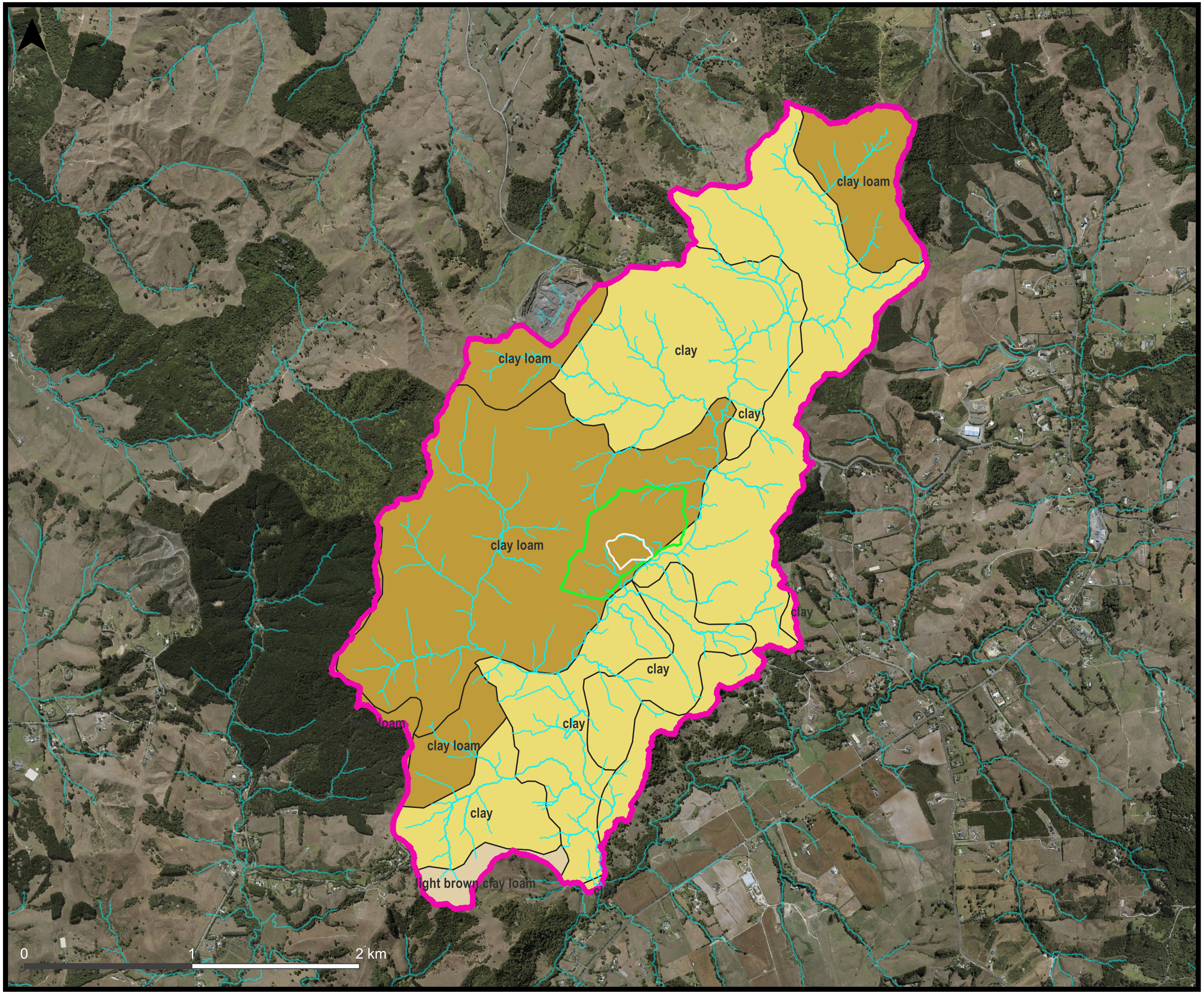
The AUP Wetland Management Areas Overlay was reviewed for the presence and location of wetlands within the Waitoki Catchment to be referenced in the assessment of environmental effects included in this analysis. One wetland was found, approximately 350 m south of the existing quarry, as is shown in **Figure 4**.

2.4 Soils

Soils over the study area were assessed based on information from the Fundamental Soils Layer (FSL) developed by Manaaki Whenua Landcare Research (1999). Data indicates that the soils across the model area are clay to the north of the proposed excavation area and to the south of the Waitoki Stream, with clay loam through the proposed quarry and in the area to the west of the quarry (**Figure 5**).

