Volume 3: Conceptual Design and Costing

Northland Water Storage and Use Project

NORTHLAND REGIONAL COUNCIL

WWLA0156 | Rev. 3

27 March 2020

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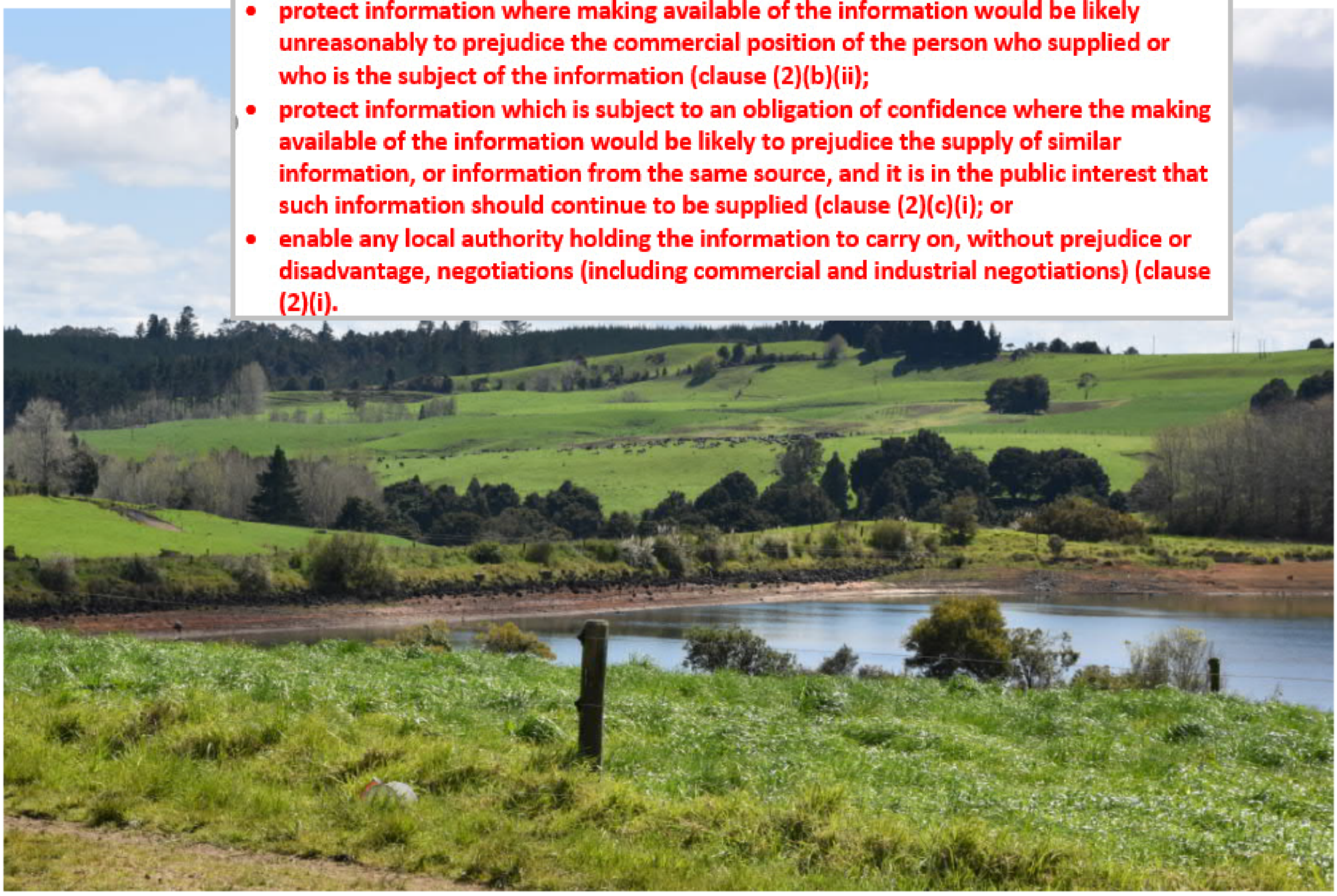

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Project no:	WWLA0156
Document title:	Conceptual Design and Costing
Revision:	3
Date:	27 March 2020
Client name:	Northland Regional Council
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File name:	G:\My Drive\Projects\NRC\WWLA00156\Consortium\Deliverables\3 Conceptual Design and Costing\Report Vol3_Conceptual Design and Costing_Rev3.docx

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Document history and status

Rev	Date	Description	By	Review	Approved
0	08 Nov 2019	Working document – provided for feedback on structure and indicative content only	RILEY		
1	21 Jan 2020	First draft for client review	RILEY, WWLA	Peter Lilly, Jon Williamson	Jon Williamson
2	21 Feb 2020	Updated following client and peer review comments and incorporation of Lake Omapere variation	WWLA, RILEY	WWLA, RILEY	
3	27 Mar 2020	Updated following client and peer review comments	WWLA, RILEY	WWLA, RILEY	Jon Williamson

Distribution of copies

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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 Irrigation Demand and Infrastructure 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 enable 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;
3. ***Volume 3:*** Conceptual Design and Costing (**this report**); and
4. ***Volume 4:*** Analysis and Recommendations.

1.1 Report Structure

This report details the conceptual design and costing component of the pre-feasibility assessment, considering scheme configuration scenarios, storage optimisation, reticulation network and storage (reservoir) design and costings.

This report is structured as follows and comprises of:

- analysis methodology (**Section 2**);
- conceptual scheme configurations (**Section 3**);
- reservoir design considerations (**Section 4**);
- consideration of the power network (**Section 5**);
- overview of scheme component costs (**Section 6**);
- capital costs (**Section 7**);
- operational costs (**Section 8**); and
- discussion (**Section 0**).

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

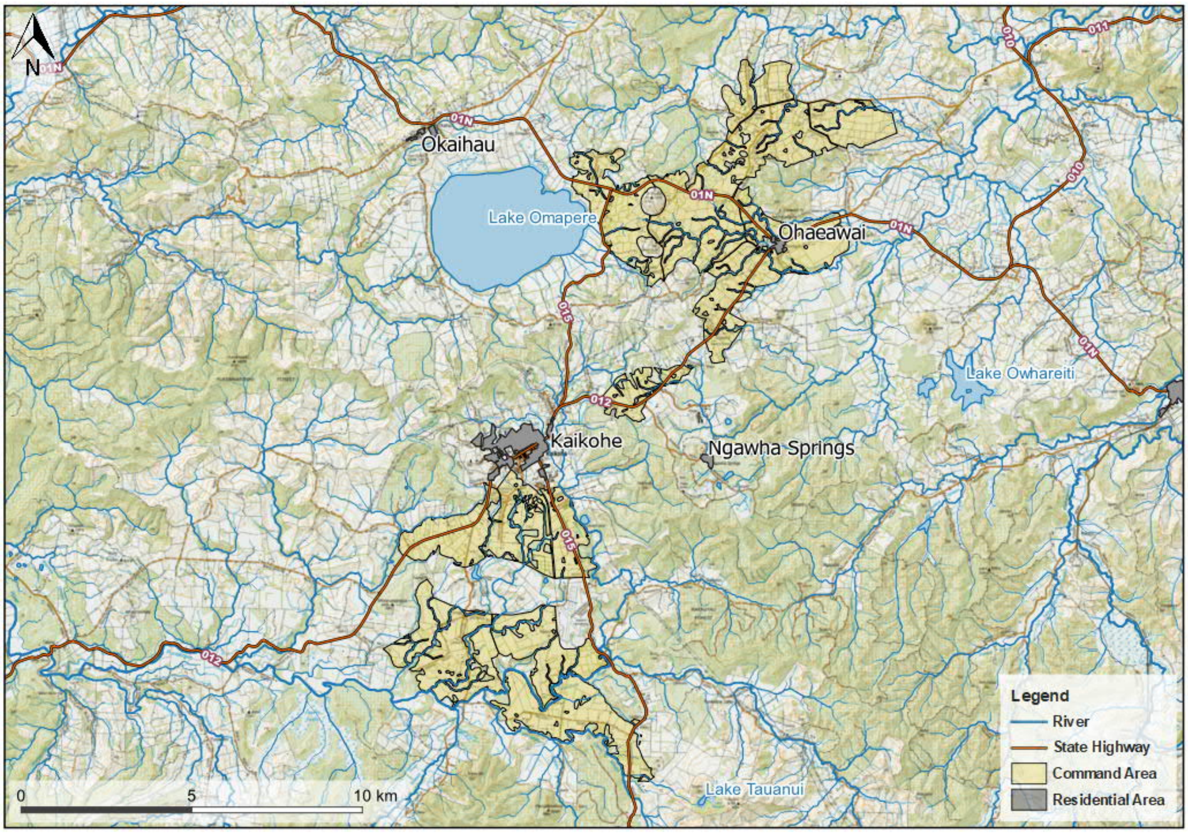

Figure 1. Mid-North study area locality.

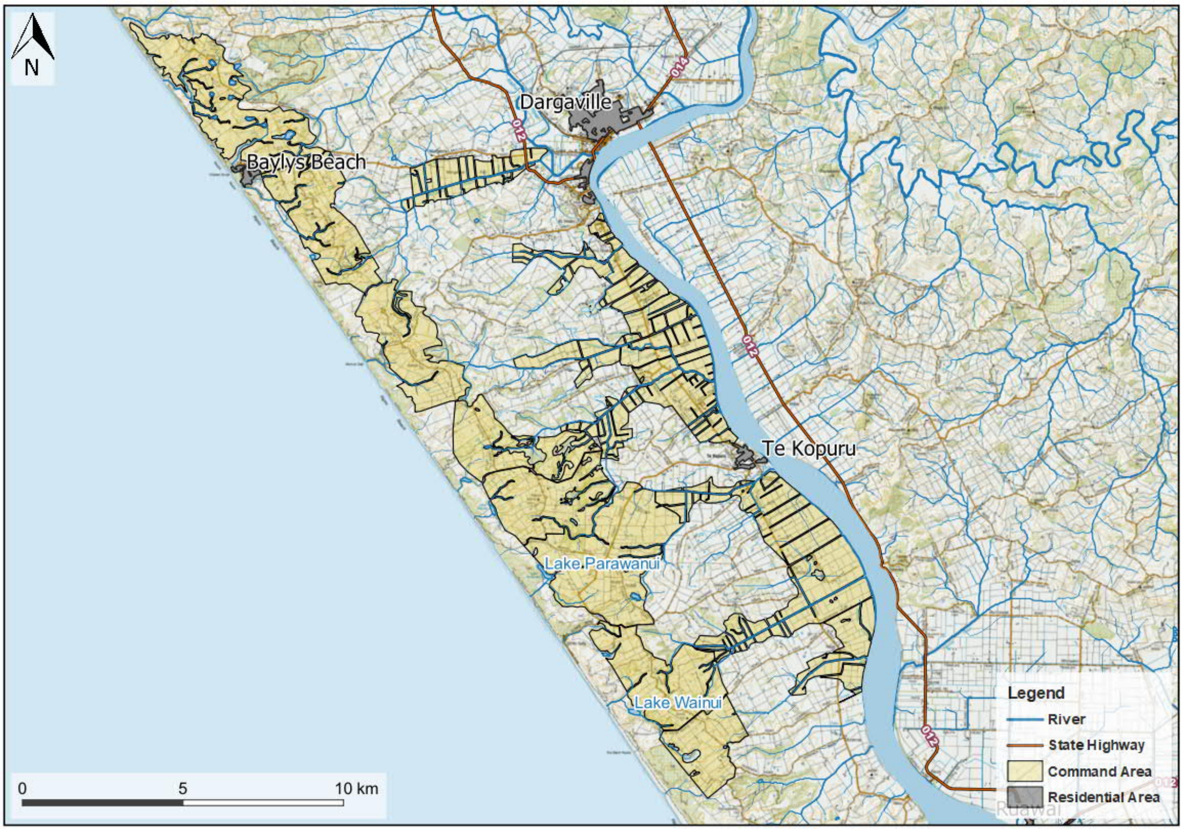

Figure 2. Kaipara study area locality.

1.2 Key Findings from Volumes 1 and 2

The spatial extent for the conceptual scheme design, as well as the potential water requirements were determined in **Volume 1: Command Area Analysis and Refinement.**

This involved analysing key features that influence suitability of land for horticultural production, such as soil types, slope and aspect, as well as removing any potential "no-go" areas. The Kaipara and the Mid-North regions were sub-divided into 15 and 14 zones, respectively, with each zone representing a pragmatic area of land for contiguous infrastructure to irrigate.

