Volume 2: Water Resources Analysis

Northland Water Storage and Use Project

NORTHLAND REGIONAL COUNCIL

WWLA0156 | Rev. 6

27 March 2020

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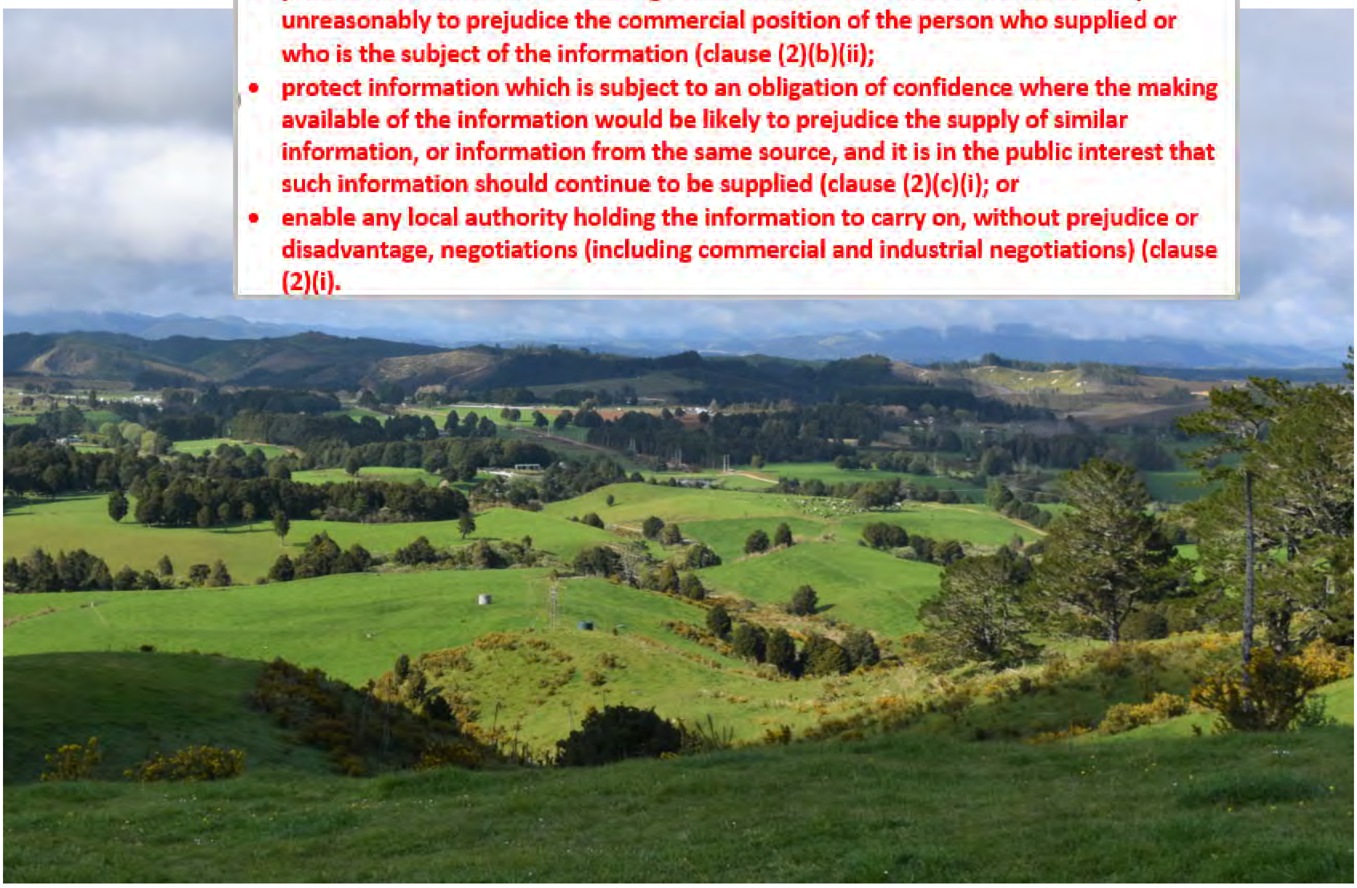

Northland Water Storage and Use Project

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1. Introduction

Williamson Water & Land Advisory (WWLA) was commissioned as the lead contractor with partners Riley Consultants and a number of other experts by Northland Regional Council (NRC) in August 2019 to undertake the Northland Water Storage & Use Project (NWSUP): Pre-feasibility Demand Assessment and Design Study.

NRC has previously undertaken two studies[1] that identified two areas within the Mid North and Kaipara worthy of further investigation for potential irrigation and water supply through reservoir storage. These areas are being investigated in conjunction with the Far North District Council (FNDC) and Kaipara District Council (KDC) respectively, with support from the Provincial Growth Fund.

This Pre-feasibility Demand Assessment and Design Study is the next phase in the investigation of viable water storage and water use infrastructure within the Mid-North (**Figure 1**) and Kaipara areas (**Figure 2**).

The goal of the project is to allow environmental improvement and economic development to occur within the water use command areas, with a net positive socio-economic impact to the surrounding local communities.

The following suite of reports have been prepared to determine the viability of potential schemes:

1. ***Volume 1:*** Command Area Refinement;
2. ***Volume 2:*** Water Resources Assessment (this report);
3. ***Volume 3:*** Conceptual Design and Costing; and
4. ***Volume 4:*** Analysis and Recommendations.

1.1 Report Structure

This report details the water resources analysis component of the pre-feasibility assessment, considering local regulations, the sources and quantity of water available for harvesting, and first pass high level identification of where such water could be stored. Consideration of how water sources (rivers/streams) and storage options are linked is presented in Volume 3 – Conceptual Design and Costings.

This report is structured as flows and comprises of:

- review of relevant regulatory frameworks **(Section 2)**;
- catchment delineation (**Section 3**);
- catchment flow modelling (**Section 4**)
- considerations of alternative water sources (**Section 5**);
- potential implications of climate change (**Section 6**);
- high-level storage identification (**Section 7**);
- development and refinement of a long list of storage options (**Section 8**); and
- summary and conclusion (**Section 9**).

[1] Opus (2015) Northland Strategic Irrigation Infrastructure Study.
Opus (2017) Scoping of Irrigation Scheme Options in Northland.

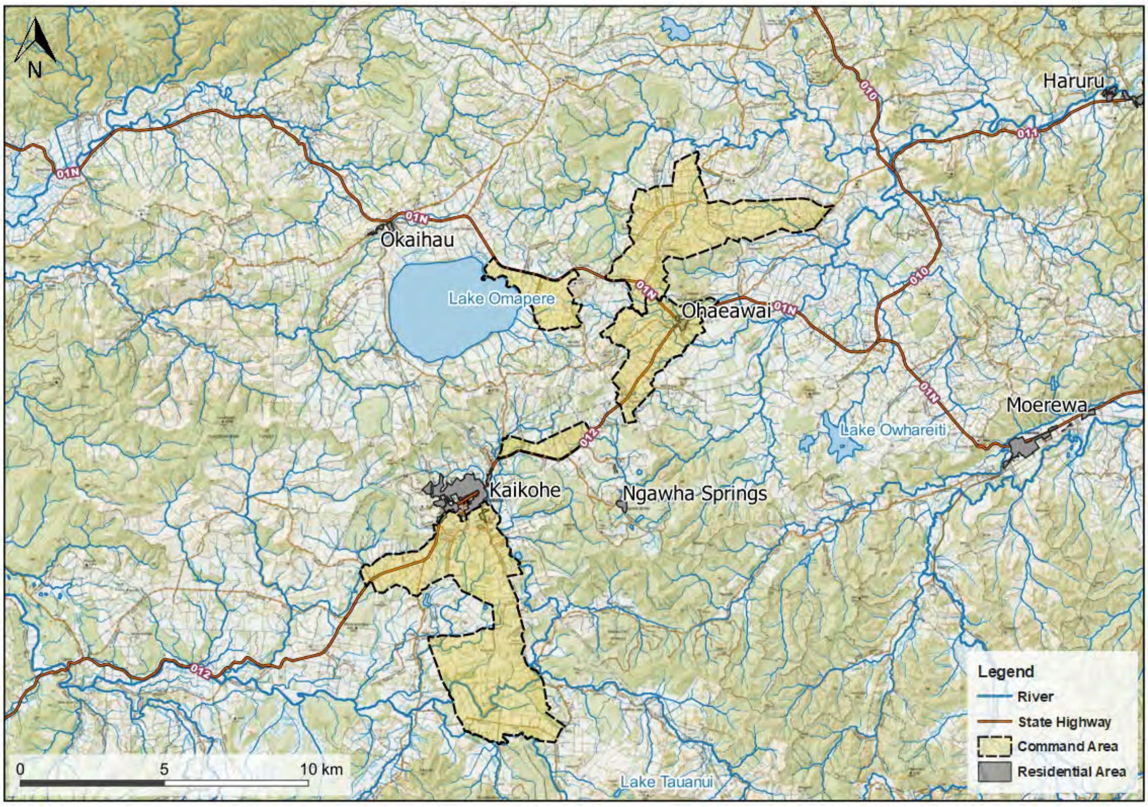

Figure 1. Mid-North study area locality.

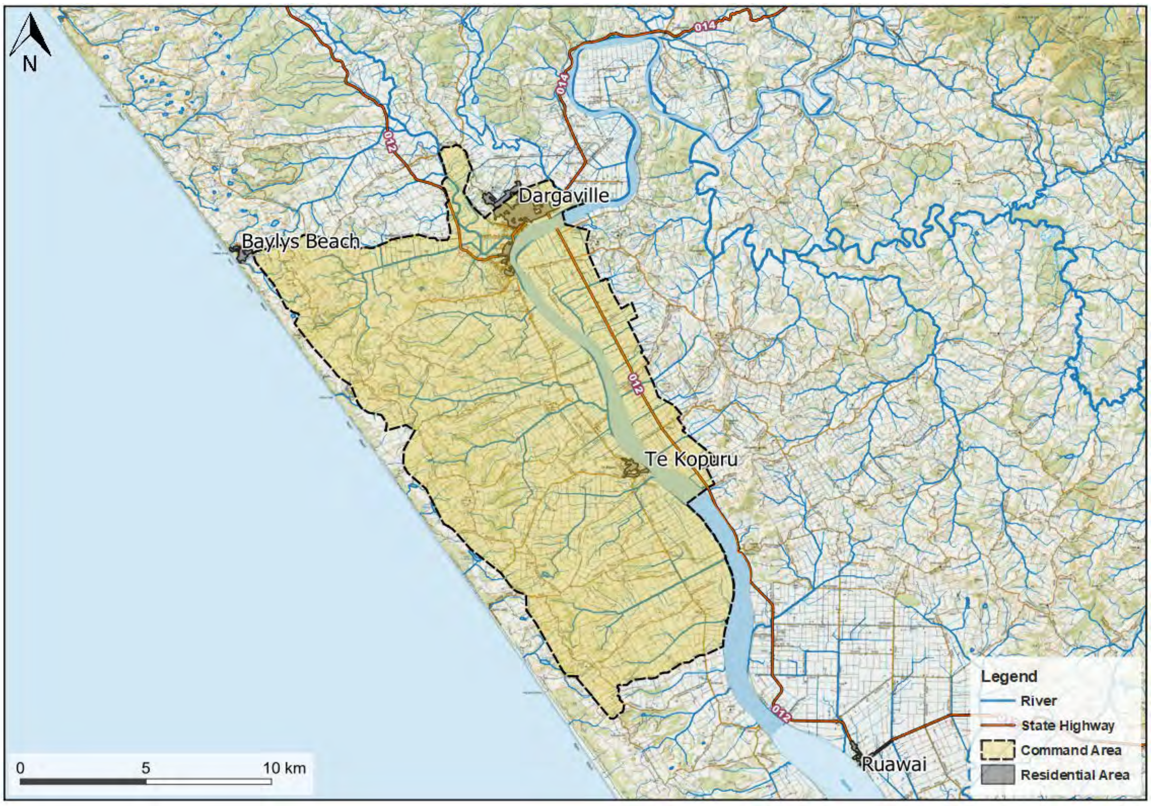

Figure 2. Kaipara study area locality.

2. Water Allocation, Harvesting Regimes & the Storage of Water

2.1 Overview

Primary production is the backbone of Northland's economy. The sector is dependent on access to and the use of water, which means that security of supply is very important. Consequently, water storage facilities offer a means of resilience for this sector against likely increases in the frequency of droughts and reductions in overall annual rainfall.

While water storage reservoirs can have significant negative effects and thus tend to be extensively regulated, they can also have considerable positive effects and so rules and standards offer the capability to balance the opportunities within future management proposals for water storage options, including that greater security of supply will allow for more future planning and investments, which in turn will lead to increased productivity.

The following sections look at the regulatory framework which applies to the use and development of freshwater resources in the Kaipara and Mid-North study areas.

2.2 Relevant Regulatory Framework

Section 14 of the Resource Management Act 1991 (RMA) restricts the taking, use, damming, diversion or use of water. Under s14 RMA, a person is prohibited from taking, using, damming, diverting or using fresh water unless allowed by a:

- national environmental standard; or
- rule in a regional plan as well as a rule in a proposed regional plan for the same region (if there is one); or
- resource consent; or
- it is for an individual's reasonable domestic needs or the reasonable needs of a person's animals for drinking water; or
- emergency or training purpose in accordance with Section 48 of the Fire and Emergency New Zealand Act 2017.

There is currently no national environmental standard which overrides the restriction set down in s14 RMA.

The relevant plan and proposed regional plan that contain rules relating to s14 RMA in the Kaipara and Mid-North study areas are the:

- Regional Water and Soil Plan for Northland 2004 (RWSP); and
- Proposed Regional Plan for Northland (Appeals Version – 29 July 2019) (PRPN).

It is noted that the rules in the RWSP are only relevant where rules in the PRPN are under appeal.

The following sections summarise the rules directly relating to the harvesting and storage of water along with their classifications.

2.3 Water Allocation and Harvesting Consenting Requirements

The following sections of this document summarise the planning framework that pertain to water resource use and development.

2.3.1 Policy Direction

Both the RWSP and PRPN contain objectives and policies which guide all persons exercising functions and powers under the RMA as to what they should be considering for development proposals.

Objectives and policies will be used in consenting decisions to establish the relative importance of competing considerations, and to inform the ultimate determination of grant or decline of consents. Furthermore, the nature of objectives and policies are extremely important to resource development proposals that are subject to Non-complying activity rule classifications in the relevant plans as is discussed below in **Section 2.4**.

The PRPN contains objectives which translate regional nuances from higher-order policy documentation – in particular, the New Zealand Coastal Policy Statement 2010, the National Policy Statement for Freshwater Management 2014 (Amended 2017) and the Regional Policy Statement for Northland 2016 (RPS). PRPN policies have been included to better implement the objectives stated.

The freshwater policy direction in the PRPN provides more of an instructional vision for Northland's freshwater resources through a balanced approach to social, cultural, and economic benefits of infrastructure proposals, and in particular infrastructure proposals of regional significance, when assessing the adverse effects of an activity on the natural and physical resources being developed. Regionally significant infrastructure includes regional and district council water storage, trunk lines and treatment plants. Overall, a water storage proposal of the conceptualised scale, nature, and locality are not likely to be completely contrary to the policy direction that has been set in the PRPN.

While objectives and policies of the PRPN are subject to appeal, the policy direction of the RWSP must be considered. However, only those objectives and policies in the RWSP that are statutorily more 'stringent' than those in the PRPN will be given weight. Currently, there are no objectives or policies in the RWSP which fit these criteria when compared to the PRPN so none are stated here.

2.3.2 Water Quantity Management Provisions

The PRPN and RWSP contain the following provisions which seek to manage the restrictions implied under s14 RMA with regard to the use and development of water, as outlined in **Table 1**.

Table 1. Rules regulating the use and development of water.

Permitted Activity Rules			
RWSP		PRPN	
Rule No.	**Activity**	**Rule No.**	**Activity**
24.01.01	Minor taking and use of surface water	C.3.1.1	The damming or diversion of rainfall runoff, including in sediment ponds and stormwater detention structures, or water in an artificial watercourse
24.01.03	The taking, use, damming or diversion of surface water in an artificial watercourse	C.3.1.2	The use, erection, reconstruction, placement, alteration or extension of a dam in a lake, river or natural wetland, any associated disturbance of the

			bed of a river or lake and deposition of material on the bed, and damming and diversion of water
24.01.04(1)	damming and diversion of rainfall runoff (but not water from a river, lake or indigenous wetland) into an off-stream reservoir which is not in the bed of a river, lake or indigenous wetland, and the unlimited taking and use of that stored water	C.5.1.1	Minor taking and use of water
24.01.04(2)	diversion and storing of water lawfully taken under the permitted rules in Sections 24 or 25 of this Plan or by way of a resource consent, into an off-stream reservoir not on the bed of a river, lake or indigenous wetland, and the unlimited taking and use of that stored wate	C.5.1.4	Water take from an off-stream dam
		C.5.1.5	Water take from an artificial water course
Restricted Discretionary Activity Rules			
RWSP		**PRPN**	
Rule No.	**Activity**	**Rule No.**	**Activity**
NA	NA	C.5.1.10	The taking and use of water from a river when the flow in the river is above the median flow
Discretionary Activity Rules			
RWSP		**PRPN**	
Rule No.	**Activity**	**Rule No.**	**Activity**
PRPN rule is operative.		C.3.1.7	The use, erection, reconstruction, placement, alteration or extension of a dam in the bed of a river, lake or natural wetland, any associated disturbance of the bed of a river or lake and deposition of material on the bed, and the associated damming and diversion of water that is not the subject of any other rule in this Plan
PRPN rule is operative		C.5.1.12	The taking and use of water, or the taking and use of heat or energy from water or heat or energy from the material surrounding geothermal water, that is not the subject of any other rule
Non-Complying Activity Rules			
RWSP		**PRPN**	
Rule No.	**Activity**	**Rule No.**	**Activity**
28.04.01	Any activity which takes place within a significant indigenous wetland identified in accordance with Appendix 13B is a non-complying activity.	C.3.1.9	The damming or diversion of water in a significant wetland, an outstanding freshwater body or mapped Outstanding Natural Character Area, or Outstanding Natural Feature, or Site or Area of Significance to tangata whenua that is not a permitted activity.
24.04.02	The taking, use, damming or diversion of water from within a significant indigenous wetland identified in accordance with Appendix 13B, which does not meet the requirements of the permitted activity rules is a noncomplying activity.	C.5.1.13	The taking of fresh water from a river, lake or natural wetland when the flow in the river or water level in the natural wetland or lake is below a minimum flow or minimum level set in H.4 Environmental flows and levels
NA	NA	C.5.1.14	The taking and use of fresh water that would cause an allocation limit set in H.4 Environmental flows and levels for a river or aquifer to be exceeded

There are now no Section 14 RMA activities which are Prohibited in the PRPN and none of the Prohibited activities under the RWSP are relevant to the use and development of water resources.

2.3.2.1 Allocation Limits and Minimum Flows

Allocation limits for streams are set to protect the health of aquatic ecosystems by capping the amount of water that can be taken from a water body above a minimum flow or level for lakes. This enables natural fluctuations in stream flow to occur, while providing somewhat for security of supply. An allocation limit along with a minimum flow criterion is defined, with restrictions applying when stream flow reduces below the minimum flow rate.

The RWSP includes policies requiring that minimum flows be applied to rivers as follows:

- Mean annual low flow (MALF) for flow sensitive rivers and rivers which have a MALF of less than 300 L/s; and
- 7-Day, 1 in 5-year return period low flow statistic (typically 70-84% of mean annual low flow) for large rivers (MALF of >300 L/s).

However, these are not absolute, and policy allows exceptions to be made. Furthermore, the RWSP contains no allocation limits for freshwater units.

Under the PRPN, Policies H.4.1 and H.4.3 set out the standards for environmental flows and limits of Northland’s freshwater management units. These provisions are subject to appeal however.

To establish these environmental flows and limits, the NRC grouped networks of streams into freshwater management units based on common values of the water bodies and the sensitivity of the values to change in flow as follows:

- Large River;
- Small River;
- Coastal River; and
- Outstanding Value River.

Policy H.4.3 of the PRPN states, the quantity of river flow available for abstraction below the median must not exceed the criteria outlined in **Table 2,** provided a minimum river flow is maintained (**Policy H.4.1**).

Table 2. Minimum flow criteria and allocation limits for Northland’s rivers.

Management Unit	Minimum Flow (% of 7-day MALF)	Allocation Limit (% of 7-day MALF)
Outstanding rivers	100%	10%
Coastal rivers	90%	30%
Small rivers	80%	40%
Large river	80%	50%

The benefit of water storage proposals is that the water being proposed for storage is often the component of water that is not subject to a ‘primary’ allocation limit. In particular, it is noted that the PRPN does not set an allocation limit for takes above median flow as Policy H.4.3 only applies to the quantity of freshwater to be taken from a river at flows below the median flow. Similarly, there is no 'stepped' approach to minimum flows with a singular expectation that taking above median flow occurs for 'high-flow allocation' taking. However, the timing, rate and volume of taking under the high-flow allocation take rule must still be considered in the context of avoiding or mitigating effects on existing authorised takes and aquatic ecosystem health. Subsequently, survey of the natural and human use values of the affected waterbodies would still be necessary to understand what measures are required to achieve the avoid or mitigate gateways.

2.4 Water Resource Consenting Conclusions

Rules in both the RWSP and PRPN have three main functions:

1. To permit activities that can be carried out without a resource consent, provided the appropriate environmental standards set out in the plans are complied with. These activities are classified as **Permitted**.

2. To restrict activities where site specific environmental conditions are required to ensure the actual and potential adverse effects of the activity are avoided, remedied or mitigated. These activities are classified as **Controlled, Restricted Discretionary, Discretionary, or Non-Complying**.

3. To prevent activities occurring which would result in unacceptable adverse effects. These activities are classified as **Prohibited**.

Activities classified as Controlled and Restricted Discretionary indicate that the adverse effects are generally well understood but that consent is required to include conditions which will better allow for site or activity specific management controls. Controlled activities must be granted consent unless there is insufficient information do so. Restricted Discretionary activities may be granted or declined but must only be declined on the matters for which discretion has been reserved. Equally, consents granted for either Controlled or Restricted Discretionary activities must only contain conditions which relate to those matters for which Control or Discretion has been reserved.

Discretionary consent requires a broader assessment approach and consenting authorities may grant or decline consent on the basis of any matter it considers reasonably necessary to make such determinations. Equally, consent conditions may be imposed for any matter the consenting authority deems appropriate for a Discretionary activity.

An activity that is classified as Non-complying also requires a broad assessment of effects of the activity and consent for such an activity may be granted or declined, and if granted, may be subject to conditions deemed appropriate. However, consent may only be granted for a Non-complying activity if at least one of two tests is satisfied: either that adverse effects of the activity on the environment will be minor, or that the application is for an activity that will not be contrary to objectives and policies of any relevant plan. It follows that a proposal must fail both tests before the consent authority is obliged to refuse consent. Review of case law suggests that a judgement has to be made as to whether an activity will be contrary overall to the objectives and policies of the relevant plans. Being contrary to one or more objectives or policies should not be considered a fatal flaw if the activity is regarded as not being contrary to the overall objectives and policies.

An application is not able to be made for a Prohibited activity. No water use and development is prohibited under either the RWSP or the PRPN.

Overall, the use and development of water resources for harvesting and storing water would be bundled for assessment as a Discretionary consent provided the development occurs outside of significant indigenous wetland environments.

Should development be required within an indigenous wetland then such activity would be subject to the most stringent classification as a Non-complying activity. However, this does not necessarily mean that the site should be removed from feasibility as the policy direction in the PRPN and RPS can be used to support development of this nature provided suitable measures to avoid, remedy or mitigate adverse effects are identified so that such adverse effects are no more than minor on indigenous taxa that are listed as threatened or at risk or that are significant[2], or are areas set aside for full or partial protection of indigenous biodiversity under other legislation.

[2] As per the Appendix 5 RPS criteria.

3. Watershed / Catchment Delineation

3.1 Overview

The purpose of the watershed and catchment delineation was to:

1. identify catchments that could potentially support water harvesting or run of river takes for storage and subsequent irrigation use, and
2. divide the study areas into sub-catchments of homogeneous physical characteristics to enable parameterisation of the catchment flow models (**Section 4**).

Catchments that flowed through or adjacent to the commend areas were selected for analysis. It was initially proposed to undertake detailed catchment delineation utilising the recently captured (2019) LiDAR data of the Northland Region. However, due to delays in post-processing of the LiDAR data, it was not available in time for this component of the project. It was therefore agreed with NRC to proceed using the New Zealand River Environment Classification (REC) dataset produced by the Ministry for the Environment (MfE, 2010), as a starting point, and refine catchments where appropriate.

3.2 Catchment Delineation

River Environment Classification (REC) Catchments Order 4 and 5 were used to identify initial sub-catchments. The catchments were further delineated based on differing physical characteristics such as slope and underlying geology. Finally, the catchments were adjusted to continuous gauge locations (**Section 4.2.3**), to enable more efficient and accurate model calibration.

3.2.1 Topography

Elevations of the Mid-North study area range from approximately 630 m above mean sea level (mAMSL), at the peak of Hikurangi Mountain, at the south-east extent of the study area, to ~50 mAMSL in the western extent along the plains of the Punakitere River. A number of steep sided volcanic cones occur throughout the study area, such as Te Ahuahu, Tarahi, Maungaturoto, and Pouerua.

Elevations in the Kaipara study area range from approximately 770 mAMSL at the peak of Tutamoe Mountain, in the upper reaches of the Awakino River, down to ~1-5 mAMSL on the flat plains of the Poutō Peninsula, to the west of the lower Wairoa River. To the west of the flats, elevated (~70-150 mAMSL) sand dune ridges run north-west to south-east along the western margin of the Poutō Peninsula, with incised stream networks flowing both west and east down the dunes.

Elevation and topography of the Mid-North and Kaipara study areas are shown in **Figure 3** and **Figure 4**, respectively.

Figure 3. Mid-North study area elevation and topography. (Refer A3 attachment at rear).

Figure 4. Kaipara study area elevation and topography. (Refer A3 attachment at rear).

3.2.2 Geology

An overview of the underlying geology for the Mid-North and Kaipara study areas are presented in in **Figure 5** and **Figure 6**, respectively.

The Mid-North study area is characterised by Quaternary volcanic deposits of the Kaikohe – Bay of Islands Volcanic field cover the majority of the area. The field extends from the southwest of Kaikohe to the north east coast. Basaltic lava flows, shield volcanoes and steep sided scoria cones of the Kerikeri Volcanic Group emplaced in the early – late Pleistocene (2.6 Mya to 12 Kya) are typically up to 10m thick and some reach 20 km in length, usually flowing into and partly filling former valley.

The volcanics overlie thrust-bounded formations of the Northland Allochthon in the west and basement terrane sandstones (greywacke) and argillite of the Waipapa Group to the east. The youngest material in the area is the Tauranga Group alluvial, swamp and estuarine deposits which are present locally within the valley floor near active or remnant watercourses.

The Northern Allochthon can be subdivided into several main complexes, with the Mangakahia Complex comprising the largest. This is the most disrupted and problematic group of materials with varying degrees of shearing and crushing. It can be distinctly recognised by its long and gentle grading hummocky slopes (~7-15º) often with springs and swampy ground. Lithological units within the Mangakahia Complex include the siliceous mudstone and glauconitic sandstone interbeds of the Whangai Formation and the alternating quartzofeldspathic sandstone and mudstone of the Punakitere Sandstone. Mixed sheared zones and major thrust fault blocks of the Mangakahia Complex units are called the “undifferentiated melange” which has been sheared so extensively, that it has been reduced to a hard soil.

The thickness of the allochthonous material is highly variable across the Northland region, from about 2 km beneath central Northland becoming progressively shallower towards the north-east, until pinching out in a NW-SE trend near Pakaraka, where it intersects the underlying Waipapa Group basement rock.

The Kaipara study area is characterised by Quaternary sands of the Tauranga and Karioitahi Groups which form an elongate complex of mobile and fixed parabolic dunes at the coast. Inland, is a complex of dune, lake, fluvial and estuarine sediments, with many interdune lakes present in low areas along the barrier.

The younger more unconsolidated sands on the west coast are likely to provide very high rainfall infiltration rates and therefore surface water runoff from these geological units would typically be lower compared to the older more consolidated sands. This is evidenced by a distinct lack of streams discharging from these areas particularly in the more elevated areas.

Figure 5. Mid-North study area main geological units. (Refer A3 attachment at rear).

Figure 6. Kaipara study area main geological units. (Refer A3 attachment at rear).

3.3 Identified Catchments

The following sections presents the final set of catchments delineated, and used in the development of the catchment flow models (**Section 4**). The names assigned to each sub-catchment reflect the primary river or stream, or section of river/stream within, along with any smaller tributaries that also occur within the sub-catchment.

3.3.1 Mid-North

Fourteen sub-catchments were delineated in the Mid-North study area, as shown in **Figure 7**, and summarised in **Table 3**. Sub-catchments range in size from approximately 15 km^2 (1,500 ha) to 58 km^2 (5,800 ha), and cover a diverse range of topographies, both in terms of elevation and slope.

Figure 7. Overview map of catchments identified in the Mid-North study area. (Refer A3 attachment at rear).

Table 3. Summary of catchments identified in the Mid-North study area.

SC ID	Name	Area (km^2)	Average Elevation (m)	Median Slope (°)
1	Huehue Stream	53.1	165	12.8
2	Mangaone Stream	50.0	155	9.0
3	Upper Punakitere River	42.9	177	9.8
4	Wairoro Stream	47.0	206	5.5
5	Mangatoa Stream	46.7	185	5.5
6	Punakitere River	58.2	98	6.4
7	Mangamutu Stream	37.7	200	5.2
8	Upper Waiaruhe River	39.5	139	2.3
9	Puketotara Stream	43.8	106	2.6
10	Manania Stream	37.2	112	1.6
11	Waiaruhe River	14.7	85	3.9
12	Waitangi River at Waimate North Rd	50.5	183	3.5
13	Waitangi River at SH10	32.2	112	2.4
14	Waitangi River	45.8	61	6.2

3.3.2 Kaipara

Twenty sub-catchments were delineated in the Kaipara study area, as shown in **Figure 8** and summarised in **Table 4**. Sub-catchments range in size from approximately 10 km^2 (1,000 ha) to 52 km^2 (5,200 ha), and comprise a reasonably narrow range in catchments with low to moderate elevation (20-375 mAMSL) with flat to only moderately rolling (0.6-11.8°) topography.

Figure 8. Overview map of catchments identified in the Kaipara study area. (Refer A3 attachment at rear).

Table 4. Summary of catchments identified in the Kaipara study area.

SC ID	Name	Area (km^2)	Average Elevation (mAMSL)	Median Slope (°)
1	Waima River	54.5	301	8.6
2	Mangatu Stream	34.5	375	11.5
3	Ngaiore Stream	16.3	175	4.1
4	Kaihu at Gorge	10.0	170	10.1
5	Kaihu at Awakiwi Take	42.5	245	9.4
6	Kaihu at Waiatua Confluence	52.4	74	6.3

SC ID	Name	Area (km²)	Average Elevation (mAMSL)	Median Slope (°)
7	Taita Stream	28.4	38	6.5
8	Waiatua Stream	13.0	61	3.3
9A	Kaihu at Rotu	16.0	25	0.6
9B	Kaihu at Wairoa Confluence	36.5	20	0.9
10	Korariwhero Flats Drains	27.4	40	3.9
11	Mangatara Stream	32.0	31	2.1
12	Awakino River at Lawson Rd	45.5	176	11.8
13	Awakino River at Avoca Rd	28.1	66	8.0
14	Awakino at Wairoa Confluence	44.0	24	2.8
15	Oruariki Creek	15.4	20	0.6
16	Aratapu Creek	41.2	25	1.6
17	Makaka Creek	20.9	21	0.8
18	Tatararaiki Drains	20.7	21	1.5
19	Taihu Creek	18.6	32	0.8

4. Catchment Flow Modelling

4.1 Overview

In order to quantify the volume of water available for harvesting and storage, catchment models were developed for each of the sub-catchments identified in **Section 3**.

The following subsections describe the available data used in developing the catchment flow models and the development and calibration of these catchment flow models.

4.2 Available Data

The following sections detail the range of datasets used in the development of the SMWBM catchment models.

4.2.1 Climate Data

Evaporation and rainfall data were obtained from the National Institute of Water and Atmospheric Research (NIWA) virtual climate station network (VCSN). The VCSN data provides estimates of daily rainfall and potential evapotranspiration on a 5 km regular grid, covering all of New Zealand. Estimates of climate parameters are produced for each VCSN point on a daily time-step based on spatial and temporal interpolation of recorded observation data at the nearest reliable meteorological sites.

From a catchment modelling perspective, the advantage of using NIWA's VCSN climate data is that it provides a temporally and spatially continuous dataset, processed in a consistent way across the whole region and between studies. Therefore, the data does not require processing to fill in periods of missing data (e.g. due to rain gauge malfunction or different record durations). A potential disadvantage of the data is that it's accuracy is dependent on the observation datasets, and if these are sparse or unreliable, the VCSN data is hindered with a similar level of accuracy.

A statistical comparison of the VCSN data and measured rainfall from a number of representative NRC rain gauges was undertaken to confirm the accuracy and appropriateness of VCSN data for this project. Comparisons were undertaken on an annual and monthly basis, and on average the VCSN data were found to be within +3% and +10% of measured rainfall data. This is considered acceptable and appropriate for the purpose of a pre-feasibility study. Full documentation on the comparison of VCSN rainfall to NRC's observed rainfall data is provided in **0**.

The VCSN rainfall and evaporation data were interpolated to the centroid of each sub-catchment (outlined in **Section 3.3**) using radial basis interpolation function, and used as inputs to the catchment models.

4.2.2 Catchment Characteristics Data

A summary of the catchment data utilised to aide parameterisation of the SMWBM is presented in **Table 5**.

Table 5. Summary of catchment data.

Data	Description	Data Origin
NZ 8 m Digital Elevation Model (2012)	Raster file 8 m resolution Digital Elevation Model (DEM). The DEM was used to determine sub-catchment elevation and slope statistics for parameterisation of the SMWBM.	LINZ
Geological Map of New Zealand (QMAP)	Shapefile 1:250,000 geological map of New Zealand. This data was used to characterise the underlying geology for parameterisation of the SMWBM.	GNS

Data	Description	Data Origin
FLS New Zealand Soil Classification	Shapefile Fundamental Soil Layer contains spatial information for key soil attributes. This data was used to characterise soil infiltration for parameterisation of the SMWBM.	LRIS

4.2.3 Continuous Gauged Flow Data

Observed flow gauge data were available from eight locations across the Mid-North and Kaipara study areas. Continuous gauged flow data were used as the primary calibration dataset for the catchment models. A summary of available continuously gauged flow data is provided in **Table 6**, and their locations shown in **Figure 9** and **Figure 10**, for the Mid-North and Kaipara, respectively.

Table 6. Summary of available continuous gauged flow data.

Command Area	Gauge Name	Record Start	Record End	Notes / Comments
Kaipara	Kaihu at Gorge	03/03/1970	16/05/2016	
	Kaihu at Rotu	30/05/1977	15/09/1980	
	Manganui at Permanent Station	20/05/1960	21/12/2015	
Mid-North	Te Tunaomaku at Rock Weir	05/01/1989	24/01/1996	
	Wairahue at Puketona	01/02/1984	10/05/2000	Significantly greater magnitude across all flows than spot gauge at same location, signalling a possible issue with the rating curve or the spot gauge data.
	Waikaka at Totara Trees Weir	10/01/1989	30/10/1996	
	Waitangi at SH10	16/11/2012	21/07/2015	Negative flow records removed between 11/11/2014 and 12/12/2014.
	Waitangi at Waimate North Rd	04/10/2011	03/07/2015	

Figure 9. Locations of gauged flow data in the Mid-North study area. (Refer A3 attachment at rear).

Figure 10. Locations of gauged flow data in the Kaipara study area. (Refer A3 attachment at rear).

4.2.4 Spot Gauge / Low Flow Data

Low flow spot gauging data of various record lengths were available at a wide range of locations across the study areas. These spot gauges were used as a secondary calibration check, in addition to the continuous gauged flow data for the catchment models. Spot gauge data with the largest number of gauging, and providing representative spatial coverage across the two study areas were utilised for the secondary calibrations. A summary of spot gauged data, the period and number of gaugings is provided in **Table 7**, and their locations shown in **Figure 9** and **Figure 10**, for the Mid-North and Kaipara, respectively.

Table 7. Summary of available low flow / spot gauge data used for model calibration.