The soil metadata corresponding to the soils with the Waitoki Catchment indicate that the clays have poor to moderate (“imperfect”) drainage, with the slowest draining areas to the north of the quarry area. Areas of clay loam, which predominantly occur on steeper terrain are shown to be well drained.

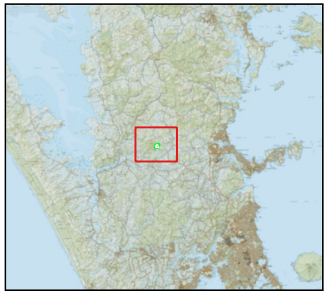
This information was used to inform the soil infiltration related parameter (ZMAX) in the SMWBM.



Map Title:
Soil classifications

Project:
Kings Quarry Groundwater Model

Client:
Semenoff Group Ltd.



Legend

- **Waitoki Catchment (Model boundary)**
- **Streams / rivers**
- **Proposed quarry**
- **Existing quarry**

FSL soil classifications

- **clay**
- **clay loam**
- **light brown clay loam**

Data Provenance
Aerial imagery and land parcels from Land Information New Zealand

Drawn by: J Scherberg
29/10/2023

Layout Name
Soil type

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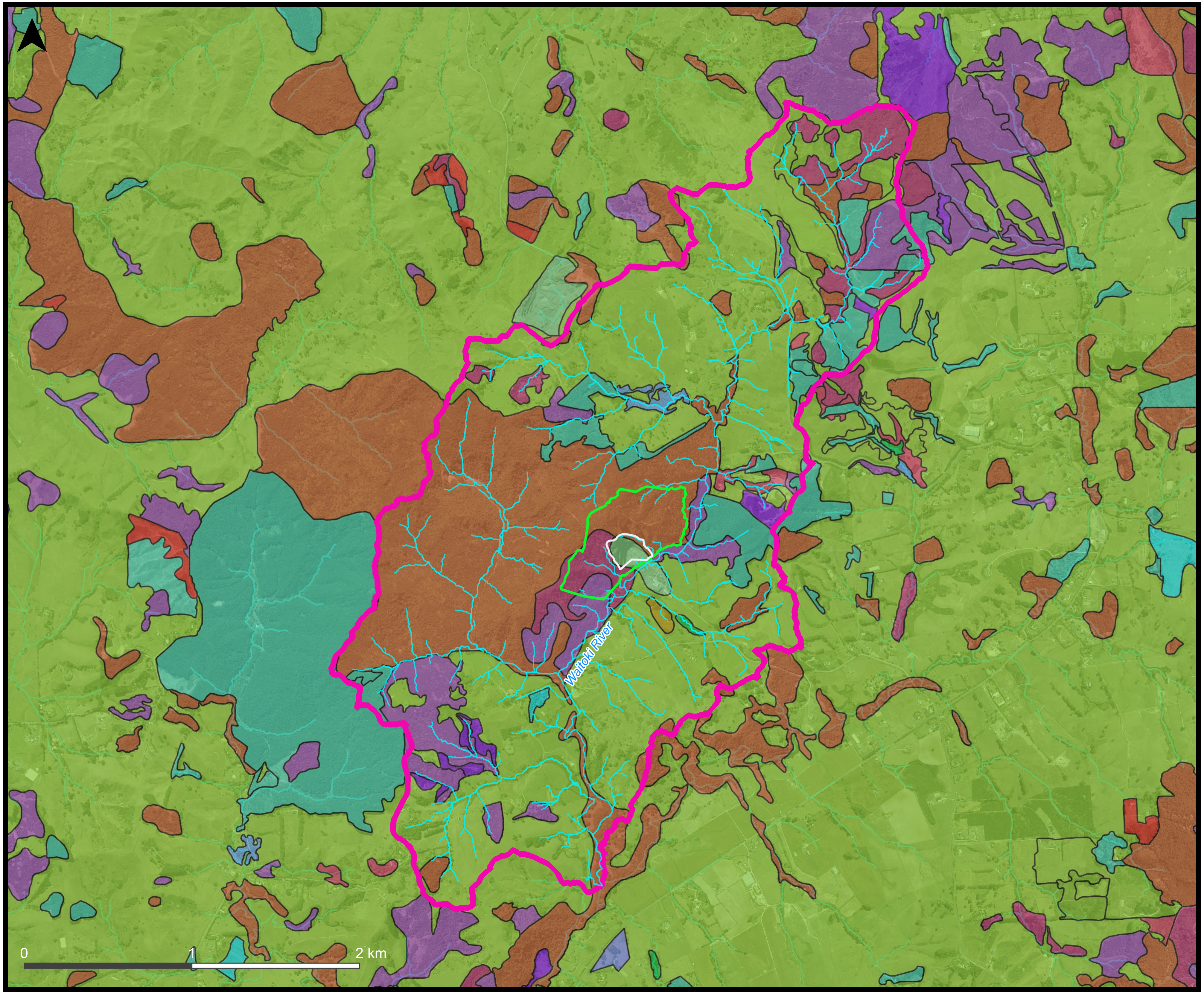
Figure 5.