Irrigation demand models were developed for four representative crop types (pasture, citrus, avocado, and kiwifruit) for each region. Assumptions were made concerning the canopy and diversification factor values, which were used to determine the potential maximum water requirements of each zone.

Table 1 summaries the refined scheme details to be progressed forward to conceptual design within this report.

Table 1. Summary of refined scheme areas.

District	Area (ha)			Irrigation Water Requirement	
	Total	Total (with Exclusions)	Proposed Irrigable Area	Peak Daily (m^3)	Annual (Mm^3)
Kaipara	10,150	9,215	2,607	104,298	10.4
Mid-North	6,016	5,208	1,906	76,231	7.6

In addition to the irrigation requirements shown in **Table 1**,other consumptive water demands such as municipal and Ngawha Park have been allowed for. In summary, this means that the indicative potential water requirements derived for the Kaipara are 11-12 Mm^3 and 8-9 m^3 in the Mid-North.

The Water Resources Analysis (**Volume 2: Water Resources Analysis**) considered available sources and quantity of water available for harvesting, and provided a first pass high-level identification of where such water could be stored.

This analysis determined 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 flow volumes occur during high flow periods, albeit a combination of storage reservoirs and/or river intakes would be required to harvest this water.

A large number of potential storage sites were identified before being narrowed down to a short-list based on experienced judgement to 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, hence the intention of the MCA was to help inform decisions during development of the conceptual design (within this report).

1.3 Overarching Objective and Methodology

The primary objective of this stage of the pre-feasibility was to:

> *Identify conceptual scheme layouts that deliver to the user, with particular emphasis on Maori owned land, a reliable water supply that provides a high level of certainty that demand will be met.*

To advance toward this objective, potential scheme components, especially storage sites that ranked high during the previous stages, were selected in preference to those that ranked lower. The MCA scored each storage location against 20 criteria including; technical, physical and non-physical attributes. At this stage of the project, the intent was to balance cost, risk and value across the whole scheme, but also through the early periods of uptake, rather than identifying the lowest cost scheme.

Seeking to achieve a cost-effective solution was however embedded in the MCA process through criteria such as; geotechnical conditions, storage efficiency and potential sensitive land or location issues. There will be a direct beneficial impact on scheme costs and risk by advancing sites where these criteria ranked higher.

At a pre-feasibility level assessment, it is inappropriate to lock down a single scheme configuration. There remains too much uncertainty, hence, to limit flexibility at this stage is to increase the risk of insurmountable challenges halting progress in the future. A secondary objective was therefore to;

> *Retain flexibility in scheme components and configuration option, including component location, size and development sequencing.*

The development of an irrigation scheme is quite unique in comparison to other large infrastructure developments. Typically, for large infrastructure developments a “market” already exists, and the infrastructure is being developed to increase supply, or service to that market. As such, it is easier to quantify the level of value from the development. For irrigation schemes, the market for the product (i.e. water) typically needs to be developed in parallel to the supply of the product and associated infrastructure. On one hand, users typically do not have a choice of alternative options for supply, which makes signup to the scheme more compelling; yet on the other hand they do not necessarily have experience with achieving value from the product, hence are tentative about committing to the scheme until the benefits are better understood.

Collectively this means that uncertainty around how the market will develop (i.e. uptake) dominates project risk. Therefore, a further secondary objective was to:

> *Understand and where practical minimise the impact of uptake risk on scheme feasibility.*

2. Methodology

2.1 Definition of Zones

To achieve the primary objective[2] requires an understanding of the demand areas, the likely diversity of use in the demand areas and potential uptake profiles. Further, all irrigation schemes are designed to have a maximum limit on supply, beyond which deficits in supply are induced. These can arise from either:

- ***capacity constraints*** - where peak demand exceeds supply capacity; or
- ***volume constraints*** - where insufficient storage volume remains to meet demand for the foreseeable future.

To help quantify these key design considerations, the two regional areas were sub-divided into sub-areas or 'Zones'. This allows the variability in expected demand between areas to be effectively captured, and in turn the implication of potential deficits in supply. Key attributes considered for each zone includes:

- likely use and associated demand diversity that arises from that use;
- likely uptake, both initially and ultimately; and
- implications on users from the management of supply shortfalls (deficit management).

2.2 Scheme Configurations

Achieving the primary objective also requires a scheme configuration that supports progressive and adaptive development with time, cognisant of the variable distribution and diversity of use. Given that there will always be uncertainty associated with uptake and use, the scheme configuration also needs to meet the secondary objective of flexibility.

To deliver to these objectives, a "bookends" approach has been utilised for this pre-feasibility assessment. This advances two scheme configurations that broadly represent the two reasonable but extreme limits of what is ultimately anticipated to be delivered. This approach seeks to deliver two viable development scenarios that meet the scheme objectives, while recognising that the optimum development scenario almost certainly lies somewhere between these two "bookends". This seeks to avoid selecting a preferred configuration too early in the development sequence while high levels of uncertainty that will impact on the viability of any given solution still exist.

A complementary benefit of the bookend approach is that it is easier to consider options for progressive development of the scheme as the range of overall scheme concepts have been bounded by the two bookends. Any options for progressive development can draw on components adopted in one or other bookend, somewhere in between, or may alter their size of configuration to facilitate progressive development. Put another way, all the main components that are likely to be required to deliver a final optimised development solution are contained within one or the other of the bookends. However, the development order of components, their ultimate sizing, and how they are integrated together is likely to evolve through subsequent development stages.

As the irrigation developments in the Kaipara and Mid-North are almost entirely, if not completely, reliant on stored water, storage is the main attribute that defines the bookends. In broad terms the two bookends adopted are:

- **Large Storage Scenario –** Most of the storage for the scheme is contained at a single location with conveyance extending from that location to the command areas. Some minor storages may be included predominantly for operational reasons, such as to manage conveyance or pump capacity limits during peak periods of demand. One or more sources may be required to fill the storage.

[2] A *reliable water supply that provides a high level of certainty that demand will be met.*

- **Distributed Storage Scenario –** The scheme will utilise several storages distributed across the total scheme area. These typically will be predominantly dedicated to nearby zones but interlinked through the wider scheme distribution network. Each storage will be filled from nearby sources first but may also transfer excess to or from other storages or river intakes as necessary.

As both bookend scenarios are developed to achieve an equivalent level of supply reliability and certainty, and hence value to the end user, the main difference between the bookends will be relative cost (both capital and operational), and management of risk. The following is a high-level summary of the likely differences and demonstrates some of the factors considered as part of the assessment methodology.

Table 2. Comparison of key aspects between the irrigation scheme configurations.

		Large Storage	Distributed Storage
Costs	Capex	L kely to be cheaper overall due to economies of scale, providing the main storage site is not significantly remote from the demand area.	Likely to be higher overall cost as more locations are involved with associated sunk costs (e.g. development costs, land etc.) and loss of the economy of scale.
	Cashflow	Limited ability to spread development cashflow as financing needs to be secured for most of the scheme from the start. Nearly all of the scheme will need to be built before any supply is possible.	Reasonable ability to spread cashflow as scheme components can be financed and brought online in progressive stages. Separate areas could also be developed in isolation and linked at a later date.
	Operational	L kely to be cheaper provided the large storage does not induce high pumping costs, either to fill or supply, and is not too remote from the command area.	Likely to be more expensive due to the larger number of components and associated ongoing operational and maintenance costs.
Risks	Uptake	Limited flexibility to deal with uncertainty and variability in uptake. Significant portions of the scheme (and associated cost) needs to be provided before any supply is achieved. Scheme will effectively be in an oversupply situation until it reaches full uptake.	Significant flexibility as components can be progressively brought online to more directly reflect demand uptake. This may however produce some minor or ancillary component redundancy and associated costs. Progressive development can be managed to limit oversupply during uptake and even potentially adopt periods of undersupply between progressive stages.
	Fatal Flaw	Higher as there is likely to be limited or no alternatives to the storage site. Further, the risk is higher of a fatal flaw arising late in the development project due to the limited design flexibility. Significant risk of a full redesign being required.	Lower as alternatives are more easily incorporated to avoid fatal flaws. May have a cost implication or impact on supply to one or more sub-area but less l kely to derail the project in its entirety.
	Approval	Probably less likelihood of approvals not being achieved predominantly because there are fewer components involved. However, the consequence of failing to achieve approval for any single component is much greater as each component is more critical, with limited opportunity for alternatives to be substituted.	Probably higher likelihood of some approvals not being achieved as the greater number of components will affect a wider portion of the community. The consequence, however, is lower as each component is less critical to the overall scheme and typically there are alternatives that can be used to substitute.

2.3 Selection of Reservoir Sites

Site criteria for characterising and comparing a site's suitability for constructing a reservoir (i.e. acceptability criteria for storage sites) is dependent on several factors including, but not limited to:

- storage characteristics;
- technical challenges with siting the dam embankment and reservoir;
- location to source and demand;
- land acquisition;
- historic, cultural, and/or ecological values and impacts; and
- consentability.

These same factors formed the basis for the multi-criteria analysis discussed in **Volume 2 - Water Resources Analysis, Section 8.4**. Reservoir sites scoring highly in the MCA process should be more suitable overall compared to those with lower scores (although some individual factors will inevitably be less).

The identification, ranking and selection of storage sites was developed and refined in three steps:

1. High-level identification of potential storage sites using the Reservoir Identification Tool (RIT). This automated process identified 300+ sites for both command areas, termed the 'long list'.
2. Shortlisting of favourable sites down to 20 sites for each command area considering storage efficiency, flexibility, water source, and spatial coverage. Filtering and ranking of shortlisted sites through the MCA process. Further information regarding this step and the one above is outlined in the accompanying **Volume 3 - Water Resources Assessment, Section 8.0.**
3. Selection of reservoir sites from the higher-ranking sites determined through the MCA process. In some cases, there was only limited alternatives nearby and hence necessitated selection of a particular site. For the large storage scenario there was typically only one or two sites capable of storing the required water volumes. Once the reservoir site had been selected, an initial optimisation loop was performed before arising at the final dam structure alignment. This involved a review of possible alternative alignments immediately up- and down-stream, and earthworks modelling of embankments utilising 12d (civil modelling software) so that storage efficiencies at various storage volumes/dam heights could be compared. In Kaipara, [redacted] was ultimately selected for the Large Storage Scenario and [redacted] for the Distributed Storage Scenario. In the Mid-North, [redacted]) and [redacted] were selected for the Large and Distributed Storage Scenarios, respectively.

Reservoir sites ultimately incorporated into the concept design achieve a reasonable balance between compatibility to command areas, technical suitability (**Section 3**), and cost (**Section 7 and Section 8**). It should be appreciated that these will not necessarily be the final sites but should be generally representative of the storage potential across the two areas. Sufficient flexibility exists across shortlisted options to vary and/or modify storage locations and storages volumes during feasibility and detailed design.

2.4 Initial Storage Optimisation

Scheme storage optimisation was undertaken in order to determine optimum (ideally smallest possible) storage volume for each reservoir, balancing direct catchment inflows, additional supply takes, and transfers between storages to supply irrigation to command areas at an appropriate level of reliability, which was defined at full supply in 19 out of 20-years.

The objectives of the scheme storage optimisation were to determine:

- the command areas serviced by each reservoir;
- inflow requirements from external sources e.g. nearby river takes (in addition to direct catchment inflows);
- transfer rates between reservoirs for the distributed concept schemes; and
- optimum storage volume of each of the storage reservoirs, considering command areas serviced, required reliability and storage efficiency of each individual reservoir.

The SOURCE modelling framework was utilised for the scheme storage optimisation. SOURCE is a hydrological modelling platform developed by the Australian research and not for profit organisation eWater. The platform is comprised of an interface integrating various models (as plugins) and internal tools designed to simulate and extract results for all aspects of water resource systems at a range of spatial and temporal scales.