Command Area	Gauge Name	First Gauging	Last Gauging	No. Gaugings	Notes / Comments
Kaipara	Awakino at Lawson Rd	7/01/1985	13/05/1996	9	
Kaipara	Awakino at Avoca Rd	14/07/1992	13/05/1996	4	High and low flow gaugings available
Kaipara	Kaihu (Babylon Drain) Trib at SH12	19/10/1977	19/01/2006	37	
Kaipara	Mangatara Drain at SH1 Bridge	8/02/1995	8/02/1995	1	
Kaipara	Aratapu Creek Trib at Guy Ropes	24/02/1995	6/04/2005	2	
Mid-North	HueHue at Mataraua Rd	20/01/1994	13/04/1994	4	
Mid-North	Mangaone at Piccadilly Rd	20/01/1994	3/02/1994	2	
Mid-North	Omanu Stream at Te Irigna Rd	18/12/1985	26/01/1994	16	
Mid-North	Otangaroa at Barneys Crossing	2/03/1989	26/01/1994	17	
Mid-North	Otangaroa at Jordon Rd	17/12/1985	13/02/1986	2	
Mid-North	Punakitere at Picadilly Rd	29/03/1990	17/05/1994	10	
Mid-North	Punakitere at above waterfall, Mangakahia Rd	18/03/1983	16/12/1993	2	
Mid-North	Te Opua Stream at Gubbs	8/01/1985	12/02/1985	3	
Mid-North	Wairoro at Quarry	15/12/1981	13/03/1991	12	

4.2.5 Consented Takes

Surface water take consent data were provided by NRC covering the full extent of the Mid-North and Kaipara study areas. Consented take locations are shown in **Figure 11** and **Figure 12**, respectively. Consented takes were aggregated for each sub-catchment and subtracted from the sub-catchment modelled flow. Rates of takes were calculated as the daily equivalent of the maximum consented annual take. Irrigation takes were only included October to April.

A summary of consented surface water take details are provided in **Appendix D.**

Figure 11. Mid-North consented surface water takes. (Refer A3 attachment at rear).

Figure 12. Kaipara consented surface water takes. (Refer A3 attachment at rear).

4.3 SMWBM Overview

The Soil Moisture Water Balance Model (SMWBM) was utilised as the rainfall runoff model for this project. The SMWBM is a semi-deterministic model based on the algorithms of Pitman (1967), who originally developed the model to simulate river flows in South Africa. Model functionality has since been extended by WWLA to incorporate a surface ponding function, evaporation functions for differing land cover, an irrigation demand module, and vadose zone flow process - although this was not switched on for this project.

The model utilises daily rainfall and evaporation input data to calculate the soil moisture conditions under natural rainfall conditions. The model operates on a daily time step during dry days, however when rain days occur, a finer hourly calculation step is implemented to enable peak flows to be assessed more accurately than a daily time step model.

The SMWBM incorporates parameters characterising the catchment in relation to the following characteristics, and are further described in **Table 8**.

- Interception storage;
- Evaporation losses;
- Soil moisture storage;
- Surface runoff;
- Soil infiltration;
- Sub-soil drainage;
- Stream base flows; and
- The recession and/or attenuation of ground and surface water flow components.

Table 8. SMWBM parameter descriptions.

Parameter	Name	Description
ST (mm)	Maximum soil water content	ST defines the size of the soil moisture store in terms of a depth of water.
SL (mm)	Soil moisture content where drainage ceases.	Soil moisture storage capacity below which sub-soil drainage ceases due to soil moisture retention.
FT (mm/day)	Sub-soil drainage rate from soil moisture storage at full capacity	Together with POW, FT (mm/day) controls the rate of percolation to the underlying aquifer system from the soil moisture storage zone. FT is the maximum rate of percolation through the soil zone.
ZMAX (mm/hr)	Maximum infiltration rate	ZMAX and ZMIN are nominal maximum and minimum infiltration rates in mm/hr used by the model to calculate the actual infiltration rate ZACT. ZMAX and ZMIN regulate the volume of water entering soil moisture storage and the resulting surface runoff. ZACT may be greater than ZMAX at the start of a rainfall event. ZACT is usually nearest to ZMAX when soil moisture is nearing maximum capacity.
ZMIN (mm/hr)	Minimum infiltration rate	
POW (>0)	Power of the soil moisture-percolation equation	POW determines the rate at which sub-soil drainage diminishes as the soil moisture content is decreased. POW therefore has significant effect on the seasonal distribution and reliability of drainage and hence baseflow, as well as the total yield from a catchment.
PI (mm)	Interception storage capacity	PI defines the storage capacity of rainfall that that is intercepted by the overhead canopy or vegetation and does not reach the soil zone.
AI (-)	Impervious portion of catchment	AI represents the proportion of the catchment that is impervious and directly linked to surface water drainage pathways.
R (0,1)	Evaporation – soil moisture relationship	Together with the soil moisture storage parameters ST and SL, R governs the evaporative process within the model. Two different relationships are available. The rate of evapotranspiration is estimated using either a linear (0) or power-curve (1) relationship relating evaporation to the soil moisture status of the soil. As the soil moisture capacity approaches, full, evaporation occurs at a near maximum rate based on the daily pan evaporation rate, and as the soil moisture capacity decreases, evaporation decreases according to the predefined function.
DIV (-)	Fraction of excess rainfall allocated directly to pond storage	DIV has values between 0 and 1 and defines the proportion of excess rainfall ponded at the surface due to saturation of the soil zone or rainfall exceeding the soils infiltration capacity to eventually infiltrate the soil, with the remainder (and typically majority) as direct runoff.
TL (days)	Routing coefficient for surface runoff	TL defines the attenuation and time delay of surface water runoff.
GL (days)	Groundwater recession parameter	GL governs the attenuation in groundwater discharge or baseflow from a catchment.
QOBS (m^3/s)	Initial observed streamflow	QOBS defines the initial volume of water in the stream at the model start period and is used to precondition the soil moisture status.
AA, BB	Coefficients for rainfall disaggregation.	Used to determine the rainfall event duration and pattern.

A conceptual diagram of the SMWBM structure and functionality is provided in **Figure 13**.

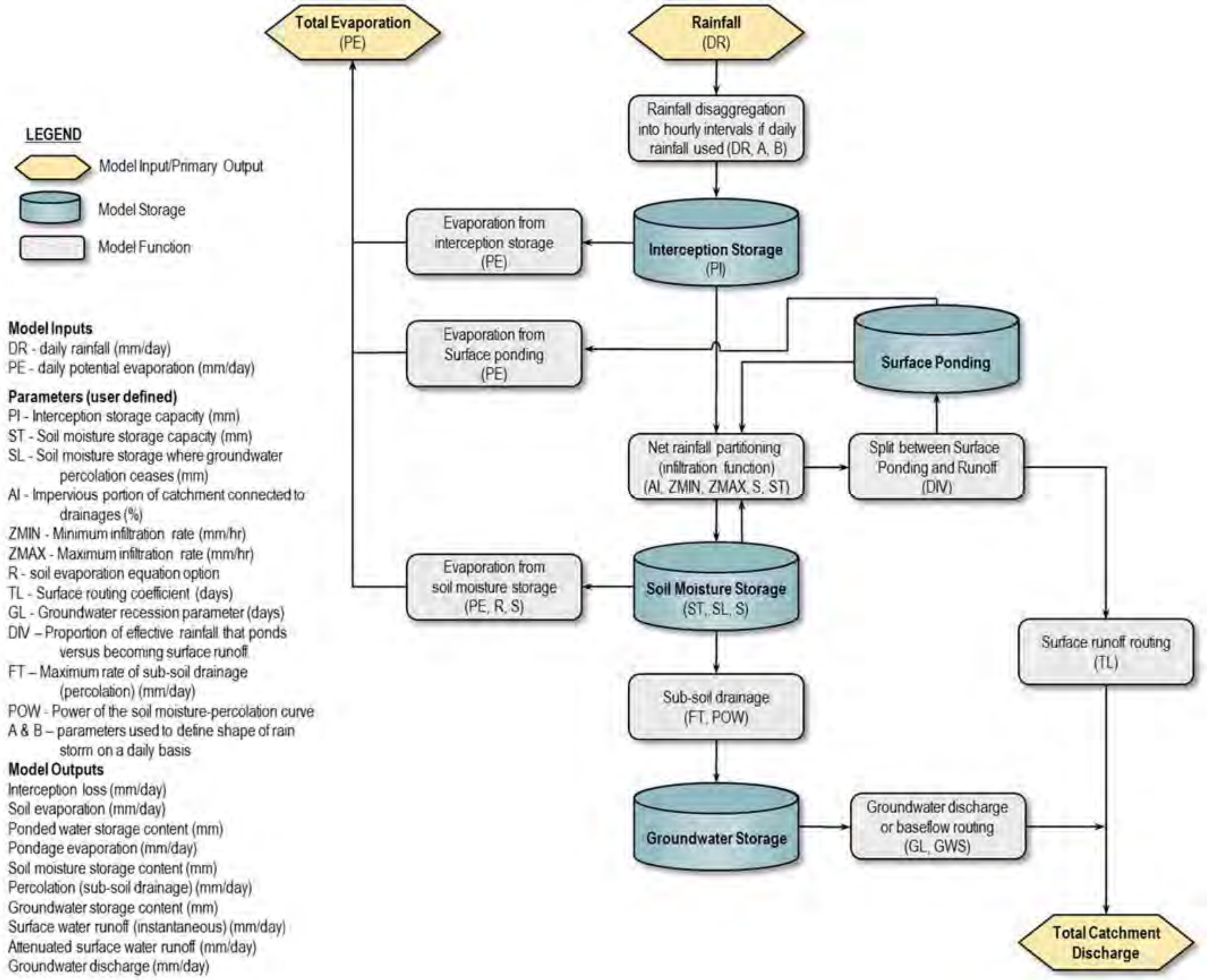

Figure 13. Flow diagram of the SMWBM structure and parameters.

4.4 SMWBM Parameterisation

Catchment physical characteristics are important to recognise and understand as they play a key role in governing the hydrological functioning of a catchment. One of the key advantages of the SMWBM is that it's semi-conceptually based, with model parameter values linked to physical characteristics of the catchment, such as slope, and soil and rock hydraulic characteristics.

The SMWBM parameterisation process involved mapping the key physical characteristics linked to model parameters, then calculating the area-weighted average within each sub-catchment.

An overview of the process is illustrated in **Figure 14** and the relationships between sub-catchment parameters and their corresponding physical characteristics are presented in **Appendix C.**

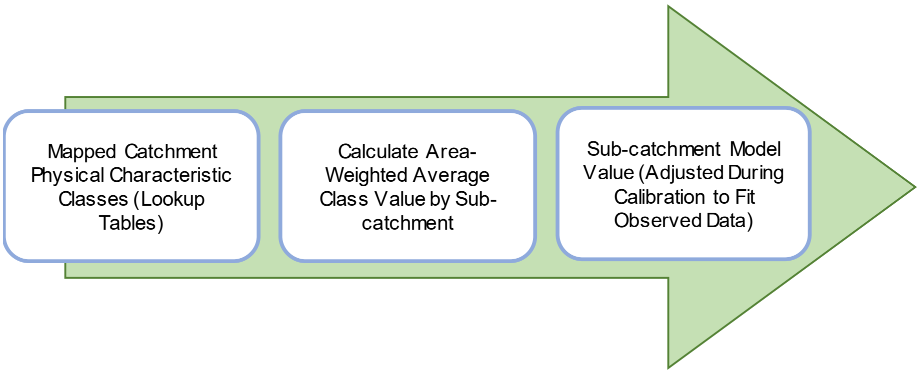

Figure 14. Process for assigning physical characteristics to model parameters in each sub-catchment.

4.4.1 Simulation Period

All catchment models were simulated for the full duration of available VCSN data (1972 – 2018). The first year of model output (1972) was discarded from all analyses to ensure the SMWBM stores (e.g. soil moisture storage) had reached a dynamic equilibrium (i.e. the model warm-up period).

4.5 SMWBM Calibration - Mid-North

4.5.1 Calibration Process

The calibration process was carried out systematically working downstream. Calibration simulations were repeated multiple times, with SMWBM parameter values manually adjusted in each subsequent run until the simulated flow accurately represented the measured flow as well as practically possible. The parameter adjustment process maintained a consistent relationship between the model parameters and the physical characteristics (**Appendix C**) of the sub-catchment, which ensured that parameter changes maintained the relative difference in sub-catchment class value and fundamental hydrological principals.

A combination of visual qualitative calibration assessment metrics was used to assess the accuracy of flow calibration. These included flow hydrograph time series plots and flow duration curves.

Flow hydrographs provide a visual comparison of observed and modelled flow through time. The types of plots provide a useful means of assessing a model's ability to simulate temporal variations such as season cycles and patterns.

Flow duration curves provide a graphical comparison of the frequency distribution of the observed and modelled flow regime. The curves provide a comparison of the percentage of time observed and modelled flow exceeds a specified flow rate.

During the calibration process, equal consideration was given to both the flow hydrograph and flow duration curves, with the aim of producing the highest level of agreement between observed and modelled flows as practically possible to both metrics.

Model calibration to NRC's continuous flow gauge data, and key spot gauge locations in the Mid-North study are presented in the sub-sections below. Additional low flow / spot gauging data were considered a secondary calibration check, and are presented in **Appendix E**.

4.5.2 Waitangi River

As described in **Section 4.4** and **Appendix C**, the SMWBM was parameterised using relationships between key sub-catchment physical characteristics (such as soil depth, underlying geology, slope etc.), and these relationships provided reasonable to good levels of agreement to observed data at all model calibration sites with the exception of the Waitangi River.

Applying the physical characteristic to model parameter relationships developed for all other gauges resulted in a continual under-prediction of streamflow to the Waitangi at Waimate gauge as shown in **Figure 15**. Improvements in model calibration was only possibly by increasing the sub-soil drainage rate (FT model parameter) beyond the limits of what could reasonably be expected at this location. Therefore, it was concluded an additional source of water was likely flowing into the sub-catchment, not accounted for by the model in its current configuration.

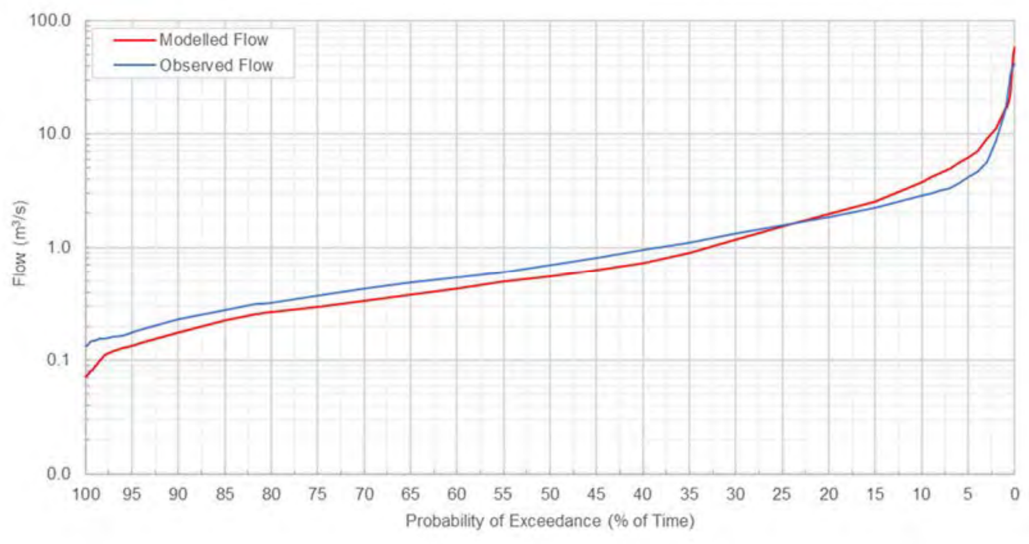

Figure 15. Flow duration curve comparison of modelled and observed flow at Waitangi at Waimate gauge

Through consideration of the local topography, it was thought an additional component of groundwater could be entering the catchment from Lake Omapere, as shown by the cross-section and conceptual hydrogeological flow diagram presented in **Figure 16**. To test this hypothesis, half of the surface area of Lake Omapere was added to the groundwater flow component of the SMWBM for the Waitangi River.

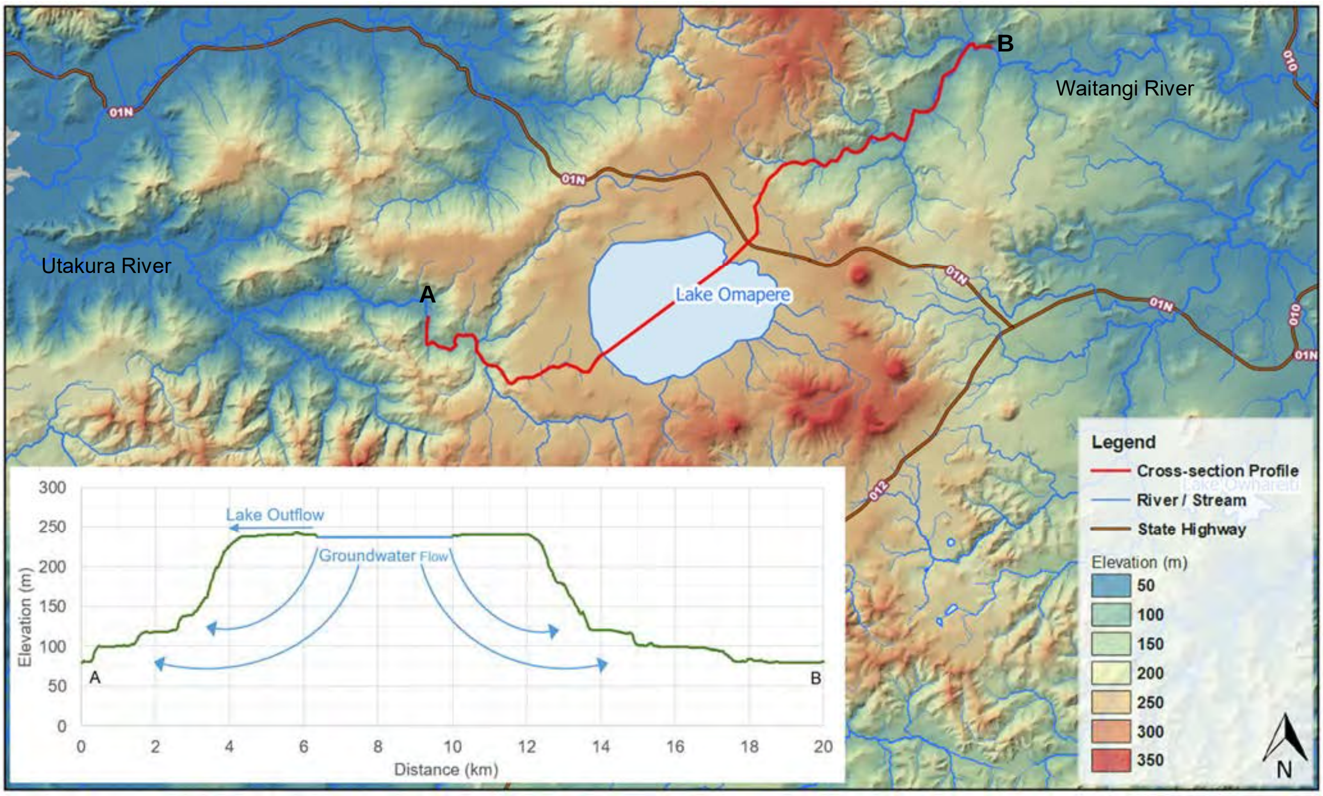

Figure 16. Lake Omapere cross-section and conceptual hydrogeological flow diagram.

A comparison of modelled and observed flow hydrograph and flow duration curve for Waitangi at Waimate, including the additional groundwater inflow are presented in **Figure 17** and **Figure 18**, respectively. The flow duration curve showed significant improvement with the additional groundwater flow included. This is consistent with the thoughts of local iwi who have long thought water from Lake Omapere flows in both directions from the lake. While this modelling does not prove conclusively, it does suggest there may be a component of groundwater from Lake Omapere that flows to the east.

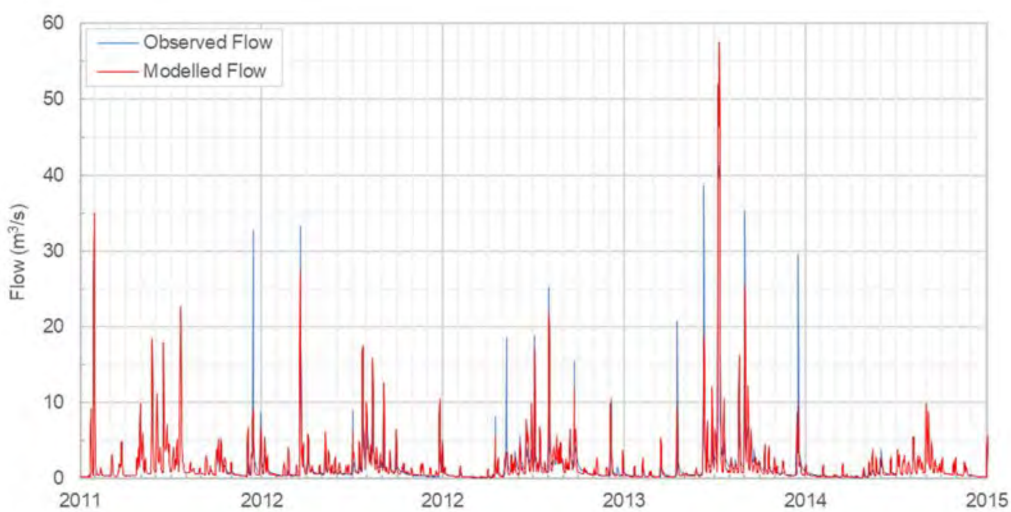

Figure 17. Flow hydrograph comparison of modelled and observed flow at Waitangi at Waimate gauge.

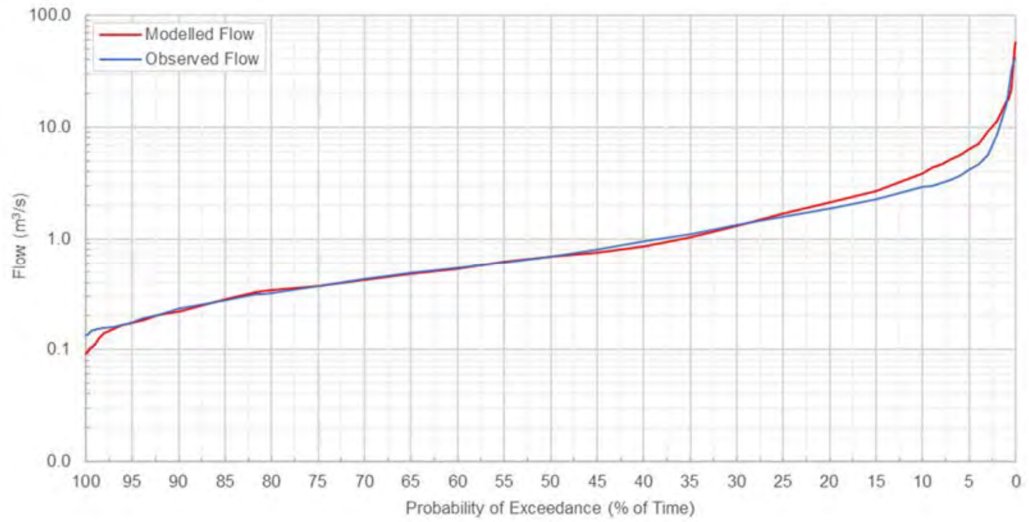

Figure 18. Flow duration curve comparison of modelled and observed flow at Waitangi at Waimate gauge including additional groundwater.

The flow duration curve for the additional groundwater component flowing into the Waitangi catchment from the Lake Omapere is presented in **Figure 19**. It shows the additional groundwater component ranges from approximately 0.05 to 0.19 m^3/s, with a median flow of approximately 0.12 m^3/s.

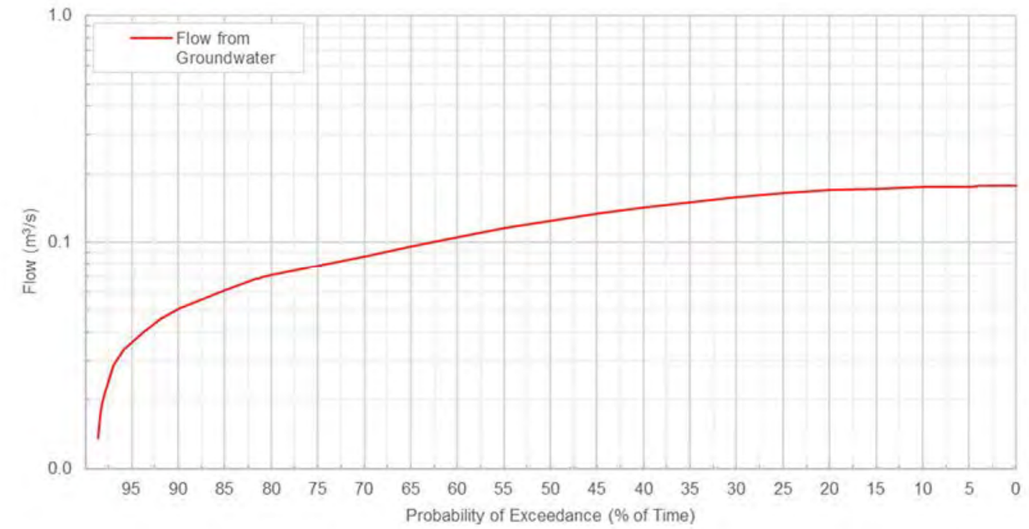

Figure 19. Additional groundwater flow as a result of increased groundwater catchment area into the Waitangi River catchment.

A comparison of modelled and observed flow for Waitangi at SH10 is presented in **Figure 20**, and includes the additional groundwater flow component from Lake Ompaere. The hydrograph shows good agreement of the timing and general magnitude of modelled flow to measured flow with a slight under prediction of peak flows.

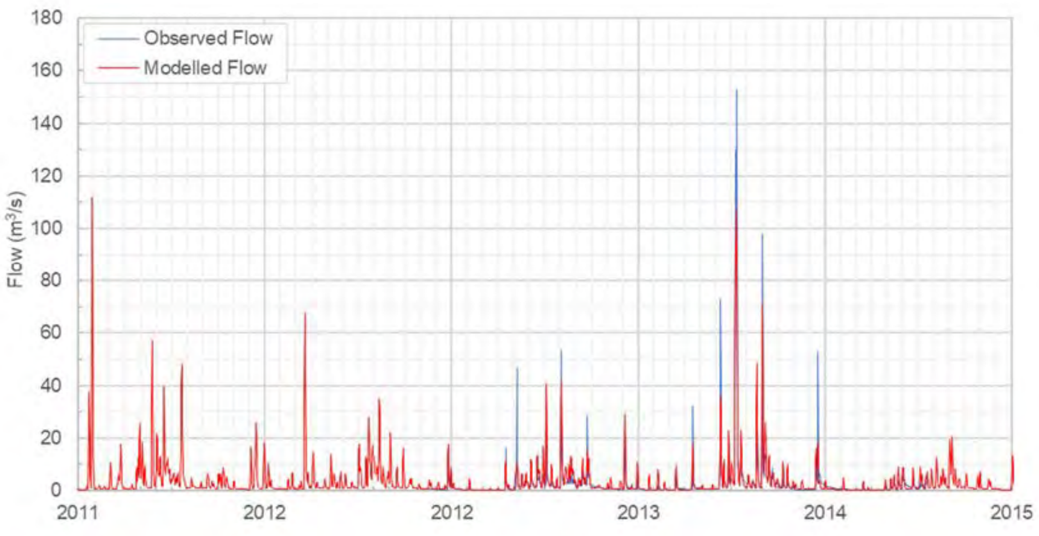

Figure 20. Flow hydrograph comparison of modelled and observed flow at Waitangi at SH10 gauge.

A comparison of the modelled and measured flow duration curve is presented in **Figure 21**. The comparison shows the SMWBM predicts close agreement to flows that are exceeded more than 35% of the time. However, it over predicted flows that are exceeded between 2.5% and 30% of the time.

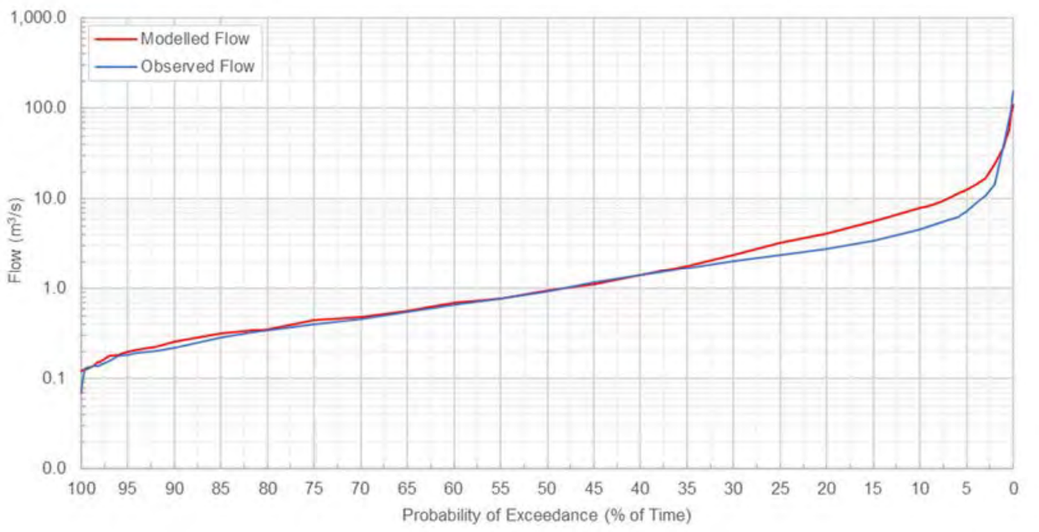

Figure 21. Flow duration curve comparison of modelled and observed flow at Waitangi at SH10 gauge.

4.5.3 Waiaruhe River

A comparison of modelled and observed flow for Waiaruhe at Puketona is presented in **Figure 22**. The hydrograph successfully simulates both the timing and general magnitude observed in the measured flow, with some over-prediction and some under-prediction. This is also highlighted in the flow duration shown in in **Figure 23**.

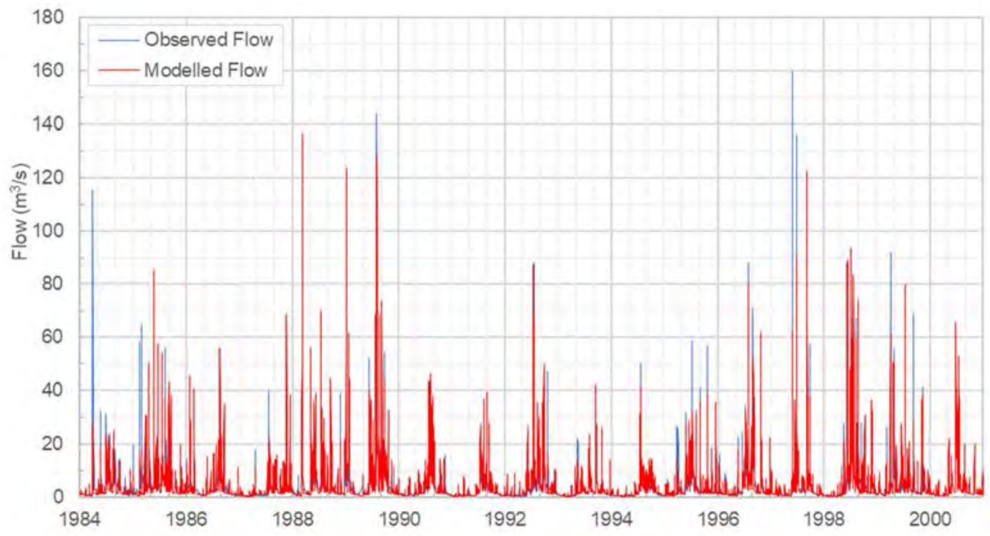

Figure 22. Flow hydrograph comparison of modelled and observed flow at Waiaruhe at Puketona gauge.

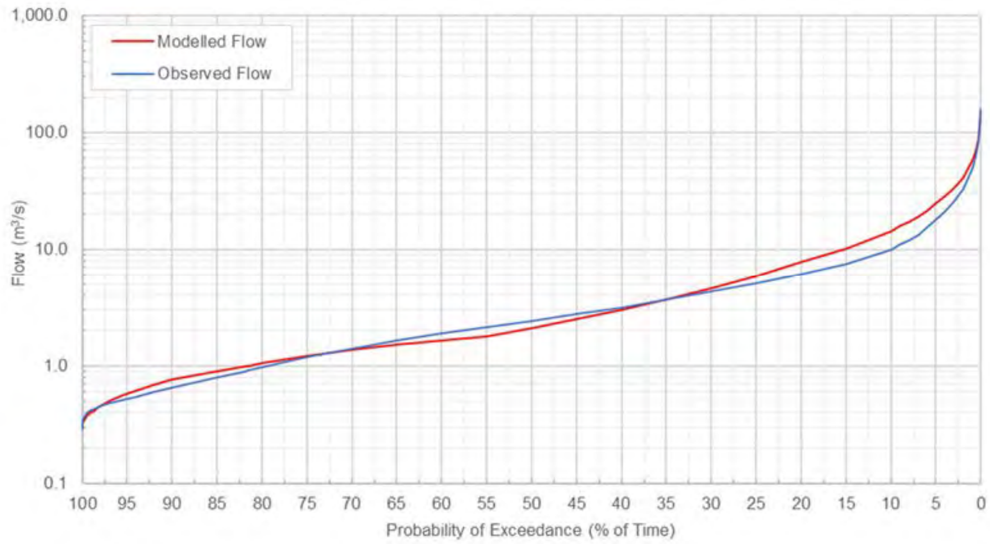

Figure 23. Flow duration curve comparison of modelled and observed flow at Waitangi at SH10 gauge.

4.5.4 Wairoro Stream

A comparison of modelled and observed spot gauge flow for the Wairoro Stream at Quarry gauge is presented in **Figure 24.** There is close agreement to magnitude of low flow spot gauging, indicating that there is confidence in the model to successfully simulate summer base flow. No high flow gaugings were available.

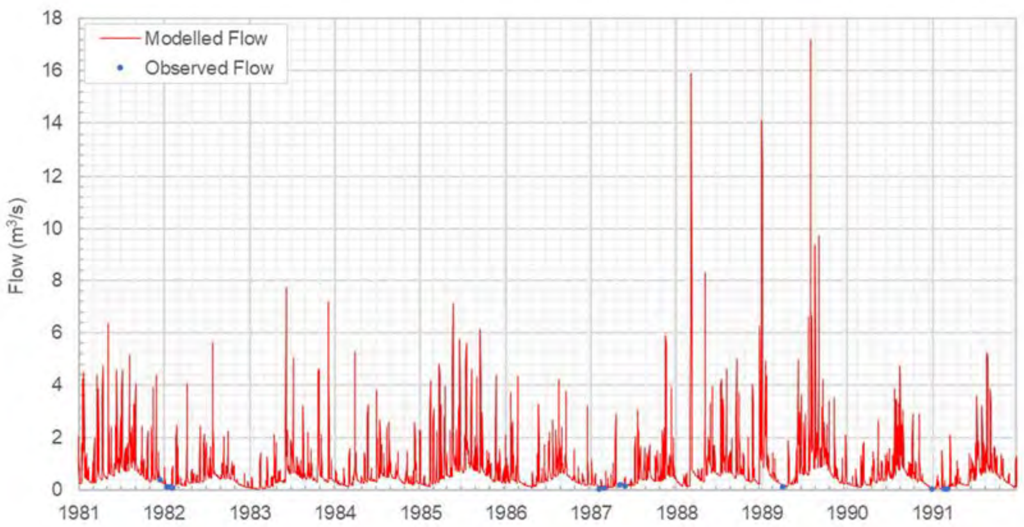

Figure 24. Flow hydrograph comparison of modelled and observed flow at Wairoro Stream at Quarry gauge.

4.5.5 Punakitere River

A comparison of modelled and observed flow for Punakitere River at Above Waterfall gauge is presented in **Figure 34**. The SMWBM was shown to simulate good agreement to available observed spot gauges.