2.5 Land Cover

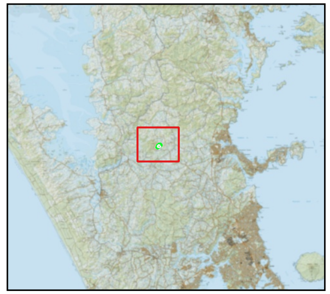
Land use across the Waitoki Catchment was assessed based on the New Zealand Land Cover Database (Figure 6). High Producing Exotic Grassland is the predominant land cover, accounting for 50% of the study area, including the hillsides directly south of the quarry. The hills to the north and northeast of the quarry are covered in indigenous forest, with Broadleaved Indigenous Forest and Manuka/Kanuka scrubland in the stream valley below the quarry.



Map Title:
Land use

Project:
Kings Quarry Groundwater Model

Client:
Semenoff Group Ltd.



Legend

- Waitoki Catchment (Model boundary)
- Streams / rivers
- Existing quarry
- Proposed quarry

Land Cover Classification
- Broadleaved Indigenous Hardwood
- Deciduous Hardwoods
- Exotic Forest
- Forest - Harvested
- Gorse and/or Broom
- Freshwater Vegetation
- High Producing Exotic Grassland
- Indigenous Forest
- Lake or Pond
- Low Producing Grassland
- Manuka and/or Kanuka
- Orchard, Vineyard
- Short-rotation Cropland
- Surface Mine or Dump

Data Provenance
Aerial imagery and land parcels from Land Information New Zealand

Drawn by: J Scherberg
01/11/2023

Layout Name
Land Cover

WILLIAMSON WATER & LAND ADVISORY

Figure 6.