The schematic modelling component of SOURCE was used to develop conceptual scheme models for the Large and Distributed Storage scheme options for the Kaipara and Mid-North study areas. A schematic model is defined as a series of linked nodes, representing individual components of the scheme, and rules and constraints on the transfer of water between nodes. The key node types used in the scheme storage optimisation modelling included:

- **Storage Nodes** – are used to represent storages such as dams, reservoirs, weirs and ponds. Storage Nodes calculate the daily water balance and are governed and constrained by inflows, physical limits on discharges (i.e. outflow pipe or pump capacities), downstream demands and gains (direct rainfall on reservoirs) and losses (evaporation for the reservoir surface).
- **Inflow Nodes –** provide a source (inflow) of water to Storage Nodes. Inflow Nodes were configured with time series extracted from the catchment models (described in **Volume 2 - Water Resources Analysis**), representing direct catchment inflows to each of the reservoirs, and both low (run-of-river) and high flow takes from additional sources as required during the optimisation process.
- **Supply Point Nodes** – define a location where water can be extracted to meet a demand required by Water User Nodes. Supply Point Nodes provide a means of constraining extractions (takes) based on physical constraints such a maximum pumping capacity, or when reservoir storage volumes are above a specified level.
- **Water User Nodes** – define a water take demand profile, and are always located immediately downstream of a Supply Point Node. These were configured using the irrigation demand models developed in **Volume 1 – Command Area Refinement**. Water user nodes simply represent a water take (demand) from a Storage Node, on the condition that sufficient volume of water is available within the storage, and the take is within the constraints of the upstream Supply Point Node.

The schematic models were simulated on a daily timestep over the period 1972 to 2018.

An iterative approach was employed whereby rules were configured and adjusted controlling the inflow pumping rates (for both low flow and high flow takes from neighbouring sources), the transfer rate and trigger levels for the transfer of water between reservoirs, and total storage volumes, with the objective of achieving an approximate 19 in 20-year irrigation supply reliability.

Outputs from the storage optimisation analysis are provided individually for each Large and Distributed Storage scenarios schemes in **Section 3**.

2.5 Reticulation Network Analysis

Hydraulic analysis of the Large and Distributed Storage schemes for the Kaipara and Mid-North was undertaken using the US Environmental Protection Agency's EPANET software. EPANET calculates the pipe diameter and pressure ratings required to meet the flow and pressure requirements of the supply and distribution scenarios, in accordance with set design criteria. For this project, the design criteria was defined by maximum and minimum water velocities recommended by Irrigation New Zealand (INZ), as summarised in **Table 3** and **Table 4**, respectively. This was undertaken in a systematic way to enable capital and operational costs to be developed for comparison between scenarios.

For the pre-feasibility stage, a nodal network approach linking sources to storages and storages to command area zones was assumed. Further distribution from the command area zones to on farm networks are not considered at this stage.

The maximum water velocity is recommended to minimise pressure losses (as pressure is inversely proportional to flow velocity), while a minimum flow velocity is recommended to ensure sufficient velocities to enable flushing of any sediment that may enter the network, in order to prevent deposition and build-up.

The design criteria utilised for the modelling of all scenarios is summarised in **Table 5**.

A target pressure of 35 m (~3.5 bar) above the 75th percentile land surface elevation of each irrigation command area zones was assumed. This means 75% of the command area will receive sufficient pressure to not need additional on-farm pressurisation, while the remaining 25% of the area will require some on-farm booster pumping. This approach is adopted as an initial balance between directly providing pressurisation while avoiding needing to over specify the pressure rating of pipes. This aspect will benefit from further optimisation in subsequent design stages.

Table 3. Recommended maximum water velocities (INZ Design Standard, 2013).

Condition / Location	Velocity (m/s)
Less than 150 mm, open ended, controlled start and stop	3.0
150 mm or greater, open ended, controlled start and stop	2.0
Less than 150 mm, uncontrolled start and stop	1.5
150 mm or greater uncontrolled start and stop	1.0

Table 4. Recommended minimum water velocities (INZ Design Standard, 2013).

Condition / Location	Velocity (m/s)
Flushing fine sediment (e.g. in tapes)	0.4
Flushing coarse sediment	0.5
Flushing air, particularly in small diameter pipes	0.6
Flushing water containing solid material	1.0

Table 5. Reticulation modelling criteria.

Condition / Location	Value
Minimum water velocity (m/s)	0.5
Maximum water velocity (m/s)	2.0
Pipe Roughness [Hazen-Williams] (mm)	150

Outputs from the Reticulation Network Analysis are provided individually for each Large and Distributed Storage scenarios schemes in **Section 3**.

3. Scheme Configurations

Sections 3.1 to 3.4 outline the concept scheme configurations and describe the supply, storage, and reticulation network configuration. Concept reticulation networks that meet the command area demand are also described, and schedule of quantities of pipe lengths, diameters, pressure ratings and pump station requirements provided as input to scheme costings (**Section 6**).

3.1 Kaipara Large Storage Scenario

3.1.1 Overview of Main Components

The Kaipara Large Storage scenario schematic is shown in **Figure 3**. The scenario consists of [redacted] that supplies the entire command area. The reservoir will be filled through direct upstream catchment inflows and a combined low and high flow take from [redacted]. The size of the reservoir and rate of take from the [redacted] are detailed in the Storage Optimisation **Section 3.1.3**.

Figure 3. Kaipara Large Storage scenario main structure locations. (Refer A3 attachment at rear).

3.1.2 Storage Features - Compatibility to Command Areas

The [redacted] site has been selected because it provides a good balance between:

- Proximity to a reliable and large water supply source [redacted]
- Proximity to [redacted] should it be used for urban water supply;
- Excellent storage efficiency and flexibility across a wide range of storage volume; and
- Ability to feed into conveyance systems that can be predominantly aligned along existing roads.

The main consequence of selecting this as [redacted] storage design concept is that the command area is largely located to the south of the storage rather than being distributed around the storage. This slightly increases the length and diameter of pipes within the reticulation network and associated pump-stations. It also induces an increase in energy demand as the supply has to be pushed further to reach the command areas.

Alternative storage sites examined that were capable of storing the full volume of water required were either more remote from the source or the command area. The next best site was [redacted], which is one of the sites used in the Distributed Storage design concept and as such provides a viable alternative should [redacted] prove less attractive in the future.

Overall, the concept provides the best balance between proximity to source and command areas as well as providing flexibility for potential future additional uses.

3.1.3 Storage Optimisation

Storage optimisation was undertaken as decribed in **Section 2.4** and with the following assumptions:

- that all high flow (above median) within the [redacted] and within [redacted] internal catchment are harvested; and
- the low flow run-of-river take from the [redacted] operates at all available times, except when reservoir storage is full.

The optimisation modelling therefore balanced the storage volume of [redacted], with irrigation demand requirements and the high flow (above median flow) take rate from the [redacted].

The Kaipara Large Storage schematic model is shown in **Figure 4**.

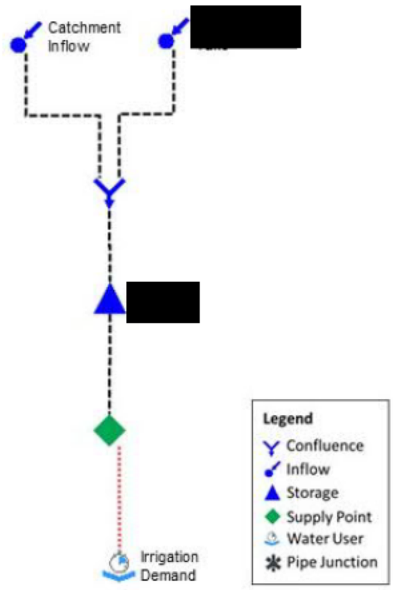

Figure 4. Kaipara Large Storage scheme schematic model.

The optimisation modelling tested high flow transfer rates ranging from 0.1 m^3/s to an upper limit of 0.5 m^3/s, above which pipe size and pump costs were considered prohibitive. The result of the optimisation testing provided what was considered the most favourable balance of storage size and pumping rate, while delivering the required irrigation supply reliability of 19 in 20 years, comprised the following:

- [redacted] storage volume of [redacted] Mm^3;
- [redacted] high flow take rate of [redacted] m^3/s.

Table 6. Optimised Kaipara Large Storage scheme summary.

Reservoir	Storage Volume (Mm^3)	Source Take Rate (m^3/s)	Command Areas Serviced	Comments
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

A summary of the optimised scenario statistics is provided in **Table 7**. The mean and maximum annual total demand represent the annual average and maximum irrigation demand volume simulated over the 46-year simulation period, while the mean and maximum total supply represent the volume of water supplied. As the mean and maximum demand are larger than the mean and maximum supply, it indicates the scheme does not provide 100% reliability (i.e., there are periods of drought where there is insufficient stored water to meet irrigation requirements). The remaining statistics in **Table 7** show the reservoir emptied in three sperate years during the 46-year period, for a combined total of 103 days (i.e. 34 days once every 15 years on average). However, this represents less than 1% of the total simulation period.

Table 7. Kaipara Large Storage scheme simulation results.

Statistic	Units	[redacted]
Mean annual total demand	Mm^3/year	[redacted]
Mean annual total supply	Mm^3/year	[redacted]
Maximum annual total demand	Mm^3/year	[redacted]
Maximum annual total supply	Mm^3/year	[redacted]
No. years when storage empties (>1 day)	Count	3
Total of days storage empties	Count	103
% of time storage is empty	%	0.60

3.1.4 Reticulation Network

The Kaipara Large Storage Scheme scenario reticulation network is presented in **Figure 5**.

The Kaipara Large Storage scenario consists of a [redacted] mm diameter inflow pipe running from the [redacted] take point to the [redacted] reservoir. This inflow pipe was sized to allow the reservoir fill transfer of up to [redacted] m^3/s from the [redacted] during high flow. A pipe pressure rating of at least [redacted] is required immediately after the [redacted] intake and pump station. The required pressure rating decreases with distance along the pipeline, to a minimum requirement of at least [redacted] pressure as the pipe enters [redacted]

An alternative approach enabling lower pressure rated pipe would be to space a number of smaller pump stations along this reach. It is anticipated that such optimisations will be investigated during the feasibility phase of this project.

From the [redacted] reservoir, three distribution branches extend to the north, south, and east of the reservoir supplying water throughout the command areas. These distribution branches were sized to meet the individual irrigation demand of each command area (**Volume 1 – Command Area Refinement, Section 10.3**), while meeting the design criteria outlined in **Table 5**. Therefore, pipe diameters progressively decrease, with increasing distance along the branches as command areas serviced decreases.

Due to the variable nature of the topography along the western command areas (Command Areas 1, 2, 3, 7, 9,10, 12, and 13), the pipe network from the reservoir requires higher initial delivery pressure from [redacted] pump station, and therefore higher pressure rated pipe than required for the east of the command area. Pipe pressure ratings range from 120 m immediately downstream of the [redacted] pump station, to 40 m at the far ends of the pipeline.

Figure 5. Kaipara Large Storage scenario reticulation network. (Refer A3 attachment at rear).

3.2 Kaipara Distributed Storage Scenario

3.2.1 Overview of Main Components

The Kaipara Distributed Storage scenario utilises four storage reservoirs as shown in **Figure 6** and summarised in **Table 8** to service the Kaipara command areas as shown in **Figure 6**. Supply to the reservoirs consists of:

- high flow (above median flow) direct catchment inflows into each reservoir; and
- available low flow (run-of-river) allocation and high flow take from the [redacted] into [redacted].
- Stored water is then cascaded from north [redacted] to south [redacted] through each reservoir, until all four are full.

Figure 6. Kaipara Distributed Storage scenario main structure locations. (Refer A3 attachment at rear).

Table 8. Kaipara Distributed scheme summary.

Reservoir	Command Areas Serviced	Additional water sources (supplies)
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

3.2.2 Storage Features - Compatibility to Command Areas

The design concept for this scenario utilises four storages ranging from 13% to 40% of the total storage required. Site [redacted], used in the [redacted] is retained but is reduced to approximately a quarter of the size and acts as the main distribution storage, receiving inflow from the intake and re-distributing to the other storages.

The largest storage is located at [redacted] This site holds nearly 40% of the total storage required and is close to the centroid of the command area thereby improving distribution efficiency and has the best storage efficiency of all sites. The last two storages hold the remaining 35% of storage and are distributed within the command area.

These sites provide:

- Proximity of [redacted] to a reliable source of supply to fill the storage, [redacted];
- Proximity to [redacted] should it be used for Urban water supply;
- Excellent storage efficiency and flexibility particularly at [redacted] and [redacted];
- Relatively even distribution of storage throughout the command area;
- Ability to utilise conveyance systems for both fill and use cycles; and
- Ability to fed into conveyance systems that can predominantly be aligned along existing roads.

The main consequence of selecting this configuration is that most of the supply to fill the storages is derived from the [redacted], and hence must be conveyed progressively down through each storage. This increases the operational cost of the scheme in terms of energy use. The four storages however do gain greater local catchment inflow than the [redacted] Large Storage scenario placing less overall demand on the main river intake.