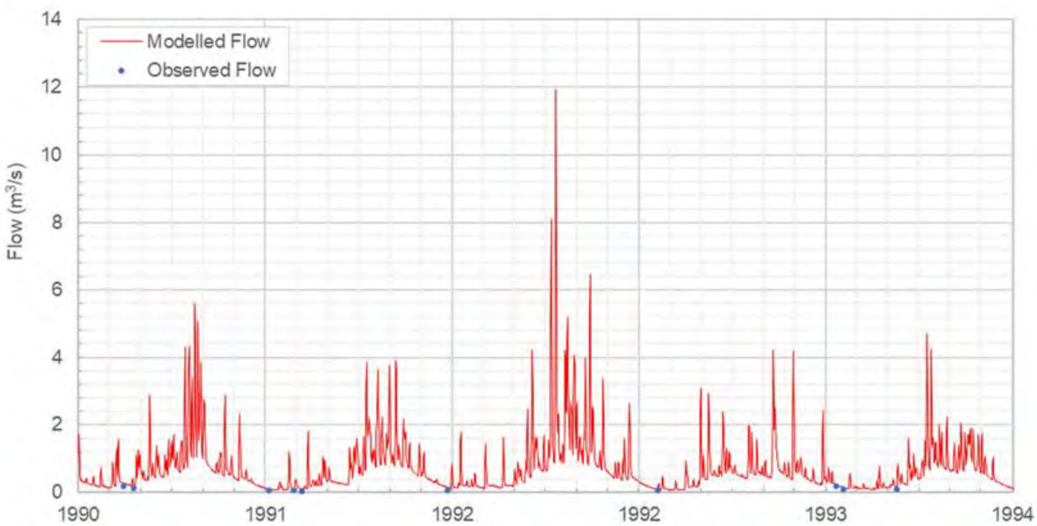

Figure 25. Flow hydrograph comparison of modelled and observed flow at Punakitere River at Above Waterfall gauge.

4.6 SMWBM Calibration - Kaipara

4.6.1 Calibration Process

The calibration process and visual metrics used to quantify the level of calibration achieved followed those as outlined for the Mid-North (**Section 4.5.1**). The results are presented for catchments moving north to south along the study area, and are grouped by main rivers (e.g. Kaihu and Awakino Rivers), and location (Poutō Peninsula).

4.6.2 Kaihu River

A comparison of modelled and observed flow for Kaihu at Gorge is presented in **Figure 26**. The hydrograph shows good agreement of the timing and general magnitude of simulated flow to measured flow, however peak flows were generally under predicted. This is also indicated in the flow duration curve (**Figure 27**), which shows the SMWBM tended to slightly under-predict flows that are exceeded less than 2.5% time, but predicted close agreement to all other flows.

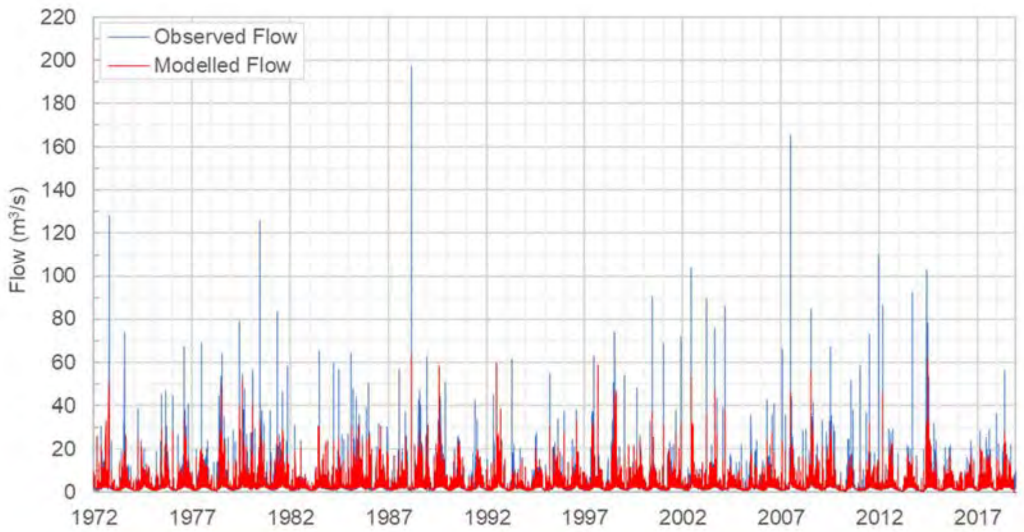

Figure 26. Hydrograph of modelled and measured flow for Kaihu at Gorge.

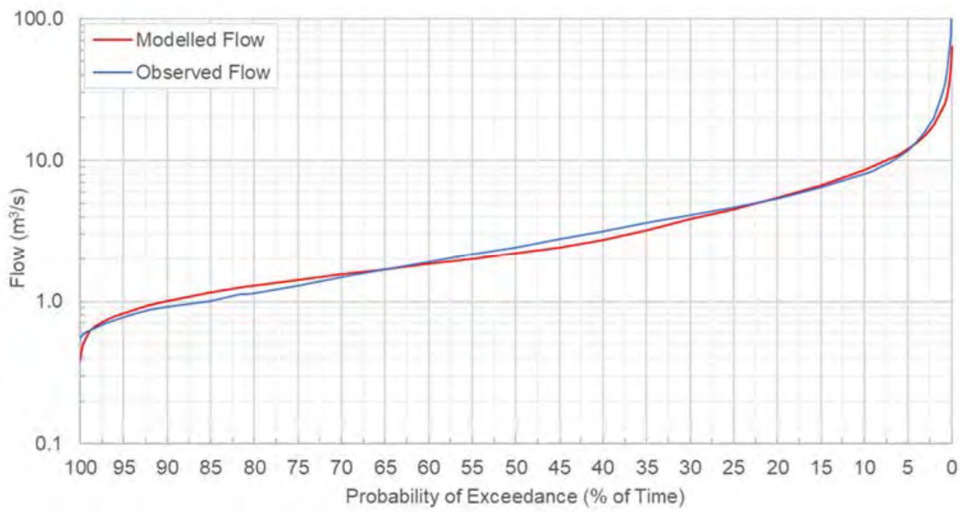

Figure 27. Flow duration curve of modelled and measured flow for Kaihu at Gorge.

A comparison of modelled and observed flow for Kaihu at Roto is presented in **Figure 28**. This shows there is good agreement in the timing of flows and there is a good match between low to mid flows. However, in contrast to the upstream gauge Kaihu at Gorge, peak high flows are over predicted.

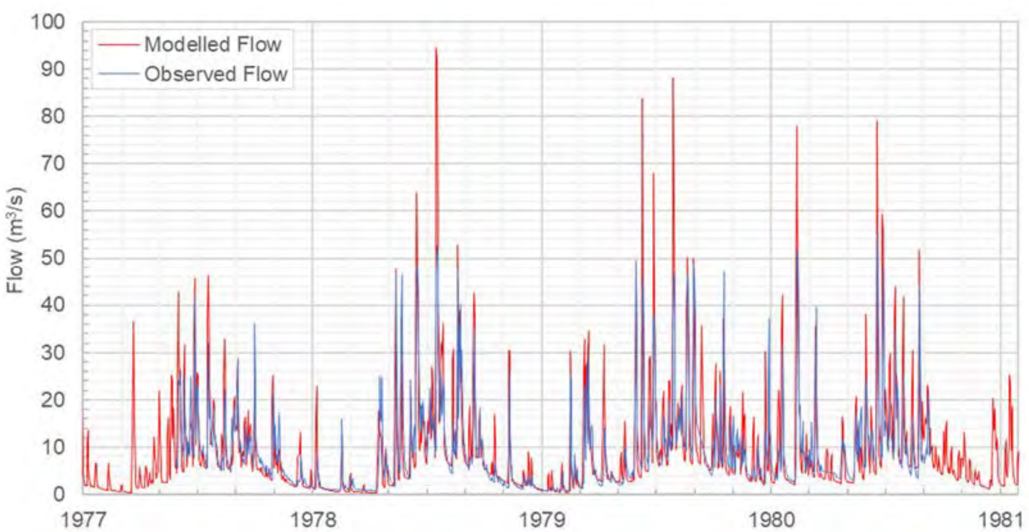

Figure 28. Hydrograph of modelled and measured flow for Kaihu at Roto.

A comparison of the modelled and measured flow duration curve is presented in **Figure 29.** There is a close agreement in flows that are exceeded between 35% and 90% of the time. The flow duration curve indicates the SMWBM tends to under-predict baseflow conditions and over predict high flow conditions. However, given the objectives of this project, under-prediction of baseflow conditions is not considered a major concern.

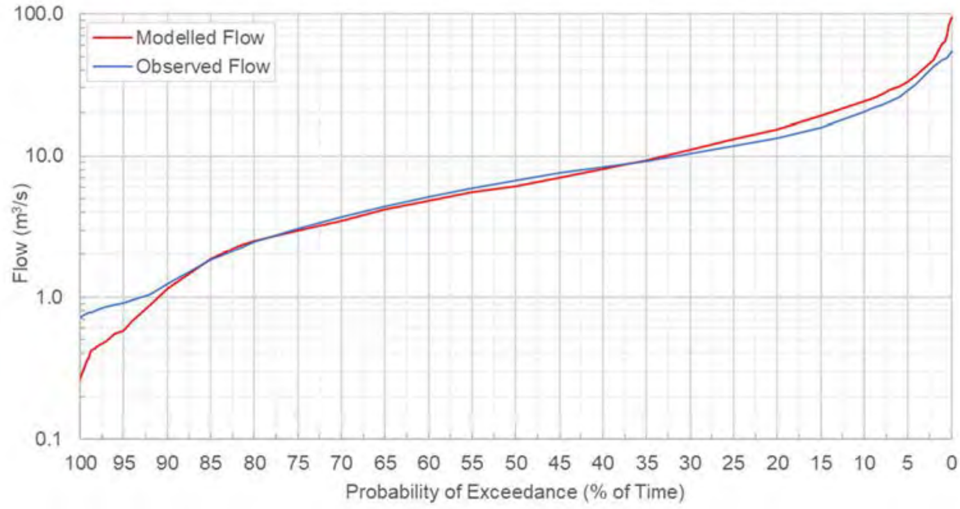

Figure 29: Flow duration curve of modelled and measured flow for Kaihu at Roto.

4.6.3 Awakino River

A comparison of modelled and observed flow for Awakino at Lawson Rd is presented in **Figure 30**. Visual observation of the hydrograph shows that the SMWBM successfully predicts that timing and magnitude of baseflow, based on the limited number of spot gauging's available.

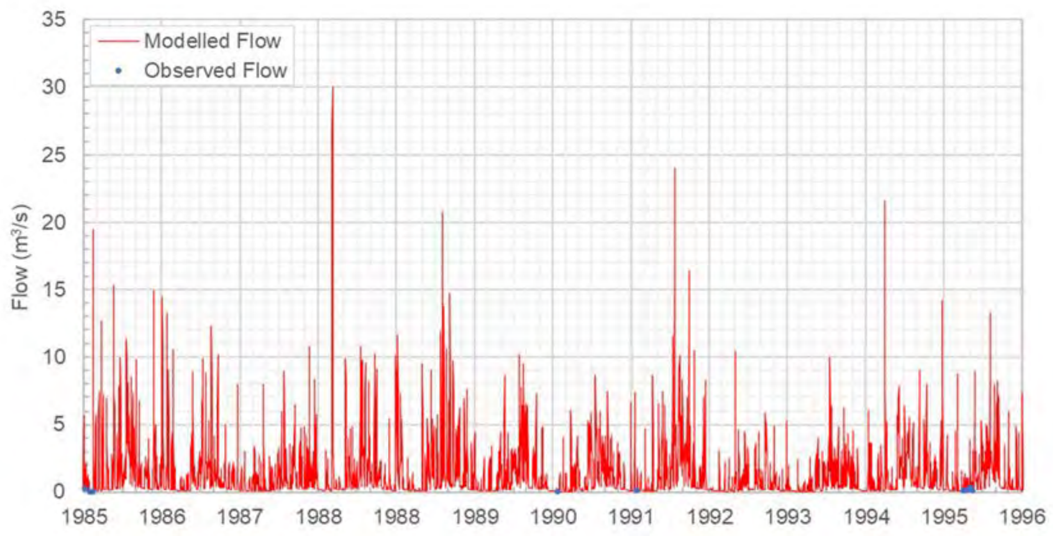

Figure 30. Hydrograph of modelled and measured flow for Awakino at Lawson Rd.

A comparison of modelled and observed flow for Awakino at Avoca Rd is presented in **Figure 31.** Visual observation of the hydrograph shows that the SMWBM successfully predicts that timing and magnitude of baseflow, based on the limited number of spot gauging's available.

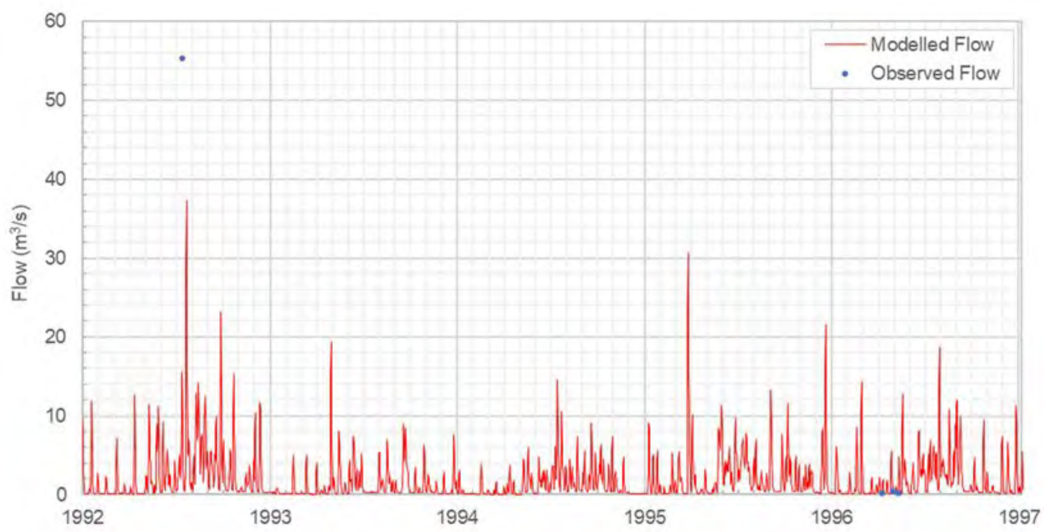

Figure 31. Hydrograph of modelled and measured flow for Awakino at Avoca Rd.

4.6.4 Poutō Peninsula

Comparisons of modelled and observed flow for Kaihu (Babylon Drain) Trib at SH12 are presented in **Figure 32** and **Figure 33**. Across the full time period of 1977 to 2007 there is good agreement to the magnitude of base flows indicating that there is confidence in the model to successfully simulate base flow. However, as no high flow gaugings were available, the level of confidence in the model's ability to predict high flows is undetermined.

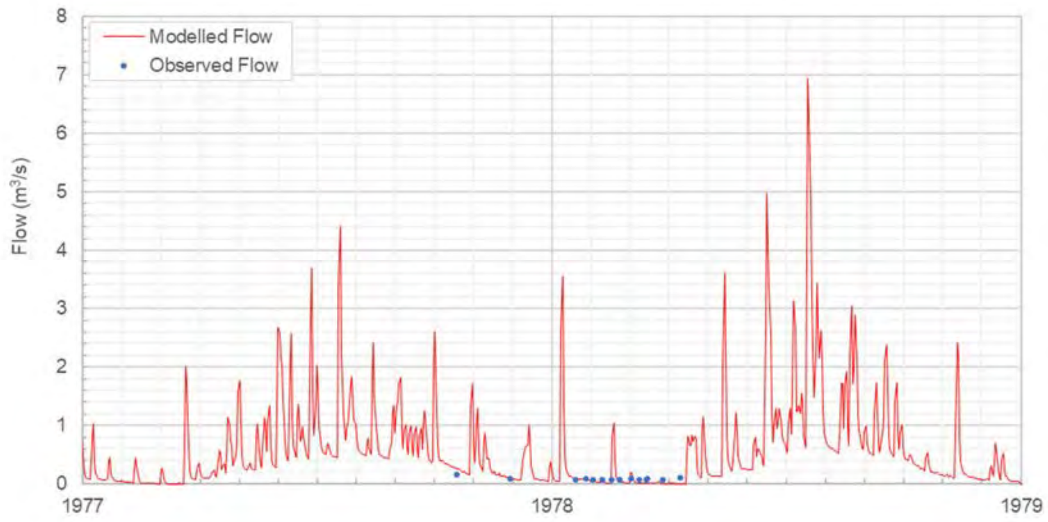

Figure 32. Hydrograph of modelled and measured flow for Kaihu (Babylon Drain) Trib at SH12 (1977-1979).

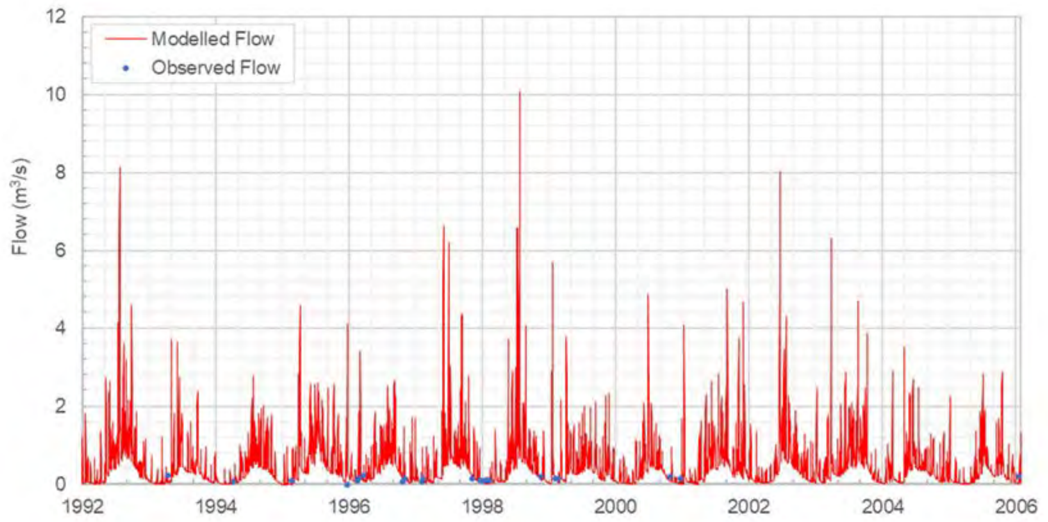

Figure 33. Hydrograph of modelled and measured flow for Kaihu (Babylon Drain) Trib at SH12 (1992-2007).

A comparison of modelled and observed flow for Mangatara Drain at SH1 Bridge is presented in **Figure 34**. The model simulated good agreement to the singular observed flow gauging, however overall the lack of gauging makes it difficult to assess the accuracy of the model.

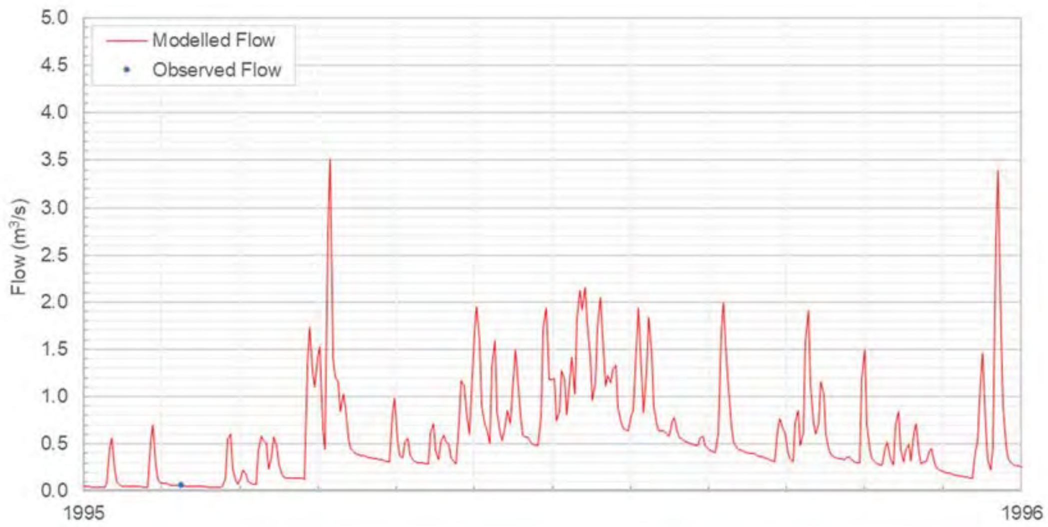

Figure 34. Hydrograph of modelled and measured flow for Mangatara Drain at SH1 Bridge.

A comparison of modelled and observed flow for Aratapu Creek at Guy Ropes is presented in **Figure 34**. Based on visual observation of the simulated hydrograph, the model simulates the general timing of baseflow events, albeit there are only two data points that were available to make this assessment.

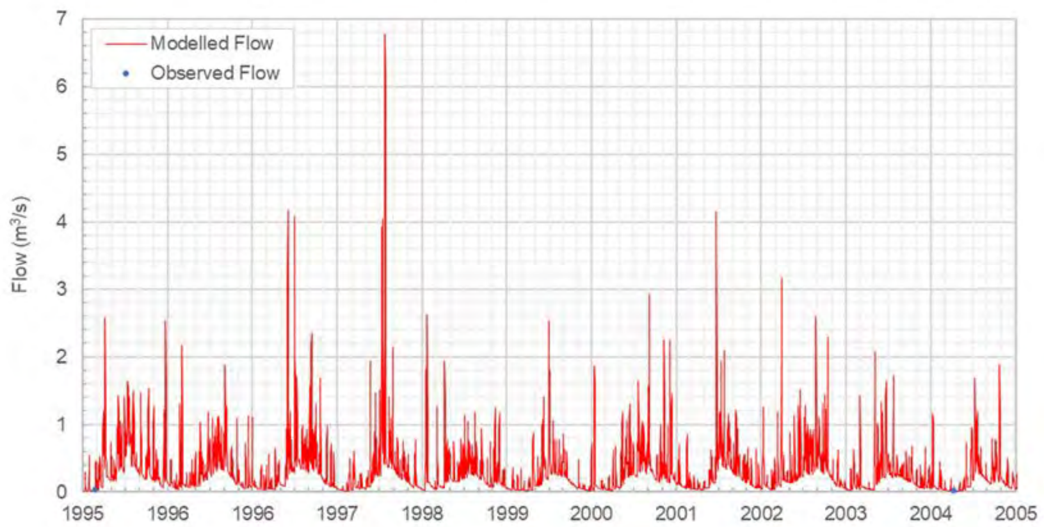

Figure 35. Hydrograph of modelled and measured flow for Aratapu Creek at Guy Ropes.

4.7 Flow Regime Summary

The following sections provide a summary of the hydrological flow regime for each of the catchments identified for the Mid-North and Kaipara study areas (**Section 3**). Hydrological flow regime statistics were calculated at the downstream extent of each sub-catchment. It should be noted, these statistics represent the total sub-catchment flow, and not just the flow of the main watercourse used to label the sub-catchments. Where applicable, key catchment statistics were normalised by catchment area, which was undertaken specifically for direct comparison between sub-catchments and across study areas.

The key flow regime statistics calculated were:

- **Mean flow** – long term mean flow (1973-2018).
- **Specific discharge** – mean flow divided by catchment area.
- **Normalised 7-day mean annual low flow** – the 7-day MALF divided by catchment area.
- **Normalised mean annual high flow** – mean annual high flow divided by catchment area.
- **Harvesting index** – the 1 in 10-year minimum above median flow volume divided by catchment area.

The mean flow and specific discharge characterise mean flow conditions. The 7-day MALF (normalised by catchment area) characterises low flow conditions, and forms the base statistic of the RPN run of river surface water allocation criteria (**Section 2.3.2**). The normalised mean annual flow and harvesting index provide description of the mean annual high flow and above median flow variability, respectively. The statistics represent the cumulative flow (i.e. flow generated within each individual sub-catchment and all those upstream).

4.7.1 Mid-North

A summary of flow regime statistics for each of the Mid-North sub-catchments is presented in **Table 9**.

Sub-catchment specific discharges range from 0.024 to 0.046 m^3s^{-1}/km^2, with an average of 0.031 m^3s^{-1}/km^2. Sub-catchment 10 (**Figure 7**) has the lowest specific discharge, due to lower annual average rainfall and less permeable underlying geology (greywacke), in comparison to other sub-catchments. Conversely, Sub-catchments 12 and 13 have higher specific discharges than surrounding sub-catchments due to the inclusion of additional groundwater flow from Lake Omapere.

Table 9. Summary of Mid-North flow regime statistics.

SC ID	Name	Catchment Area (km^2)	Mean Flow (m^3/s)	Specific Discharge (m^3s^{-1}/km^2)	Normalised 7-Day MALF (m^3s^{-1}/km^2)	Normalised Mean Annual High Flow (m^3s^{-1}/km^2)	Harvesting Index (Mm^3/km^2)
1	Huehue Stream	53.1	1.5	0.028	0.003	0.364	0.46
2	Mangaone Stream	50.0	1.3	0.027	0.002	0.421	0.48
3	Upper Punakitere River	42.9	1.4	0.033	0.005	0.334	0.50
4	Wairoro Stream	47.0	1.4	0.030	0.004	0.306	0.44
5	Mangatoa Stream	46.7	1.4	0.031	0.004	0.277	0.45
6	Punakitere River	251.3	7.2	0.029	0.004	0.336	0.47
7	Mangamutu Stream	37.7	1.2	0.031	0.003	0.462	0.52
8	Upper Waiaruhe River	77.2	2.4	0.031	0.003	0.476	0.53
9	Puketotara Stream	43.8	1.2	0.028	0.002	0.444	0.50

SC ID	Name	Catchment Area (km^2)	Mean Flow (m^3/s)	Specific Discharge (m^{3}s^{-1}/km^2)	Normalised 7-Day MALF (m^{3}s^{-1}/km^2)	Normalised Mean Annual High Flow (m^{3}s^{-1}/km^2)	Harvesting Index (Mm^3/km^2)
10	Manania Stream	37.2	0.9	0.024	0.003	0.356	0.33
11	Waiaruhe River	172.9	4.9	0.028	0.003	0.433	0.47
12	Waitangi River at Waimate North Rd	50.5	1.9	0.037	0.004	0.531	0.62
13	Waitangi River at SH10	82.7	3.8	0.046	0.003	0.686	0.80
14	Waitangi River	301.3	9.9	0.033	0.003	0.485	0.56

4.7.2 Kaipara

A summary of flow regime statistics for each of the Kaipara sub-catchments is presented in **Table 10**.

Sub-catchment specific discharges range from 0.017 to 0.034 m^{3}s^{-1}/km^2, with an average of 0.026 m^{3}s^{-1}/km^2. There is a general trend of decreasing specific discharge from north to south, consistent with the rainfall gradient across the Kaipara study area. For example, annual average rainfall is approximately 1,830 mm in headwaters of the Kaihu River, reducing to approximately 1,100 mm at Te Kopuru, on the Poutō Peninsula. The lower specific discharges in the Kaipara study area in comparison to Mid-North are predominately due to the lower average annual rainfall in the majority of the Kaipara.

Table 10. Summary of Kaipara flow regime statistics.

SC ID	Name	Catchment Area	Mean Flow	Specific Discharge	Normalised 7-Day MALF	Normalised Mean Annual High Flow	Harvesting Index
		(km^2)	(m^3/s)	(m^{3}s^{-1}/km^2)	(m^{3}s^{-1}/km^2)	(m^{3}s^{-1}/km^2)	(Mm^3/km^2)
1	Waima River	54.5	1.8	0.033	0.007	0.307	0.50
2	Mangatu Stream	34.5	1.2	0.036	0.008	0.328	0.60
3	Ngaiore Stream	16.3	0.6	0.034	0.007	0.242	0.48
4	Kaihu at Gorge	115.2	3.9	0.034	0.007	0.294	0.52
5	Kaihu at Awakiwi Take	157.7	5.4	0.034	0.007	0.290	0.52
6	Kaihu at Waiatua Confluence	251.6	7.9	0.031	0.005	0.263	0.51
7	Taita Stream	28.4	0.6	0.023	0.002	0.232	0.40
8	Waiatua Stream	13.0	0.4	0.027	0.003	0.249	0.45
9A	Kaihu at Rotu	267.6	8.2	0.031	0.005	0.257	0.51
9B	Kaihu at Wairoa Confluence	358.1	10.0	0.028	0.004	0.236	0.49
10	Korariwhero Flats Drains	27.4	0.5	0.020	0.001	0.189	0.35
11	Mangatara Stream	26.6	0.5	0.018	0.002	0.152	0.31

SC ID	Name	Catchment Area	Mean Flow	Specific Discharge	Normalised 7-Day MALF	Normalised Mean Annual High Flow	Harvesting Index
		(km^2)	(m^3/s)	(m^3s^{-1}/km^2)	(m^3s^{-1}/km^2)	(m^3s^{-1}/km^2)	(Mm^3/km^2)
12	Awakino River at Lawson Rd	45.5	1.4	0.030	0.001	0.352	0.57
13	Awakino River at Avoca Rd	73.6	2.1	0.028	0.001	0.336	0.53
14	Awakino at Wairoa Confluence	117.7	3.0	0.026	0.001	0.307	0.49
15	Oruariki Creek	15.4	0.3	0.018	0.001	0.187	0.32
16	Aratapu Creek	41.2	0.7	0.018	0.002	0.165	0.32
17	Makaka Creek	20.9	0.4	0.018	0.001	0.181	0.32
18	Tatararaiki Drains	20.7	0.4	0.017	0.002	0.165	0.30
19	Taihu Creek	18.6	0.3	0.018	0.001	0.190	0.35

4.8 Summary of Available Water Resources

Using the calibrated catchment flow models developed above, a range of flow statistics were calculated to provide an overview and comparison between sub-catchments of potential water available for harvest of run of river take. Harvestable flows (flows median) were calculated at the downstream extent of each sub-catchment and run of river takes summarised for two specific locations.

4.8.1 Harvestable Flow

Average recurrence interval (ARI) flow volume statistics for differing flow frequencies are presented for the outlet (most downstream extent) for each modelled sub-catchment in the Mid-North and Kaipara in **Table 11** and **Table 12**, respectively. The flow volumes represent the total volume of water available above median flow. It should be noted, these volumes are indicative only for comparative purposes, and do not take into account operational considerations for storage such as bypass flows (e.g. for example when storage is full).

Following the high-level identification of potential storage locations (**Section 7**) and refinement and shortlisting of storage options (**Section 8**), the above median flows outlined below were pro-rated (scaled) by catchment area to locations upstream, representative of the shortlisted storage locations, providing an indication the ability of each storage location to support (fill) themselves due to upstream catchments flows.

Table 11. Mid-North above median flow volumes.

SC ID	Name	Catchment Area (km^2)	Above Median Flow (m^3/year)		
			1 in 20-year ARI Minimum Flow	1 in 10-year ARI Minimum Flow	1 in 2-year ARI Minimum Flow
1	Huehue Stream	53.1	22,130,000	24,380,000	39,810,000
2	Mangaone Stream	50.0	21,540,000	23,980,000	39,560,000
3	Upper Punakitere River	42.9	20,290,000	21,400,000	37,590,000
4	Wairoro Stream	47.0	20,190,000	20,590,000	37,370,000

SC ID	Name	Catchment Area (km²)	Above Median Flow (m³/year)		
			1 in 20-year ARI Minimum Flow	1 in 10-year ARI Minimum Flow	1 in 2-year ARI Minimum Flow
5	Mangatoa Stream	46.7	19,720,000	20,890,000	38,160,000
6	Punakitere River	251.3	106,200,000	118,300,000	201,200,000
7	Mangamutu Stream	37.7	18,600,000	19,710,000	33,050,000
8	Upper Waiaruhe River	77.2	39,070,000	40,920,000	69,820,000
9	Puketotara Stream	43.8	19,880,000	21,770,000	35,390,000
10	Manania Stream	37.2	10,920,000	12,310,000	23,490,000
11	Waiaruhe River	172.9	76,560,000	82,010,000	137,600,000
12	Waitangi River at Waimate North Rd	50.5	29,810,000	31,560,000	53,220,000
13	Waitangi River at SH10	82.7	62,860,000	65,940,000	109,100,000
14	Waitangi River	301.3	155,000,000	169,300,000	276,400,000

Table 12. Kaipara above median flow.

SC ID	Name	Catchment Area (km²)	Above Median Flow (m³/year)		
			1 in 20-year ARI Minimum Flow	1 in 10-year ARI Minimum Flow	1 in 2-year ARI Minimum Flow
1	Waima River	54.5	25,320,000	27,420,000	46,090,000
2	Mangatu Stream	34.5	19,870,000	20,680,000	30,880,000
3	Ngaiore Stream	16.3	6,746,000	7,761,000	13,750,000
4	Kaihu at Gorge	115.2	54,560,000	59,350,000	98,460,000
5	Kaihu at Awakiwi Take	157.7	75,590,000	82,160,000	137,800,000
6	Kaihu at Waiatua Confluence	251.6	119,800,000	128,900,000	201,700,000
7	Taita Stream	28.4	10,620,000	11,220,000	18,440,000
8	Waiatua Stream	13.0	5,330,000	5,903,000	9,490,000
9A	Kaihu at Rotu	267.6	125,700,000	135,300,000	210,800,000
9B	Kaihu at Wairoa Confluence	358.1	157,100,000	176,000,000	257,900,000
10	Korariwhero Flats Drains	27.4	9,398,000	9,625,000	15,050,000
11	Mangatara Stream	26.6	7,696,000	8,163,000	12,940,000
12	Awakino River at Lawson Rd	45.5	24,890,000	26,080,000	40,080,000
13	Awakino River at Avoca Rd	73.6	38,630,000	39,060,000	60,600,000
14	Awakino at Wairoa Confluence	117.7	56,790,000	57,980,000	88,250,000
15	Oruariki Creek	15.4	4,795,000	4,871,000	7,918,000
16	Aratapu Creek	41.2	11,970,000	12,990,000	20,240,000
17	Makaka Creek	20.9	6,466,000	6,722,000	10,490,000
18	Tatararaiki Drains	20.7	5,922,000	6,266,000	9,831,000
19	Taihu Creek	18.6	6,032,000	6,498,000	9,666,000

4.8.2 Run of River Takes

While run of river water takes were not considered in the refinement and shortlisting of potential storage locations (**Section 8**), two run-of-river take locations were identified and considered to have potential to support horticultural irrigation alongside takes from storage at the conceptual design stage of this assessment. Therefore, a summary of potential run of river sources are presented here.

The two run-of-river take options locations were identified based on a combination of:

- proximity to command areas;
- upstream catchment area (and thus likely higher river flows); and
- indicative existing remaining available allocation.

The sites identified were the Punakitere River at Matarua Road in the Mid-North study area, and the Kaihu River at Rotu in the Kaipara.

The total run-of-river take for each location was calculated as 40% of the 7-day MALF (**Section 2.3.2**). The current level of allocation was estimated from the NRC online indicative surface water allocation maps**,** assuming the middle of band (e.g. assumed 50% current allocation for the Moderate (25% – 75%) allocation band). Remaining Allocation was estimated as the product of the total run-of-river take rate and current allocation level (**Table 13**).

Table 13. Run-of-river takes.

Location	7-day MALF (m^3/s)	Total run-of-river take (m^3/s)	Indicative current allocation (%)	Estimated remaining allocation (m^3/s)
Punakitere at Mataraua Road	0.59	0.24	50	0.12
Kaihu at Rotu	1.38	0.56	87.5	0.07

Current surface water take consents are shown in **Figure 11** and **Figure 12**, and tabulated in **Appendix D**. It is understood a number of existing surface water irrigation take consents, particularly relying on the Kaihu River, are due to expire within approximately the next 5 years. Where this is the case there is likely to be the opportunity to rationalise the volumes of water being abstracted by individual irrigators, and potentially increase available allocation.

Supply reliability of the run-of-river takes was analysed by calculating the average number of days per irrigation season where streamflow in each river was below the minimum streamflow requirement (**Section 2.3.2**), and the average recurrence interval of 3, 7, and 14 consecutive days of take restrictions due to minimum flow criteria (**Table 13**).

Table 14. Run of river supply reliability – ARI (years) of various restriction criteria.

Location	Average restricted (no Take) days per year (count)	ARI (years)		
		3 consecutive days	7 consecutive days	14 consecutive days
Punakitere at Mataraua Road	11	3	4	6
Kaihu at Rotu	8	4	5	10

The temporal variation in run of river supply reliability was assessed by calculating on a monthly basis the number of no take days during the irrigation season for the two proposed run of river take sites (**Table 15** and

Table 16). The analysis showed run of river restrictions (no take days) typically tend to happen during mid to late summer (February to April).

Table 15. Statistical summary of monthly no take days from the 47-year simulated flow record of the Punakitere River.

Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Minimum	0	0	0	0	0	0	0	0
Median	0	0	0	0	0	0	0	0
Average (Mean)	0	0	0	2	3	4	2	0
Maximum	0	0	2	26	24	29	30	0

Table 16. Statistical summary of monthly no take days from the 47-year simulated flow record of the Kaihu River.

Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Minimum	0	0	0	0	0	0	0	0
Median	0	0	0	0	0	0	0	0
Average (Mean)	0	0	0	0	1	2	1	0
Maximum	0	0	0	9	12	29	14	0

5. Consideration of Alternative Water Sources

In addition to the sources analysed in **Section 4**, there are multiple alternative water sources that could potentially meet all or part the needs of community in current or future states, that have not been further investigated in any detail as part of this study due to the complexity, scale, or fit with the project funding criteria and brief. This does not mean these sources are not suitable, nor could they not be considered in the future as part of the optimum solution.

These include:

- groundwater that shows a degree of hydraulic disconnection to surface water;
- lake water;
- catchments further afield;
- water in the tidal zone; and
- saltwater (i.e. desalination).

We however acknowledge the expectation from within the communities of interest that [redacted] and the Northern Wairoa River should be considered as part of the solution. To our knowledge, there is nothing to suggest at the current time that both water bodies could not be technically feasible solutions.

That being said, it is evident that both of the options above are unlikely to be implementable in the "short term" and will also potentially face lengthy consultation and consenting processes. As they both have potentially significant environmental benefits in addition to the potential economic benefits they could provide as part of the solution to their respective community water supply schemes, the environmental aspect will require a multi-faceted approach in regard to both project governance and funding (discussed further below).

5.1 Wairoa River

A report undertaken by BECA (1995), considered the merit of a barrage across of the Northern Wairoa River at several locations with a construction cost estimated in the order of $60M for the barrage alone. This project was funded by the Northern Dairy Co-operative at the time, with as specific focus upon pastoral irrigation.

If this was to be re-evaluated now, it would likely be a much more costly exercise and likely harder to consent although possibly wider arching in terms of consideration of effects, both positive and negative.

Through discussions with land owners held throughout this project, it is evident that there is an expectation that this should be considered. Further to this we understand that both the KDC and Iwi in particular are interested in this concept to address a multitude of challenges facing the Kaipara Community in the future – renaming the project the "Wairoa Lock".

[redacted]

[redacted]

The study clearly outlined that the processes required to enable Lake Omapere to be considered a reliable source of water would cost tens of millions of dollars, and could take several decades before it could be considered for productive use.

Through discussions with land owners, Lake Omapere was thought of as an obvious source of water, as due to its elevation it could act as a “header tank” for a water distribution scheme. Lake Omapere was not assessed from an available water resources perspective during this project, however it was assumed recharge and available water resources were sufficient to support irrigation demand for the Mid-North command area for a conceptual design scenario (Volume 3 – Conceptual Design and Costing). It is understood potential available water resources from Lake Omapere will be investigated as part of a larger Lake Omapere hydrology assessment.

5.3 Water from within Tidal Zone

Taking of fresh water from the upstream interface of the tidal zone of the lower Kaihu River closer to proposed storage may be a viable option albeit after careful consideration to the daily and seasonal changes in availability. Potentially this could include the incorporation of a control structure or sorts close to Dargaville to minimise the distance that water would need to be transferred.

This arrangement is considered to be relatively complex and initially there is likely more merit in pumping water from the lower reaches of drainage districts within the command areas prior to this water entering the Northern Wairoa River via floodgates.

It is suggested that this would be best considered a supplementary source in the future, should demand require further water to be secured, rather than a core source of water for the scheme.

5.4 Concluding Statement

Both the Wairoa River and [redacted] almost certainly will not form part of the solution in the short term. However, they could form part of the medium to long term solution should an incremental or staged approach be determined as the optimum way to progress. This would allow time for these sources to be further investigated with the possibility of both the Wairoa River and [redacted] forming part of the medium to long term solution.

Any scheme reliant on the Wairoa River and [redacted] as future components will need to have a backup plan (Plan B), in case they are not ready in time and/or it becomes evident they are not a viable option following feasibility studies.

6. Potential Implications from Climate Change

Climate change will likely affect both water availability (rainfall and subsequently streamflow) and irrigation water demands in the future. Northland is expected to warm into the future, giving rise towards a more subtropical climate (Pearce, 2017).

The following summary of projected changes for Northland are presented in Pearce (2017):

- the number of days exceeding 25°C may increase from 25 days now, to 99 days by 2090;
- frosts may decline from one frost every two years, to one frost every ten years;
- rainfall changes are small by 2040, with up to 10% decrease in spring rainfall in some areas;
- by 2090 further reduction in spring rainfall (up to 20%), and increased rainfall in autumn/summer; and
- increased risk of drought is highest for east and west coasts and southern inland areas of Northland.

There is some uncertainty in future climate change and in particular rainfall, as changes will depend on global future greenhouse gas emissions. We acknowledge climate, and impacts of climate change will likely differ between the two study areas and Whangarei. However, Whangarei is discussed below by way of example of potential uncertainty and variability. Projected changes in precipitation across Northland are then discussed below.

The range (variability) of projected changes in precipitation for Whangarei by 2090 are shown **Figure 36** for four Representative Concentration Pathway (RCP) emission scenarios. The range of possible outcomes is indicated by the length of the bars and inset starts (that show individual climate model results for each RCP). However, even when acknowledging the uncertainty and range of potential future emission scenarios, future climate model results generally show consensus in reduced precipitation for Whangarei in winter and spring, only a slight increase in summer and no change in autumn.

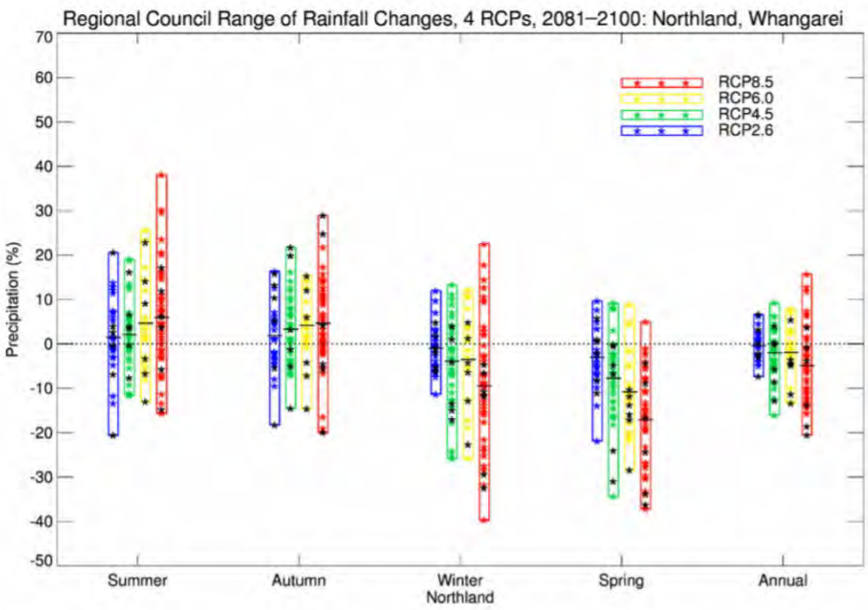

Figure 36. Range of model outcomes for seasonal and annual rainfall by 2090 for Whangarei (from Pearce, 2017).

Projected changes in seasonal rainfall for 2040 and 2090 in Northland, for the worst-case scenario (RCP 8.5) are illustrated in **Figure 37**. By 2040, spring rainfall is project to decrease by 5-10%, and small changes (±5%) are projected for summer, autumn and winter.

Spring rainfall is projected to further decrease by 2090 by up to 20% in eastern Northland. Eastern areas are projected to experience increased rainfall of approximately 5-10% during autumn and summer, with decreases of 5-10% likely during winter. While rainfall may slightly increase in summer, such increases are likely to be offset by increased evaporation rates associated with elevated temperatures.

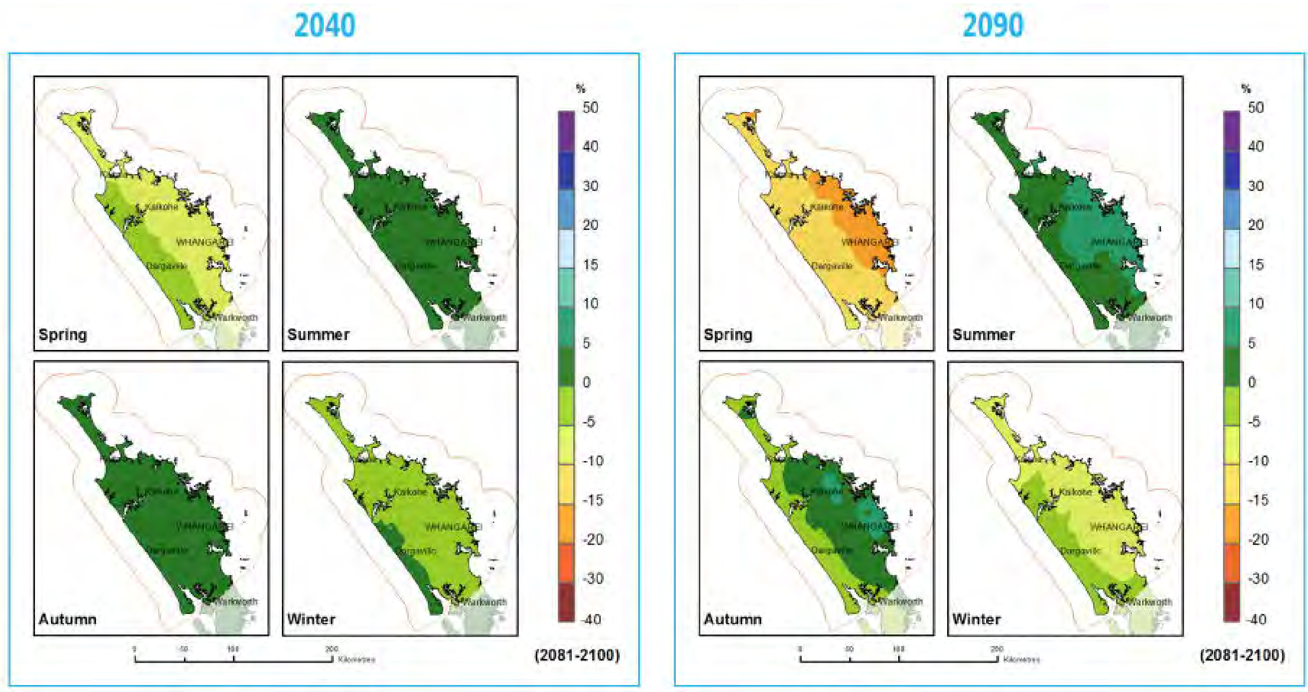

Figure 37. Projected seasonal rainfall changes for 2040 and 2090, compared to seasonal averages for 1986-2005, for RCP 8.5 'worst case' scenario (from Pearce, 2017).

Changes in surface water flows due to climate change remain uncertain. The following points are summarised from Pearce (2017) outlining potential changes in flow within the Wairoa River as a case study example:

- Results were variable between model runs, and were shown to be highly sensitive to where rainfall falls within the catchment.
- Mean annual flow decreased, consistent with decreases in total precipitation under the worst-case scenario by 2090.
- Changes in average maximum flood flows were variable between scenarios. The worst-case scenario projects a decrease in maximum flood by 2040 of 3%, and an increase of 22% by 2090.
- Reductions in low flows at 2040 and 2090 are projected under most scenarios. Under the worst-case scenario a reduction of 24% is projected at 2090.
- Decreases in summer, winter and spring flows, with small increases autumn flows are projected.

Extrapolating the conclusions drawn above for the Wairoa River by Pearce (2017) to catchments of interest for this project, the following potential implications on water supply and storage are made:

- Decreases in mean annual flows will likely result in a reduction in direct inflows from the upstream catchment of the storage reservoirs. Therefore, additional or larger volumes of water may need to be sourced from external catchments (e.g. neighbouring streams, or pumped from lower in the catchment).
- Decreases in summer and spring flows will reduce direct inflows into the storage reservoirs during times at which demand and use is high. Therefore, either larger volume reservoirs, additional or larger volumes of

water may need to be sourced from external catchments in order to provide the same level of service reliability as present.

- Reductions in low flows will reduce the viability of any run-of-river takes, as the minimum flow criteria and allocable flow limit are set based on the 7-day MALF.

Given the large variability and uncertainty in climate projections across Northland, particularly in regards to changes in streamflow, it is recommended potential impacts of climate change across the command areas and water resource catchments are investigated in further detail in the next phase (feasibility assessment) of the project.

Potential implications of climate change on irrigation demand are discussed in report **Volume 1 – Command Area Analysis.**

7. High-Level Storage Area Identification

7.1 Overview

The objective of the high-level storage area identification was to provide an initial long list of potential storage locations selected based on storage volume and storage efficiency (defined below) only. Once a long list of potential storage locations had been identified, these were further refined based on a wider range of criteria (**Section 8**).

The high-level identification of potential storage sites was undertaken using WWLA's Reservoir Identification Tool (RIT), which is an automated geospatial analysis tool modified from the Impoundment Size Index (ISI) component of the Whitebox Geospatial Analysis Tools package developed by Lindsay (2016). ISI was developed for mapping and quantifying the extent of topographic incisions in DEMs and functions by:

- iteratively identifying cross-section profiles that can be impounded in a local area;
- applying a priority-flood operation to determine flow direction and the number of inflowing cells for each DEM grid cell; and subsequently
- performs a flow accumulation to identify the upstream cells that reside under the maximum impoundment wall height.

WWLA further developed the ISI tool to identify and rank potential storage locations based on specific input criteria including:

- minimum and maximum reservoir storage size required;
- maximum embankment wall length and height; and
- reporting on only a specified number of highest ranked locations (discussed further below).

Additional modifications included the ability to output:

- identified storage reservoirs footprints (surface area);
- metadata including storage volume, surface area, embankment fill volume estimates; and
- the rank of reservoirs identified calculated by storage volume (reservoir size) or storage efficiency (defined as storage volume / embankment fill volume).

Estimates of embankment fill volumes were calculated assuming: a 3:1 embankment fill slope, valley floor as 25% of crest length, and site stripping of 0.5 m + 5% of embankment height using the following equation:

$$Embankment\ fill\ volume = 3.37\ x\ Crest\ Length\ x\ Crest\ Height^{1.82}$$

Outputs of the high-level storage area identification were them refined and shortlisted based on criteria such as proximity to command area (distance and elevation), storage volume, storage efficiency etc. prior to undertaking site visits and initial multi-criteria analysis (MCA) (**Section 8**). The resulting storage locations subsequently proceed for conceptual design and costing (**Report Volume 3**).

7.2 Inputs, Exclusions and Scenarios

The primary input into the RIT is a high-resolution DEM. LiDAR data were not initially available at the time the work commenced and initial testing using the LINZ 8 m DEM, which was developed from the Topo50 20 m contour data, demonstrated the importance of high-resolution DEM, with a number of known potential storage locations not identified. Once the NRC LiDAR data became available, all further testing and scenario analyses was undertaken using the LiDAR resampled to a 5 m resolution raster.

Areas considered high priority exclusions were explicitly excluded from the analysis of high-level storage options. All other exclusions were then accounted for during the Multi-Criteria Analysis (MCA) stage (**Section 8.4**). High priority exclusions explicitly removed included:

- Urban areas;
- State Highways;
- Native Forests; and
- Significant Wetlands.

Three scenarios were run for both the Mid-North and Kaipara study areas, representing large, medium, and small storage options. All three scenarios used the same LiDAR DEM as input, with exclusions removed as outlined above. The only changes between scenarios were the storage volumes and embankment heights and lengths. The input parameters for the three scenarios are outlined in **Table 17**.

Table 17. High-level storage identification scenarios.

Parameter	Scenario		
	Large Storage (S1)	Medium Storage (S2)	Small Storage (S3)
Minimum Volume (m^3)	500,000	500,000	500,00
Maximum Volume (m^3)	5,000,000	2,000,000	1,000,000
Maximum Embankment Height (m)	30	25	20
Maximum Embankment Length (m)	60 grid cells (300 m North-South, East West & 425 m diagonally)		

The scenarios outlined in **Table 17** were simulated in the RIT, and the top 20 identified storage locations based on storage volume and top 20 locations based on storage efficiency exported as standard format GIS shapefiles. Prior to running the RIT, both the Mid-North and Kaipara study areas were split into six sub-areas of approximately equal size, while ensuring full catchment boundaries remained within a sub-area. This ensured widespread spatial coverage of potential storage locations.

7.3 Outputs

The RIT identified between 100 to 120 possible sites per storage scenario (as defined in **Table 17**) for both the Mid-North and Kaipara study area. Collated outputs for the three storage size scenarios for the Mid-North and Kaipara study areas are presented in Error! Reference source not found. and **Figure 38.** Mid-North high-level storage identification outputs. **(Refer A3 attachment at rear).**

Figure 39, respectively. As seen in both of these figures, a large number of locations identified across the three scenarios appear as variations of the same approximate location. The locations are presented of the range and type of locations identified for contextual purposes only. Details for each location have been specifically withheld at this stage due to the large number identified and the fact that in the next section (**Section 8**), only a select few are further refined and shortlisted based on a range of additional criteria through MCA analysis.

Figure 38. Mid-North high-level storage identification outputs. (Refer A3 attachment at rear).

Figure 39. Kaipara high-level storage identification outputs. (Refer A3 attachment at rear).

8. Development and Refinement of a Long List of Storage Options

8.1 Initial Screening Stage

As outlined in **Section 7.3**, the RIT identified between 100 to 120 possible sites per storage scenario (**Table 17**) for both the Mid-North and Kaipara study area. Several of the sites were found to be at the same location, or slightly up or downstream, but with a different embankment height and storage. From this, a qualitative shortlisting exercise was undertaken to refine the number of sites to be taken forward for the Multi Criteria Analysis (MCA).

A target of two to three times the total maximum storage requirement for both areas was set for the shortlisting exercise, thereby ensuring sufficient flexibility remained for the MCA ranking process. Preference was given to sites with good storage efficiencies; multiple storage options; an obvious water source and distribution layout; and to those sites maintaining an even spatial coverage within catchments and across the area generally. Some of the sites were eliminated based on certain undesirable characteristics, for example, large ponded areas having average reservoir depths <0.5 m or those lying well outside the subject areas without merit.

It was necessary during this phase to envisage a logical conceptual layout for both single or distributed storage systems, to provide confidence that a concept design could be readily developed in future stages from the shortlisted sites. This included reviewing the surrounding topography (utilising the LiDAR DEM), and considering appropriateness of additional saddle dams and spillway layout etc. Outputs from the initial screening stage included a list of about 20 sites for each Mid-north (**Figure 40**) and Kaipara (**Figure 41**) areas to be brought forward to the site walkover (**Section 8.3**).

Figure 40. Initial screening stage shortlisted storage options in the Mid-North. (Refer A3 attachment at rear).

Figure 41. Initial screening stage shortlisted storage options in the Kaipara. (Refer A3 attachment at rear).

8.1.1 Storage Hydrology Characteristics

A part of the refinement and shortlisting of the long list of storage options, considerations was given to the ability of each storage site to be filled by inflows from the catchments upstream. Average recurrence interval (ARI) statistics are presented for the inflows of each of the shortlisted storage locations identified in **Table 18** and **Table 19** for the Mid-North and Kaipara, respectively. The inflow volumes were calculated using the catchment flow models developed in **Section 4**, and represent the total volume of water available above median flow. It should be noted, these volumes are indicative only, and do not take into account operational considerations such bypass flows (e.g. for example when storage is full). The inflow volumes are provided for comparative purposes to enable the MCA.

Table 18. Summary of catchment inflows to the initial screening shortlisted storage options in the Mid-North.

Storage ID	Storage Volume (m^3)	Minimum Inflow Volume (m^3)		
		1 in 20 Year ARI	1 in 10 Year ARI	1 in 2 Year ARI
[redacted]	1,120,000	318,900	356,400	641,100
[redacted]	2,100,000	1,386,000	1,469,000	2,437,000
[redacted]	580,000	119,500	133,500	240,200
[redacted]	670,000	568,000	634,800	1,142,000
[redacted]	1,000,000	143,700	164,700	268,600

Storage ID	Storage Volume (m^3)	Minimum Inflow Volume (m^3)		
		1 in 20 Year ARI	1 in 10 Year ARI	1 in 2 Year ARI
[redacted]	990,000	1,206,000	1,287,000	2,247,000
[redacted]	4,000,000	6,004,000	6,408,000	11,190,000
[redacted]	1,100,000	4,965,000	5,299,000	9,255,000
[redacted]	610,000	451,500	481,800	841,500
[redacted]	730,000	240,800	247,400	484,400
[redacted]	2,500,000	208,000	223,200	391,500
[redacted]	2,000,000	1,271,000	1,364,000	2,393,000
[redacted]	3,700,000	211,900	227,300	398,800
[redacted]	1,800,000	1,174,000	1,206,000	2,361,000
[redacted]	400,000	52,390	53,820	105,400
[redacted]	4,900,000	2,244,000	2,425,000	4,947,000
[redacted]	940,000	931,900	1,007,000	2,054,000
[redacted]	430,000	1,310,000	1,569,000	2,746,000
[redacted]	600,000	177,300	212,200	371,600
[redacted]	1,800,000	808,300	967,800	1,694,000

Table 19. Summary of catchment inflows to the initial screening shortlisted storage options in Kaipara.

Storage ID	Storage Volume (m^3)	Minimum Inflow Volume (m^3)		
		1 in 20 Year ARI	1 in 10 Year ARI	1 in 2 Year ARI
[redacted]	4,929,000	1,644,000	1,742,000	2,714,000
[redacted]	4,981,000	472,100	496,300	884,600
[redacted]	1,057,000	580,200	624,800	1,008,000
[redacted]	1,230,000	153,400	161,300	287,500
[redacted]	2,006,000	234,192	254,793	476,253
[redacted]	18,100,000	1,150,000	1,251,000	2,338,000
[redacted]	583,800	32,740	35,620	66,580
[redacted]	4,989,000	205,000	219,100	381,400
[redacted]	4,989,000	177,300	189,600	329,900
[redacted]	4,989,000	1,077,000	1,152,000	2,004,000
[redacted]	1,255,000	238,800	248,900	417,800
[redacted]	670,500	183,900	196,600	342,100
[redacted]	1,223,000	929,400	993,500	1,729,000
[redacted]	4,965,000	467,100	499,400	869,000
[redacted]	3,356,000	393,600	412,400	686,700
[redacted]	1,991,000	165,600	178,900	308,600
[redacted]	16,250,000	635,200	686,500	1,184,000
[redacted]	3,861,000	366,100	395,700	682,400
[redacted]	2,363,000	527,900	588,100	916,300
[redacted]	10,500,000	3,319,000	3,353,000	4,878,000

8.2 Desktop Geotechnical Analysis

The follow sections describe the desktop geotechnical analysis undertaken on shortlisted storage options.

8.2.1 Information Sources

A high-level review of available geotechnical information encompassing the two areas has been undertaken to identify likely ground conditions and the potential variability across reservoir sites, and for highlighting any known regional hazards that should be considered in the context of shortlisting and concept design.

The desktop analysis involved a review of:

- Published geological maps;
  - 1:250k Geological Map 2 – Whangarei, GNS Science 2009;
  - New Zealand Geology Webmap v.2.3 https://data.gns.cri.nz/geology/
  - New Zealand Active Fault Database v3.3 https://data.gns.cri.nz/af/
  - New Zealand Landslide Database v.4.1 https://data.gns.cri.nz/landslides/
- Geotechnical investigation information contained in the New Zealand Geotechnical Database accessible via the weblink: https://www.nzgd.org.nz
- Photoblique images captured in 2017 and 2018; and
- Information relating to known recent large dam projects nearby.

8.2.2 Geotechnical Considerations at Reservoir Sites

An overview of the regional geological setting is provided in **Section 3.2.2** of this report. A high-level summary of the geotechnical significance associated with the main geological units are provided below.

Mid-North:

- **Recent deposits (Tauranga Group)** comprising variable peat, sand, gravel in low-lying areas near active watercourses. Certain soils will contain organics, be weak/compressible, be highly permeable, and possible susceptible to liquefaction. Will require undercutting or remediation beneath dam embankment. Selected soils will be suitable for reuse as earthfill for dam construction.
- **Volcanic rock (Kerikeri Volcanic Group)** split into either basalt lava flows or scoria. Basalt will typically be highly jointed and have high strength in its unaltered/unweathered state; scoria contains large voids and can be much weaker making it less favoured than basalt. Both could require treatments at dam foundation depending on conditions (e.g. grouting, lining etc.). Excavated rock could be suitable for reuse as a liner/core material or free-draining aggregate depending on weathering and properties.
- **Northern Allochton** highly complex and variable sedimentary rocks, and erosional products derived from the rock. Reservoir stability, particularly under rapid drawdown, and temporary construction batter stability will need to be assessed on a case by case basis. Excavated material possibly suitable as low-permeability liner/core fill.
- **Basement Rock (Waipapa Group)** weakly metamorphosed greywacke sandstone and argillite, generally mapped to the northwest of the study area. Most favoured of the geological units but will still require assessment. Minimal foundation treatment envisaged, and suitable for reuse as earthfill dependant on weathering profile.

Kaipara:

- **Recent deposits (Tauranga Group)** comprising variable peat, sand, gravel in low-lying areas near active watercourses. Some older, partly consolidated deposits in areas. Certain soils will contain organics, be weak/compressible, be highly permeable, and possible susceptible to liquefaction. Will require undercutting or remediation beneath dam embankment. Selected soils will be suitable for reuse as earthfill for dam construction.
- **Sand dunes** which can be split into three sub-groups depending on age and composition; ranges from active, loose sand with interdune swamp deposits through to cemented, consolidated sandstone and lignite. Could have a range of permeabilities depending on the any hard pan layers or voids (e.g. 'tomos'). Synthetic lining could be considered at dam to minimise losses; partial upstream lining to the dam may be required to reduce foundation seepage. Undercutting of interdune swamp deposits likely beneath any dam embankments and below synthetic liner (if required).
- **Northern Allochton** highly complex and variable sedimentary rocks, and erosional products derived from the rock. Mapped to the north and east of study area only [redacted]. Reservoir stability, particularly under rapid drawdown, and temporary construction batter stability will need to be assessed on a case by case basis. Excavated material possibly suitable as low-permeability liner/core fill.

Table 20 broadly characterises the main geological units depending on their geotechnical complexity, associated hazard and whether there is any precedence for large storages. Precedence is a particularly useful indicator as to the likely challenges with building large storages in a given area. In general, based on our experience of the areas:

- There is some precedence for large storages in the Mid-North, particularly to the north and east in areas of more favourable geology (e.g. volcanic or basement rock). We are not aware of any significant dam safety instances at those locations and have largely performed well. Some challenges have been observed at large dam sites owing to poor foundation conditions in recent geological deposits, which have needed to be overcome by significant engineering works.
- There is little to no precedent for large storages in the Kaipara area. Small storages/effluent ponds/dune lakes were observed but may not accurately reflect the same challenges as for larger storage.

Table 20. Favourability of Geological Settings.

Management Unit	More challenging	Neutral	More favourable
Mid-North	• Recent deposits (Tauranga Group) • Melange (Northern Allochthon) • Scoria (of the Kerikeri Volcanics)	• Northern Allochthon • Basalt (of the Kerikeri Volcanics)	• Basement Rock (Waipapa group)
Kaipara	• Sand dunes (younger) • Recent deposits (Tauranga Group) • Northern Allochthon	• Sand dunes (older)	

8.2.3 Natural Hazards

Regional natural hazards have been considered in the context of the shortlisted reservoir sites, and are summarised in **Table 21**.

Table 21. Regional Natural Hazards Across Study Areas from Published Information.

Hazard	Mid-North	Kaipara
Land Instability	• Shallow, creep failures common within Northern Allochthon even on gentle slopes (<15°), especially Mangakahia Complex and melange. Large landslide features mapped within study area. • Rock toppling and/or translational failures possible in Kerikeri Volcanics.	• Erosional features including sinkholes/tomos commonly observed in active dune deposits along coastal cliffs (Q1d) and less so in consolidated older dunes (eQd, IPId). • At least five large landslides mapped within or nearby study area, some coinciding with specific reservoir sites (e.g. [redacted]
Seismicity	• Generally low by national standards. No recorded large earthquakes since records began (c.1840). • No active faults noted with nearest c.200km south. Several inactive faults associated with emplacement of Northland Allochthon noted.	• Generally low by national standards. No recorded large earthquakes since records began (c.1840). • No active faults noted with nearest c.150km south. Several inactive faults associated with emplacement of Northland Allochthon noted.
Geothermal/Volcanic	• Kaikohe-Bay of Islands and Whangarei Volcanic Fields not extinct, with last known eruption c.40,000 years ago and possible return period ~10,000-50,000 years although is difficult to predict. • Ngawha geothermal field only high-temperature geothermal field in NZ outside the Taupo Volcanic Zone (TVZ). Surrounding rocks possibly geothermally altered.	• N/A
Flooding	• Localised flooding of flat land possible, associated with nearby watercourses.	• Flooding to low-lying land on either side of the Wairoa River possible. • Some areas mapped south of Dargaville mapped within coastal flood hazard zone.
Coastal Inundation/Tsunami	• N/A	• Kaipara Tsunami evacuation/inundation zone does not extend within the subject area.
Aquifers	• Aquifers present within volcanics and may be present locally in Northland Allochthon.	• Portions of the southern and eastern areas overly mapped extents of the Kaipara Flats aquifer.
Mine Hazard	• Hazard identified in Kamo and Hikurangi. Other mines at Kiripaka, Whareora and Whauwhau may need evaluation.	

8.3 Site Walkovers

Field reconnaissance of the two study areas was undertaken by WWLA and RILEY staff on 7 and 8 October 2019. It included a general drive through of the areas to gain a regional appreciation, and an on-site walkover of shortlisted sites. Photographs were taken at possible dam locations and upstream into the reservoir. It was not possible to view every dam site due to access and time constraints. In these few locations, the nearest convenient vantage point (often looking into the reservoir area) was utilised.

Discussions and field observations were noted on field sheets that had been prepared in advance of the walkover. Where possible, attention was given to dam abutment/foundation conditions, nearby geological exposures, layout arrangements for spillways and inlet/outlet pipes, site access for construction, downstream environment etc. Key findings from the site walkover are summarised below.

Mid-North:

- Geology and topography were highly variable across the dam sites. Geological exposures, where present, indicate that: volcanic rock lies near the surface in mapped areas; areas underlain by allochthonous rocks generally had flat, hummocky terrane with springs/swampy ground.
- Both surficial and large-scale land movement was observed. The former was generally where a shallow blanket of recent deposits overlies competent rock; the latter in allochthonous rock.
- Several of the sites were located upstream of multiple dwellings or townships.
- Dam embankments were generally constrained to single locations by topographic changes and/or landslips. Interconnection between dams may require pumping in places, and gravity in others (e.g. northwest vs. mid-northeast).
- Site access to most locations for construction equipment is generally straightforward through existing farm tracks.

Kaipara:

- A number of the sites were in broadly similar terrane and at similar elevation along the eastern side of the ridgeline within natural gully features. Swampy deposits and high groundwater are possible at several of these locations.
- Geological exposures within silage pit cuts indicate weakly cemented sandstone with discontinuous hardpan layers in places. Voids present in some of the exposures could be suggestive of sinkholes/'tomos'.
- Numerous shallow erosional/landslip features are present in recent dune deposits along the western coastline and in coastal cliffs along Bailey's beach. Discussions with farmers suggest that sinkholes/'tomo' features do occur within the study area.
- Dam abutments were often gently to moderately sloping with no significant signs of mass movement/global instability. Reservoir slopes generally appeared stable, although views were often obscured due to topography changes and/or forestry.
- Multiple dam alignments, spillway locations, and inlet/outlet arrangements could be envisaged at most sites. Interconnection between dams appeared straightforward.
- Reservoirs were generally remote and had reasonably flat, broad floodplains with sparsely located residential and farm buildings between the dam site and the Wairoa River.
- Site access to most locations for construction equipment is generally straightforward through existing farm tracks.

8.4 Multi Criteria Analysis

A multi-criteria analysis 'MCA' was adopted to filter the list of storage prospects for advancement to subsequent assessment stages. MCA's provide a mechanism for filtering and ranking a large number of options without the need for intensive quantitative analysis. They provide a sense of the comparative differences when there are many, broadly similar, options to assess rather than a definitive assessment of feasibility. This approach is therefore an appropriate mechanism for differentiating options in a pre-feasibility stage of a potential development.

Each criterion within the MCA was rated for every storage option on a scale of 0 to 3. A score of '0' was considered a fatal flaw that effectively ruled that particular site out from further consideration. A rating of zero was therefore only used if a particular issue is identified that cannot be eliminated or mitigated.

Scores of 1 to 3 broadly correspond to the following descriptors:

1. ***Un-desirable*** - characteristics that make the site challenging or of less value.
2. ***Neutral*** - neither negative nor positive.
3. ***Desirable*** - Has characteristics that are positive or of increased value.

The MCA was grouped into five broad assessment categories being;

a) ***Storage*** - covers the broad characteristics of the storage at each location primarily associated with its size.
b) ***Dam*** - considers the main technical aspects, and corresponding technical feasibility, associated with construction of a dam and reservoir filling at each storage location.
c) ***Location*** - considers the storage in terms of is location relative to adjacent sources of water to fill the storage, and proximity to demand areas that would be supplied by the storage.
d) ***Land*** - examines the implications on land associated with each storage and dam location.
e) ***Consentability*** - takes a high-level view of the likely challenges associated with gaining resource and building consent for each storage location.

Each of these categories contain four sub-categories to provide increased definition of site characteristics, challenges and opportunities. All sub-categories and corresponding rating descriptors are provided in **Table 22**.

Table 22. Multi Criteria Analysis (MCA) scoring table.

Criterion	Descriptor	1	2	3
Storage				
Efficiency	Ratio of water stored to volume of dam earthworks	<10	10 to 20	>20
Reservoir Hazard	Level of hazard the reservoir presents to houses, infrastructure and the environment downstream. Relative risk compared to other sites.	High	Medium	Low
Catchment Size	How closely does the catchment size align with storage volume?	Significantly too large	Too small or too big	Close match
Site Flexibility	Can multiple storages options be formed at a given location?	Nil or minimal flexibility	Some flexibility	Very flexible
Dam				
Regional Natural Hazards	How prone is the dam and storage to regional hazards?	Highly	Moderately	Minimal
Geotechnical Complexity	Can a dam be constructed without significant engineering works?	Challenging	OK	Favourable
Site Configuration	How convenient is the site for arranging components e.g. spillways and outlets?	Challenging	OK	Convenient
Construction Considerations	Can a dam be safely constructed using locally available materials?	Challenging	Generally suitable	Suitable
Location				
Distance from Source	How far is the storage from the source of water to fill?	>5 km	< 5 km	Local catchment
Distance to Demand	How far is the storage from the irrigation supply area?	>5 km	<5 but >2	Within or Adjacent
Elevation vs Source	What is storage level relative to the source?	Well Above	Similar	Below (gravity feed)
Elevation vs Demand	What is the storage level relative to the supply area?	Well Below	Similar	Above (gravity feed)
Land				
Number of Properties	How many properties are potentially impacted by the storage	Several	2-3	1-2
Land Value	What is the comparative value of the land	High	Moderate	Low
Cultural/Heritage	Are there specific cultural or heritage considerations	High or several	Moderate or few	Minimal
Irrigator	Are the landowners effected potentially irrigators?	Unlikely	Possible	Likely
Consentability				
Ecological	What is the anticipated level of ecological impact?	High	Moderate	Low
Sensitivity	Does the location have particular aspects that make it sensitive?	High or several	Moderate or few	Minimal
Hydrological Change	What level of change to the natural flow regime might arise?	Significant	Moderate	Minimal

Criterion	Descriptor	1	2	3
Technical Challenges	Are there specific technical challenges that induce impacts?	Significant or many	Moderate or few	Minimal

For this initial MCA process, certain categories and sub-categories have been assigned a weighting factor to reflect project value and risk.

[redacted]

[redacted]	[redacted]	[redacted]								[redacted]						
[redacted]	[redacted]	[redacted]														
[redacted]		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

Summary MCA: Kaipara	Wt'd	Kaipara - South					Kaipara - Middle							Kaipara - North							
Group	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Averaged		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Minimum		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Storage	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Dam	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Location	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Land	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

Full MCA: Mid North			Mid North - South	Mid North - North
Sub-Category	Unit	1 - 5	[redacted]	
Storage			[redacted]	[redacted]
[redacted]	[redacted]			
Dam			[redacted]	[redacted]
[redacted]				
Location			[redacted]	[redacted]
[redacted]	[redacted]			
Land			[redacted]	[redacted]
[redacted]				
Consentabililty			[redacted]	[redacted]
[redacted]				

[redacted]

Full MCA: Kaipara			Kaipara - South	Kaipara - Middle	Kaipara - North
Sub-Category	Unit	1 - 5	[redacted]	[redacted]	[redacted]
Storage			[redacted]	[redacted]	[redacted]
[redacted]	[redacted]				
Dam			[redacted]	[redacted]	[redacted]
[redacted]					
Location			[redacted]	[redacted]	[redacted]
[redacted]					
Land			[redacted]	[redacted]	[redacted]
[redacted]					
Consentabililty			[redacted]	[redacted]	[redacted]
[redacted]					

9. Summary and Conclusions

The Water Resources Analysis component of the pre-feasibility assessment considered available sources and quantity of water available for harvesting, and first pass high-level identification of where such water could be stored.