2.6 Geology

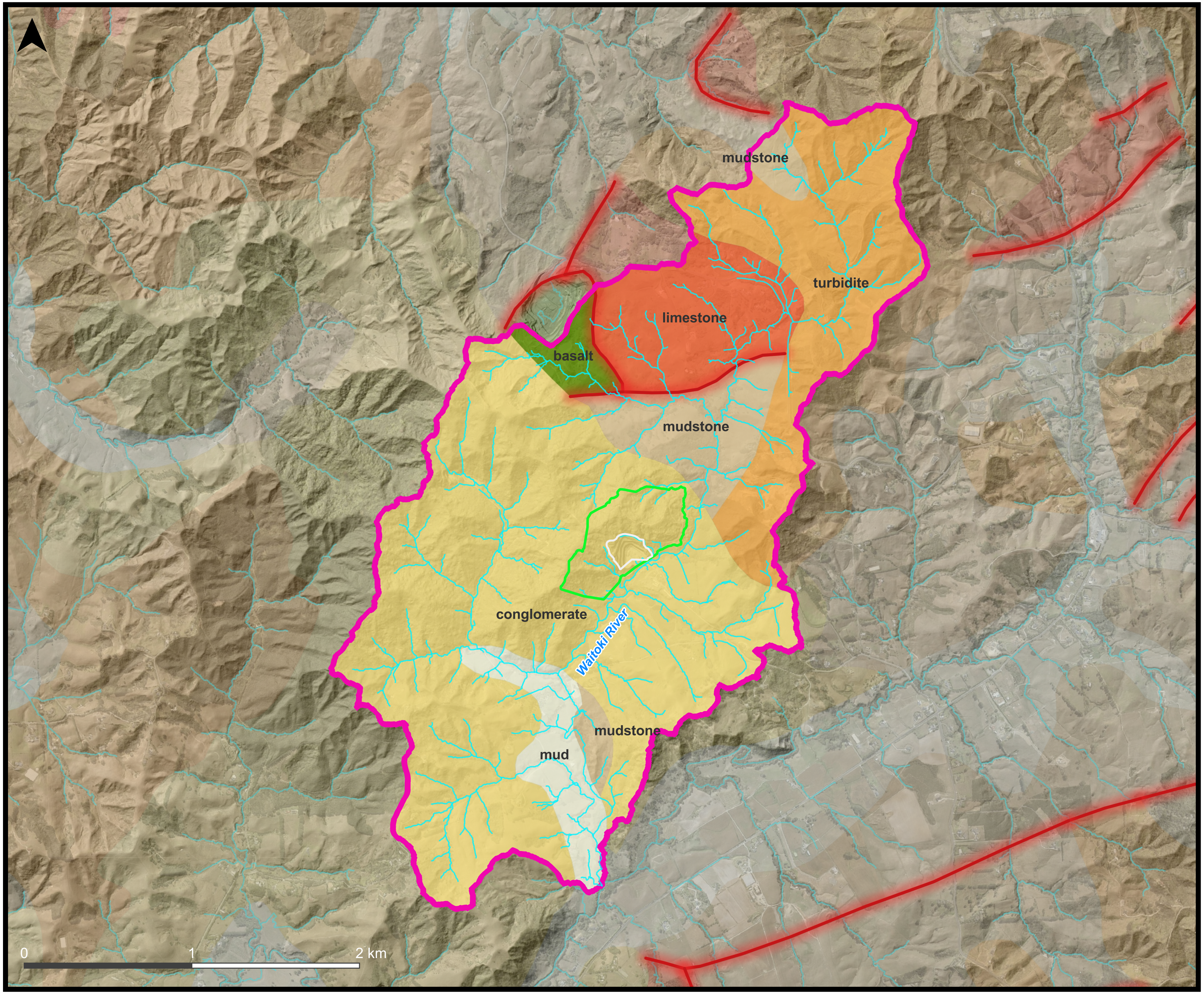
Kings Quarry is situated within the Northland Sedimentary Basin, in an area featuring thick deposits of Albany Conglomerate of the Waitemata Group, deposited approximately 20 million years ago in slurries of gravel, sand and mud (Grant Fisher Industrial Geology (GFIG), 2009). This conglomerate is the target material for quarry production and underlies nearly the entire property where the quarry is located. Four classifications of conglomerate are noted to occur at the site, which vary in terms of the proportion of sandstone, limestone, and mudstone content within the matrix. Further details of the conglomerate material and their bedding structures is provided in GFIG (2009).

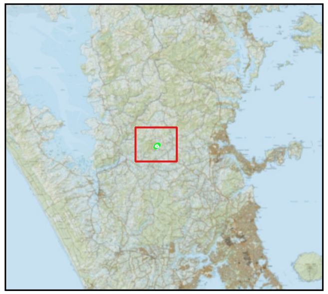
The surface geology of the broader catchment that comprises the complete study area for this analysis includes areas of Northern Allochthon mudstone, limestone, and basalt to the north/northwest of the quarry and Tauranga Group mud alluvial deposits in the low-lying valley of the lower reach of the Waitoki Stream (Tonkin & Taylor 2017).

The geology across the Waitoki Stream Catchment as defined in QMAP[1] is shown in **Figure 7**. The geology coverage shown in **Figure 7** was the basis for the distribution of geologic materials through the study area. There are several mapped faults within the catchment, though none directly intersect the quarry area and all are listed as being inactive.

There appears to be an unmapped faut dipping at approximately an 80 degree angle, visually evident in the quarry headwall, as highlighted in the left-hand photo in **Figure 8**, which shows the Albany Conglomerate in situ. The right-hand photo in **Figure 8** shows conglomerate material that has eroded from the bank of a nearby stream.

[1] GNS Science. (2012). 1:250 000 Geological Map of New Zealand [Data set]. GNS Science. https://doi.org/10.21420/QF82-7D42





Map Title:
Surface geology

Project:
Kings Quarry Groundwater Model

Client:
Semenoff Group Ltd.

Legend

- **Waitoki Catchment (Model boundary)**
- **Streams / rivers**
- **Proposed quarry**
- **Existing quarry**
- **Faults (GNS)**

Geology units (QMAP)

- **Tangihua Complex Basalt**
- **Albany Conglomerate**
- **Mahurangi Limestone**
- **Tauranga Group Mud**
- **Hukerenui Mudstone**
- **East Coast Bays Formation Turbidite**

Data Provenance
Aerial imagery and land parcels from Land Information New Zealand

Drawn by: J Scherberg
01/11/2023

Layout Name
Geology

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Figure 7.