For the Large Storage scenario, [redacted] is the logical source for urban supply to Dargaville. It is however noted that the irrigation supply networks from both [redacted] and [redacted] come within close proximity to Dargaville so could also be used as the primary storage sites for urban supply.

A principal benefit of the design concept is that the spatial distribution of storage sites along the length of the command area makes progressive development of the scheme relatively straight forward. In addition, within the storage sites used in the concept there is additional capacity which provides flexibility to adjust the concept as uptake becomes more defined. A further benefit is that pressurisation from the pump-stations is achieved on a sub-area basis (centred around each storage) reducing the need for additional booster pumping along the conveyance system.

The concept provides the best balance between proximity to the most reliable source, alignment with command areas, as well as providing flexibility for progressive development and potential future additional uses.

A limitation of this approach, however, is the requirement to construct the scheme from north to south with the reliance on the [redacted] as a source. It has been observed that a significant portion of the water requirements to fill the storages may be able to be sourced from within the command areas from the existing local drainage network below the reservoir embankment. However, these local sources are unlikely to be able to meet all refill needs particularly following a high demand season (i.e. drought).

This is discussed in further detail in **Section 10.2.**

3.2.3 Storage Optimisation

The Kaipara Distributed Storage schematic model is shown in **Figure 7**. Storage optimisation was undertaken on the assumption that all direct catchment high flow (above median) into each reservoir are captured, and the low flow run-of-river take from [redacted] operates at all times available, except when reservoir storage is full. Optimisation modelling was undertaken to determine the required storage volume of each reservoir (taking into account storage efficiency), trigger levels and transfer rate between reservoirs, and [redacted] high flow take rate required to deliver approximately 19 in 20-year supply reliability.

The optimisation modelling tested high flow transfer rates from the [redacted] and between storage reservoirs ranging from 0.1 m^3/s to an upper limit of 0.5 m^3/s, above which both pipe size and pump costs were considered prohibitive.

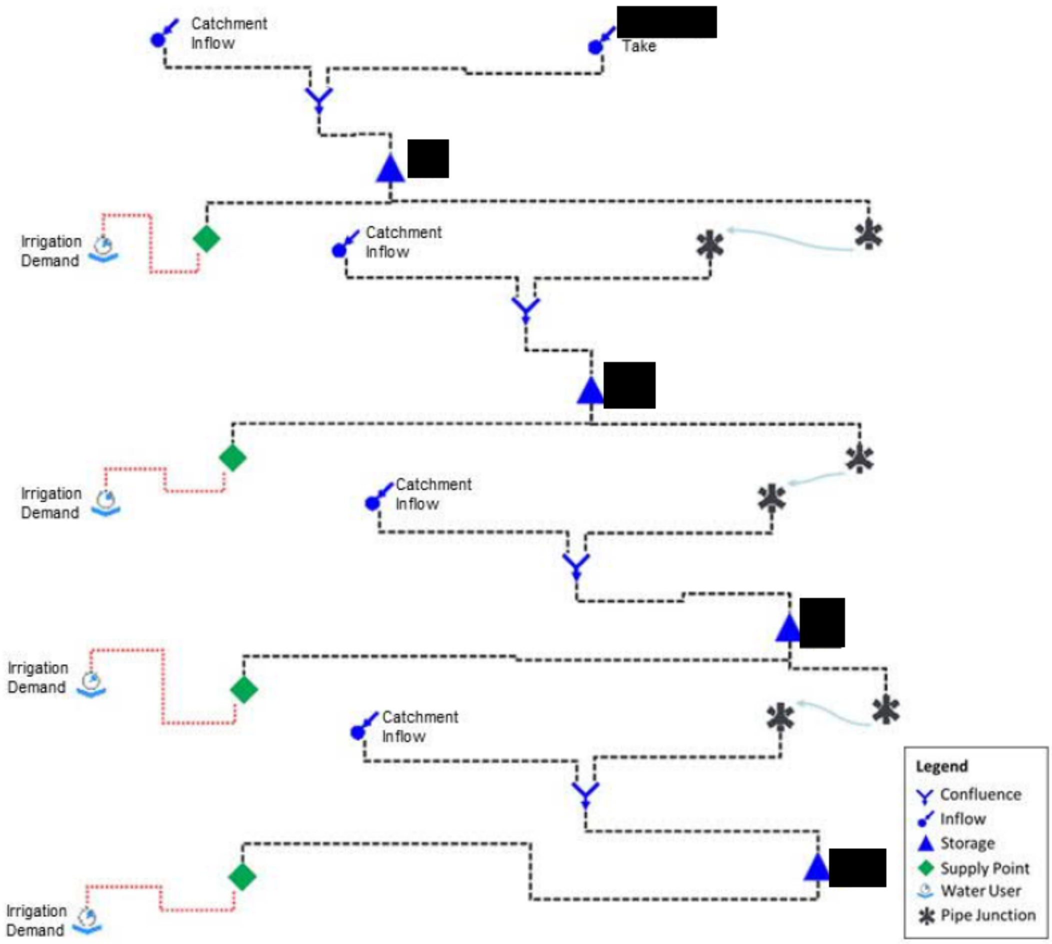

Figure 7. Kaipara Distributed scheme schematic model.

A summary of the optimised Kaipara Distributed Scenario scheme is provided in **Table 9**. The individual reservoirs were sized based on the storage volume required to reliably service their surrounding command areas, while maintaining the highest storage efficiency possible through iterative simulation.

The transfer and redistribution of water between the four storage reservoirs will likely involve continual operational management based on factors such as the spatial variation in actual demand, and forecast inflows. For the purposes of pre-feasibility optimisation, trigger levels for the initiation of transfer between storages was set as a fixed percentage of storage volume for the duration of the simulation and iteratively adjusted as an optimisation parameter.

A uniform maximum transfer rate between reservoirs of 0.3 m^3/s was determined. However, the fixed constant trigger level rules for initiation of transfers varied between reservoirs. The following trigger levels were set:

- [redacted] – 50% full;
- [redacted] 80% full; and
- [redacted] – 50% full.

For example, once the storage volume of [redacted] reached 50% full, a transfer of 0.3 m^3/s was initiated to [redacted]. Once [redacted] storage volume reached 80% a transfer of 0.3 m^3/s was initiated to [redacted], and so on until all four reservoirs were full.

Table 9. Optimised Kaipara Distributed scheme summary.

Reservoir	Storage Volume Mm^3	Inflow and Reservoir Transfer Rates m^3/s	Command Areas Serviced	Notes
[redacted]	[redacted]	Inflow from [redacted] = 0.45 m^3/s	[redacted]	[redacted] take includes both a low flow (run-on-river) and high flow take (up to 0.45 m^3/s).
[redacted]	[redacted]	Transfer from [redacted] 0.3 m^3/s	[redacted]	
[redacted]	[redacted]	Transfer from [redacted] 0.3 m^3/s	[redacted]	
[redacted]	[redacted]	Transfer from [redacted] = 0.3 m^3/s	[redacted]	

A summary of the optimised scenario output statistics is provided **Table 10**. A key feature of the pre-feasibility simulations is that the storage scheme as currently configured is highly reliable. In later stages of work, it may be possible to reduce these storages to reduce capital costs and if a lower level of reliability was considered acceptable.

Table 10. Kaipara Distributed scheme simulation results.

Statistic	Units	[redacted]	[redacted]	[redacted]	[redacted]
Mean annual total demand	Mm^3/year	[redacted]	[redacted]	[redacted]	[redacted]
Mean annual total supply	Mm^3/year	[redacted]	[redacted]	[redacted]	[redacted]
Maximum annual total demand	Mm^3/year	[redacted]	[redacted]	[redacted]	[redacted]
Maximum annual total supply	Mm^3/year	[redacted]	[redacted]	[redacted]	[redacted]
No. years when storage is empty (>1 day)	Count	0	0	0	1
No. of days storage is empty	Count	0	0	0	45
% of time storage is empty	%	0	0	0	0.26

3.2.4 Reticulation Network

The Kaipara Distributed Scheme scenario reticulation network is presented in **Figure 8**.

Similar to the Kaipara Large Storage scenario, the Kaipara Distributed scheme is primarily supplied by a [redacted] mm diameter supply pipe, running from the [redacted] take point to the [redacted] reservoir. This pipe was sized to allow the transfer of up to [redacted] m^3/s from the [redacted] during high flow. Pipe pressure rating requirements for the supply line is the same as those outlined for the Kaipara Large Storage scenario.

A [redacted] mm diameter combined supply and distribution pipe runs from north-west to south-east along the western margin of the scheme, and enables the transfer of up to [redacted] m^3/s between reservoirs, cascading from [redacted] to [redacted]. This pipeline also supplies the command areas through which it passes via offtakes.

Distribution pipes ranging in diameter from [redacted] mm extend eastward from reservoirs [redacted] to supply the command areas to the east on the lower flats. These pipelines were also sized such that they could be used to refill the storage reservoirs from temporary or permanent intakes located on the streams and [redacted] during the early stages of development while demand is low. This would allow construction of the large and potentially expensive [redacted] intake pipeline to be deferred until it becomes required by higher demand.

Figure 8. Kaipara Distributed Storage scenario reticulation network. (Refer A3 attachment at rear).

3.3 Mid-North Large Storage Scenario

3.3.1 Overview of Main Components

The Mid-North Large Storage scheme utilises two storages; [redacted] for the northern section of the scheme and [redacted] for the southern section of the scheme as shown in **Figure 9**. [redacted] is supplied by direct above median catchment inflows and three additional high flow river takes, while [redacted] is supplied entirely by direct above median catchment inflows.

Figure 9. Mid-North Large Storage scenario main structure locations. (Refer A3 attachment at rear).

3.3.2 Storage Features - Compatibility to Command Areas

No individual storage sites capable of supplying the full command area were identified within or immediately nearby, [redacted], however, this was not considered as a stand-alone option due to [redacted] A scenario considering the inclusion of [redacted] as part of a staged development is presented in **Section 3.5** where it has been assumed [redacted] would become a viable option in the near future.

As the command area for the Mid-North is effectively two sub-areas, one to the north and the other to the west, a single storage site would need to be centrally located or have a large transfer pipe between the areas. To overcome this, two sites in reasonable proximity to the sub-areas were selected, [redacted] for supply for the west area and [redacted] for supplying the north. These sites provide:

- Proximity to a reliable source of supply to fill the storages. [redacted] is self-filling and [redacted] can be filled by a range of local streams;
- Relatively close to the command areas; and
- Avoids unrealistic pumping to reach the elevation of the command areas.

The principal consequence of selecting this configuration is that the two areas are almost fully separated and hence lose any potential benefit of integrated development. As such both areas have to deal with risks such as uptake uncertainty separately. The two storage sites are also relatively remote from urban centres reducing their attractiveness for other consumptive water demands.

The two sites within the shortlist of potential sites identified have favourable storage characteristic and efficiency and are therefore likely to be more cost effective than the smaller but closer sites selected in the Distributed Storage scenario. Both sites also feed relatively conveniently into the command areas allowing conveyance to largely follow existing infrastructure routes (e.g. road).

3.3.3 Storage Optimisation

Storage optimisation was undertaken on the assumption that all above median direct catchment inflows into the two reservoirs is captured. The optimisation modelling therefore balanced the storage volumes of [redacted] with irrigation demand requirements and the three river high flow (above median flow) takes.

The Mid-North Large Storage schematic is shown in **Figure 10**. The take locations and type (low or high flow) for both the Large Storage and Distributed Storage scenarios are listed in **Table 11**.