Catchment flow models for the Mid-North and Kaipara study areas were developed using WWLA's Soil Moisture Water Balance Model (SMWBM) to characterise and quantify the flow regimes of the rivers and streams within and neighbouring the study areas. The flow models were calibrated against measured flow data, where available. Model calibration to continuous flow data were limited to four sites in the Mid-North and two sites in the Kaipara. Secondary calibration sites consisted of comparison to manual low flow gaugings, which were sparse across the study areas. Overall, the level of calibration achieved was considered appropriate for pre-feasibility analysis.

The catchment flow models were used to simulate historic streamflow for the period 1972-2018. Analysis of the simulated streamflow records demonstrated that run of river sources would only be capable of satisfying a small portion of the potential requirements for water, both in terms of volume and reliability. However, significant volumes exist during periods of high flow. As such storage would be required.

High-level identification of potential storage sites was undertaken using WWLA's Reservoir Identification Tool (RIT). The RIT makes use of Digital Elevation Models (DEM) based on high-resolution LiDAR data to rapidly identify potential reservoir impoundment sites in natural topographic depressions.

A large number of potential storage sites were identified before being narrowed down based on experienced judgement to a short-list of approximately 20 sites in both the Kaipara and Mid North. The short-list within each region was then subjected to a more formal Multi Criteria Analysis (MCA).

This analysis did not identify any critical flaws in any of these sites at this early stage, however it did identify some sites that are more desirable than others. These sites were then taken forward for conceptual design and costing, presented in report **Volume 3 – Conceptual Design and Costing**.

10. References

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Appendix A. Water Allocation, Harvesting, and Storage Regulations

Table 27. General policy requirements from RPN Section D.2.

Regulatory Consideration	Description	Requirements
D.2.1 Management of natural and physical resources	Including rules to manage the use, development and protect of natural and physical resources that:	1) are the most efficient and effective way of achieving national and regional resource management objectives, and
		2) are as internally consistent as possible, and
		3) use or support good management practices, and
		4) minimise compliance costs, and
		5) enable use and development that complies with the Regional Policy Statement for Northland and the objectives of this Plan, and
		6) focus on effects and, where suitable, use performance standards.
D.2.2 Social, cultural and economic benefits of activities	--	Regard must be had to the social, cultural and economic benefits of a proposed activity, recognising significant benefits to local communities, Māori and the region including local employment and enhancing Māori development, particularly in areas of Northland where alternative opportunities are limited.
D.2.3 Climate change and development	--	Particular regard must be had to the potential effects of climate change on a proposed development requiring consent under this Plan, taking into account the scale, type and design-life of the development proposed and with reference to the latest national guidance and best available climate change projections.
D.2.4 Adaptive management	Regard should be had to the appropriateness of an adaptive management approach where:	1) there is an inadequate baseline of information on the receiving environment, and
		2) the occurrence of potential adverse effects can be effectively monitored, and
		3) thresholds can be set to require mitigation action if more than minor adverse effects arise, and
		4) potential adverse effects can be remedied before they become irreversible.
D.2.5 Benefits of regionally significant infrastructure	--	Particular regard must be had to the national, regional and locally significant social, economic, and cultural benefits of regionally significant infrastructure.
D.2.6 Minor adverse effects arising from the establishment and operation of regionally significant infrastructure	Enable the establishment and operation (including reconsenting) of regionally significant infrastructure by allowing any minor adverse effects providing:	1) The regionally significant infrastructure proposal is consistent with: a) all policies in Section D.1 Tangata whenua, and b) Rule D.2.14 Managing adverse effects on historic heritage, and c) Rule D.2.15 Managing adverse effects on natural character, outstanding natural landscapes and outstanding natural features, and d) Rule D.2.7 Managing adverse effects on indigenous biodiversity, and 2) the regionally significant infrastructure proposal will not likely result in over-allocation having regard to the allocation limits in H.4.3 Allocation limits for rivers, and 3) other adverse effects arising from the regionally significant infrastructure are avoided, remedied, mitigated or offset to the extent they are no more than minor.

Regulatory Consideration	Description	Requirements
D.2.8 Appropriateness of regionally significant infrastructure proposals	When considering the appropriateness of a regionally significant infrastructure activity in circumstances where adverse effects are greater than envisaged in Policies D.2.6 and D.2.7, have regard and give appropriate weight to:	1) the benefits of the activity in terms of D.2.5, and
		2) whether the activity must be recognised and provided for by a national policy statement, and
		3) any demonstrated functional need for the activity, and
		4) the extent to which any adverse environmental effects have been avoided, remedied or mitigated by route, site or method selection, and
		5) any operational, technical or location constraints that limit the design and location of the activity, including any alternatives that have been considered which have proven to be impractical, or have greater adverse effects, and
		6) whether the activity is for regionally significant infrastructure which is included in Schedule 1 of the Civil Defence Emergency Management Act as a lifeline utility and meets the reasonably foreseeable needs of Northland, and
		7) the extent to which the adverse effects of the activity can be practicably reduced, inclusive of any positive effects and environmental offsets proposed, and
		8) whether an adaptive management regime (including modification to the consented activity) can be used to manage any uncertainty around the occurrence of residual adverse effects, and
		9) whether the activity helps to achieve consolidated development and the efficient use of land and resources, including within the coastal marine area.
D.2.9 Protection of regionally significant infrastructure	--	When considering new use and development activities that could adversely affect the ongoing operation, maintenance, upgrade or development of regionally significant infrastructure; ensure that the regionally significant infrastructure is not compromised.
D.2.11 Marine and freshwater pest management	Manage the adverse effects from marine pests, and pests within the beds of freshwater bodies, by:	1) recognising that the introduction or spreading of pests within the coastal marine area and freshwater bodies could have significant and irreversible adverse effects on Northland's environment, and
		2) recognising that the main risk of introducing and spreading pests is from the movement of vessels, structures, equipment, materials, and aquaculture livestock, and
		3) decision-makers applying the precautionary principle when there is scientific uncertainty as to the extent of effects from the introduction or spread of pests, and
		4) imposing conditions on resource consents requiring that best practice measures are implemented so that risk of introducing or spreading pests is effectively managed as a result of the consented activity.
D.2.12 Resource consent duration	When determining the expiry date for a resource consent, have particular regard to:	1) security of tenure for investment (the larger the investment, then generally the longer the consent duration), and
		2) the administrative benefits of aligning the expiry date with other resource consents for the same activity in the surrounding area or catchment, and
		3) certainty of effects (the less certain the effects, the shorter the consent duration), and

Regulatory Consideration	Description	Requirements
		4) whether the activity is associated with regionally significant infrastructure (generally longer consent durations for regionally significant infrastructure), and
D.2.13 Recognising other plans and strategies		When considering a resource consent application have regard to issues, uses, values, objectives and outcomes identified in an operative plan or strategy adopted by the Regional Council that has followed a consultation process carried out in accordance with the consultative principles and procedures of the Local Government Act 2002, to the extent that the content of the plan or strategy has a bearing on the resource management issues of the region.
D.2.14 Managing adverse effects on historic heritage	Manage the adverse effects of activities on historic heritage by:	1) avoiding significant adverse effects on the characteristics, qualities and values that contribute to historic heritage, and
		2) recognising that historic heritage sites and historic heritage areas in the coastal marine area identified in I Maps |Ngā mahere matawhenua have been identified in accordance with the criteria outlined in Policy 4.5.3 of the Regional Policy Statement for Northland, and
		3) recognising the following as being significant adverse effects to be avoided: a) the destruction of the physical elements of historic heritage, and b) relocation of the physical elements of historic heritage, and c) alterations and additions to the form and appearance of the physical elements of historic heritage, and d) loss of context to the surroundings of historic heritage, taking into account the scale of any proposal, and
		4) recognising that despite (2), there are not likely to be significant adverse effects if: a) the historic heritage has already been irreparably damaged as assessed by a suitably qualified and experienced heritage professional and there are significant health and safety or navigational safety risks if it were to remain, or b) alterations, additions, repair or maintenance will not result in the loss, or significant degradation of, any values contributing to it being historic heritage in accordance with Policy 4.5.3 of the Regional Policy Statement, or c) the context of the historic heritage in its present location has already been lost and any damage to the historic heritage during relocation can be avoided, and

Regulatory Consideration	Description	Requirements
		5) determining the likely adverse effects of proposals by taking into account: a) the historic heritage values of the historic heritage sites or historic heritage areas as described in the assessment reports available on the Regional Council's website, and b) the outcomes of any consultation with: i. Heritage New Zealand Pouhere Taonga (particularly where an item is listed by Heritage New Zealand Pouhere Taonga and/or is an archaeological site requiring an 'authority to modify'), the Department of Conservation or any other appropriate body with statutory heritage protection functions, and ii. tangata whenua in instances where historic heritage has identified values of significance to tangata whenua, and c) where considered necessary, a historic heritage impact assessment produced by a suitably qualified and experienced heritage professional, and d) any values identified in addition to those listed in Policy 4.5.3 of the Regional Policy Statement for Northland 2016 including: i. vulnerability (the resource is vulnerable to deterioration or destruction or is threatened by land use activities), and ii. patterns (the resource is associated with important aspects, processes, themes or patterns of local, regional or national history), and iii. public esteem (the resource is held in high public esteem for its heritage or aesthetic values or as a focus of spiritual, political, national or other social or cultural sentiment), and iv. commemorative (the resource has symbolic or commemorative significance to past or present users or their descendants, resulting from its special interest, character, landmark, amenity or visual appeal), and v. education (the resource contributes, through public education, to people's awareness, understanding and appreciation of New Zealand's history and cultures), and
		6) recognising that appropriate methods of avoiding, remedying or mitigating adverse effects may include: a) careful design, scale and location proposed in relation to historic heritage values, including proposed use and development adjacent to historic heritage, and b) the use of setback, buffers and screening from historic heritage, and c) reversing previous damage or disturbance to historic heritage, and d) improving the public use, value, or understanding of the historic heritage, and e) the development of management and conservation plans, and f) gathering and recording information on historic heritage by a suitably qualified and experienced heritage professional, and g) implementing the stabilisation, preservation and conservation principles of the ICOMOS26 New Zealand Charter Revised 2010, and
		7) determining if an archaeological advice note or Accidental Discovery Protocol advice note should be included if there is a possibility of unrecorded archaeology being encountered or the proposal will or may affect recorded archaeological sites. An advice note will outline that work affecting archaeological sites is subject to an authority process under the Heritage New Zealand Pouhere Taonga Act 2014, and

Regulatory Consideration	Description	Requirements
		8) recognising that for the purposes of Section 95E of the RMA, Heritage New Zealand Pouhere Taonga under the Heritage New Zealand Pouhere Taonga Act 2014 is an affected person in relation to resource consent applications under the RMA affecting: a) any listed items in this Plan, also listed under the Heritage New Zealand Pouhere Taonga Act 2014, and b) are pre-1900 recorded and unrecorded archaeological sites.
D.2.15 Managing adverse effects on natural character, outstanding natural landscapes and outstanding natural features		Avoiding adverse effects of activities where there may be significant adverse effects on the characteristics, qualities and values that contribute to natural character oustanding natural features.
		2) recognising that in relation to natural character in waterbodies (where not identified as outstanding natural character), appropriate methods of avoiding, remedying or mitigating adverse effects may include: a) ensuring the location, intensity, scale and form of activities is appropriate having regard to natural elements and processes, and b) in areas of high natural character in the coastal marine area, minimising to the extent practicable indigenous vegetation clearance and modification (seabed and foreshore disturbance, structures, discharges of contaminants), and c) in freshwater, minimising to the extent practicable modification (disturbance, structures, extraction of water and discharge of contaminants), and
		3) recognising that in relation to outstanding natural features in water bodies outside the coastal environment, appropriate methods of avoiding, remedying or mitigating adverse effects may include: a) requiring that the scale and intensity of bed disturbance and modification is appropriate, taking into account the feature's scale, form and vulnerability to modification of the feature, and b) requiring that proposals to extract water or discharge contaminants do not significantly adversely affect the characteristics, qualities and values of the outstanding natural feature, and
		4) recognising that uses and development form part of existing landscapes, features and waterbodies and have existing effects.
D.2.16 Managing adverse effects on indigenous biodiversity	Manage the adverse effects of activities on indigenous biodiversity by:	2) outside the coastal environment: a) avoiding, remedying or mitigating adverse effects so they are no more than minor on: i. indigenous taxa that are listed as Threatened or At Risk in the New Zealand Threat Classification System lists, and ii. areas of indigenous vegetation and habitats of indigenous fauna, that are significant using the assessment criteria in Appendix 5 of the Regional Policy Statement, and iii. areas set aside for full or partial protection of indigenous biodiversity under other legislation, and b) avoiding, remedying or mitigating adverse effects so they are not significant on: i. areas of predominantly indigenous vegetation, and ii. habitats of indigenous species that are important for recreational, commercial, traditional or cultural purposes, and iii. indigenous ecosystems and habitats that are particularly vulnerable to modification, including wetlands, wet heathlands, headwater streams, spawning and nursery areas, and

Regulatory Consideration	Description	Requirements
		3) recognising areas of significant indigenous vegetation and significant habitats of indigenous fauna include: a) Significant Ecological Areas, and b) Significant Bird Areas, and c) Significant Marine Mammal and Seabird Areas, and
		4) recognising damage, disturbance or loss to the following as being potential adverse effects: a) connections between areas of indigenous biodiversity, and b) the life-supporting capacity of the area of indigenous biodiversity, and c) flora and fauna that are supported by the area of indigenous biodiversity, and d) natural processes or systems that contribute to the area of indigenous biodiversity, and
		5) assessing the potential adverse effects of the activity on identified values of indigenous biodiversity, including by: a) taking a system-wide approach to large areas of indigenous biodiversity such as whole estuaries or widespread bird and marine mammal habitats, recognising that the scale of the effect of an activity is proportional to the size and sensitivity of the area of indigenous biodiversity, and b) recognising that existing activities may be having existing acceptable effects, and c) recognising that discrete, localised or otherwise minor effects impacting on the indigenous biodiversity may be acceptable, and d) recognising that activities with transitory effects may be acceptable, and
		6) recognising that appropriate methods of avoiding, remedying or mitigating adverse effects may include: a) careful design, scale and location proposed in relation to areas of indigenous biodiversity, and b) maintaining and enhancing connections within and between areas of indigenous biodiversity, and c) considering the minimisation of effects during sensitive times such as indigenous freshwater fish spawning and migration periods, and d) providing adequate setbacks, screening or buffers where there is the likelihood of damage and disturbance to areas of indigenous biodiversity from adjacent use and development, and e) maintaining the continuity of natural processes and systems contributing to the integrity of ecological areas, and f) the development of ecological management and restoration plans, and
		7) recognising that significant residual adverse effects on biodiversity values can be offset or compensated: a) in accordance with the Regional Policy Statement for Northland Policy 4.4.1, and27 b) after consideration of the methods in (4) above, and
		8) recognising the benefits of activities that: a) include the restoration and enhancement of ecosystems, habitats and indigenous biodiversity, and b) improve the public use, value or understanding of ecosystems, habitats and indigenous biodiversity.

Regulatory Consideration	Description	Requirements
D.2.17 Managing adverse effects on land-based values and infrastructure	When considering an application for a resource consent for an activity in the coastal marine area or in, on or under the bed of a freshwater body, recognise that adverse effects may extend beyond the coastal marine area or the freshwater body to:	1) significant areas and values including: a) Areas of outstanding and high natural character, and b) Outstanding natural landscapes, and c) Outstanding natural features, and d) Historic heritage, and e) Areas of significant indigenous biodiversity, and f) Places of significance to tangata whenua, and
		2) land-based infrastructure including: a) toilets, and b) car parks, and c) refuse facilities, and d) boat ramps, and e) boat and dinghy storage, and
		3) decision-makers should have regard to: a) the nature and scale of these effects when deciding whether or not to grant consent for activities in the coastal marine area or on the beds of freshwater bodies, and b) the need to impose conditions on resource consents for those activities in order to avoid, remedy or mitigate these adverse effects.
D.2.18 Precautionary approach to managing effects on significant indigenous biodiversity	The greatest extent of adverse effects reasonably predicted by science must be given the most weight where there is scientific uncertainty about the adverse effects of activities on:	1) species listed as Threatened or At Risk in the New Zealand Threat Classification System including those identified by reference to the Significant Bird Area and Significant Marine Mammal and Seabird Area maps (refer Maps), or
		2) any values ranked high by the Significant Ecological Areas maps (Refer Maps in RPN).

Table 28. Land and water management policy requirements from RPN Section D.4 that pertain to the Northland Regional Water Storage project.

Regulatory Consideration	Description	Requirements
D.4.10 Avoiding over-allocation	For the purpose of assisting with the achievement of Objective F.1.1 of the RPN:	1) apply the allocation limits set in H.4 Environmental flows and levels when considering and determining applications for resource consents to take, use, dam or divert fresh water, and
		2) ensure that no decision will likely result in over-allocation.
D.4.12 Minimum flows and levels	--	1) For the purpose of assisting with the achievement of Objective F.1.1 of the RPN, ensure that the minimum flows and levels in H.4 Environmental flows and levels apply to activities that require water permits pursuant to rules in this Plan, and
		2) Notwithstanding this general requirement, for rivers an alternative minimum flow (comprising the minimum flow set in H.4 Environmental flows and levels less a specified rate of flow particular to an activity) may be applied where the water is to be taken, dammed or diverted for: a) the health of people as part of a registered drinking water supply, or b) root stock survival water, or c) an individual's reasonable domestic needs or the reasonable domestic needs of a person's animals for drinking water that is, or is likely to be, having an adverse effect on the environment and is not permitted by a rule in this Plan, or d) a non-consumptive take.
D.4.13 Reasonable and efficient use of water – irrigation	An application for a resource consent to take water for irrigation purposes must include an assessment using a water balance model that considers land use, crop water use requirements, on-site physical factors such as soil water holding capacity, and climate factors such as rainfall variability and potential evapotranspiration. The model must reliably predict annual irrigation volume. The annual volume calculated using the model must meet the following criteria:	1) an irrigation application efficiency of at least 80 percent, and
		2) crop water requirements that occur in nine out of 10 years.
D.4.14 Reasonable and efficient use of water – group or community water supplies	An application for a resource consent to take or use water for community or public water supplies must include a water management plan to demonstrate water use efficiency and must set out the current and likely future demand for water that addresses:	1) the number and nature of the properties that are to be supplied, and
		2) how the water supplier will manage water availability during summer flow periods and drought events, and
		3) the effectiveness and efficiency of the distribution network.
D.4.15 Reasonable and efficient use of water – other uses	--	An application for resource consent to take water for any use of water other than that addressed under D.4.13 or D.4.14 must include an assessment of reasonable and efficient use by, taking into account the nature of the activity, and identifying if water will potentially be wasted, and opportunities for re-use or conservation.
D.4.16 Water user groups	The formation of water user groups should be encouraged to allow permit	1) all water permits are subject to conditions that specify a maximum rate of take, a daily volume, and a seasonal or annual volume; and

Regulatory Consideration	Description	Requirements
	holders who choose to work with other water permit holders in the same catchment or sub-catchment to temporarily share all or part of the water take authorised by their water permit provided:	2) metering and telemetry of water abstraction data is undertaken for all takes, and
		3) all water permits are subject to common water take restriction conditions, or any discrepancies in restriction conditions are addressed prior to the formation of the group.
D.4.17 Conditions on water permits	Water permits for the taking and use of water must include conditions that:	1) clearly define the take amount in instantaneous take rates and total volumes, including by reference to the temporal aspects of the take and use, and
		2) unless there are exceptional circumstances, or the water permit is for a temporary take or a non-consumptive take, require that: a) the water take is metered and information on rates and total volume of the take is provided electronically to the Regional Council, and b) for water permits for takes equal to or greater than 10 litres per second, the water meter to be telemetered to the Regional Council, and
		3) clearly define when the water take must be restricted or cease to ensure compliance with environmental flows and levels, and
		4) require the use of a backflow prevention system to prevent the backflow of contaminants to surface water or ground water from irrigation systems used to apply animal effluent, agrichemical or nutrients, and
		5) ensure intake structures are designed, constructed and maintained to minimise adverse effects on fish species in accordance with good practice guidelines, and
		6) specify when and under what circumstances the permit will be reviewed pursuant to Section 128(1) of the RMA, including by way of a common review date with other water permits in a catchment.
D.4.18 Transfer of water permits	An application to transfer a water permit, permanently or temporarily, pursuant to Section 136 of the RMA will generally be granted if:	1) both sites are in the same catchment (either upstream or downstream) or aquifer, and
		2) other authorised takes are not adversely affected, and
		3) there is no increase in the level of adverse effects on the health of aquatic ecosystems
D.4.19 Transitional policy under Policy B7 of the National Policy Statement for Freshwater Management 2017	The policy applies until the provisions in this plan that give effect to Policy B1 (allocation limits) and Policy B2 (allocation) have become operative.	1) When considering any application, the consent authority must have regard to the following matters: a) the extent to which the change would adversely affect safeguarding the life-supporting capacity of fresh water and of any associated ecosystem, and b) the extent to which it is feasible and dependable that any adverse effect on the life-supporting capacity of fresh water and of any associated ecosystem resulting from the change would be avoided.
		2) This policy applies to: a) any new activity, and b) change in the character, intensity or scale of any established activity – that involves any taking, using, damming or diverting of fresh water or draining or any wetland which is likely to result in any more than minor adverse change in the natural variability of flows or level of any fresh water, compared to that which immediately preceded the commencement of the new activity of the change in the established activity (or in the case of a change in an intermittent or seasonal activity, compared to that on the last occasion on which the activity was carried out).

Regulatory Consideration	Description	Requirements
		3) This policy does not apply to any application for consent first lodged before the National Policy Statement for Freshwater Management 2011 took effect on 1 July 2011.
D.4.20 Activities affecting flood control schemes	Avoid activities that are likely to:	1) compromise the functional integrity of flood control schemes, or
		2) impede access to flood control schemes for maintenance purposes.
D.4.22 Natural wetlands – requirements	Activities affecting a natural wetland should:	1) maintain the following important functions and values of wetlands, including: a) water purification and nutrient attenuation, and b) contribution to maintaining stream flows during dry periods, and c) peak stream flow reduction, and d) providing habitat for indigenous flora and fauna, including ecological connectivity to surrounding habitat, and e) recreation, amenity and natural character values, and
		2) must avoid, remedy, or mitigate adverse effects on important wetland functions and values, or
		3) must provide biodiversity off-setting or environmental biodiversity compensation, so that residual adverse effects on the important functions and values of wetlands are no more than minor.
D.4.23 Wetland – values	When considering resource consents for activities in wetlands, recognise:	1) the benefits of wetland creation and restoration, and the enhancement of wetland functions, and
		2) that the values of induced wetlands or reverted wetlands are likely to relate to: a) the length of time the wetland has been in existence (ecological values are generally lower in newly established wetlands), and b) whether long-term viability of the wetland relies on maintenance works to maintain suitable hydrological conditions (wetlands that do not require maintenance are of greater value), and
		3) that the consent duration should be for as long as active restoration or enhancement works are required.
D.4.24 Freshwater fish	When considering resource consent applications for activities in freshwater bodies recognise:	1) that in the absence of alternative evidence, most Northland continually or intermittently flowing rivers and some lakes and natural wetlands provide habitat for Threatened or At Risk indigenous fish species, and
		2) that all fish species have varying degrees of sensitivity to habitat disturbance, changed water flow and degraded water quality, particularly increased turbidity or sedimentation, and
		3) the need to maintain the ability for non-pest fish species to effectively move up and downstream of the activity site, and
		4) opportunities to reduce the risk of spreading or introducing pest species, and
		5) the benefits of avoiding: a) activities in continually or intermittently flowing rivers during fish migration periods, and b) spawning habitat disturbance, particularity during spawning periods.
D.4.25 Benefits of freshwater structures, dams and diversions	Recognise the significant benefits activities in water bodies can provide to local communities, Māori and the region, including:	1) socio-economic well-being and resilience of communities or industry, and
		2) regionally significant infrastructure, and
		3) enhanced fish passage and ecological connectivity between the coastal marine area and the upstream extent of water bodies, and

Regulatory Consideration	Description	Requirements
		4) flood protection and the safeguarding of public health and safety, and
		5) public access along, over or in the water body, and
		6) enabling community resilience to climate change, and
		7) enhancing recreation opportunities including walking, bird watching, fishing, game bird hunting and boating, and
		8) education and scientific research, and
		9) enhancing amenity and natural character.
D.4.26 Land preparation, earthworks and vegetation clearance	When assessing an application for a resource consent for an earthworks, vegetation clearance or land preparation activity and any associated discharge of a contaminant, ensure that the activity:	1) will be done in accordance with established good management practices, and
		2) avoids significant adverse effects, and avoids, remedies or mitigates other adverse effects on: a) drinking water supplies, and b) areas of high recreational use, and c) aquatic ecosystem health, aquatic species, and receiving environments that are sensitive to sediment or phosphorus accumulation.

Appendix B. Validation of VCSN Rainfall Data

During project initiation, NRC raised questions on the applicability and accuracy of VCSN rainfall data in the Northland Region. A range of tabulated and visual outputs were created to compare VCSN data to gauged rainfall from NRC's weather monitoring network, to determine the appropriateness of VCSN rainfall. Two representative locations were selected in each command area, and rainfall statistics compared on an annual and monthly basis.

Overall, the VCSN rainfall at the two command areas was shown to be within approximately 110% of gauged rainfall, and exhibit close agreement in monthly/seasonal variation. Given the advantages of utilising the VCSN rainfall (**Section 4.2.1)**, and the relatively close agreement to gauged rainfall, we conclude the VCSN rainfall is appropriate for the purposes of a pre-feasibility assessment.

Mid-North

The following sub-sections provide tabulated and graphical comparisons of NIWA's national VCSN rainfall and measured rainfall from the NRC rain gauge from NRC's weather monitoring network for the Mid-North Command Area.

In the Mid-North command area, VCSN point 30154 was compared to the Waitangi at Ohaewai rain gauge, and VCSN point 21418 compared to the Mangamutu at Kaikohe Hill rain gauge. The locations of these sites are shown in **Figure 42**.

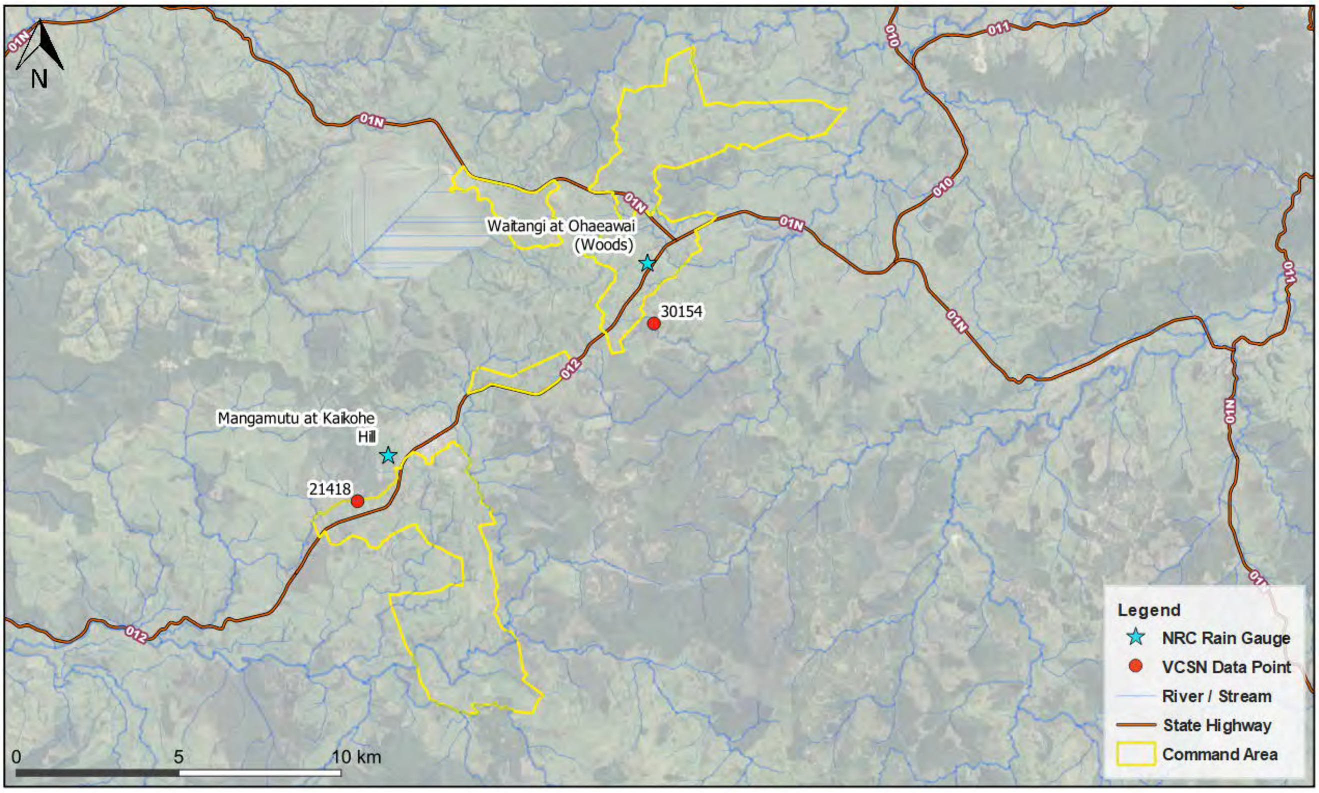

Figure 42. Location of the NRC rain gauges and VCSN data points used in the rainfall comparison for the Mid-North Command Area.

Annual Statistics

Table 29. Comparison of annual rainfall (mm) between Waitangi at Ohaeawai Gauge and NIWA VCSN 30154.

Year	Wairoa at Ohaeawai Gauge	NIWA VCSN 30154	Percentage Difference
1999	2,068	2,064	100%
2000	1,425	1,567	110%
2001	2,053	2,163	105%
2002	1,685	1,685	100%
2003	1,723	1,904	111%
2004	1,431	1,534	107%
2005	1,144	1,306	114%
2006	1,429	1,536	108%
2007	1,847	1,992	108%
2008	1,942	2,133	110%
2009	1,582	1,735	110%
2010	1,356	1,410	104%
2011	1,958	2,055	105%
2012	1,506	1,796	119%
2013	1,515	1,562	103%
2014	1,926	2,187	114%
2015	1,048	1,157	110%
Average	1,589	1,743	110%

Table 30. Comparison of annual rainfall (mm) between Mangamutu at Kaikohe Hill and NIWA VCSN 21418.

Year	Mangamutu at Kaikohe Hill	NIWA VCSN 21418	Percentage Difference
1992	1,654	1,810	109%
1993	1,390	1,315	95%
1994	1,437	1,224	85%
1995	1,818	1,842	101%
1996	1,794	1,714	96%
1997	1,591	1,623	102%
1998	1,931	2,040	106%
1999	1,841	1,947	106%
2000	1,373	1,458	106%
2001	1,763	2,014	114%
2002	1,315	1,604	122%
Average	1,460	1,629	110%

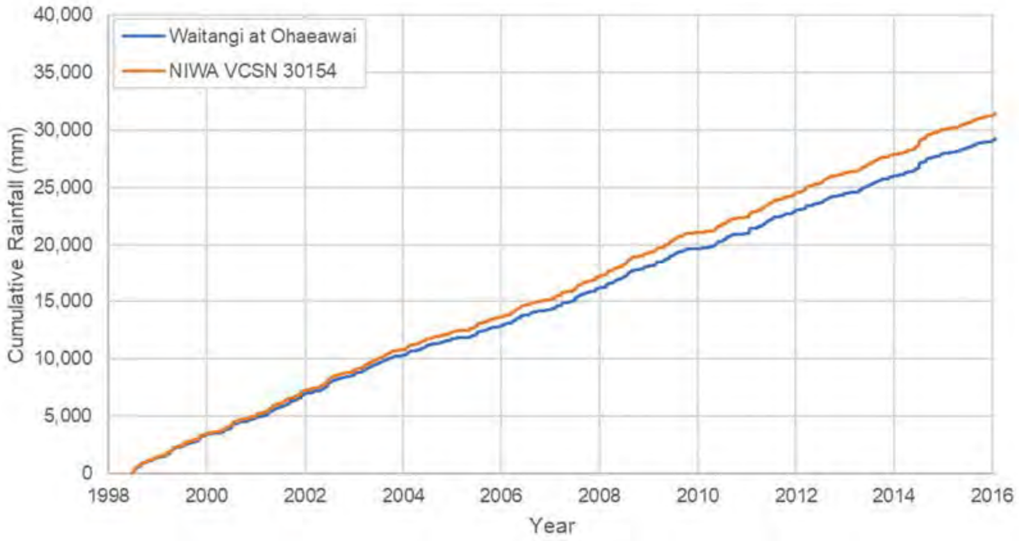

Figure 43. Cumulative rainfall comparison between Waitangi at Ohaeawai Gauge and NIWA VCSN 30154.

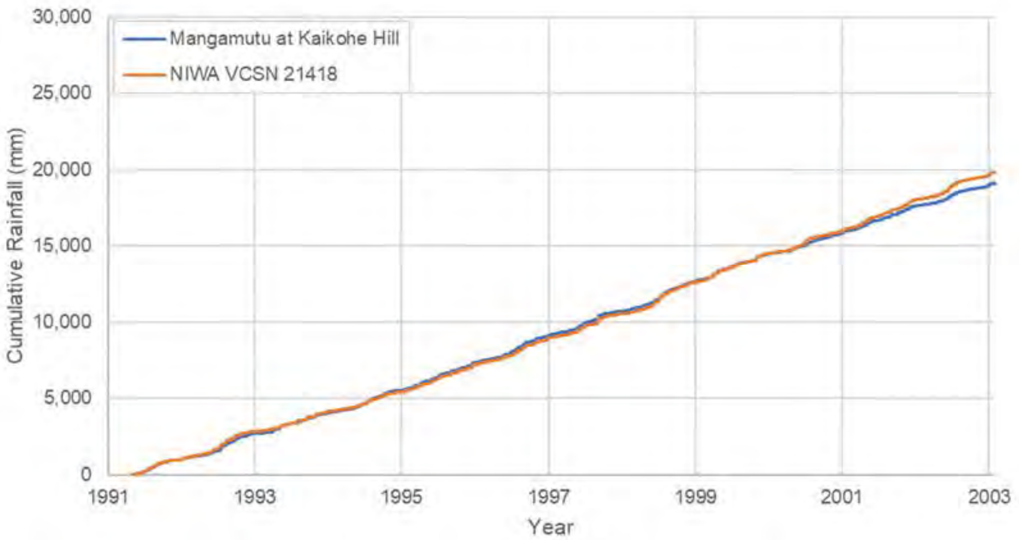

Figure 44. Cumulative rainfall comparison between Mangamutu at Kaikohe Hill and NIWA VCSN 21418.

Monthly Statistics

Table 31. Comparison of monthly rainfall (mm) between Waitangi at Ohaewai and NIWA VCSN 30154.

Month	Waitangi at Ohaewai	VCSN 21430	Percentage Difference
Jan	104	111	106%
Feb	103	114	110%
Mar	127	126	100%
Apr	141	141	100%
May	158	171	109%
Jun	158	175	111%
Jul	219	246	113%
Aug	157	181	115%
Sep	115	130	113%
Oct	89	102	114%
Nov	88	103	117%
Dec	130	143	110%

Table 32. Comparison of monthly rainfall (mm) between Mangamutu at Kaikohe Hill and NIWA VCSN 21418.