Figure 8. Site photos of geological materials. L) Headwall at King's Quarry (apparent fault is highlighted). R) Albany conglomerate and gravels.

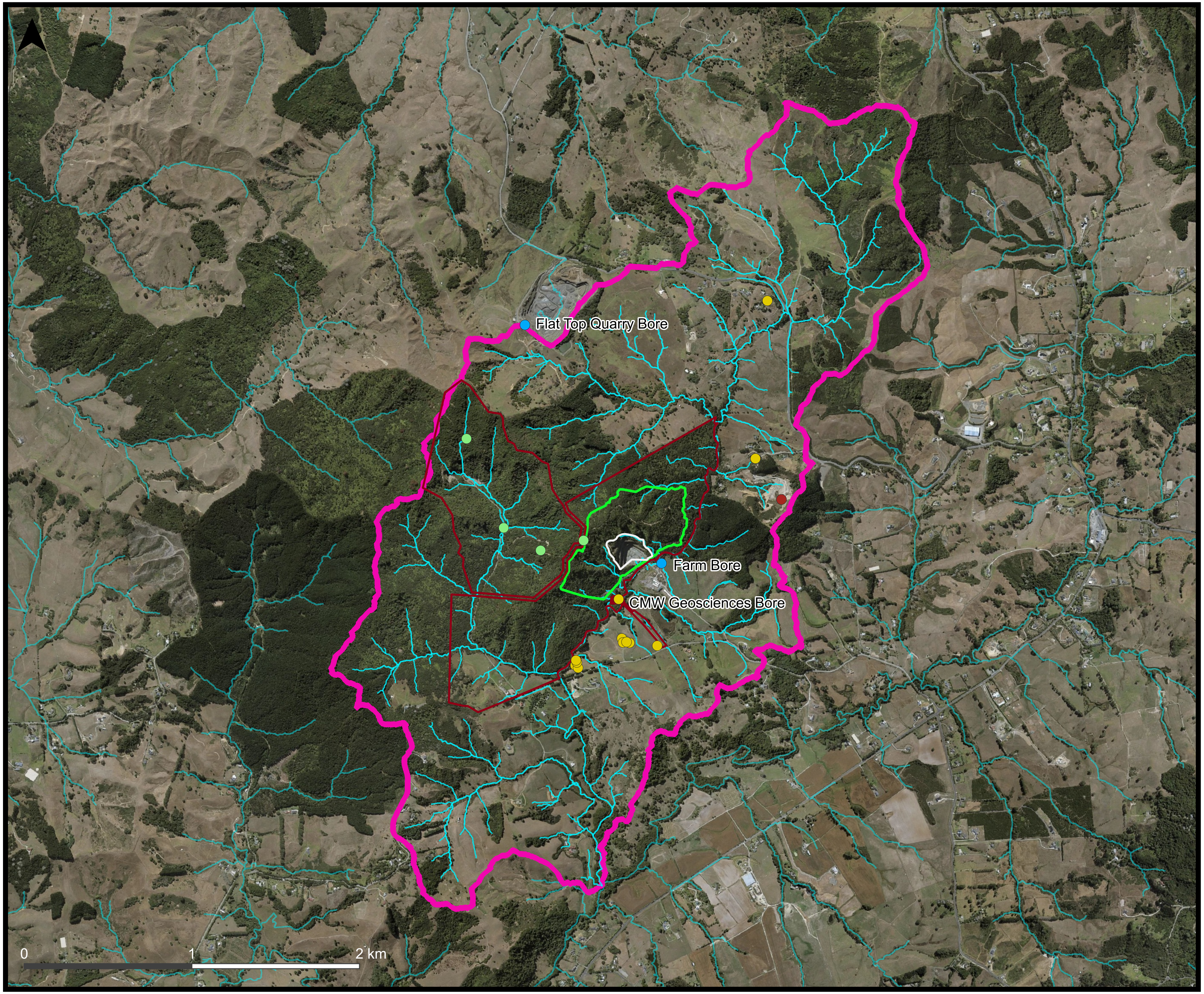
2.7 Hydrogeology and Groundwater

2.7.1 Neighbouring Bores

A review of the New Zealand Geotechnical Database was undertaken to identify bores within 2 km of the proposed quarry site. 19 bore and hand auger locations are presented in **Figure 9**. The following descriptions summarise these bores:

- There are 11 hand augers;
- One shallow (12 m depth) bore drilled by CMW Geosciences for geotechnical analysis;
- Four bores on the Kings Quarry property were drilled for geological exploration (GFIG 2009);
- One bore drilled in 1974 for Wainui Meats was not productive (dry) and abandoned; and
- Two water supply bores; one for Flat Top Quarry to the north of Kings Quarry, and one on a farm approximately 150 m south of the quarry. The Flat Top Quarry bore is noted as being dry at the time of airlift testing in the drillers notes; though the drilling notes also mention static water level measurements.