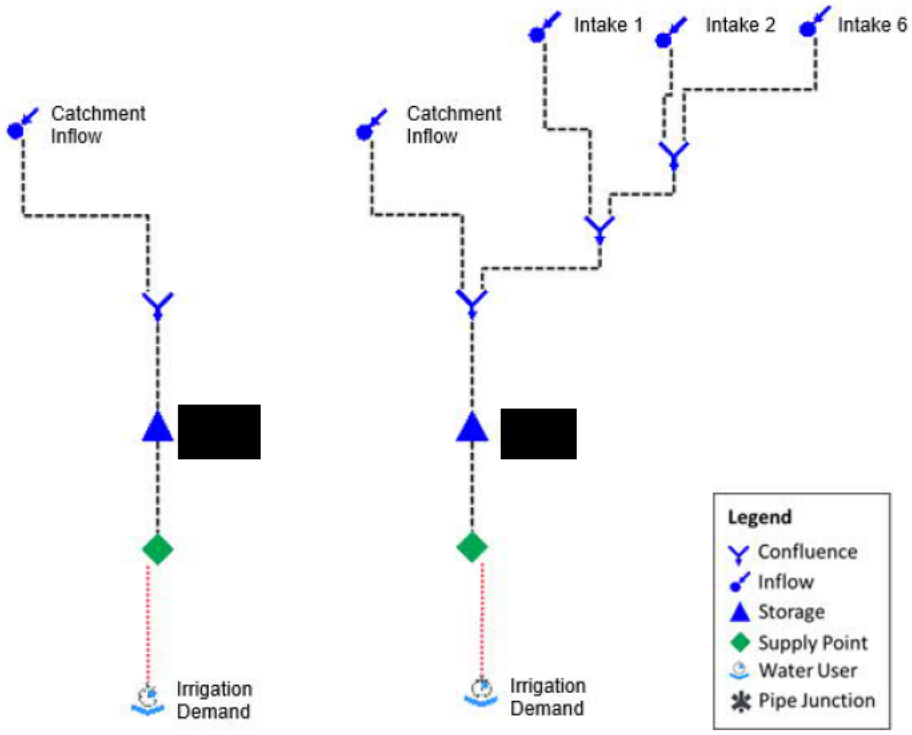

Figure 10. Mid-North Large Storage scheme schematic model.

Table 11. Mid-North river take locations (for both the Large Storage and Distributed Storage scenarios).

River Take ID	Location / Name	Take Type	Used in Scenario
Intake 1	[redacted]	High Flow	Both
Intake 2	[redacted]	High Flow	Large
Intake 3	[redacted]	High Flow	Distributed
Intake 4	[redacted]	High Flow	Distributed
Intake 5	[redacted]	Low Flow & High Flow	Distributed
Intake 6	[redacted]	High Flow	Large

A summary of the optimised Mid-North Large Storage scenario is provided **Table 12**. The optimisation modelling revealed that a storage volume of [redacted] Mm^3 and direct catchment inflows only for [redacted] would be sufficient to supply the surrounding command areas. Conversely, given the small direct catchment inflows into [redacted], three high flow river takes and a storage volume of [redacted] Mm^3 was required for [redacted]

Table 12. Optimised Mid-North Large Storage scheme.

Reservoir	Storage Volume (Mm^3)	Source Take Rate (m^3/s)	Command Areas Serviced
[redacted]	[redacted]	Take 1 = 0.45 Take 2 = 0.45 Take 6 = 0.45	[redacted]
[redacted]	[redacted]	-	[redacted]

It is noted that the useable catchment inflow to [redacted] in a dry year is less than the storage potential. For example, the yield able to be stored in a 1 in 10 Year AEP is [redacted] Mm^3 (Volume 2: Water Resources Assessment, Table 18) compared to the storage potential to full supply of [redacted] Mm^3. This means that there are some years where MN-16 may not be full at the start of the supply season, and should that season be one of high demand, a short-fall in supply may occur. This deficit is captured within the supply vs demand analysis undertaken. Scheme reliability is, as always, a function of both; demand and the ability to supply, so any limitation on storage will impact on the ability to supply.

Where any storage is not full at the start of the season, active storage management can help mitigate the consequence of any supply shortfall. Storage management is discussed in Volume 4: Analysis and Recommendations.

A summary of the optimised scenario output statistics is provided **Table 13**.

Table 13. Optimised Mid-North Large Storage scheme simulation results.

Statistic	Units	[redacted]	[redacted]
Mean annual total demand	Mm^3/year	[redacted]	[redacted]
Mean annual total supply	Mm^3/year	[redacted]	[redacted]
Maximum annual total demand	Mm^3/year	[redacted]	[redacted]
Maximum annual total supply	Mm^3/year	[redacted]	[redacted]
No. years when storage empties (>1 day)	Count	3	2
No. of days storage empties	Count	79	95
% of time storage is empty	%	0.46	0.55

3.3.4 Reticulation Network

The Mid-North Large Storage Scheme scenario reticulation network is presented in **Figure 11**.

The Mid-North Large Storage scenario essentially consists of two independent networks. A northern network linking [redacted] to the command areas north-east of Kaikohe township, and a southern network linking [redacted]6 to the command areas to the south-west of Kaikohe township.

Reservoi[redacted] is supplied by [redacted] high flow river takes, via a [redacted] mm diameter supply pipeline. This doubles as a distribution pipeline, delivering water to the command areas to the south. Offtakes from this pipeline were sized to meet the command area demand, and therefore decrease with increasing distance downstream.

Reservoir [redacted] is supplied (filled) solely through direct catchment inflows, and therefore does not have a main supply pipeline. A single [redacted] mm distribution pipeline transfers water from [redacted] to the command areas, before branching in three directions. From here, pipelines were sized to meet individual command area zone demand, and decrease in diameter with increasing distance along the network.

Figure 11. Mid-North Large Storage scenario reticulation network. (Refer A3 attachment at rear).

3.4 Mid-North Distributed Storage Scenario

3.4.1 Overview of Main Components

The Mid-North Distributed scenario consists of [redacted] storage reservoirs, spatially distributed across three essentially individual mini-schemes collectively supplying the full Mid-North command area, as shown in **Figure 12**. The northern most component, to the east of Lake Omapere, consists of [redacted] linked storages [redacted] supplied by direct catchment inflows and a highflow take from the [redacted].

The middle scheme, to the north-east of Kaikohe township, consits of a single storage reservoir [redacted], supplied by direct catchment inflows and a highflow take from [redacted], and [redacted]

The southern section, to the south-west of Kaikohe township, consits of a single storage reservour [redacted]. Reservoir [redacted] includes both a low flow (run-of-river) and high flow take from the [redacted]. In addition, MN-18 and the southern command areas (12, 13, and 14) can also be supplied from [redacted], approximately [redacted] km to the [redacted] This can be achieved by releasing water from [redacted], which flows into the [redacted], and then can be abstracted (collected) by the intake and pump station at [redacted], that is also used for the low and high flow take from the [redacted]

Figure 12. Mid-North Distributed Storage scenario main structure locations. (Refer A3 attachment at rear).

3.4.2 Storage Features - Compatibility to Command Areas

The Distributed Storage scenario uses a combination [redacted] storage sites each holding between [redacted] and [redacted] % of the total storage need. These sites provide:

- The ability to be largely self-filled, or are within proximity to a source of supply to fill the storages;
- A reasonable spatial distribution across the command area;
- Flexibility to include sub-areas to the north and west as either separate or combined;
- Opportunity for other consumptive water demands (e.g. Urban supply); and
- Progressive development in response to uptake to be facilitated.

The principal consequence of selecting this configuration is that the sites in general are less attractive in terms of storage efficiency thereby increasing storage costs. On balance however, the benefits derived from the points above largely offset the additional capital costs especially when uptake risk is considered, as discussed in **Section 7**.

3.4.3 Storage Optimisation

The Mid-North Distributed scenario consists of [redacted] individual storage reservoirs as shown in **Figure 13**. For the purposes of storage optimisation these were simplified and considered as [redacted] separate schemes (i.e. no connection or transfers between storage reservoirs). However, the the actual scheme is proposed to link [redacted] to allow transfer between and provide increase network and supply reslilance. This was allowed for and considred as part of the reticulation network deisgn (**Section 3.4.4**). It was assumed if the reservoirs can be demonstrated to operate indepentenly, then linking any number of storages will only improve network resilliance.

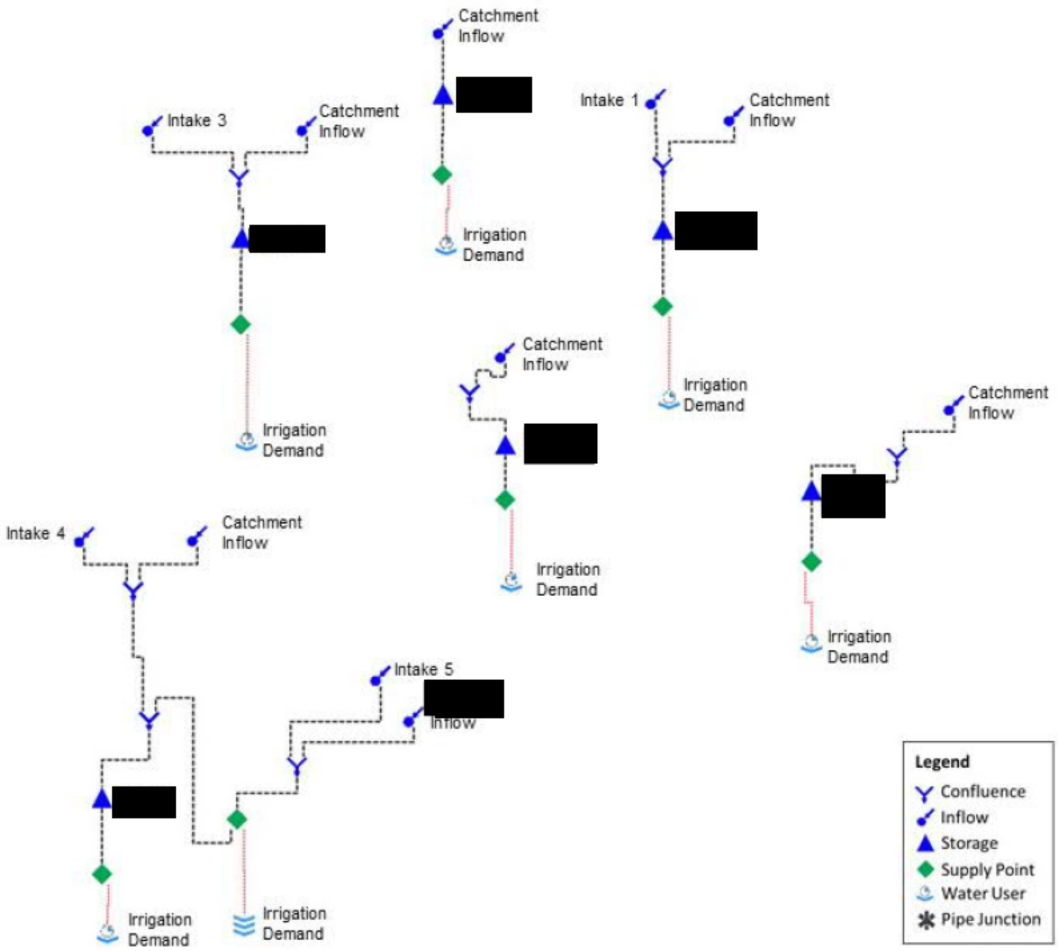

Figure 13. Mid-North Distributed scheme schematic model.

A summary of the optimised Mid-North Distributed Storage Scenario scheme is provided in **Table 14**. The optimisation modelling revealed that a range of storage volume from [redacted] Mm^3 are required across the Mid-North study areas. Of the [redacted] storages, three are solely filled from direct upstream catchment inflows, while the remaining three require high flow river takes of up to [redacted] m^3/s.

Reservoir [redacted] includes both a low flow (run-of-river) and high flow take from the [redacted] The low flow take may be used directly for irrigation rather than directed to storage.

In addition, [redacted] and the southern command areas (12, 13, and 14) can also be supplied directly, rather than pumping to storage first, from [redacted] approximately [redacted] km to the [redacted].

Table 14. Optimised Mid-North Distributed scheme summary.

Reservoir	Storage Volume (Mm³)	Source Take Rate (m³/s) *	Command Area Serviced	Comments
[redacted]	[redacted]	-	[redacted]	• Filled from direct high flow catchment inflows.
[redacted]	[redacted]	Intake 1 = 0.45	[redacted]	
[redacted]	[redacted]	-	[redacted]	• Filled from direct high flow catchment inflows.
[redacted]	[redacted]	-	[redacted]	• Filled from direct high flow catchment inflows.
[redacted]	[redacted]	Intake 3 = 0.45	[redacted]	• An additional take of 500,000 m³/yr was included from this reservoir to account for the innovation park and town water supply.
[redacted]	[redacted]	Intake 4 = 0.45 Intake 5 = 0.45	[redacted]	• [redacted]r includes both low (run-of-river) and high flow take. • A release of [redacted] Mm³/yr to the [redacted] occurs from [redacted] during the irrigation season, which is then collected at Take 5 to supplement the irrigation of these command areas.

* Take locations listed in **Table 11**.

A summary of the optimised scenario output statistics is provided **Table 15**.

Table 15. Optimised Mid-North Distributed scheme simulation results.