Month	Mangamutu at Kaikohe Hill	NIWA VCSN 21430	Percentage Difference
Jan	89	94	101%
Feb	77	91	110%
Mar	78	93	110%
Apr	120	128	100%
May	151	155	103%
Jun	156	180	116%
Jul	181	211	117%
Aug	136	161	118%
Sep	134	157	117%
Oct	121	132	109%
Nov	109	108	99%
Dec	108	118	109%

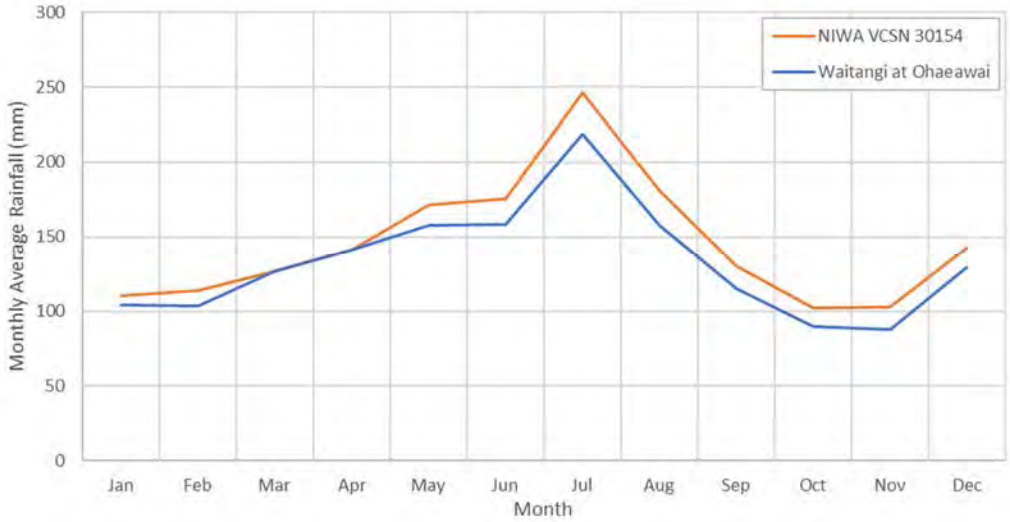

Figure 45. Average monthly rainfall between Waitangi at Ohaewai and NIWA VCSN 30154.

Figure 46. Average monthly rainfall between Mangamutu at Kaikohe Hill and NIWA VCSN 2141.

Kaipara

The following sub-sections provide tabulated and graphical comparisons of NIWA's national VCSN rainfall and measured rainfall from the NRC rain gauge from NRC's weather monitoring network for the Kaipara Command Area.

In the Kaipara command area, VSCN Point 21430 was compared tothe Wairoa at Dargaville (Hokianga Road) and Manganui at Omana (Bull) rain gauges. The locations of these sites are shown in **Figure 47.**

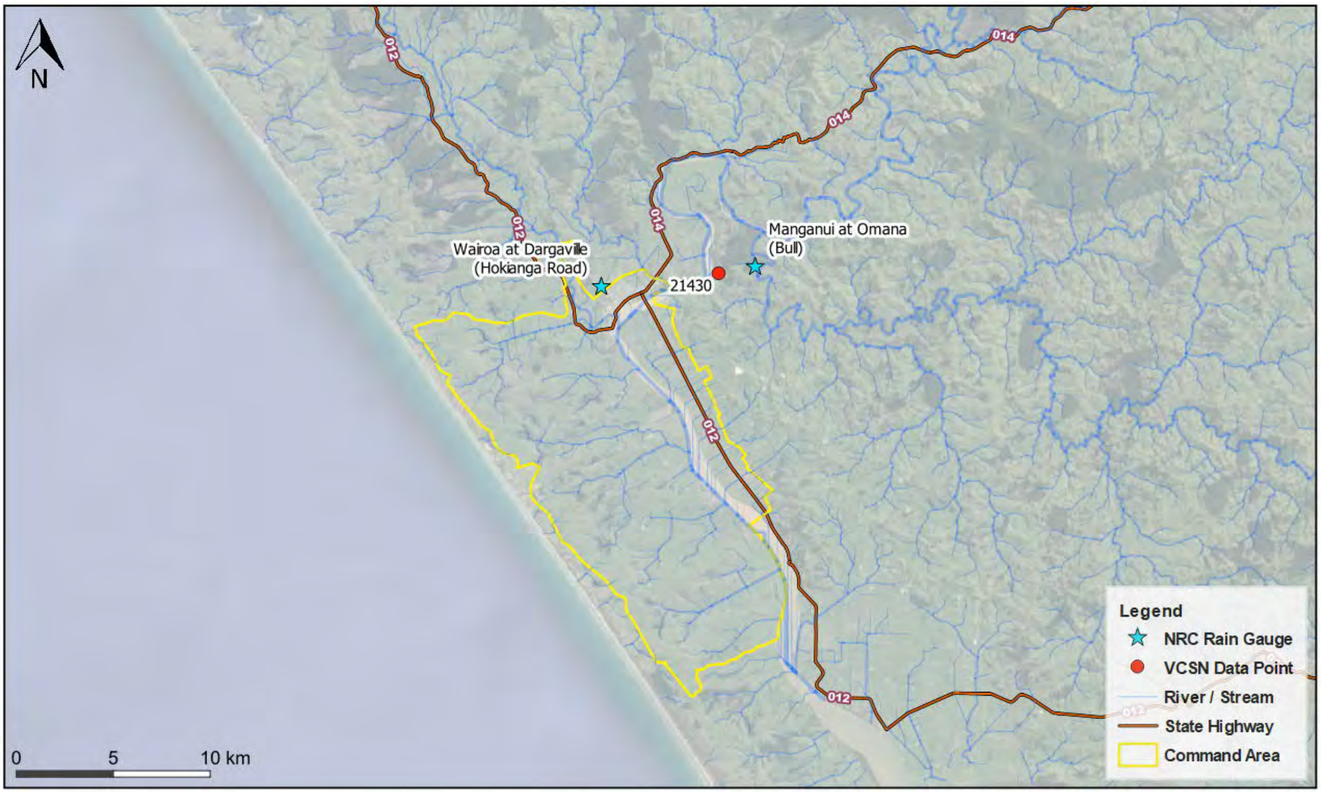

Figure 47. Location of NRC rain gauges and VCSN point used in the comparison for the Kaipara Command Area.

Annual Statistics

Table 33. Comparison of annual rainfall (mm) between Wairoa at Dargaville (Hokianga Road) and NIWA VCSN 21430.

Year	Wairoa at Dargaville	VCSN 21430	Percentage Difference
2007	1,368	1,437	105%
2008	1,105	1,436	130%
2009	1,264	1,224	97%
2010	1,176	1,225	104%
2011	1,352	1,451	107%
2012	1,121	1,169	104%
2013	1,021	962	94%
2014	1,314	1,364	104%
2015	1,073	996	93%
2016	1,140	1,121	98%
2017	1,372	1,335	97%
2018	1,464	1,352	92%
Average	**1,152**	**1,173**	**102%**

Table 34. Comparison of annual rainfall (mm) between Manganui at Omana (Bull) Gauge and NIWA VCSN 21430.

Year	Manganui at Omana	NIWA VCSN 21430	Percentage Difference
1981	1,457	1,306	90%
1982	1,033	932	90%
1983	1,249	1,158	93%
1984	1,264	1,268	100%
1985	1,564	1,570	100%
1986	1,224	1,277	104%
1987	899	1,016	113%
1988	1,222	1,266	104%
1989	1,239	1,491	120%
1990	1,121	1,102	98%
1991	1,213	1,247	103%
1992	1,494	1,486	99%
1993	972	1,013	104%
1994	1,231	1,012	82%
1995	1,581	1,552	98%
1996	1,476	1,333	90%
1997	1,421	1,400	99%
Average	**1,238**	**1,270**	**103%**

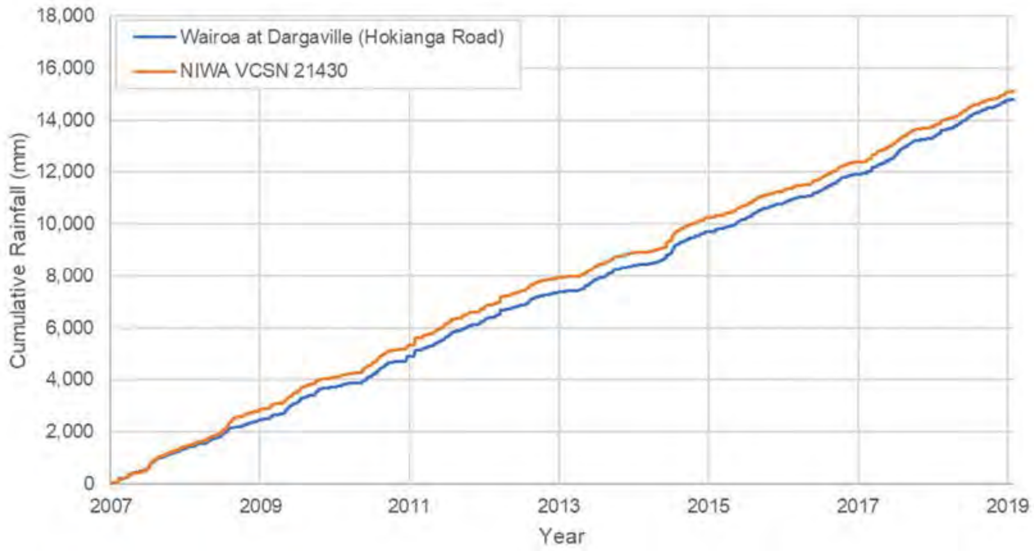

Figure 48. Cumulative rainfall comparison between Wairoa at Dargaville (Hokianga Road) and NIWA VCSN 21430.

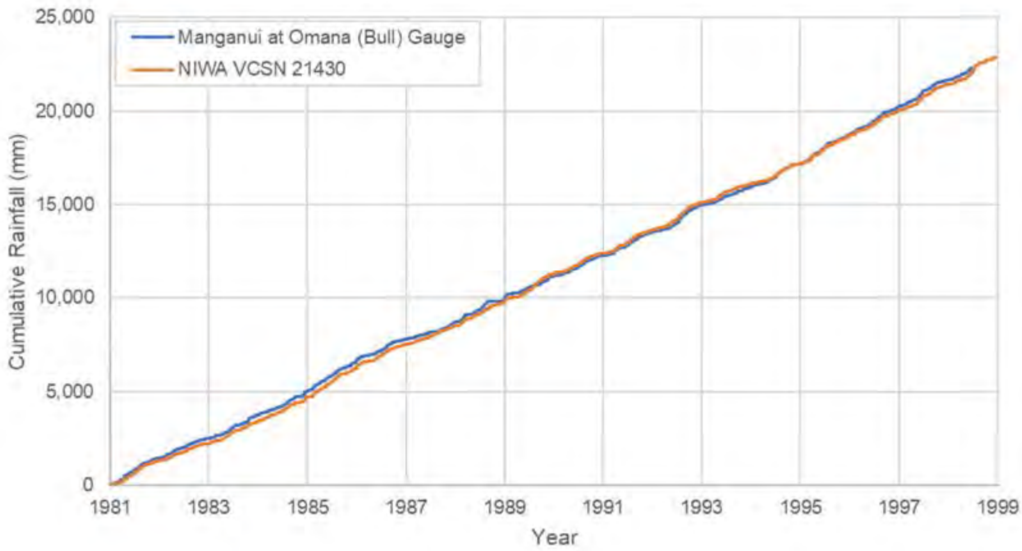

Figure 49. Cumulative rainfall comparison between Manganui at Omana (Bull) Gauge and NIWA VCSN 21430.

Monthly Statistics

Table 35. Comparison of monthly rainfall (mm) between Wairoa at Dargaville (Hokianga Road) and NIWA VCSN 21430.

Month	Wairoa at Dargaville	VCSN 21430	Percentage Difference
Jan	71	71	100%
Feb	79	80	101%
Mar	80	83	104%
Apr	76	77	101%
May	124	121	98%
Jun	124	132	106%
Jul	164	172	105%
Aug	113	130	115%
Sep	109	108	99%
Oct	75	67	89%
Nov	56	51	92%
Dec	82	82	100%

Table 36. Comparison of monthly rainfall (mm) between Manganui at Omana (Bull) Gauge and NIWA VCSN 21430.

Month	Manganui at Omana	VCSN 21430	Percentage Difference
Jan	85	71	84%
Feb	82	76	92%
Mar	101	96	95%
Apr	94	97	103%
May	113	120	106%
Jun	126	137	109%
Jul	148	161	109%
Aug	126	143	113%
Sep	111	122	109%
Oct	87	91	104%
Nov	76	72	94%
Dec	89	86	97%

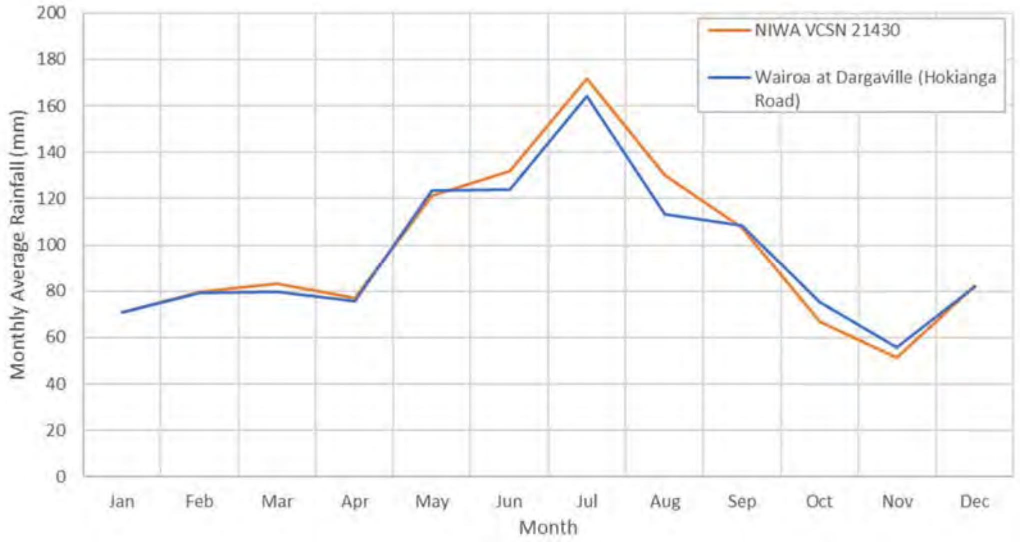

Figure 50. Average monthly rainfall between Wairoa at Dargaville (Hokianga Road) and NIWA VCSN 21430.

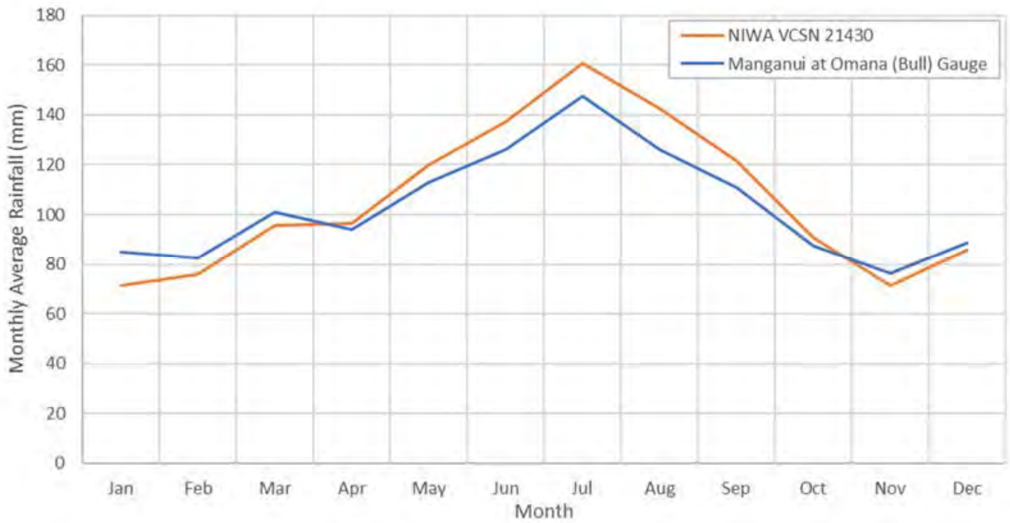

Figure 51. Average monthly rainfall between Manganui at Omana (Bull) Gauge and NIWA VCSN 21430.

Appendix C. SMWBM Parameters – Relationships with Catchment Characteristics

As described in **Section 4.3**, the SMWBM a semi-conceptual model, which means that model parameters are broadly representative of the hydraulic behaviour of catchment physical characteristics.

Relationships were established for the following four SMWBM parameters described in **Table 37** by fitting curves to the SMWBM parameter values and corresponding physical property. An iterative process was employed to determine the type of relationship (e.g. linear, exponential, etc.) for each parameter which produced the best calibration results to observed flow data. These relationships are described and presented below.

Table 37. Summary of SMWBM parameters and corresponding catchment characteristic.

SMWBM Parameter	Catchment Characteristic (unit)
ST (maximum soil moisture content)	Soil depth (m)
ZMax (maximum infiltration rate)	Soil permeability class (-)
FT (sub-soil drainage rate from soil moisture storage at full capacity)	Geological permeability (mm/day)
DIV (surface ponding coefficient)	Sub-catchment slope (°)

ST and Soil Depth

The relationship between soil depth (defined as potential rooting depth in the S-Map) and ST (maximum soil moisture content) is shown in **Figure 52**. Maximum soil moisture content increases linearly with increasing soil depth, based on an estimated soil porosity of 0.45.

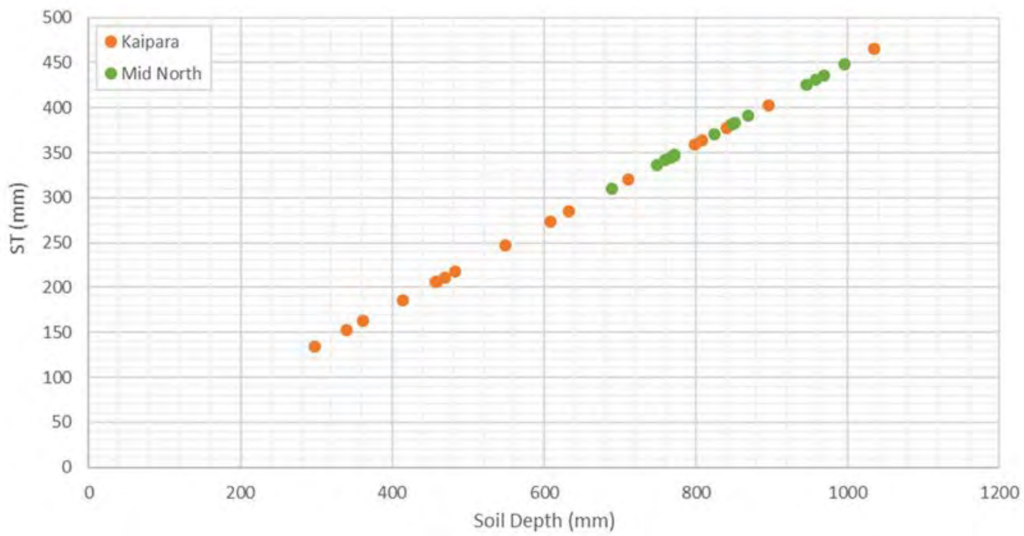

Figure 52. Relationship between Soil Depth (mm) and ST (maximum soil moisture content).

ZMax and Soil Permeability Class

The relationship between soil permeability class and ZMax (maximum infiltration rate) is shown in **Figure 53**, with maximum infiltration rate increasing with increasing soil permeability.

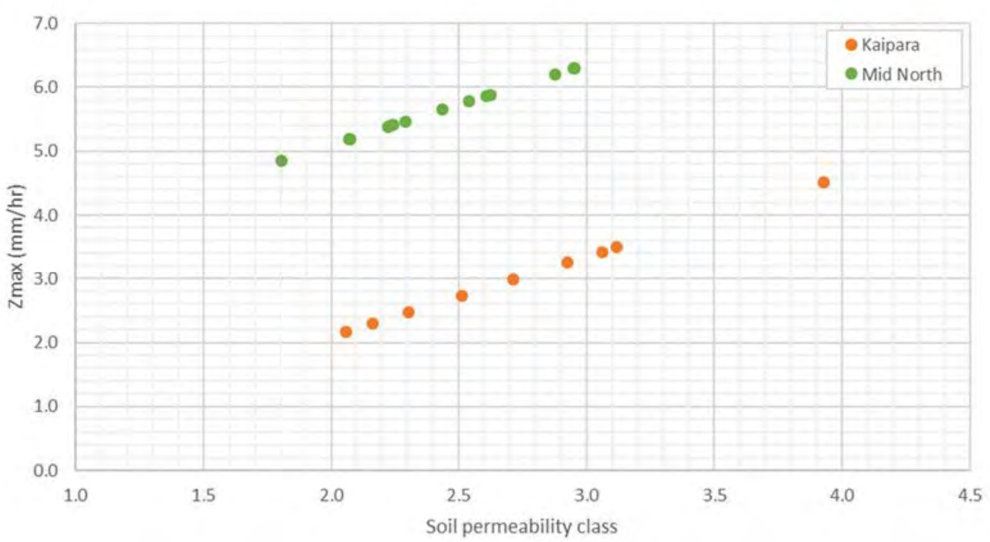

Figure 53. Relationship between soil permeability class and ZMAX (maximum infiltration rate).

FT and Rock Permeability

The relationship between FT (sub-soil drainage rate) and rock permeability shown in **Figure 54**, with sub-soil drainage rate increasing with increasing rock permeability.

Figure 54. Relationship between rock permeability and FT (sub-soil drainage rate).

DIV and Sub-catchment Slope

The relationship between sub-catchment slope and DIV (surface water ponding coefficient) is shown in **Figure 55**. Flat to gently sloped sub-catchments allow surface water to pond on the surface, whereas in steeper sloped catchments surface water will flow over the land surface rather than pond.

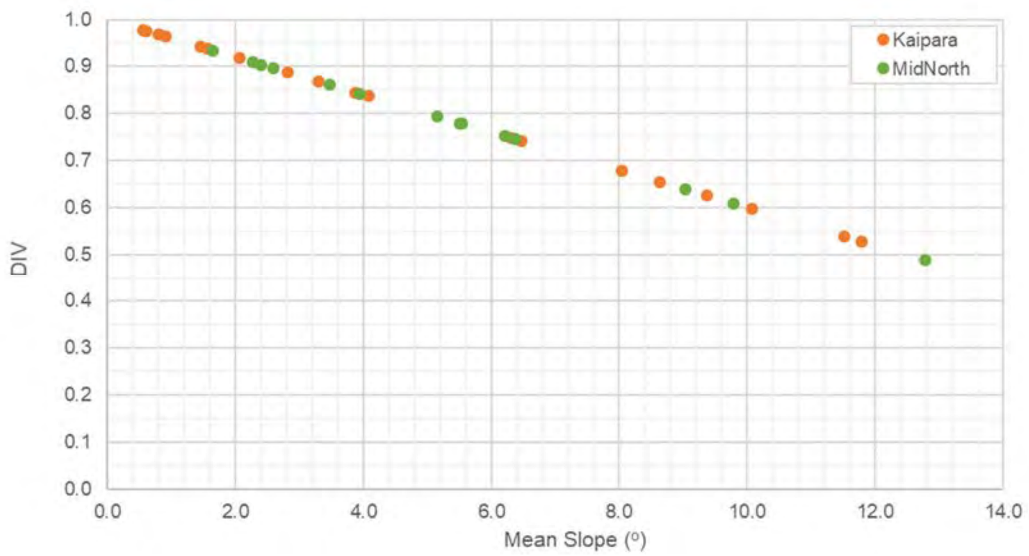

Figure 55. Relationship between catchment slope and DIV (surface water ponding coefficient).

Remaining Parameters

The remaining SMWBM parameters were set at constant values across all sub-catchments, with the exception of POW and AI where minor adjustments were required in a number of sub-catchments to achieve the appropriate calibration. The final range of values applied are presented in **Table 38**.

Table 38. Summary of minor SMWBM parameter vales applied to ungauged catchments.

Parameter	Description	Value / Range
Zmin	Minimum infiltration rate (mm/hr)	0
SL	Soil moisture content where drainage ceases (mm)	0
POW	Power of the soil moisture percolation equation (-)	1-2
R	Evaporation and soil moisture relationship	0
AI	Impervious portion of catchment connected to drainage (%)	0.0-0.1
GL	Groundwater lag time (days)	1
TL	Routing coefficient for surface runoff (days)	1

Table 39. Mid-North area weighted catchment characteristics.

Sub-catchment	Area (m^2)	Soil Depth (m)	Soil Permeability (class)	Rock Vertical Hydraulic Conductivity (m/s)	Median Slope (°)
1	53.1	848	2.6	1.97E-08	12.8
2	50.0	957	2.9	1.61E-08	9.0
3	42.9	748	2.5	2.93E-08	9.8
4	47.0	769	1.8	2.73E-08	5.5
5	46.7	690	2.1	3.16E-08	5.5
6	58.2	824	2.2	2.33E-08	6.4
7	37.7	760	2.1	2.60E-08	5.2
8	39.5	996	3.0	1.63E-08	2.3
9	43.8	946	2.6	2.06E-08	2.6
10	37.2	868	2.9	2.14E-08	1.6
11	14.7	969	2.2	2.18E-08	3.9
12	50.5	851	2.4	1.89E-08	3.5
13	32.2	772	2.2	2.13E-08	2.4
14	45.8	766	2.3	1.94E-08	6.2

Table 40. Kaipara area weighted catchment characteristics.

Sub-catchment	Area (m^2)	Soil Depth (m)	Soil Permeability (class)	Rock Vertical Hydraulic Conductivity (m/s)	Median Slope (°)
1	54.5	846	3.1	1.25E-08	8.6
2	34.5	895	3.1	1.37E-08	11.5
3	16.3	711	2.3	2.21E-08	4.1
4	10.0	1034	3.9	1.25E-08	10.1
5	42.5	840	2.9	1.94E-08	9.4
6	52.4	771	2.7	2.33E-08	6.3
7	28.4	457	3.1	3.75E-08	6.5
8	13.0	799	2.4	2.07E-08	7.1
9A	16.0	469	2.0	3.54E-08	3.3
9B	36.5	339	1.6	3.56E-08	0.6
10	27.4	483	2.5	3.78E-08	3.9
11	32.0	609	3.1	3.77E-08	2.1
12	45.5	767	2.5	2.54E-08	11.8
13	28.1	809	2.2	2.47E-08	8.0
14	44.0	633	2.1	3.05E-08	2.8
15	15.4	298	1.5	3.65E-08	0.6
16	41.2	548	2.4	3.68E-08	1.6

Sub-catchment	Area (m^2)	Soil Depth (m)	Soil Permeability (class)	Rock Vertical Hydraulic Conductivity (m/s)	Median Slope (º)
17	20.9	361	1.6	3.72E-08	0.8
18	20.7	459	1.9	3.60E-08	1.5
19	18.6	413	1.7	3.68E-08	2.1

Table 41. Mid-North parameters.

Sub-catchment	ST (mm)	ZMax (mm/hr)	FT (mm/day)	DIV (-)
1	381.8	5.9	1.2	0.5
2	430.8	6.2	0.5	0.6
3	336.8	5.8	3.1	0.6
4	346.0	4.9	2.7	0.8
5	310.4	5.2	3.6	0.8
6	370.7	5.4	1.9	0.7
7	341.9	5.2	2.6	0.8
8	448.0	6.3	0.5	0.9
9	425.9	5.9	1.4	0.9
10	390.8	6.3	1.6	0.9
11	436.1	5.4	1.7	0.8
12	382.8	5.6	1.1	0.9
13	347.5	5.4	1.5	0.9
14	344.6	5.5	1.2	0.8

Table 42. Kaipara parameters.

Sub-catchment	ST (mm)	ZMax (mm/hr)	FT (mm/day)	DIV (-)
1	380.8	4.5	1.2	0.7
2	402.9	4.4	1.7	0.5
3	320.1	3.5	3.8	0.8
4	465.4	5.6	1.5	0.6
5	377.9	0.2	3.4	0.6
6	347.1	3.9	4.3	0.7
7	205.8	3.6	1.8	0.7
8	359.3	3.4	3.8	0.7
9A	211.0	3.3	1.7	0.9
9B	152.6	3.2	1.6	1.0
10	217.2	4.7	2.3	0.8
11	274.0	5.1	2.5	0.9

Sub-catchment	ST (mm)	ZMax (mm/hr)	FT (mm/day)	DIV (-)
12	345.2	2.7	0.6	0.5
13	363.8	2.3	0.5	0.7
14	284.6	2.2	1.3	0.9
15	134.1	3.3	1.7	1.0
16	246.8	4.4	2.2	0.9
17	162.4	3.8	1.9	1.0
18	206.5	4.4	2.2	0.9
19	186.2	3.9	1.9	1.0

Appendix D. Water Takes

Table 43. Mid North Surface Water Takes.

Sub-catchment	IRIS ID	Category	Annual Take (m^3/yr)	Total Catchment Annual Take (m^3/yr)
4	AUT.004109.01.03	Drinking Public Water Supply	474,825	474,825
5	AUT.001862.02.02 AUT.001862.02.02	Drinking Public Water Supply Drinking Public Water Supply	45,000 45,000	45,000
6	AUT.004732.01.04 AUT.017683.01.02	Irrigation Horticulture Irrigation Horticulture	17,000 12,100	29,100
8	AUT.017199.01.02 AUT.028688.01.02	Irrigation Horticulture Irrigation Horticulture	7,150 28,800	35,950
9	AUT.002917.01.03	Irrigation Horticulture	7,305	7,305
10	AUT.005076.01.03	Irrigation Pasture	120,000	120,000
12	AUT.007762.03.02	Dewatering	3,653	3,653
13	AUT.007422.01.04	Irrigation Pasture	9,000	9,000

Table 44. Kaipara Surface Water Takes.

Sub-catchment	IRIS ID	Category	Annual Take (m^3/yr)	Total Catchment Annual Take (m^3/yr)
1	AUT.007642.01.03	Irrigation Pasture	150,000	150,000
4	AUT.004318.03.01	Drinking Private Supply	6,500	6,500
5	AUT.030845.01.01 AUT.030845.01.01 AUT.030845.01.01	Drinking Public Supply Drinking Public Supply Drinking Public Supply	543,241 543,241 543,241	543,241
6	AUT.008361.01.04 AUT.004653.03.03	Irrigation Pasture Industrial Timber Processing	100,000 7,305	107,305
9A	AUT.005004.01.03 AUT.008134.01.03 AUT.008367.01.02	Irrigation Pasture Drinking Public Supply Stock Dairy	460,000 2,628,000 69,000	3,157,000
9B	AUT.026700.01.01	Irrigation Pasture	420,000	420,000
10	AUT.007330.01.03 AUT.031468.01.01	Irrigation Pasture Irrigation Pasture	200,000 107,500	307,500
11	AUT.007757.01.03	Irrigation Pasture	125,000	125,000
16	AUT.007743.01.04 AUT.007772.01.03 AUT.007772.01.03	Irrigation Pasture Irrigation Pasture Irrigation Pasture	69,000 340,000 340,000	409,000
17	AUT.007442.01.04	Irrigation Pasture	300,000	300,000

Appendix E. Low flow gauge calibrations

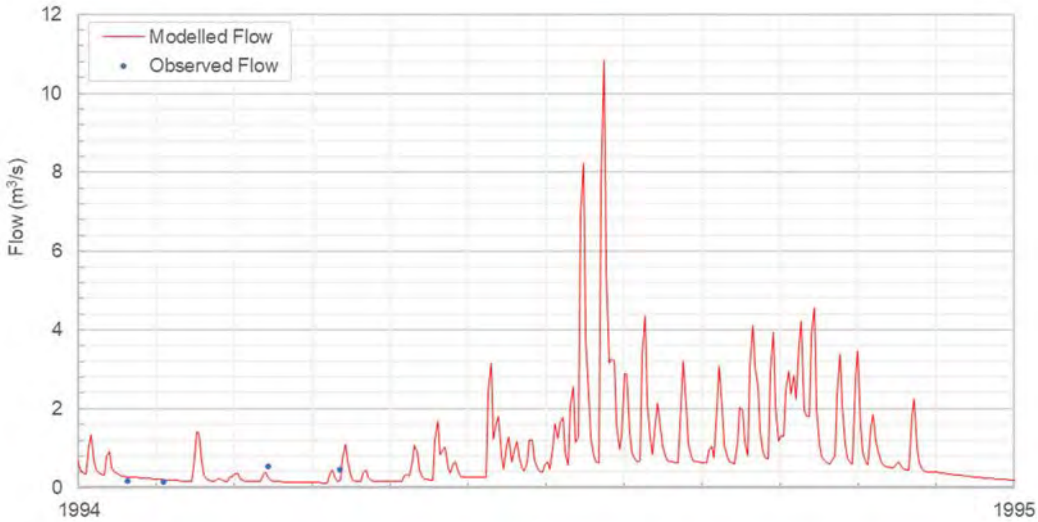

Figure 56. Flow hydrograph comparison of modelled and observed flow at Huehue at Mataraua gauge.

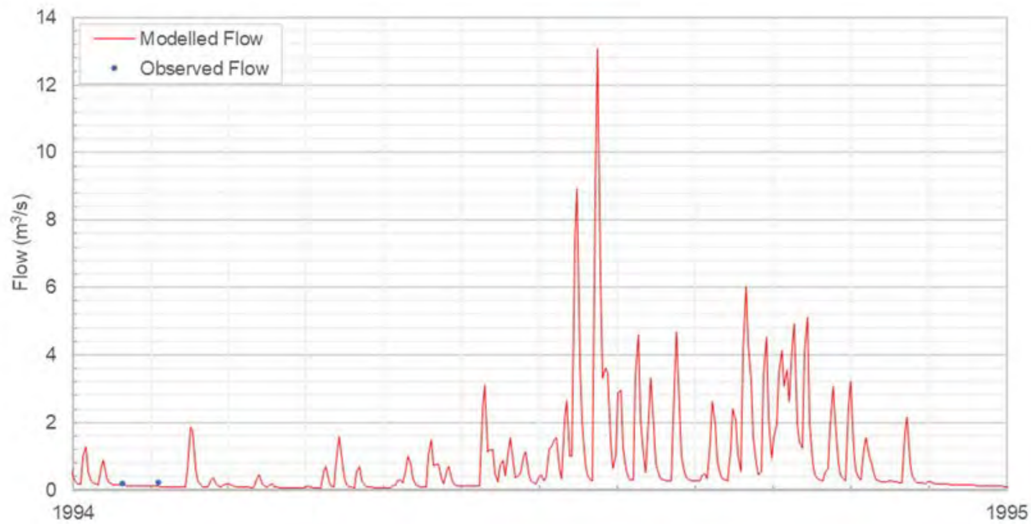

Figure 57. Flow hydrograph comparison of modelled and observed flow at Managone at Mataraua gauge.

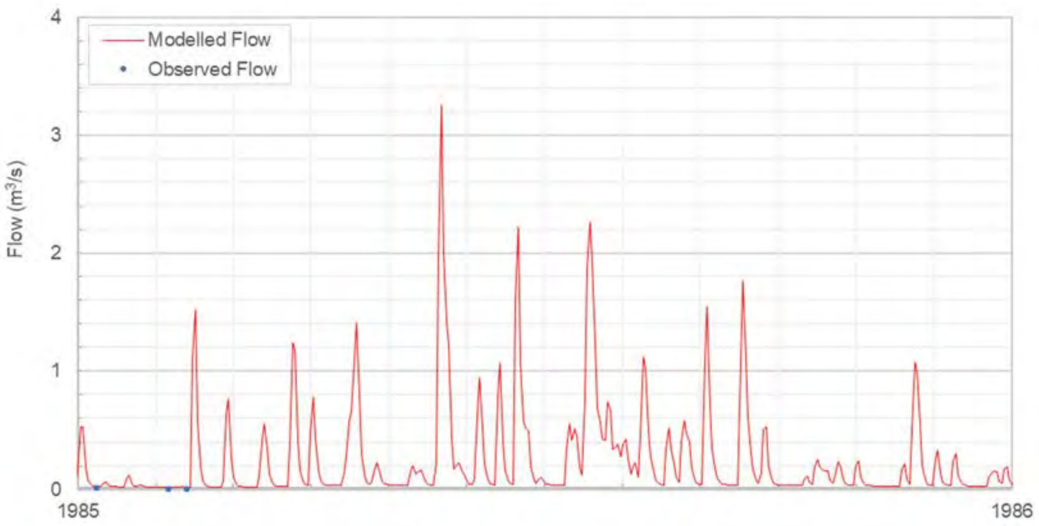

Figure 58. Flow hydrograph comparison of modelled and observed flow at Te Opua Stream at Gubbs gauge.