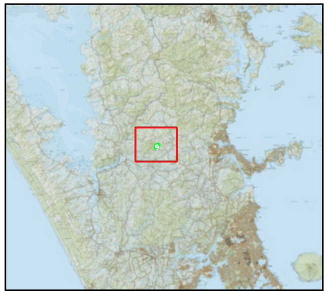
Of the bores listed, only the Farm Bore near the quarry and the CMW Geosciences bore have water level measurements that are likely to reflect regional groundwater levels. The CMW bore is directly adjacent to the Waitoki Stream and likely to be hydraulically connected to surface water.



Map Title:
Bore locations

Project:
Kings Quarry Groundwater Model

Client:
Semenoff Group Ltd.



Legend

- Waitoki Catchment (Model boundary)
- Streams / rivers
- Existing quarry
- Proposed quarry
- Parcel boundary

Bore locations

- Dry bore
- Geological exploration
- Geotechnical
- Water supply

Data Provenance
Aerial imagery and land parcels from Land Information New Zealand

Drawn by: J Scherberg
25/10/2023

Layout Name
Bore locations

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Figure 9.

2.7.2 Hydrogeological Field Testing

Estimates of the hydraulic conductivity (k) of subsurface materials are based on the previous hydraulic testing as summarised in PDP (2008). The Albany Conglomerate (Paremoremo Formation) was found to have a conductivity of $2x10^{-7}$ m/s, indicate low-moderate permeability. All other materials in the study area had lower permeability, with the Northland Allochthon and Limestone having conductivity values of $1.0x10^{-8}$ and $3.6x10^{-8}$ m/s, respectively.

3. Conceptual Hydrogeological Model

The proposed quarry will reside in the Waitoki Stream Catchment, which receives on average 1,054 mm/annum of rainfall (1972-2022). The following provides an outline of how rainfall partitions within the catchment.

- Groundwater recharge within the catchment occurs solely through the percolation of rainfall through the soil profile. It is estimated that average annual recharge amounts to 61 mm or 5.8% of annual rainfall (further discussion in **Section 4.3.2**).
- In the areas to the north of the quarry, the soils are clay based and the land is relatively flat, implying a high proportion of rainfall runoff and recharge occurring only slowly through the clay soils, and with relatively long groundwater residence time.
- The area to the west of the quarry has lower infiltration and groundwater residence time due to steeper gradients, despite somewhat higher permeability clay loam soils. A relatively high proportion of rainfall becomes direct runoff or shallow soil water that discharges to streams rapidly following rain events.
- Shallow groundwater discharges to the headwater streams and tributaries while deeper groundwater flow converges toward the Waitoki Stream.
- Several mapped and unmapped faults occur within the model area. None of these faults are known to be active. This could effectively increase or decrease groundwater flow through the faults, however any effects are currently unknown.

4. Numerical Model Development

A single layer numerical model was developed in AquaVeo's Groundwater Modelling System (GMS) using the MODFLOW Unstructured Grid (MODFLOW-USG) code developed by the United States Geological Survey (USGS). The model boundary was defined by catchment boundaries, derived using the QGIS watershed analysis function.

4.1 Modelling Methodology

Two versions of the model were developed – a steady state model for model calibration and a transient model for the predictive simulation and effects assessment. **Section 4.3.2** describes how groundwater recharge was assigned under both model states, while **Section 4.3.3.1** describes how boundary conditions for the Kings Quarry excavation were assigned for the transient model.

4.2 Grid Layout

4.2.1 Horizontal Discretisation

The model was developed using a grid refined to a higher resolution of 3 m in the main streams around the quarry and 12 m around important features such as the quarry excavation areas, as shown in **Figure 10**. In the other areas, larger cells were used increasing to 200 m resolution at the outer edges of the model domain. This spatial variation in grid size allows for high resolution in areas of potential environmental sensitivity or significant alteration during mining, while larger grid cells in the areas further from the quarry allow more efficient model run times while still providing information to assess groundwater conditions at a larger scale.