Statistic	Units	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mean annual total demand	Mm³/year	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Mean annual total supply	Mm³/year	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Maximum annual total demand	Mm³/year	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Maximum annual total supply	Mm³/year	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
No. years when storage empties (>1 day)	Count	3	1	2	2	2	1
No. of days storage empties	Count	60	37	74	51	66	45
Time storage is empty	%	0.35	0.22	0.43	0.30	0.38	0.26

3.4.4 Reticulation Network

The Mid-North Distributed Scheme scenario reticulation network is presented in **Figure 14**.

The Mid-North Distributed Scheme essentially consists of [redacted] independent networks:

- Northern network linking [redacted] and supplying the command areas to the east of [redacted];
- Central network linking [redacted] to its surrounding command areas; and
- Southern network linking [redacted] to the command areas south of Kaikohe township.

The high flow river intake supply pipelines in each of the [redacted] independent networks consist of [redacted] mm diameter pipe, enabling high flow takes of up to [redacted] m^3/s. The distribution pipelines range from [redacted] mm to [redacted] mm, sized according to demand, and therefore decrease in diameter with increasing distance along the network.

Figure 14. Mid-North Distributed Storage scenario reticulation network. (Refer A3 attachment at rear).

3.5 Mid-North Distributed Storage Scenario Incorporating Lake Omapere

This scenario was provided as a direct comparison to the other two Mid-North scenarios to demonstrate the potential impact that including Lake Omapere as a water resource has on scheme viability.

3.5.1 Overview of Main Components

The Mid-North Distributed including Lake Omapere scenario consists of two storage reservoirs [redacted], as shown in **Figure 15**, with the remainder of demand being supplied from Lake Omapere. The concept therefore is broadly similar to the Mid-North Distributed scenario but with several of the in-scheme storages replaced with supply from Lake Omapere. Two intakes are provided at Lake Omapere, one supplying the northern area via [redacted] and the other the south via stream augmentation. River intakes located in the [redacted] are then used to supply respective areas to the south.

Figure 15. Mid-North Distributed Including Lake Omapere scenario main structure locations. (Refer A3 attachment at rear).

3.5.2 Storage Features - Compatibility to Command Areas

The Mid-North Distributed Storage incorporating Lake Omapere scenario has [redacted] storage sites within the supply area collectively holding approximately [redacted] of the total storage need. The remaining storage is provided by Lake Omapere, either directly or through refill into the [redacted] storages. The [redacted] sites provide:

- the ability to be largely self-filled, or are within proximity to a source of supply to fill the storages;
- [redacted] is conveniently placed, both in terms of location and elevation, within the northern supply zones, as well as to enable early uptake to a large number of zones.
- [redacted] is conveniently placed for supply into early uptake zones and potential urban supply; and
- the potential for progressive development is retained for the short term. This could include the development of localised areas supplied directly from the in-scheme storages, with later expansion facilitated by the inclusion of Lake Omapere supply as it became available.

3.5.3 Storage Optimisation

The Mid-North Distributed Including Lake Omapere scenario consists of [redacted] storage reservoirs as shown in **Figure 16**. For the purposes of storage optimisation these were simplified and considered as two separate schemes (i.e. no connection or transfers between storage reservoirs), and a third that was directly supplied form Lake Omapere.

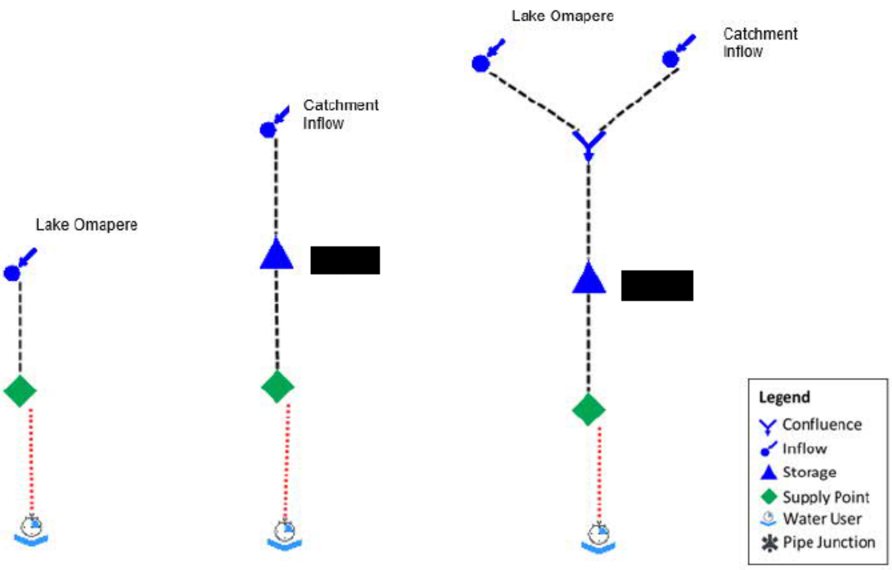

Figure 16. Mid-North Distributed Including Lake Omapere scheme schematic model.

Table 16. Optimised Mid-North Distributed Including Lake Omapere scheme summary.

Reservoir	Storage Volume (Mm³)	Source Take Rate (m³/s) *	Command Area Serviced	Comments
[redacted]	[redacted]	[redacted]	[redacted]	• Command areas supplied by [redacted] and Lake Omapere
[redacted]	[redacted]	[redacted]	[redacted]	• Remaining command areas supplied directly from Lake Omapere via flow augmentation o[redacted]

As this scheme utilises two direct takes from Lake Omapere, the supply reliability will be directly related to any water take consent conditions imposed on the takes from the Lake. For the purposes of assessing this scenario at a pre-feasibility level, it was assumed that no restrictions are imposed, and there is always sufficient volume of water available. This aspect would be considered as part of future work should the scenario be favoured.

3.5.4 Reticulation Network

The Mid-North Distributed including Lake Omapere Scheme scenario reticulation network is presented in **Figure 17**.

The scheme essentially consists of three independent networks:

- Northern network linking [redacted], to the command areas to the east of Lake Omapere and around Ohaeawai;
- central network linking [redacted] to command area [redacted]; and
- southern network linking a direct take from Lake Omapere to the command areas south of Kaikohe township through a pumped pipe network and river augmentation.

The northern network consists of a [redacted] mm diameter supply pipe, linking Lake Omapere to [redacted], that also supplies the command areas through which it passes. From [redacted], smaller distribution pipes extend to the north-east and south-east supplying the surrounding command areas. The diameter of these distribution pipes decreases with increasing distance from the reservoir, corresponding to the lower demand.

The central network consists of a single [redacted] mm diameter pipeline supplying Command Area [redacted] from [redacted]

The southern network consists of a [redacted] mm diameter supply pipe that pumps water from Lake Omapere, to the [redacted], approximately [redacted] km to the [redacted]. From here, water is transported down the [redacted] before being abstracted at either the [redacted] take points.

Figure 17. Mid-North Distributed Including Lake Omapere reticulation network. (Refer A3 attachment at rear).

4. Reservoir Design Considerations

4.1 Site Suitability

Three primary considerations for confirming technical suitability are the potential impact classification (PIC), geotechnical conditions at the dam site and reservoir, and flooding.

Potential impact classifications set out a framework for quantifying the consequences arising from uncontrolled release of the reservoir on people, property and the environment downstream. Reservoirs are assigned either a Low, Medium or High PIC which establishes the criteria for dam design, construction and operational safety assurance. Further discussions on the consequence assessment and evaluation of potential impacts, along with initial assessments of PIC's for each reservoir site, are presented in the sub-sections below.

Gaining a thorough understanding of the geotechnical conditions at a reservoir site is essential for determining how the dam and appurtenant structures will be designed and perform, and to ensure that it will safely store water. This typically involves a comprehensive programme of desktop studies, field geological mapping, intrusive ground testing with test pits, boreholes and CPT tests, and laboratory testing of retrieved samples. Geotechnical parameters are then determined, and quantitative modelling of stability performed.

Geotechnical inputs to the concept storages presented herein has involved a desktop study and initial site walkover of selected sites where access was available. This has identified the following geotechnical considerations at the two command areas:

1. **Kaipara**: All reservoir sites are located along the lower flanks of ridgelines formed of older sand dunes which have consolidated over time into a weakly cemented sandstone. Discontinuous hard pan layers and void/tomo features observed in exposures may dictate leakage rates through the reservoir floor and around abutments. Earthfill will likely comprise recompacted sand dune and alluvial deposits which could be highly variable in composition and behaviour; resulting permeabilities may be higher than desirable meaning that upstream lining of the dam will probably be required. There is limited precedent of water tightness of moderate to large reservoirs in the Kaipara area. Reservoir and dam abutment slopes will be formed in dune deposits which appears reasonable stable, with the exception of shallow, surficial failures developed in more recent deposits toward the coast. Foundation materials are likely to comprise recent alluvial sediments of clay, sand and peat to moderate depth which present some geotechnical challenges, i.e. soft and compressible soils will need to be undercut or treated, high permeability soils cut-off and drained, and soils susceptible to liquefaction may need to be remediated. Overall, the sites present some technical challenges.
2. **Mid-North:** Regional geology across the Mid-North is highly complex. Reservoir sites have been split into two broad groups based on the prevailing geology:

   2.1: Northern Allochthon [redacted]

   Known colloquially as 'chaos', the Northern Allochthon is a complex sequence of tertiary sedimentary rocks emplaced during prehistoric faulting. The rocks are highly sheared and can be unstable even at moderate slopes. Whilst no obvious large-scale movement was identified during our desktop study or site walkover, at least creep type movement is known to exist and surface expressions that are indicative of movement can be challenging to differentiate in this terrane. A cautious approach is therefore emphasised at these sites. Instability of reservoir slopes initiated by lake filling and fluctuations in water levels during operation (e.g. rapid drawdown), and temporary cuts formed during foundation preparation, will be a primary consideration for feasibility stages to understand. There is limited precedent in the response of slopes to inundation from a medium to large reservoir. Bulk permeabilities of on-site materials will generally be low meaning reservoir losses should be acceptable, and foundation and abutments seepages minimal, and are expected to perform well as low-permeability earthfill for dam construction. Foundations may require localised undercutting of alluvium within valley floors. Springs emanating in slopes at or near the dam abutments will require assessment and possible drainage.

2.2: Kerikeri Volcanics: [redacted]

These reservoir sites are either located at the lower flanks of volcanic cones or on volcanic flows comprising andesite, basalt, scoria and tuff. Older tertiary rocks (at [redacted] will generally have a much deeper weathering profile (in the orders of meters), compared to recent quaternary rock (at [redacted] which is almost unweathered in outcrops. Basalt flows will typically have high strength but could be highly jointed that may require foundation grouting beneath dam structures and possible lining to sections of the reservoir. Scoria is a weak volcanic rock often containing large voids requiring specific consideration if identified. Undercutting of soft and/or potentially liquefiable deposits is not envisaged to the same degree as in the Kaipara. Excavated rock could be suitable for reuse as a dam fill material depending on weathering and properties. Large-scale land movement in volcanic terrane appears unlikely but will be assessed as part of feasibility. Overall, reservoir sites located within volcanic terrane appear reasonable from a geotechnical perspective, subject to further assessment.

It should be appreciated that a high level of geotechnical input and review, and carefully planned construction methodology that is cognisant of the challenges with earthworks in and around the geological units, will be essential for ensuring the safe construction and operation of all reservoirs across both command areas.

Concept designs have been developed for each command area based on experience with large dam design in broadly consistent geology to those outlined above. These are further discussed in **Section 4.5**.

The size and characteristics of the catchment feeding the reservoirs is an important consideration for estimating useable recharge, and for designing low-flow bypass and spillway facilities under normal and design flood conditions. Catchment areas upslope of the reservoir sites vary from around 2 to 8 km^2 across an elevation range of 3 to 124 meters above mean sea level (mAMSL) in Kaipara, and 0.3 to 13 km^2 across an elevation range of 110-160 mAMSL in Mid-North. The Kaipara area receives around 25% less rainfall and has higher infiltration rates compared to the Mid-North area with correspondingly smaller floods. Rainfall distribution between catchments is also more consistent in Kaipara.

Design standards for, and the level of assessment required in, estimating inflow design floods (IDF) is primarily dependant on the potential impact classification. IDFs range from between a 1 in 100 annual exceedance probability (AEP) event for a Low PIC dam, up to the probable maximum flood (PMF) for High PIC dams. Temporary flood diversion works are a primary consideration for construction planning and staging of the dam structure and can be accommodated by a coffer dam and bypass conduit or tunnel. These works can be incorporated into the final structure and be used for residual flow bypass/fish passage as required and to house inflow/outlet pipes into and out from the reservoir. Further discussion is provided in **Section 4.3**.