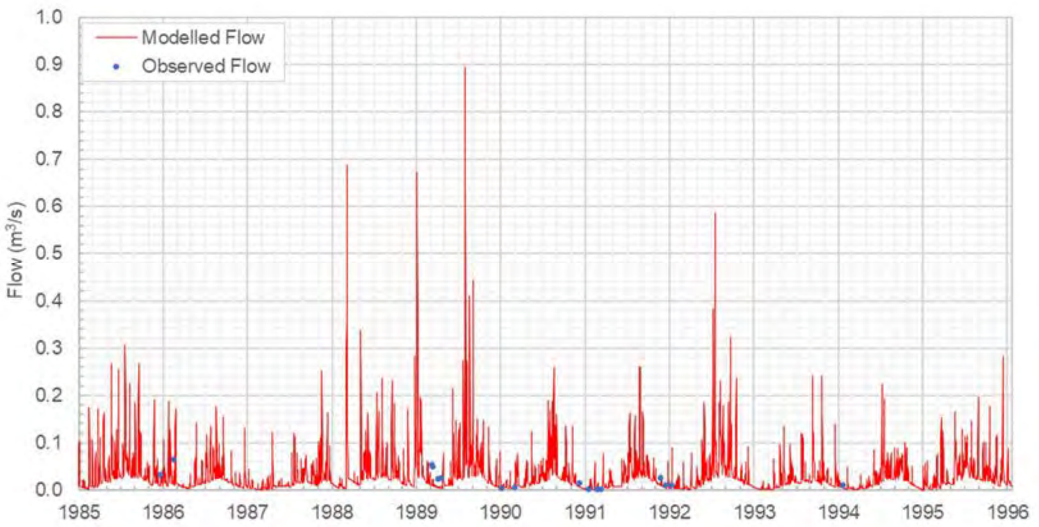

Figure 59. Flow hydrograph comparison of modelled and observed flow at Omaunu at Te Iringa gauge.

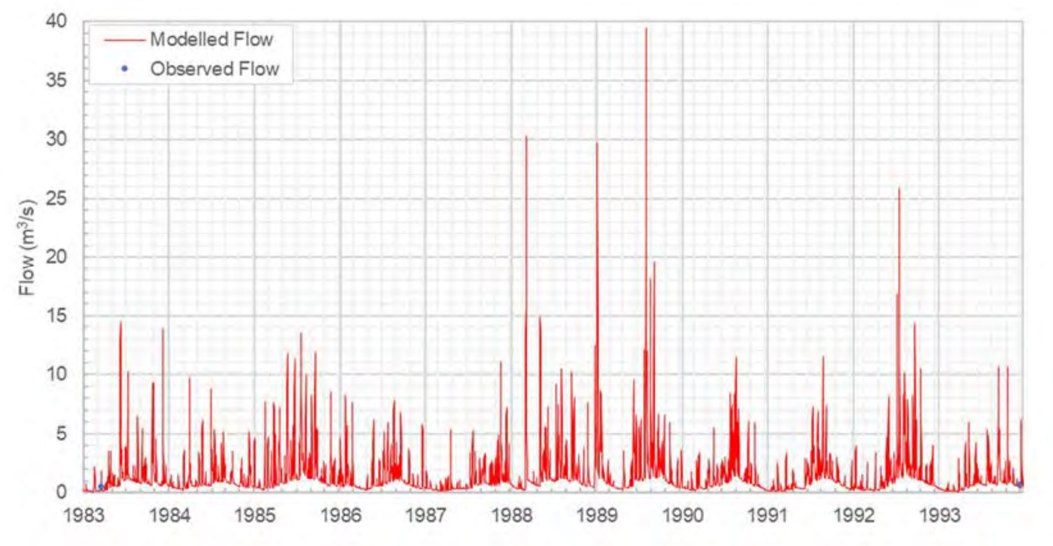

Figure 60. Flow hydrograph comparison of modelled and observed flow at Punakitere at Piccadilly Road gauge.

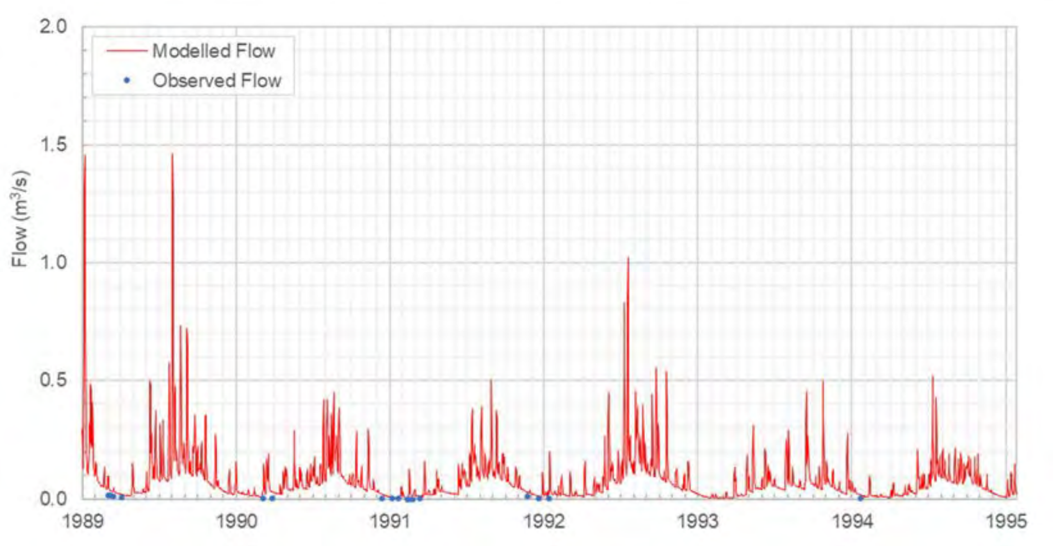

Figure 61. Flow hydrograph comparison of modelled and observed flow at Ontangaroa at Barney's Crossing gauge.

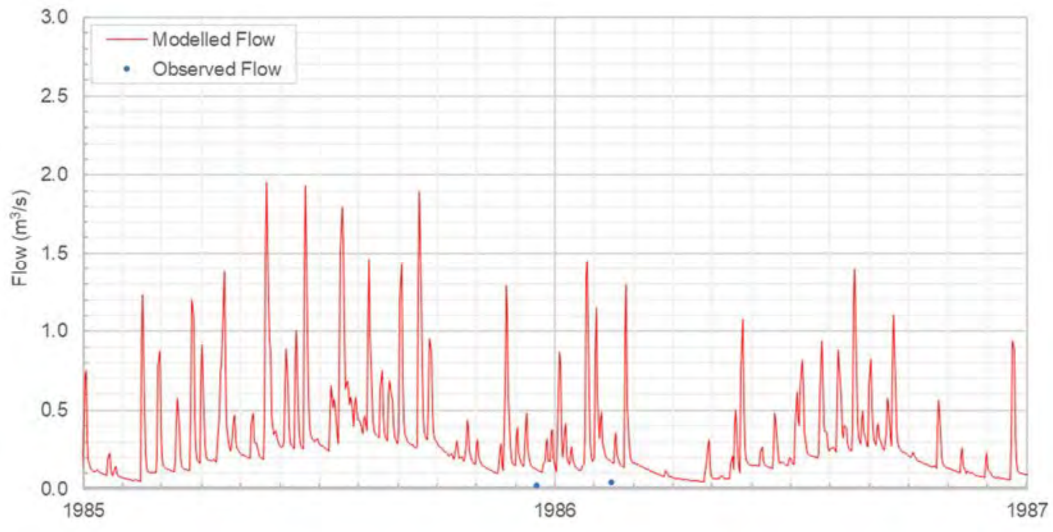

Figure 62. Flow hydrograph comparison of modelled and observed flow at Ontangaroa at Jordon gauge.

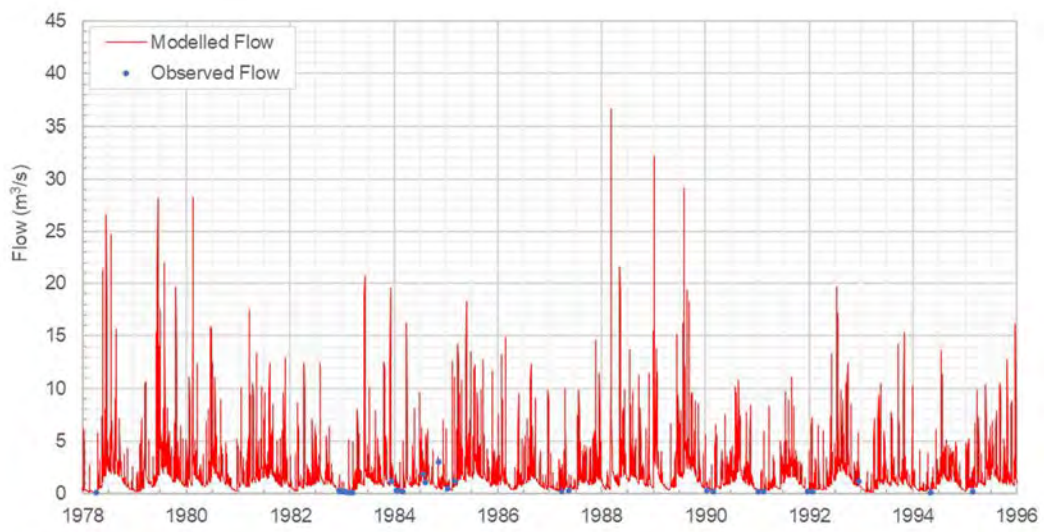

Figure 63. Flow hydrograph comparison of modelled and observed flow at Waiaruhe at SH1 gauge.

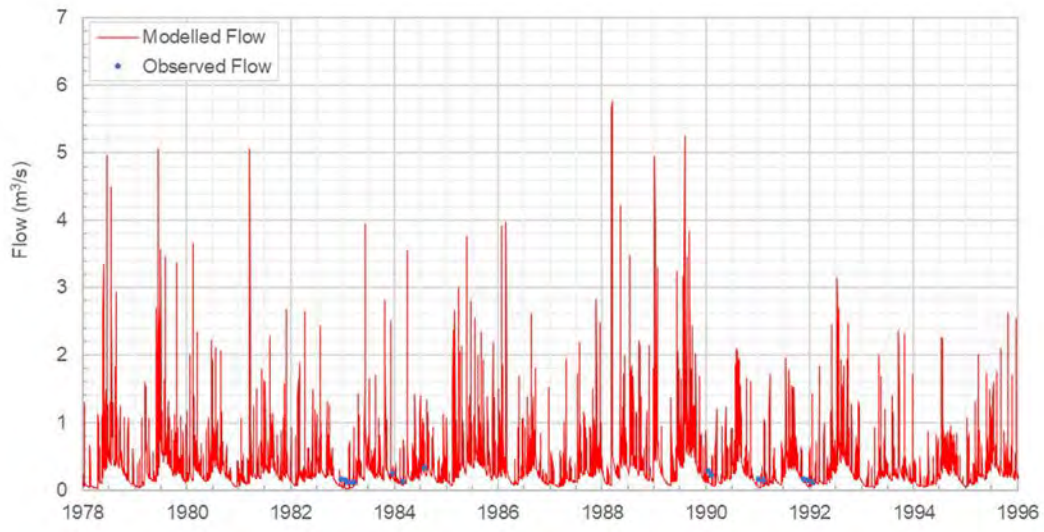

Figure 64. Flow hydrograph comparison of modelled and observed flow at Puketotara at SH1 gauge.

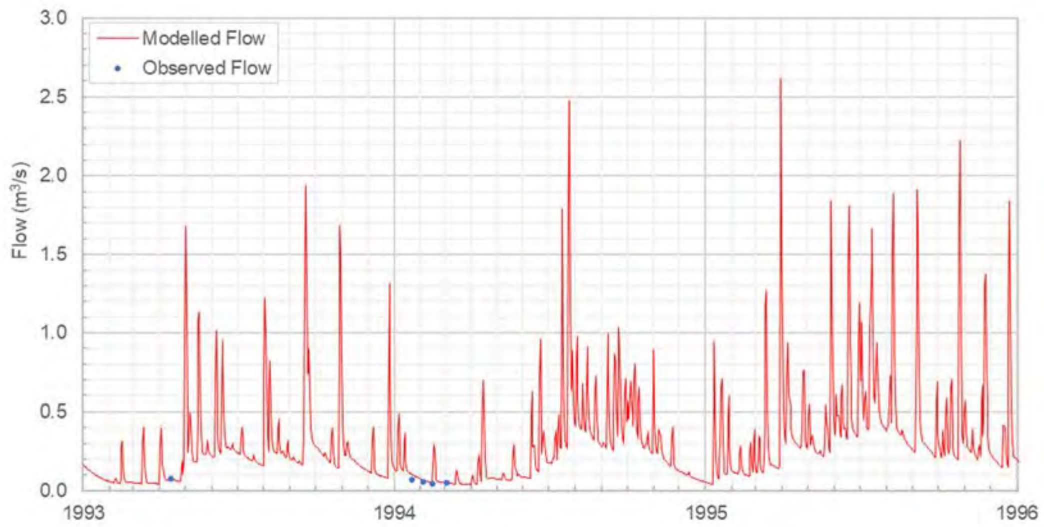

Figure 65. Flow hydrograph comparison of modelled and observed flow at Okarari at Stanners gauge.

Appendix F. Reservoir Site Assessments

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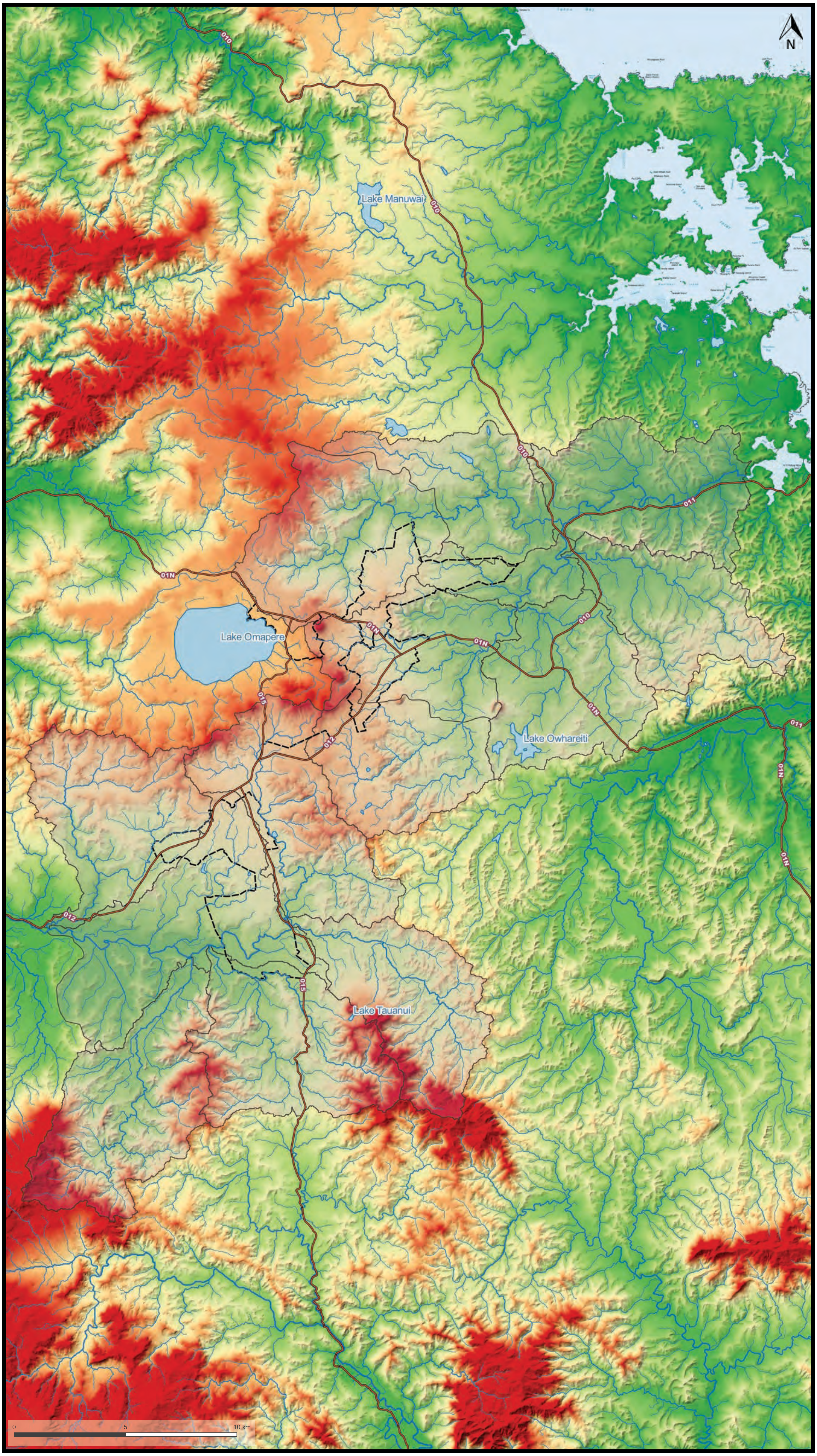
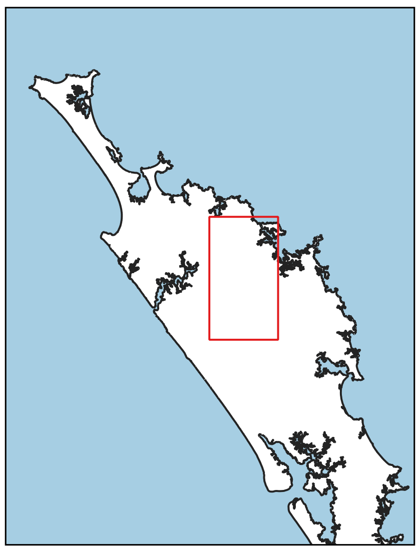


Map Title:
Mid North Study Area Elevation and Topography

Project:
Northland Water Storage and Use

Client:
Northland Regional Council



Legend

- River
- State Highway
- Command Area
- Model Sub-Catchment

Elevation (m)

- 0
- 50
- 100
- 150
- 200
- 250
- 300
- 350+

Data Provenance
Topographic Data derived from Land Information New Zealand. Crown Copyright Reserved
Relief generated from LINZ 8 m Digital Elevation Model (DEM). Crown Copyright Reserved.

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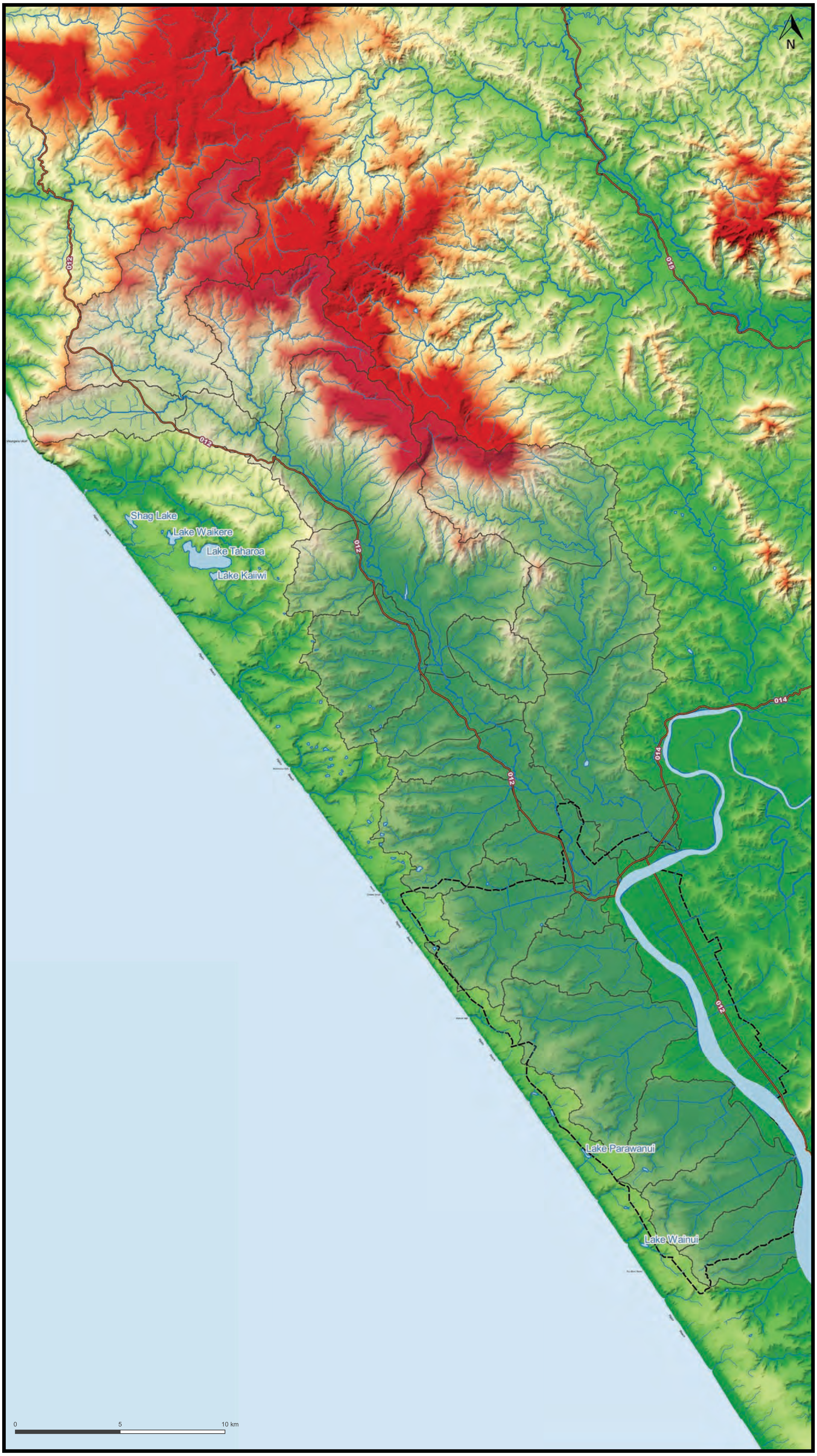
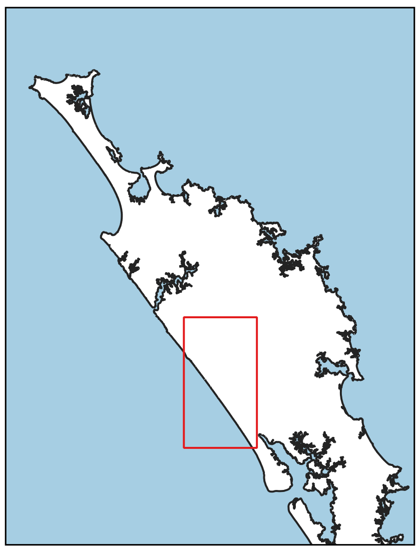
Figure 3.



Map Title:
Kaipara Study Area Elevation and Topography

Project:
Northland Water Storage and Use

Client:
Northland Regional Council



Legend
- River
- State Highway
- Command Area
- Model Sub-catchment

Elevation (m)
- 0
- 50
- 100
- 150
- 200
- 250
- 300
- 350
- 400
- 450
- 500+

Data Provenance
Topographic Data derived from Land Information New Zealand. Crown Copyright Reserved
Relief generated from LINZ 8 m Digital Elevation Model (DEM). Crown Copyright Reserved.

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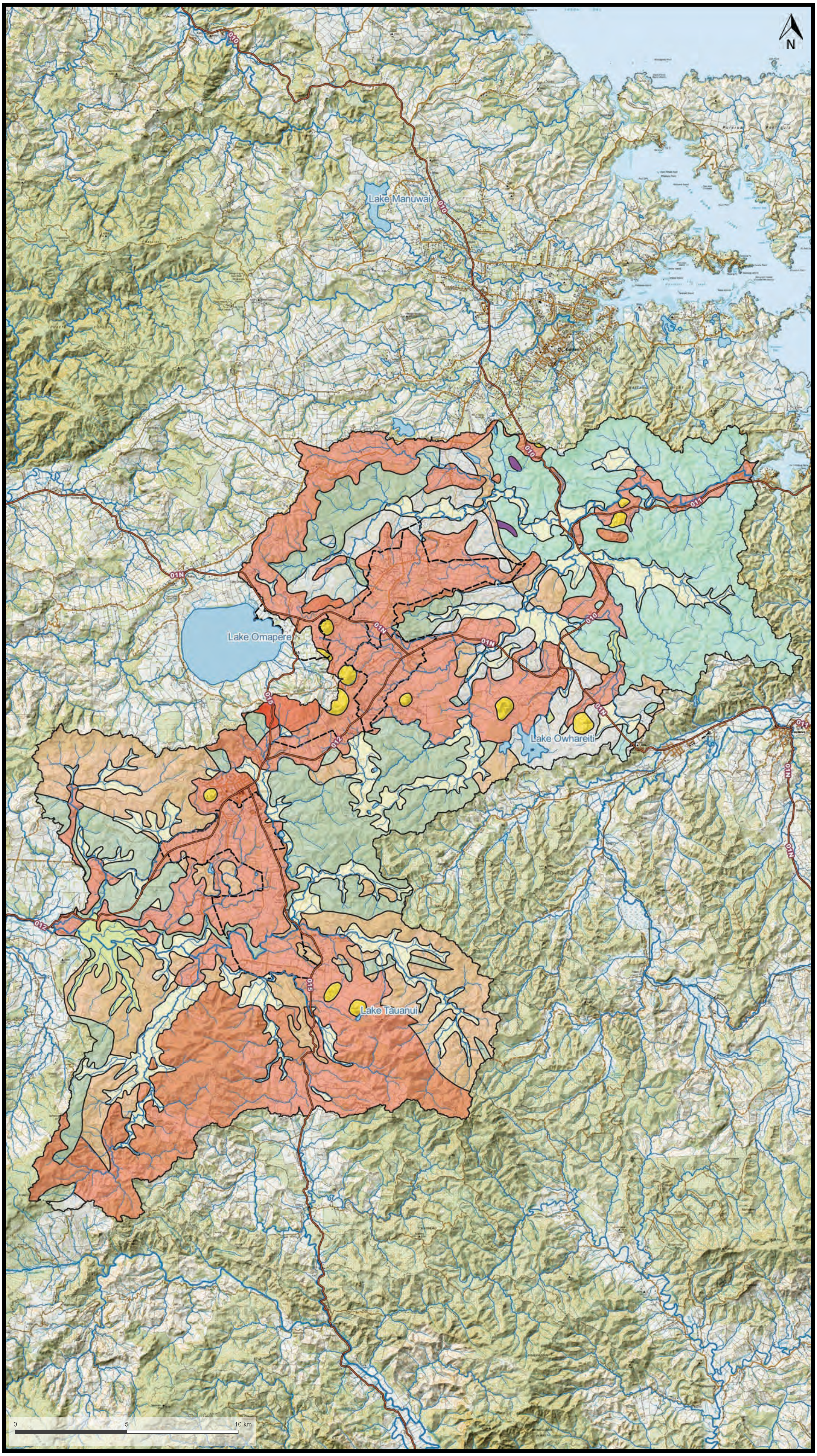
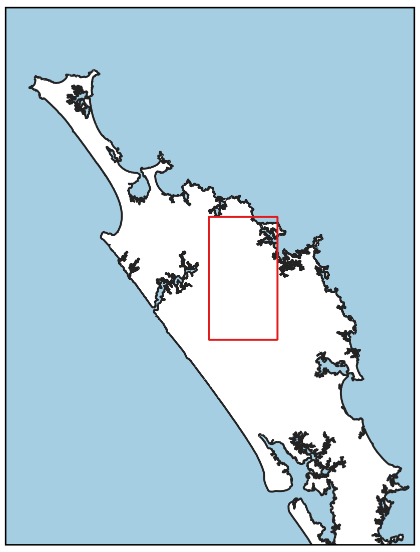
Figure 4.



Map Title:
Mid North Study Area Main Geological Units

Project:
Northland Water Storage and Use

Client:
Northland Regional Council



Legend

- State Highway
- River
- Command Area

Geology
- Rhyolite
- Basaltic Andesite
- Basalt
- Scoria
- Sandstone
- Greywacke
- Melange
- Chert
- Conglomerate
- Mudstone
- Mud
- Peat

Data Provenance
Topographic Data derived from Land Information New Zealand. Crown Copyright Reserved
Geological units derived from GNS QMap Data. Crown Copyright Reserved.

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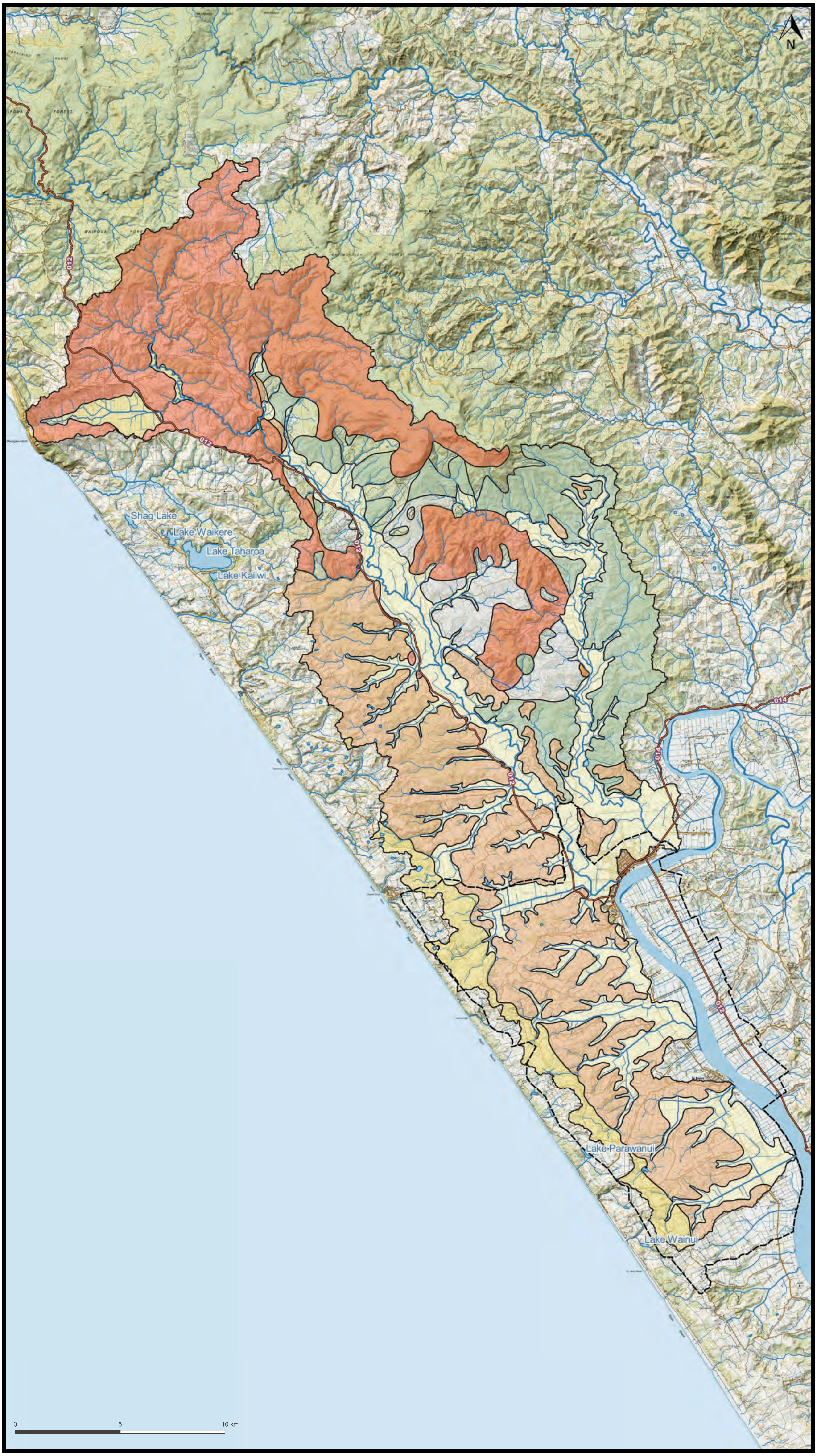
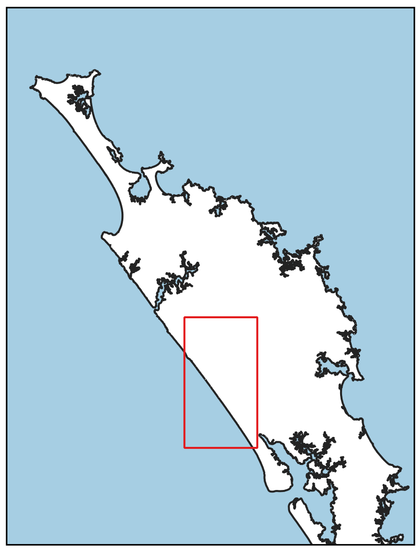
Figure 5.



Map Title:
Kaipara Study Area Main Geological Units

Project:
Northland Water Storage and Use

Client:
Northland Regional Council



Legend

- **River**
- **State Highway**
- **Command Area**

Geology
- **Andesite**
- **Basalt**
- **Melange**
- **Consolidated Sand**
- **Unconsolidated Sand**
- **Tauranga Group Mud**
- **Mudstone**

Data Provenance
Topographic Data derived from Land Information New Zealand. Crown Copyright Reserved
Geological units derived from GNS QMap Data. Crown Copyright Reserved.

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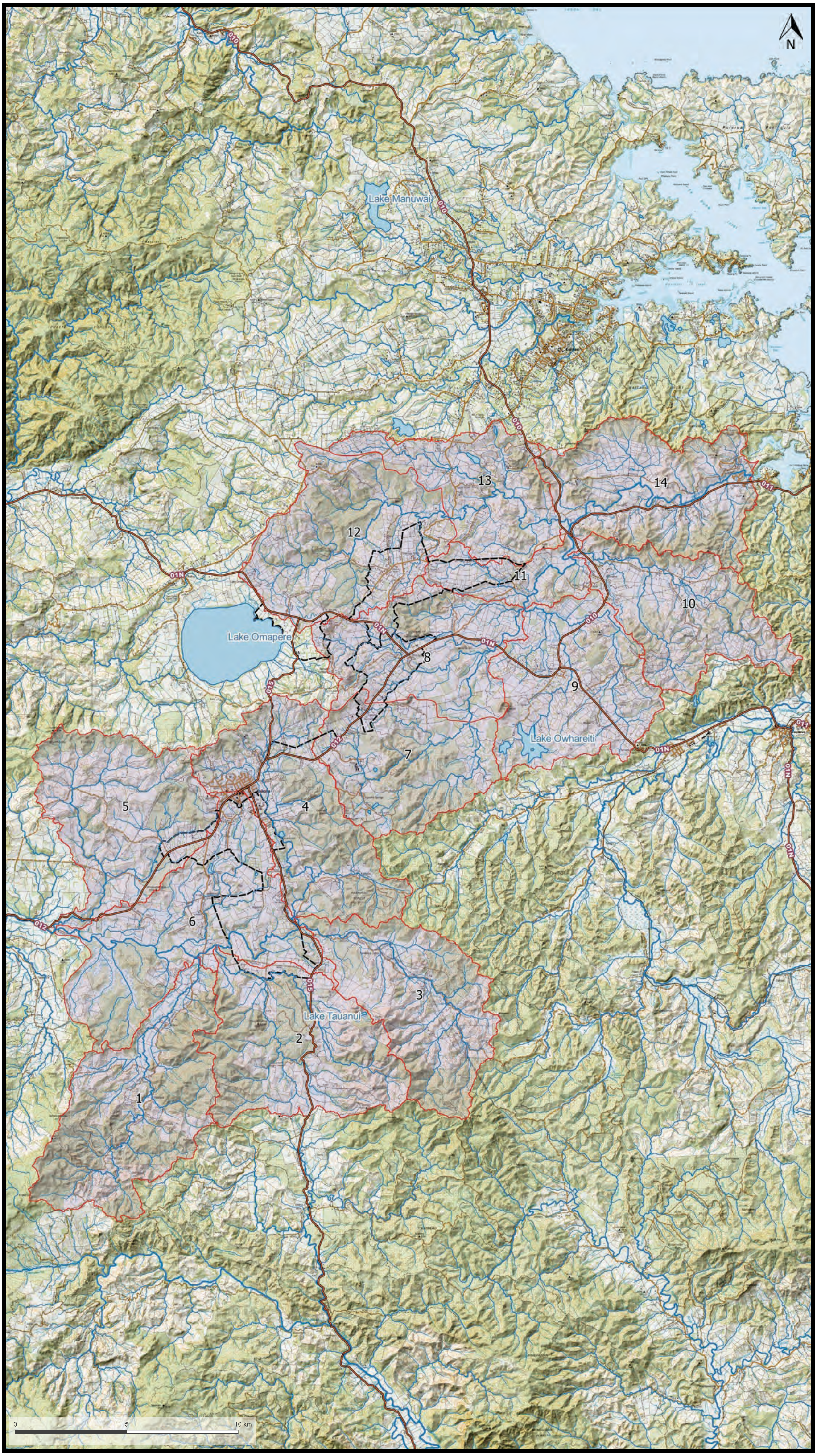
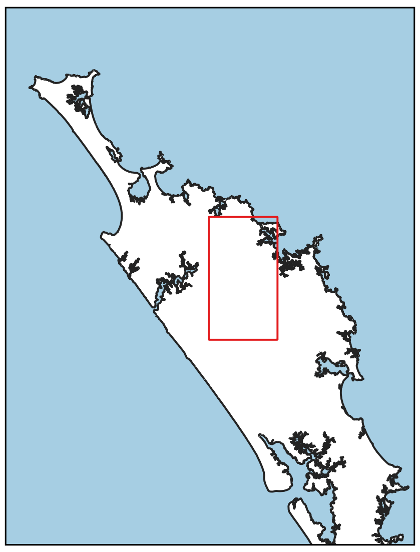
Figure 6.