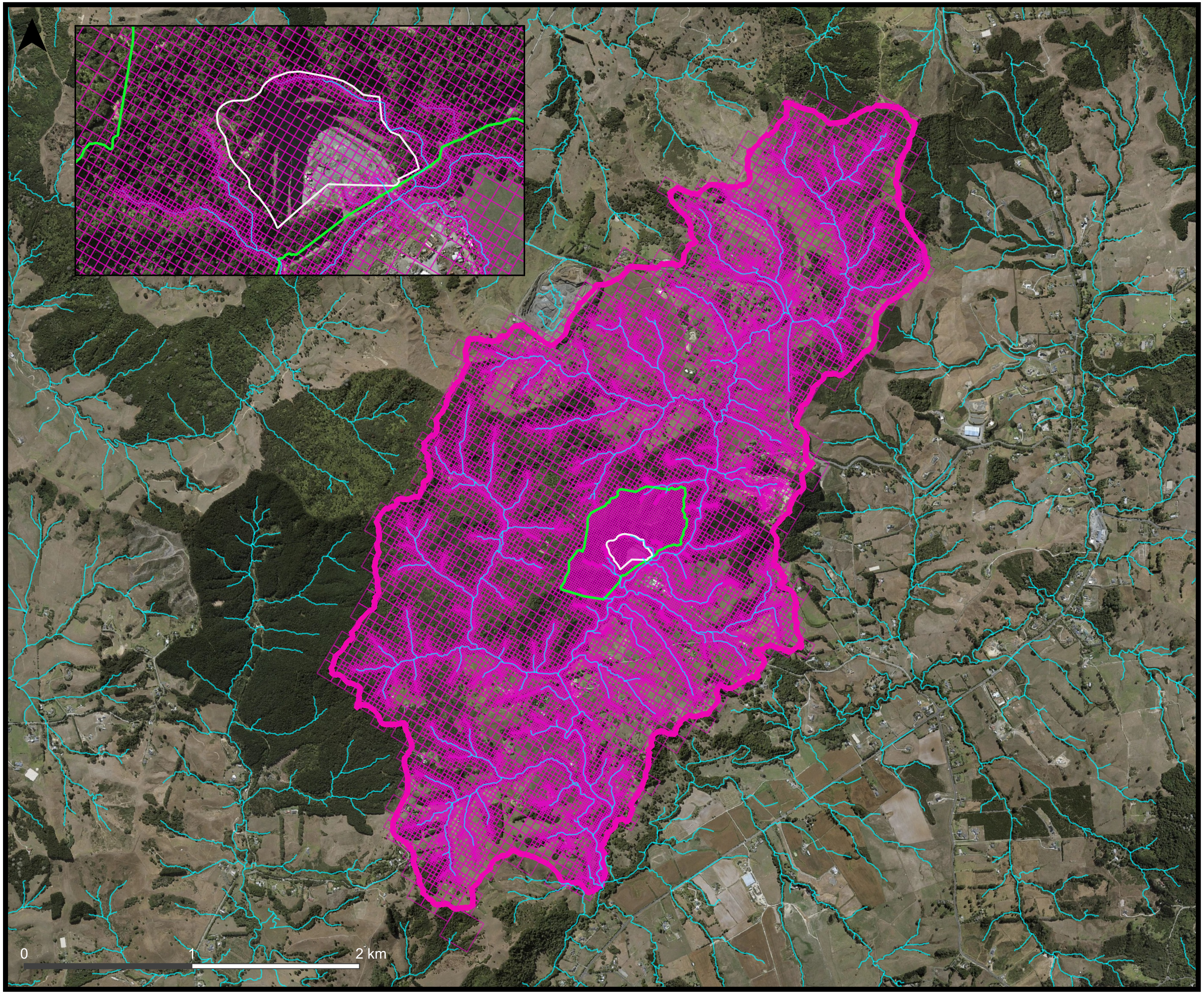
4.2.2 Vertical Discretisation

A single layer model was developed, with the surface elevations of the model cells defined by 1 m resolution LiDAR data available the LINZ[2]. The model base was set to an elevation of -100 m RL, in order that the lower boundary was well below the potential effects of the dewatering simulations. Hence, at the lowest topographical area, the model thickness is approximately 120 m and at the highest point in the model approximately 350 m.

The model was constructed with a single layer representing the geologic material as a bulk unit, with lateral variation in hydraulic conductivity based on the geologic unit identified in QMAP, and no vertical variation given that there are no reliable observations of vertical pressure gradients. Given this physically-based conceptual model premise, a single layer model was selected to avoid unnecessary complexity in the representation of the materials being modelled due to limited bore log information and a lack of monitoring data.