4.2 Evaluation of Reservoir Hazard

Uncontrolled release of the reservoirs' contents via dam failure has been simulated in order to establish the criteria for which dam design, construction, and operational safety assurance are based. This methodology is termed a potential impact classification (PIC) and aims to ensure that the dams performance requirements are consistent with the hazard posed by the impounded reservoir. The PIC is analogous to building important levels outlined in the Building Act.

The assessment involves determining dam break characteristics for a range of hypothetical failure scenarios, and hydraulically modelling these across land downstream of the dam. Dam failures are simulated under normal operating ('sunny day') and flood ('wet weather') conditions, which represent the potential and incremental hazards respectively. Common mechanisms of failure for embankment dams during normal operating conditions include internal erosion of materials within or beneath the dam, and slope instability caused by lack of effective drainage or strong earthquake shaking; under flood conditions this include overtopping and erosion; often a consequence of inadequate or improperly designed spillway facilities.

For the purposes of dam failure consequence assessment, we have undertaken a preliminary assessment based on an overtopping failure of the dams during wet weather conditions. This scenario represents the upper bound of the inundation envelope as it is based on the maximum theoretical volume and depth of water to the dam crest. Additional modelling involving sunny day failure conditions will be required as part of future work.

HEC-RAS hydraulic modelling software was used to model the hypothetical dam-break events across the floodplain in 2D. Floodplain terrain data was based on LiDAR flown in 2016 with a spatial accuracy of ±0.5 m. Dam break characteristics are calculated in HEC-RAS via the dam break function which depends on a number of factors such as depth of water, volume released, failure location, etc. These parameters were either known as part of the design (dam height and volume) or were estimated using the Froehlich (2016) method (breach characteristics and time of failure). A downstream normal depth boundary condition was applied. A check of modelled outputs against empirical methods and failure case histories indicate the results are reasonable if not conservative.

Consequences are assessed in respect of damage level (for housing, critical or major infrastructure and the natural environment), population at risk, and potential loss of life. Reservoirs are then categorised as low, medium, or high Potential Impact Category (PIC) based on the combined hazard.

It should be noted this assessment is independent of the likelihood of a failure, which, for a suitably designed, constructed and operated dam should be very small.

4.3 Potential Impact Classification

Module 2 of the New Zealand Society of Large Dams (NZSOLD) Dam Safety Guidelines (2015) outlines the consequence assessment and dam classification framework adopted in New Zealand. It considers three principal components, being:

- **Assessed damage level** in terms of damage to property, infrastructure and the environment.
- **Population at risk (PAR)** which is the number of people likely to be affected by inundation greater than 0.5m in depth.
- **Potential loss of life (PLL)** is an estimate of the number of fatalities expected to occur, which is a subset of the PAR.

Our preliminary assessment is based on the hydraulic modelling results. A conservative assessment was made in view of the uncertainties regarding downstream damage levels and the estimation of population at risk which normally requires detailed building and occupancy surveys, and consideration of itinerant population to obtain more accurate estimates. Average occupancy rates of 2.4 in Kaipara and 2.9 in Mid-North were adopted based on census information obtained through StatsMaps. **Table 17** and **Table 18** summarises the consequence assessment and resultant PIC for each of the dams incorporated in the concept design.

Table 17. Potential Impact Classification – Kaipara Storages.

Reservoir	Assessed Damage Level	Population at Risk	Potential Loss of Life	Potential Impact Classification
Large Storage Scenario				
[redacted]	Catastrophic	125	-	HIGH
Distributed Storage Scenario				
[redacted]	Moderate	7	-	MEDIUM
[redacted]	Major	26	-	HIGH
[redacted]	Minimal	0	0	LOW
[redacted]	Major	14	-	HIGH

Table 18. Potential Impact Classification – Mid-North Storages.

Reservoir	Assessed Damage Level	Population at Risk	Potential Loss of Life	Potential Impact Classification
Large Storage Scenario				
[redacted]	Major	26	-	HIGH
[redacted]	Major	26	-	HIGH
Distributed Storage Scenario				
[redacted]	Moderate	5	-	MEDIUM
[redacted]	Moderate	0	0	LOW
[redacted]	Major	72	-	HIGH
[redacted]	Minimal	0	0	LOW
[redacted]	Major	48	-	HIGH
[redacted]	Moderate	7	-	MEDIUM
[redacted]	Moderate	2	-	LOW
[redacted]	Minimal	0	0	LOW

Maximum inundation plans for each of the reservoir sites are presented in **Appendix A** with commentary on the assessed damage levels and identified buildings that would be inundated. These maps are useful for identifying potentially affected parties for resource consents and for emergency planning.

4.4 Performance Criteria

Table 1 of the NZSOLD Dam Safety Guidelines (2015) outlines the recommended performance criteria for Low, Medium and High PIC Dams, and is reproduced in **Table 19**.

Table 19. Recommended Performance Criteria for Low, Medium and High PIC Dams – reproduced from the NZSOLD Dam Safety Guidelines (2015).

Hazard	Performance Criteria	PIC		
		Low	Medium	High
Wind and Waves	Adopted freeboard for embankment dams should be the largest of the following three freeboard requirements:			
	Freeboard at Max. Normal Res. Level	Wind setup and wave runup for the highest 10% pf waves causes by a sustained wind speed, which is dependent on the fetch, with an AEP of great than 1 in 100 years.		
	Freeboard at Intermediate Flood Levels	Freeboard should be determined so that it has a remote probability of being exceeded by any combination of wind generated waves, wind setup and reservoir level occurring simultaneously.		
	Freeboard at Max. Res. Level during Inflow Design Flood (IDF)	The greater of (a) 0.9 m or (b) the sum of wind setup and wave runup for the highest 10% of waves causes by a sustained wind speed, which is dependent on he fetch, with an AEP of 1 in 10 years.		
Flood	Inflow Design Flood (IDF)	1 in 100-year to 1 in 1,000-year AEP.	1 in 1,000-year to 1 in 10,000-year AEP.	1 in 10,000-year AEP to PMP.
Earthquake	Operating Basis Earthquake (OBE)	1 in 150-year AEP.		
	Safety Evaluation Earthquake (SEE)	50th percentile level for the CME if developed by a deterministic approach, and if developed by a probabilistic approach hen at least a 1 in 500-year AEP ground motion but need not exceed the 1 in 1,000-year AEP ground motion.	50th to the 84th percentile level for the CME if developed by a deterministic approach, and need not exceed the 1 in 2,500-year AEP ground motion developed by a probabilistic approach.	84th percentile level for the CME if developed by a deterministic approach, and need not exceed the 1 in 1,000-year AEP ground motion developed by a probabilistic approach.

4.5 Concept Design

Concept designs for the two command area locations have been developed based on consideration of the local geology and experience working on large dam projects in Northland and across New Zealand.

There is little to no precedent for large storages in the Kaipara area. Key features of the dam structures in the Kaipara include:

- Homogenous earthfill dam constructed of recompacted dune sand;
- 4 m wide crest with 1(V):3(H) up and downstream batter slopes;
- Geomembrane lining to upstream slope, extending 30 m into reservoir. No additional internal drainage controls;
- Low level conduit pipe utilising diversion facility for intake, internal inlet/outlet pipe, upstream control valve and defensive filter diaphragm surround; and
- Undercut and replacement of undesirable valley soils.

There is some precedence for large High PIC storages in the Mid-North, particularly to the north and east in areas of more favourable volcanic geology, e.g. Kerikeri Irrigation Reservoirs. We are not aware of any significant dam safety instances at those locations and have appeared to have largely performed well. Some challenges have been observed at large dam sites in other areas owing to poor foundation conditions in recent geological deposits (such as alluvial and swamp deposits), which have needed to be overcome by significant engineering works.

Key features of the dam structures in the Mid-North include:

- Zoned earth-fill dam constructed of recompacted allochthon and/or volcanic rock;
- 4 m wide crest with 1(V):3(H) up and downstream batter slopes;
- Internal drainage via fully intercepting chimney drain and foundation drainage blanket/toe drains;
- Minimal undercut and replacement of undesirable soils in foundation;
- Foundation cut-off at abutments and within foundation as necessary;
- Possible foundation grouting in volcanic sites; and
- Low level conduit pipe utilising diversion facility for intake, internal inlet/outlet pipe, upstream control valve and defensive filter diaphragm surround.

These designs are considered suitable for modification across the range of potential impact classifications.

Design verification based on preliminary quantitative modelling of stability was performed, indicating the designs meet or exceed target performance criteria as outlined in the NZSOLD Dam Safety Guidelines (2015). Hydrological and hydraulic analyses were performed for each reservoir to determine construction flood inflows, size low-level conduits, and assess spillway bypass facilities. The results of these analyses are presented in **Appendix B**.

5. Power Network

Power demand from both schemes will be dominated by the summer load, arising from the supply of pressurised water to users. This includes both capacity (peak demand) and energy (volume) requirements. In comparison peak winter demand is only typically 10% of summer peak, and 15 to 25% in terms of energy.

The ability for the existing lines networks to support scheme development has been discussed with both relevant network providers; North Power and Top Energy. Based on the existing design concept, it is anticipated that the Kaipara scheme could be catered within existing transmission capacity. In the Mid-North a modest upgrade would be required for either the Large or Distributed Storage scenarios. An allowance has been made in the cost estimated for this upgrade (**Section 6**).

For the purpose of this pre-feasibility scheme design, it has been assumed that the all pump-stations are on uncontrolled supplies which means they cannot be interrupted by the line companies. This incurs the highest connection charges. Subsequent project stages could establish that a level of interruption in supply is acceptable and as such lower charges could be incurred.

5.1.1 Options for Reducing Energy Use and Costs

As peak capacity and energy demand is coincident with summer demand there is an opportunity to add renewable energy generation to the system to augment energy supply. The pump-stations provide logical locations where renewable generation such as solar could be included. This would be primarily to reduce energy demand from the grid, but at times export energy when irrigation demand is low.

The scale of any generation within the schemes will be small in comparison to the irrigation infrastructure. The scheme concepts therefore should be optimised for irrigation supply and not for energy production. If the optimised scheme configurations provide opportunities for viable localised renewable generation then these can be incorporated into the scheme design.

Wind energy has been identified in the past as having significant potential in the Kaipara area. While previous prospects were for large scale developments, the focus in this area does indicate the potential. Smaller scale wind development may be worth incorporating in to the scheme concept, particularly at later stages of development to offset the growing energy demand. It is likely that the ideal location for wind development would not coincide with specific points of demand (pump stations) and as such the incorporation of wind energy is more at a level of an overall scheme energy balance.

The schemes as designed at this pre-feasibility stage assume on-demand supply from the storages. As such pump and hence energy load is directly related to demand. There may be opportunity to introduce small buffer storages (few hours) so pumping can partially avoid peak periods of energy demand and cost. This would of course then require re-pressurisation near the area of demand and associated pump costs. It is likely that any buffer type storage would be added as the schemes approach full uptake and hence fulfil a dual purpose of reducing peak energy demand and add additional storage in to the overall scheme.

In the earlier days of scheme development, when uptake is less, there may also be benefit in providing a portion of peak demand from local diesel generation. Diesel generators are a low capital cost option but have significantly higher operational costs. They therefore provide a useful interim option as demand grows and can be relocated to different parts of the scheme as growth in different areas changes overtime. They could also provide an option for addressing peaks in energy demand that are relatively short in duration but add significantly to connection costs. It is also likely that some level of backup diesel generation may be required anyway to cover for the risk of power outages. As such, any investment in diesel generation would fulfil a dual purpose.

6. Scheme Component Costings

The following sections present component (capital) cost and operational costs for each of the four concept scenarios.

6.1 General Consideration

All scheme components have been costed as if they are part of a completed scheme, and the associated capacity to supply that scheme. Subsequent work focusing on progressive development may indicate benefit in staging installation of some components such as pump and potentially pipe capacity.

The schemes are based on fully piped and pressurised supply to 75% of the potential command area. The remaining 25% (with the highest elevation) will need to incorporate localised pressurisation. This is to avoid unnecessarily over specifying pipe and pump pressure ratings. It is anticipated that this broad design criteria can be optimised further once greater certainty is gained in the future around the distribution of demand.