Map Title:
Overview Map of Catchments Indentified in the Mid-North Study Area

Project:
Northland Water Storage and Use

Client:
Northland Regional Council

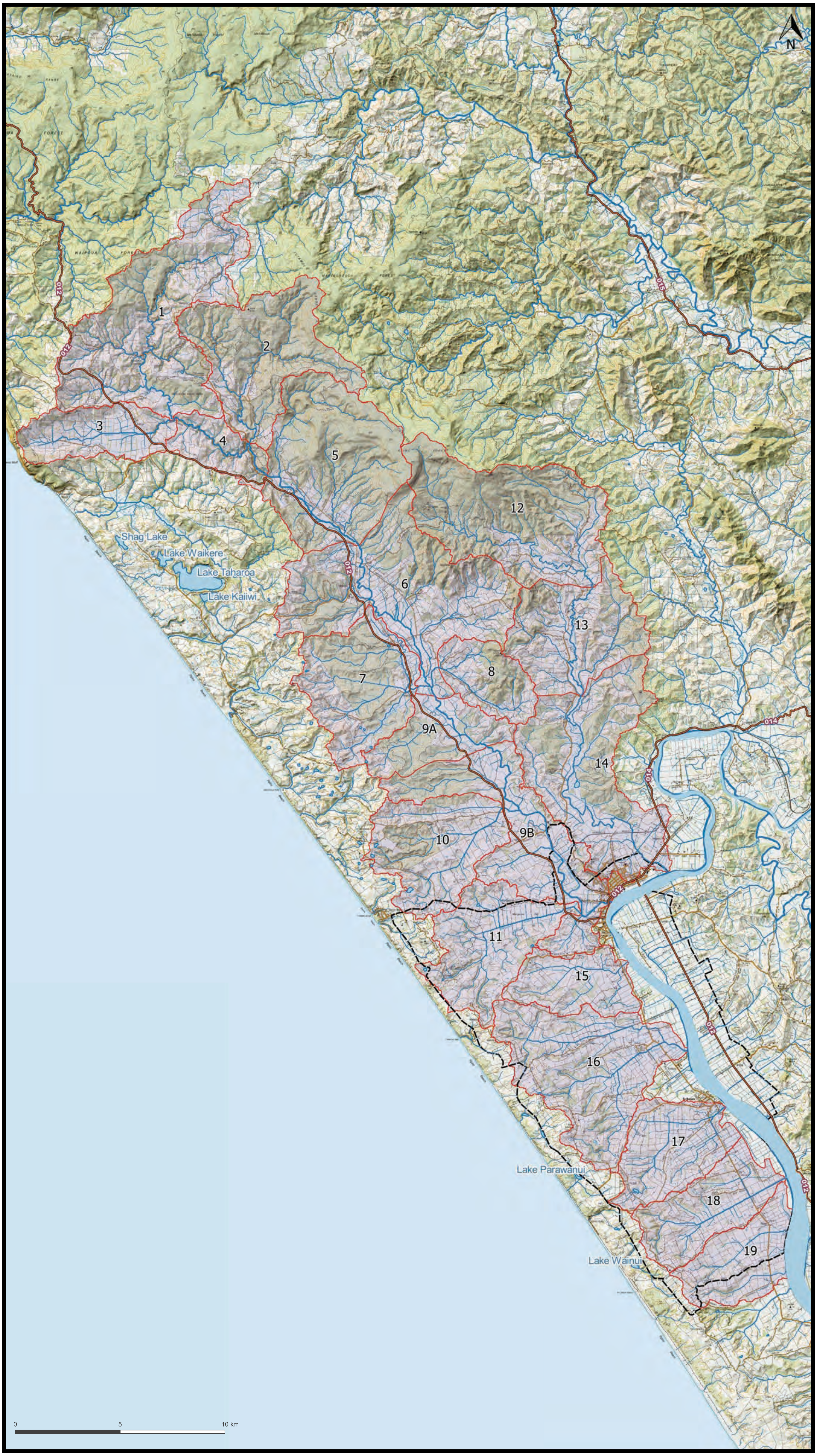


Legend

- River
- State Highway
- Command Area
- Model Sub-catchment

Data Provenance
Topographic Data derived from Land Information New Zealand. Crown Copyright Reserved

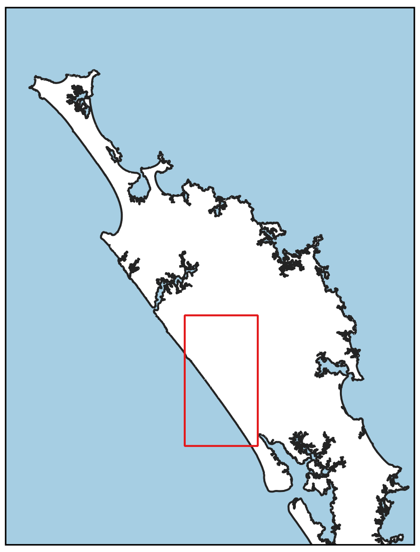
Figure 7.



Map Title:
Overview Map of Catchments Indentified in the Kaipara Study Area

Project:
Northland Water Storage and Use

Client:
Northland Regional Council



Legend

- **River**
- **State Highway**
- **Command Area**
- **Model Sub-catchment**

Data Provenance
Topographic Data derived from Land Information New Zealand. Crown Copyright Reserved

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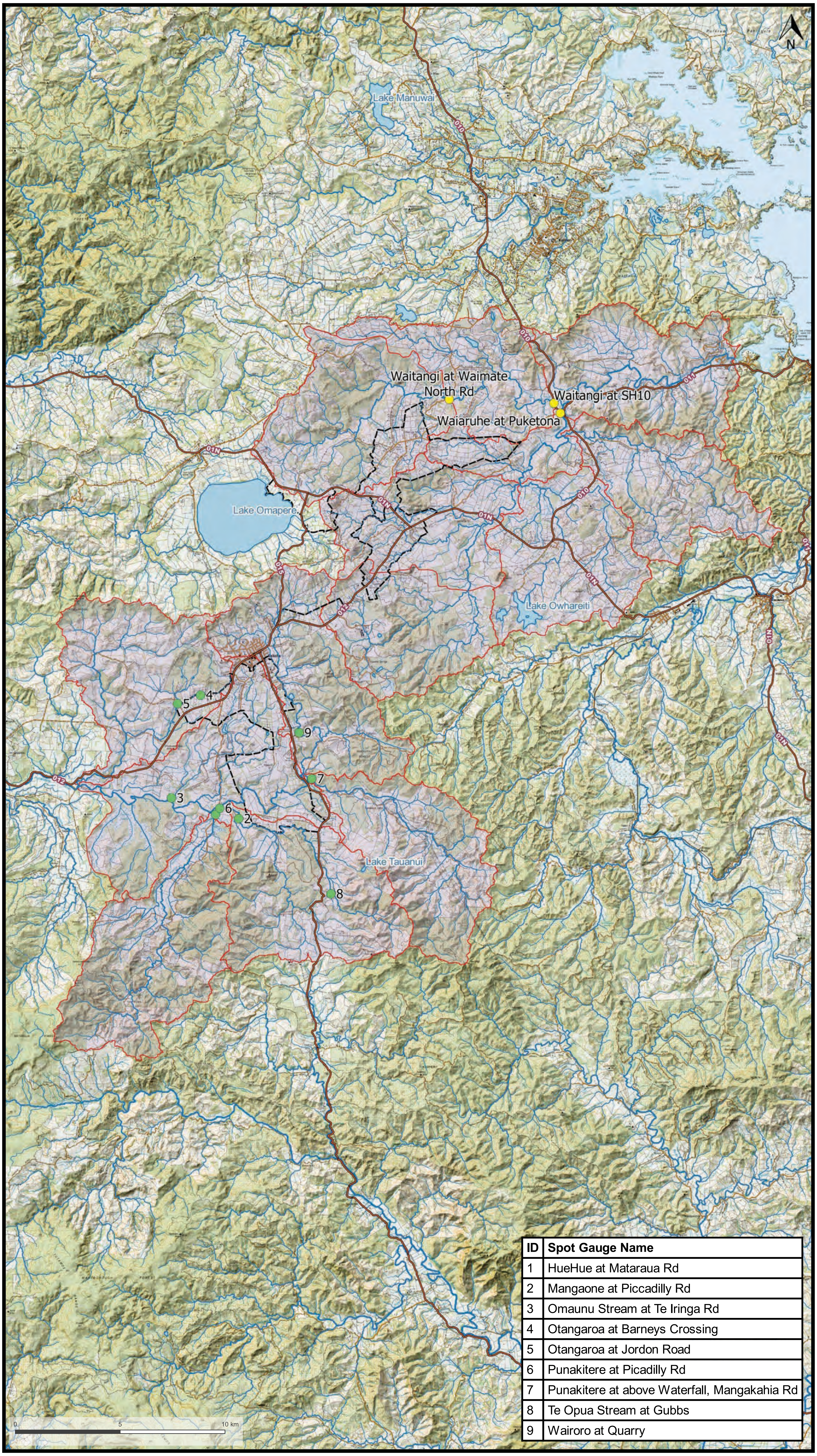
Figure 8.

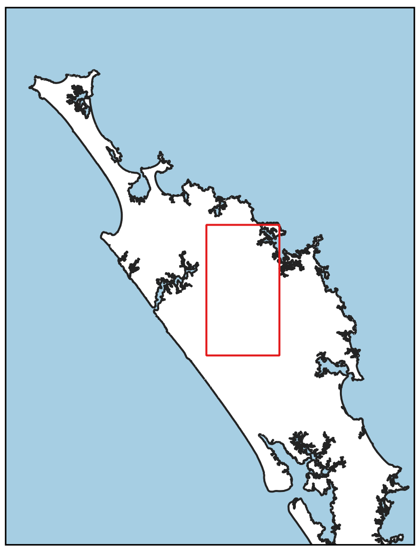
Map Title:
Locations of Gauged Flow Data in the Mid-North Study Area

Project:
Northland Water Storage and Use

Client:
Northland Regional Council



ID	Spot Gauge Name
1	HueHue at Mataraua Rd
2	Mangaone at Piccadilly Rd
3	Omaunu Stream at Te Iringa Rd
4	Otangaroa at Barneys Crossing
5	Otangaroa at Jordon Road
6	Punakitere at Picadilly Rd
7	Punakitere at above Waterfall, Mangakahia Rd
8	Te Opua Stream at Gubbs
9	Wairoro at Quarry



Legend

- Continuous Flow Gauge
- Spot Gauge
- River
- Command Area
- Model Sub-Catchment

Data Provenance
Topographic Data derived from Land Information New Zealand. Crown Copyright Reserved
Gauge Locations provided by Northland Regional Council

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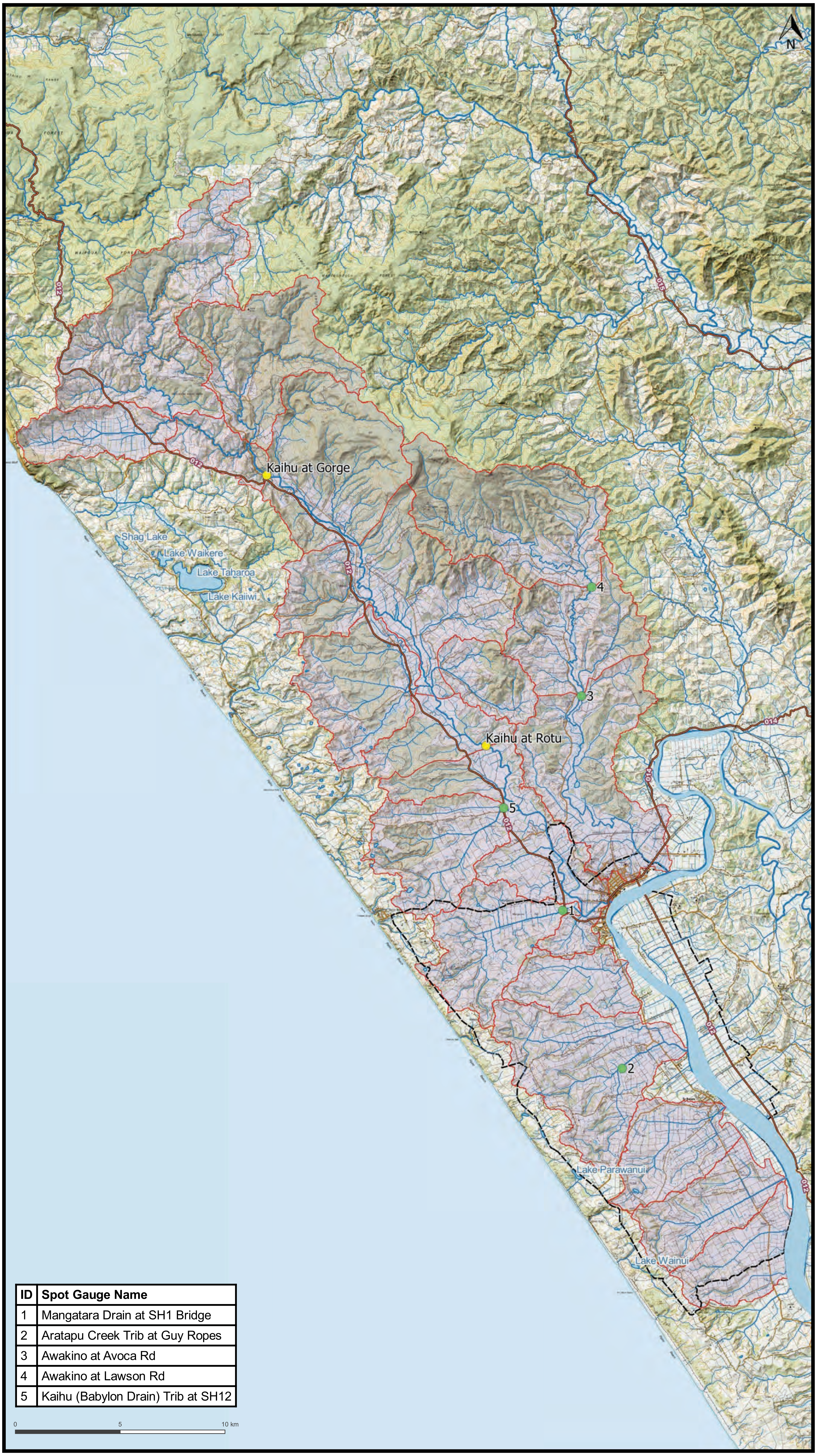
Figure 9.



ID	Spot Gauge Name
1	Mangatara Drain at SH1 Bridge
2	Aratapu Creek Trib at Guy Ropes
3	Awakino at Avoca Rd
4	Awakino at Lawson Rd
5	Kaihu (Babylon Drain) Trib at SH12

Map Title:
Locations of Gauged Flow Data in the Kaipara Study Area

Project:
Northland Water Storage and Use

Client:
Northland Regional Council

Legend
- Continous Flow Gauge
- Spot Gauge
- River
- State Highway
- Command Area
- Model Sub-catchment

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Gauge Locations provided by Northland Regional Council

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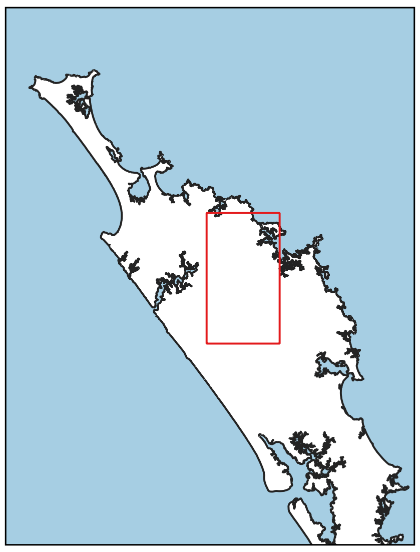
Figure 10.

Map Title:
Locations of Surface Water Takes

Project:
Northland Water Storage and Use

Client:
Northland Regional Council



Legend

- River
- State Highway
- Command Area
- Model Sub-Catchment

Surface Water Takes

- Drinking - Public Water Supply
- Irrigation - Horticulture
- Irrigation - Pasture
- Other - Dewatering

Data Provenance
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Water Take data provided by Northland Regional Council.

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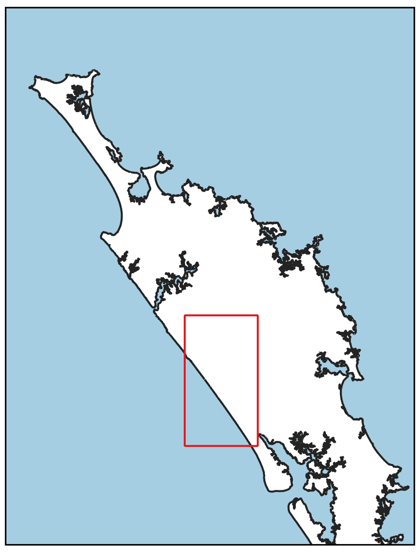
Figure 11.

Map Title:
Kaipara Consented Surface Water Takes

Project:
Northland Water Storage and Use

Client:
Northland Regional Council



Legend

- **River**
- **State Highway**
- **Command Area**
- **Model Sub-catchment**

Surface Water Takes
- **Drinking - Public Water Supply**
- **Irrigation - Pasture**
- **Drinking - Private Water Supply**
- **Industrial - Timber processing**

Data Provenance
Topographic Data derived from Land Information New Zealand. Crown Copyright Reserved
Take Locations provided by Northland Regional Council

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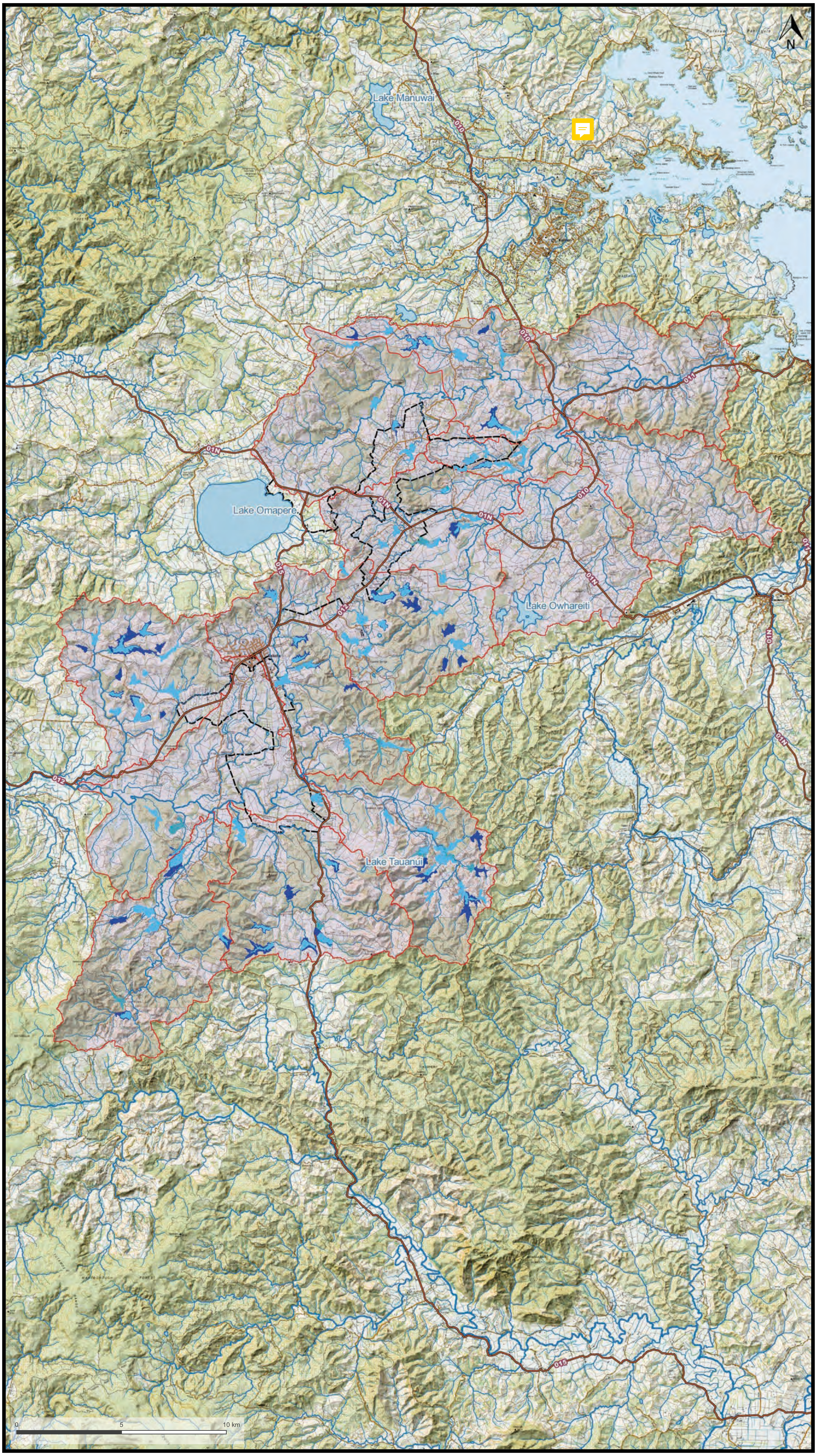
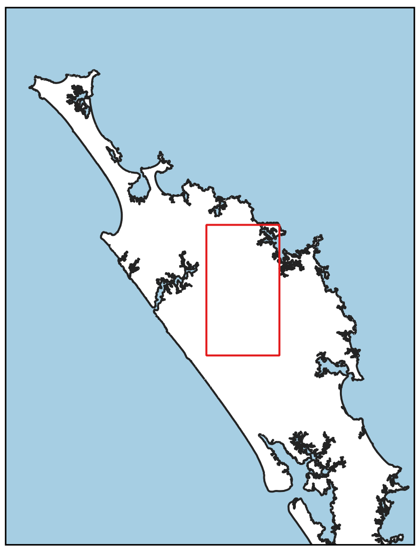
Figure 12.



Map Title:
Mid-North High-Level Storage Identification Outputs

Project:
Northland Water Storage and Use

Client:
Northland Regional Council

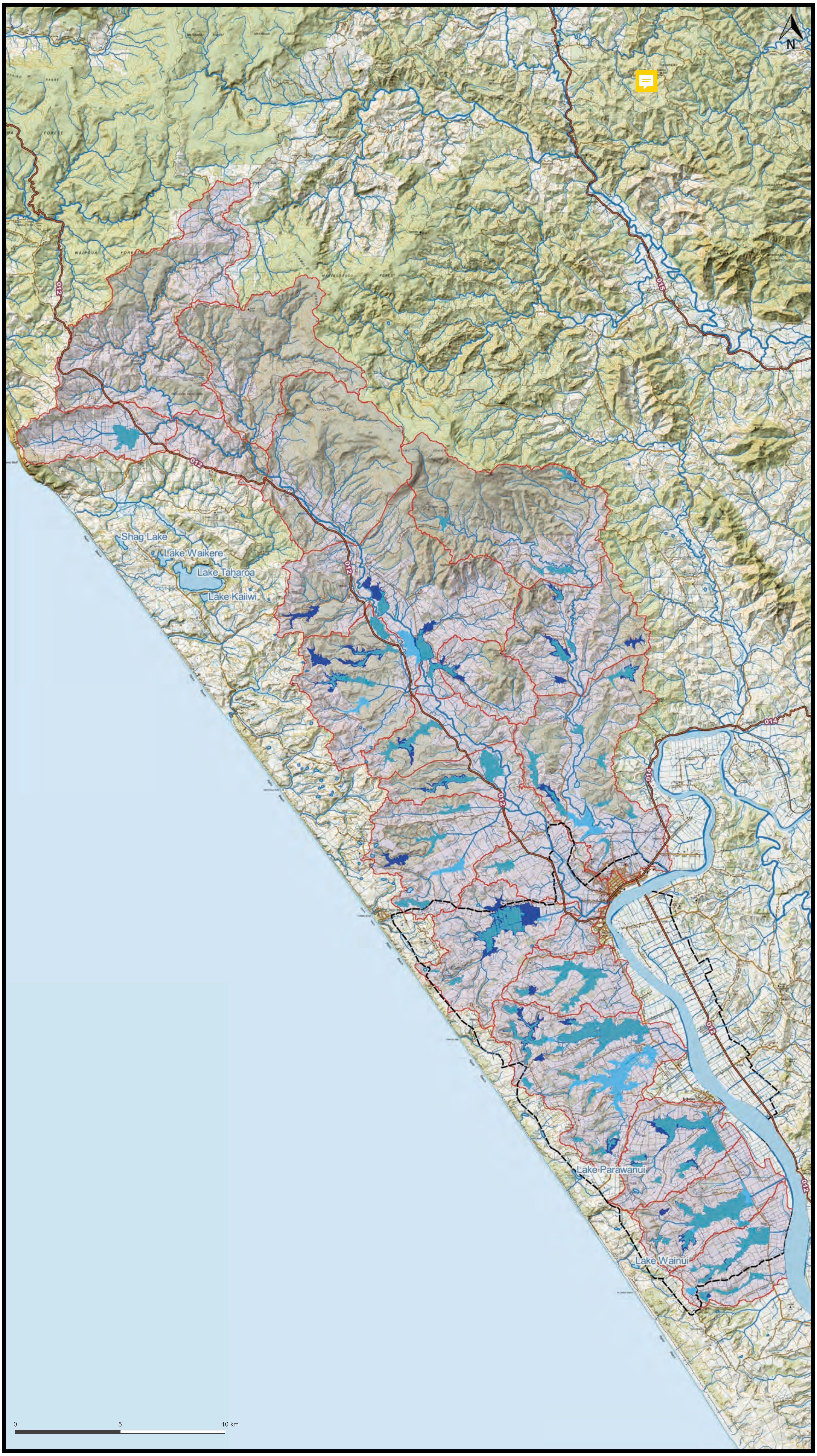


Legend

- River
- State Highway
- Command Area
- Model Sub-Catchment
- Large Storage
- Medium Storage
- Small Storage

Data Provenance
Topographic Data derived from Land Information New Zealand. Crown Copyright Reserved

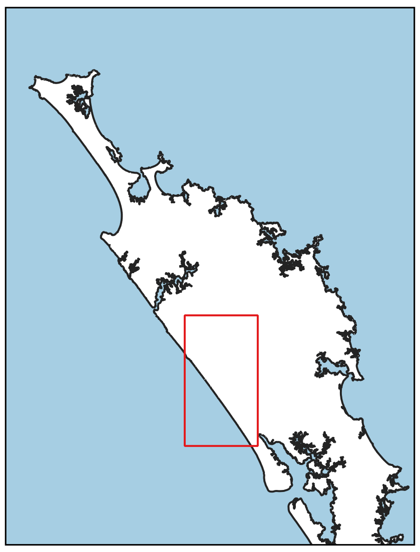
Figure 38.



Map Title:
Kaipara High-Level Storage Identification Outputs

Project:
Northland Water Storage and Use

Client:
Northland Regional Council



Legend

- River
- State Highway
- Command Area
- Model Sub-catchment
- Large Storage
- Medium Storage
- Small Storage

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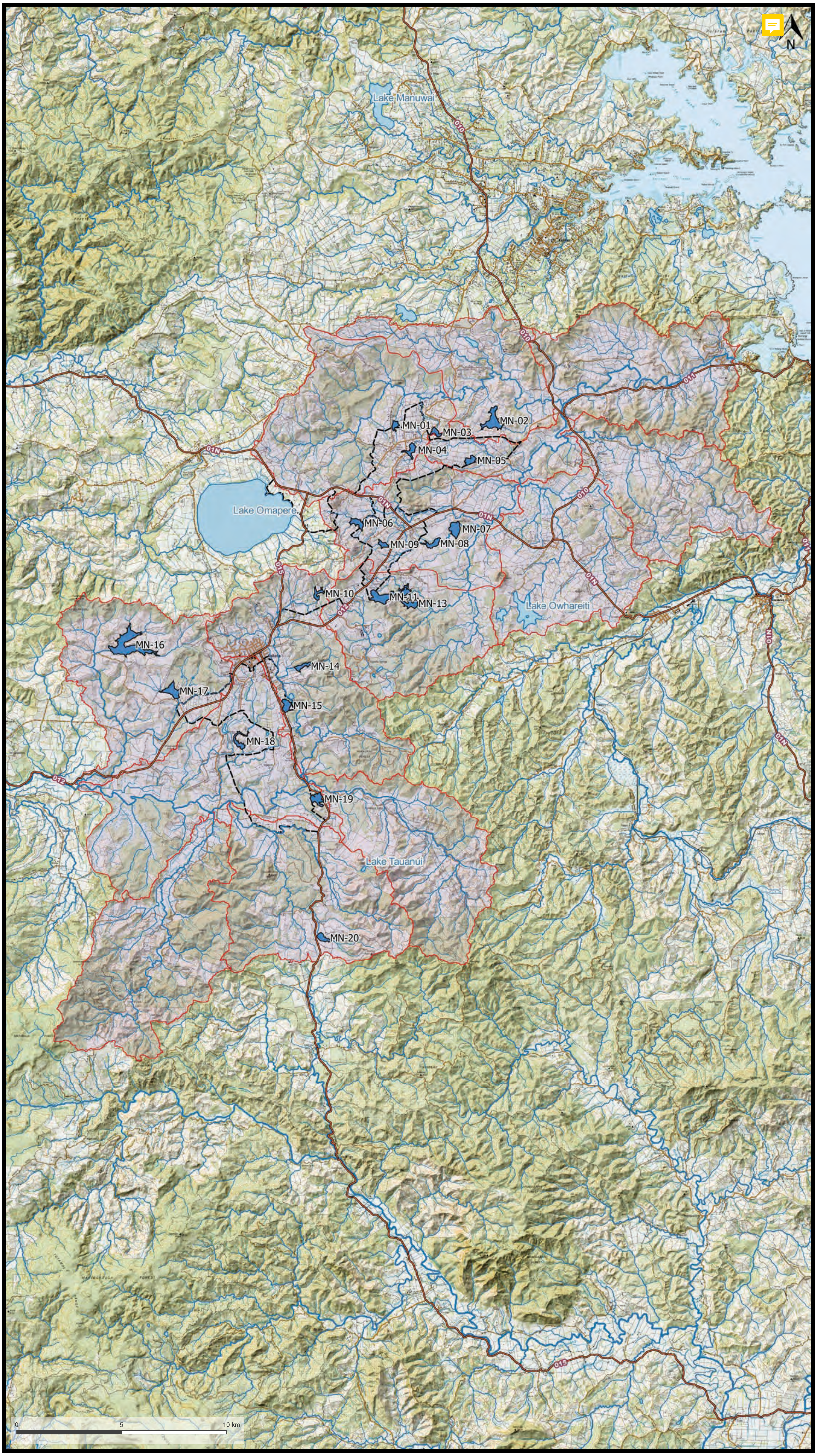
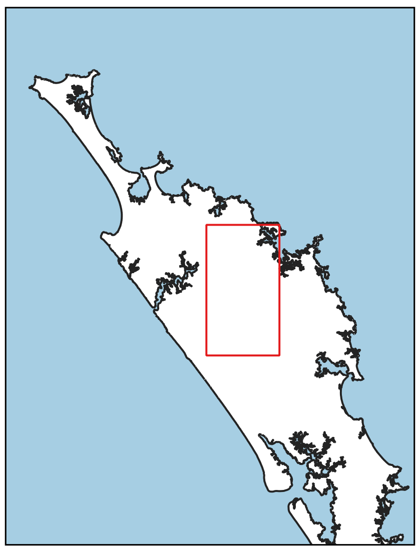
Figure 39.



Map Title:
Initial screening stage shortlisted storage options in the Mid-North

Project:
Northland Water Storage and Use

Client:
Northland Regional Council



Legend

- River
- State Highway
- Command Area
- Model Sub-Catchment
- Potential Storage

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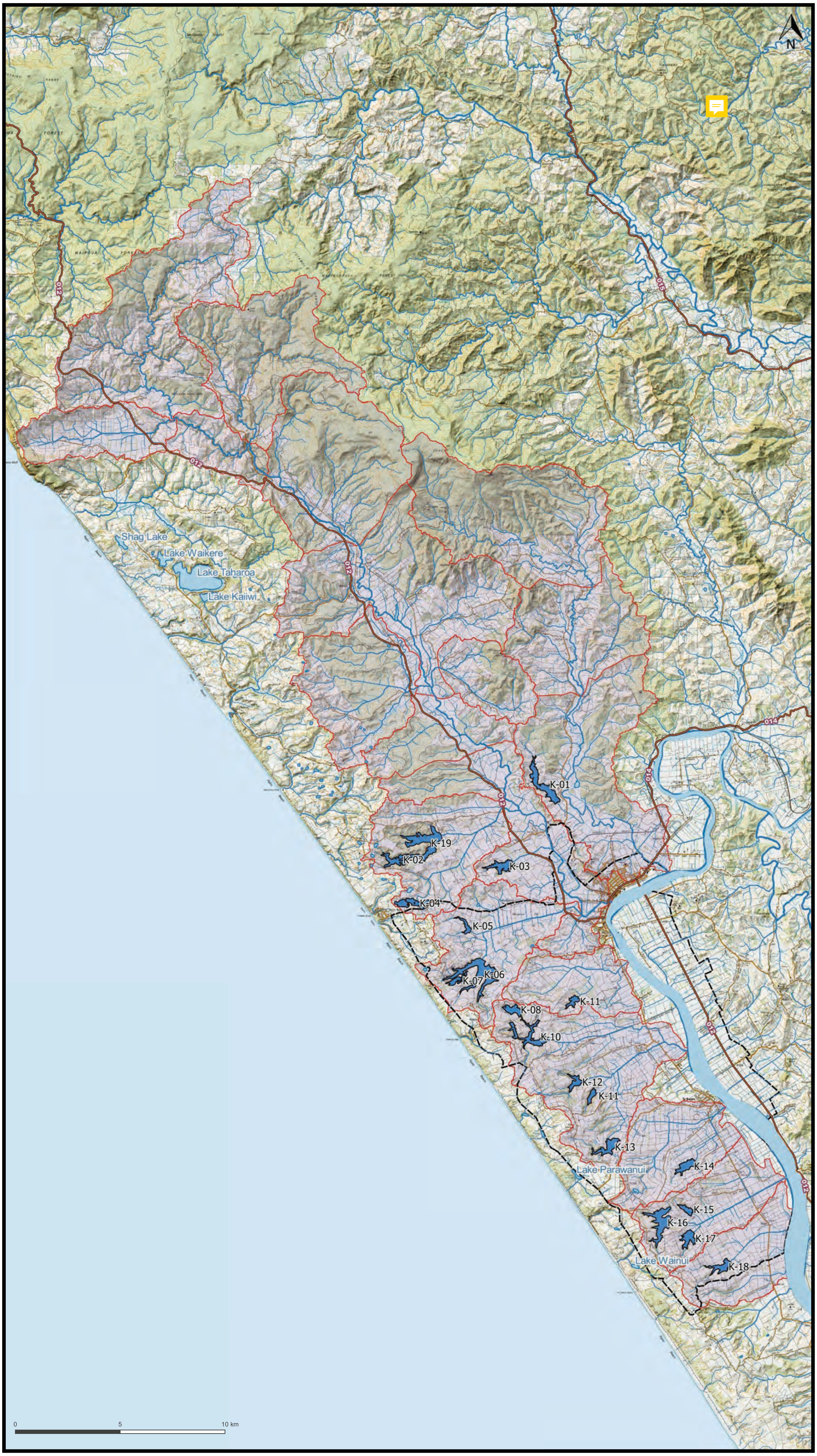
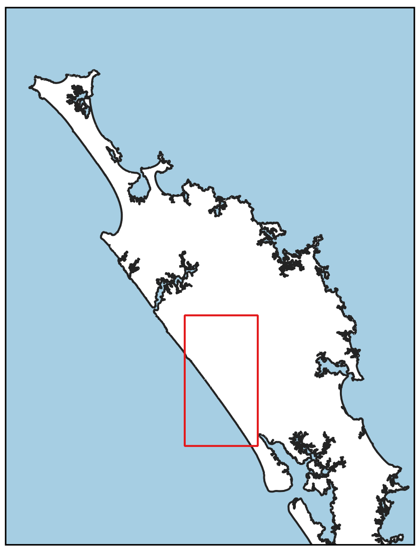
Figure 40.



Map Title:
Initial screening stage shortlisted storage options in Kaipara

Project:
Northland Water Storage and Use

Client:
Northland Regional Council



Legend

- River
- State Highway
- Command Area
- Model Sub-catchment
- Storage Options

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Figure 41.