The 1-layer modelling approach also reduces the parameterisation requirements and the computation complexity regarding issues related to re-wetting of dry cells. As explained above, this is considered an appropriate model-build decision for this application.

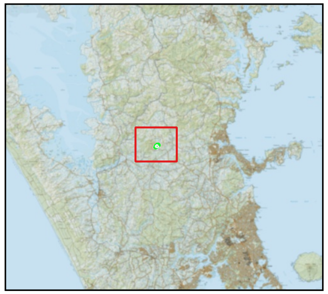
[2] https://data.linz.govt.nz/layer/106410-auckland-north-lidar-1m-dem-2016-2018/



Map Title:
Study area topography and catchment

Project:
Kings Quarry Groundwater Model

Client:
Semenoff Group Ltd.



Legend

- **Waitoki Catchment (Model boundary)**
- **Model grid**
- **Streams / rivers**
- **Existing quarry**
- **Proposed quarry**

Data Provenance
Aerial imagery and land parcels from Land Information New Zealand

Drawn by: J Scherberg
30/10/2023

Layout Name
Model Grid

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Figure 10.

4.3 Boundary Conditions

4.3.1 Streams

Stream and wetland boundary conditions were applied to all surface water features as shown in **Figure 4**.

Drain cells were assigned to the major stream corridors with stream bed elevation set using the intersection of the stream lines with the LiDAR elevation coverage. Stream conductance was set to a high value so that the only restriction on losses from the stream to the underlying groundwater system were driven by the hydraulic gradient between the stream bed and the aquifer, and the hydraulic conductivity intervening geological materials.

4.3.2 Groundwater Recharge

The calculation of groundwater recharge applied in the groundwater model was undertaken using the SMWBM to derive a catchment scale water balance based on climate and physical properties. Calibration of the SMWBM for this purpose is discussed in **Section 5**.

The key parameters used in the SMWBM are summarised in **Table 1**, with further detail provided in **Appendix A**. The resulting water balance is shown in terms of proportion of rainfall in **Table 2**. The groundwater recharge calculated in this analysis averaged 61 mm/year (5.8 % of annual rainfall).

Table 1. Land cover SMWBM parameters and water balance components.

Land Cover	SMWBM Parameters			
	ST	ZMax	FT	PI
	(mm)	(mm/hr)	(mm/d)	(mm)
Waitoki Catchment	310	1.5	0.7	2

Notes: ST is soil depth (mm); Zmax is maximum soil infiltration rate (mm/hr); FT is maximum sub-soil drainage rate; PI is canopy interception (mm).

Table 2. Simulated water balance from SMWBM.

Land Cover	Water Balance Components									
	Interception Loss		Evapo-transpiration		Surface Runoff		Groundwater Recharge		Change in soil storage	
	% of rainfall	mm/year	% of rainfall	mm/year	% of rainfall	mm/year	% of rainfall	mm/year	% of rainfall	mm/year
Waitoki Catchment	16.1	169.7	26.7	281.5	51.6	544.0	5.8	61.2	-0.1	-1.1

4.3.3 Mining Areas

4.3.3.1 Kings Quarry Excavation

To simulate the planned excavation development of Kings Quarry, a time-series was developed using the estimated surface elevation of the excavations in a sequence corresponding to the 45-year quarry development sequence provided by Aggretech. These are summarised as follows:

- ***Site A*** - comprises a cut/fill operation, where overburden material will be deposited following an initial 5 year excavation period where the site is established. The cut/fill sequence for Site A has been provided in 1 to 2 year increments for the first 5 years of quarry operation.

- ***Site B*** - Site B comprises the primary quarry pit where excavation will be carried out over the duration of quarry operations. Excavation will begin in year 6, after Site A is established. The quarry will expand to approximately 29 ha in area after the full excavation period is complete. The progression of the excavation levels has been provided as a series of 5-year excavation periods.

Drain boundaries were used in excavation areas to account for dewatering that will occur over the course of quarry development. The drain elevations were lowered in accordance with the quarry excavation sequences that were provided. The quarry is designed such that the excavation does not extend below 44 mAMSL which is several meters above the level of the Waitoki Stream bed adjacent to the quarry to assure that the quarry does not cause stream dewatering.

Figure 11 shows a detail of the post-excavation land surface at Site B and infill in Site A. **Figure 12** shows a 3-D rendering of the existing quarry and the post-excavation quarry.