No allowance has been made for costs associated with:

- the cost of establishing project-related legal entities or ownership structure,
- any costs related to land acquisition,
- costs relating to on-farm requirements,
- costs relating to other uses (e.g. urban supply) beyond the scheme infrastructure, and
- costs associated with physical mitigation measures arising from resource consents requirements.

6.2 River and Stream Intakes

No specific designs have been prepared for individual river intakes. Rather they have been broadly costed based on two intake concepts sized according to the peak rate of abstraction:

- ***Small Streams & Drains*** – a pump sump adjacent to the stream with associated screens and isolation gates.
- ***Larger Streams & Rivers*** – a river intake to a small settling pond and discharge point for excess flow back to the river. A screened pump intake structure with isolation gates is then located on the side of the settling pond.

The cost estimates for intake structures are derived from the fixed and variable cost components presented in **Table 20**.

Table 20. River and stream intake unit costs.

Cost Component	Unit	Small Streams ($)	Rivers ($)
Fixed Costs	LS	100,000	500,000
Structure and Gates	$/L/s	312	312
Screens & Fish Management	$/L/s	300	300

Intake prices have been checked against available examples, albeit most available examples are for larger intakes. No allowance has been made for any weir structure in the stream to increase water level. As pumping is only occurring when flow is above median, it is presumed that flow depths will be enough to feed pump sumps and intake structures.

In many situations pump-stations are directly connected to storage reservoirs and as such do not have a separate intake as this is already incorporated in the dam concept design.

6.3 Pump-stations

Priced based on a cassette-based approach where multiple pumps of the same size are utilised to deliver the total flow. All pumps are individually isolated and controlled by dedicated valves but linked by common inlet and outlet manifolds.

At least four pumps are typically used with some pump stations requiring more. While this tends to over-estimate the cost of larger volume pump-stations, it allows for more direct comparison between scheme options as they are developed. This is particularly relevant during the pre-feasibility stage while multiple options are being explored.

In practical terms it also means that the schemes are more flexible in terms of progressive development and uptake over time. Use of common pump sizes also assists with lowering operations and maintenance costs through the ability to utilised common spares.

No installed redundancy has been allowed for. This is not deemed to be necessary as the greatest risk in terms of pump failure is only a modest portion of the total capacity at each station. Because standard pump sizing has been adopted, and each pump can be fully isolated, replacement of any failed pump will be relatively straight forward both technically and in terms of outage time.

The pump-station costs estimated include appropriate building, control systems and connection to transmission. Costs are built up from a combination of fixed costs, flow related cost and head (pressure) related costs. There are many pump-station flow and head combinations across the supply areas and under different scenarios. For demonstration purposes **Figure 18** provides pump station cost curves.

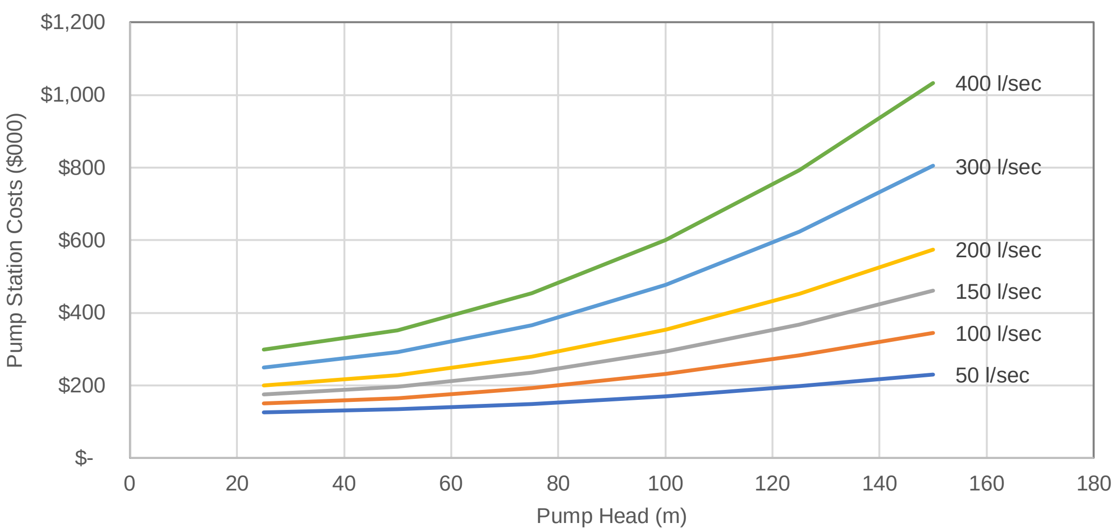

Figure 18. Pump station cost curves.

No allowance is made for on-site maintenance or storage facilities as it is envisaged that this would be centralised at local urban centres.

The derived pump-station costs have been cross-checked against industry examples.

6.4 Reservoirs

Dam costs have been developed based on standardised unit rates applied to site specific earthworks volumes and component configurations. Rates utilised in developing costs have been derived primarily from the various components of completed storage projects (i.e. the Hopua te Nihotetea Detention Dam in Whangarei and various other sites across New Zealand) supplemented where available with previous cost estimates of projects which may not have been constructed. There is little recent precedent of moderate to large irrigation storage projects in Northland and thus this approach is considered reasonable for this present prefeasibility stage.

Key dam components developed as part of the concept designs include:

- ***Dam Structure*** – based on bulk earthworks rates plus upstream geomembrane lining of the embankment in Kaipara and rip-rap wave-protection in Mid-north.
- ***Foundation Preparation*** – based on estimates with allowance for foundation under-cut and preparation.
- ***Diversion Structure*** – sized based on local catchment above the dam and associated flood size to be managed during construction.
- ***Spillway*** – sized based on local catchment above the dam and associated operational and design flood sizes to be managed throughout the dam's life.
- ***Outlet Works*** – sized based on the need to release up to median flow for maintaining stream health and peak irrigation releases. It's was presumed the outlet works will utilise much of the same infrastructure as the diversion structure.
- ***Site Specific Works*** – allowance is made at some sites for specific works associated that may include; specific leakage prevention measures such as lining and/or grouting.

Dam earthworks typically constitute 80-85% of the total cost of the dam except for dams located in larger streams where the costs of diversions and spillways increase. This particularly effects one dam [redacted]) used in the Mid-North concept design which has a large catchment. The main cost parameters adopted in developing the bottom up dam cost for each site are provided in **Table 21** . A sense check of this costing methodology was applied to escalated construction costs of the Kerikeri Irrigation dams, indicating the methodology is reasonable. Obtaining cost estimates from suitable local contractors in future stages would enable dam costs to be more accurately constrained.

Table 21. Dam cost parameters.

Component	Unit Rate ($)	Unit	Comments
Baseline Earthworks			
High	30	m^3	Combined rate for undercut to waste plus cut to certified fill
Average	20	m^3	Use as general cut to certified fill
Low	15	m^3	
Additional Earthworks			
Reservoir lining	12	m^2	Kaipara only. Assume 30 m upstream from dam
Riprap	140	m^3	Plus $3 per m^2 area for geotextile underlay
Foundation grouting	1,500	Per lineal m	Volcanic sites only. Typically, up to $200-300k / site

Diversion	30,000	per km^2 catchment	
Spillway			
Kaipara	25,000	per km^2 catchment	Lower flood yield per square kilometre
Mid-North	60,000	per km^2 catchment	Higher flood yield per square kilometre
Inlet/outlet works			
Low (small) Dam	50,000		Less than 10 m high
Medium (10-20 m)	200,000		10-20 m high
Large	500,000		>20 m high

Key assumptions applied in developing dam costings included:

- Reservoir leakage rates will be within acceptable limits, i.e. no lining of the reservoir with low-permeability fill or synthetic lining is required.
- Large-scale landslide remediation is not required.
- Liquefaction is not required to be mitigated, apart from removal/undercutting of weak/organic soils in valley floors.
- Foundation grouting on a large scale has not been allowed for, aside from the nominal allowance to applied to a few sites in volcanics in the Mid-North.
- Seepage mitigation is required at Kaipara sites by extending the liner partway up the reservoir from the embankment. Lining of the full reservoir has not been allowed for.
- Earth-fill for dam embankment construction can largely be obtained from a local borrow source (where materials are suitable) using conventional earthmoving techniques. Any specialist materials required (e.g. filter material) are within reasonable cart distance.
- Some degree of undercutting of unsuitable foundation materials will be required at most sites.
- Due to the small to moderate catchment areas, it is anticipated that a single spillway acting as both the service and emergency spillway is suitable and can be constructed adjacent to the dam or on a suitable topographic feature.
- Concreting only a portion of the spillway channel has been allowed for.
- Temporary stream diversion during construction can be achieved via a simple low-level pipe and coffer dam.
- No allowance for fish passage through or over the embankment has been made.

6.5 Pipe Networks

The pipe networks discussed in **Section 3** were priced based on installed rates used in comparable irrigation projects (i.e. Ashburton Lyndurst and Ruataniwha) for the relevant pipe diameters and pressures. Rates were adjusted to present values using the cost fluctuation adjustment methodology in Conditions of Contract for Building and Civil Engineering Construction, NZS3910:2013 which includes adjustment for the Labour Cost Index and Producers Price Index available from StatsNZ.

All pipe costs are based on HDPE except for a short section of steel pipe in the Kaipara design concept where pressures exceed the capacity of HDPE. For smaller, low pressure pipe diameters, for example less than 200 mm diameter and PN10, it is anticipated that PVC could be a more cost-effective option, and this can be explored further in subsequent project stages.

Prices adopted are provided in **Table 22**.

An additional 10% was then applied to these rates to account for structures and fittings (6.5%) and a nominal allowance for property off-takes (3.5%). Example structures and fittings include flanges and bends, air valves, isolating vales, mainline pressure reducing valves, drain points and manholes, concrete thrust blocks and/or anchor blocks, and road and stream crossings.

It should be appreciated that not all sizes may be available from suppliers in Northland, nor the appropriate equipment necessary to install them at the lengths and diameters required. Early discussion with suppliers and contractors within the area will enable these prices to be confirmed or adjusted as necessary.

Table 22. Adopted pipe costs ($/m).

Pipe Diameter (mm)	Pipe Pressure Rating (bar)				
	4	6.3	8	10	12.5
110	27	27	33	32	37
125	42	44	46	49	42
140	44	50	50	57	44
160	47	52	55	62	74
180	48	54	58	63	94
200	39	60	67	69	111
225	62	75	89	96	140
250	70	84	103	109	159
280	77	95	127	133	197
315	89	111	127	145	224
355	104	132	154	175	252
400	119	154	185	207	268
450	135	181	209	243	277
500	174	227	262	279	305
560	202	267	326	337	368
630	211	286	344	370	451
700	335	449	525	607	663
750	478	523	612	707	843

6.6 Other Allowances

Allowance has been made for full professional services associated with scheme design, supervision and commissioning during construction. In addition, provision is also made for contingency.

These rates have been derived from similar projects and are varied based on component type as shown in **Table 23**.

Table 23. Allowance for design, supervision and contingency.

Cost Component	Civil (e.g. Reservoirs etc)	Mechanical & Electrical (e.g. pumps etc)	Other
Design	5.0%	2.5%	2.5%
Supervision During Construction	5.0%	2.5%	2.5%
Contingency	15.0%	10.0%	10.0%

In addition to the above, an allowance of 15% has been made for Preliminary and General costs which allows for standard: site establishment, quality assurance (physical and environmental etc.) project management, and disestablishment.

This is comparable to industry examples that range between 13 and 18% where professional services associated with design and supervision is accounted for separately.

7. Capital Costs

Capital costs have been developed based on a combination of bottom up and top down costing[3]. Components that represent larger proportions of cost, such as dams and pipelines have been priced on a bottom-up bases utilising unit rates applied to volumes, lengths and capacity. Components that represent small proportions of total scheme cost (e.g. intakes, pump stations) have been developed on a top down basis aligned with the specific requirements of the site and required capacity.

It is normal at a pre-feasibility stage to aim to achieve a cost estimate within an accuracy band of +/-30%. This is important as it provides sufficient certainty to indicate whether a project is worth progressing to the next stage but recognises the fact that the design is only at a preliminary level.

This level of certainty (or uncertainty) is a function of several aspects including, potential variability in rates and quantities derived, smaller components not directly including costed, and uncertainty associated with the feasibility of design concepts adopted. For this pre-feasibility assessment, to allow for uncertainty in the accuracy of costs developed, two components have been considered as follows:

The first is a Contingency of +15%. This is included to address unscheduled items and modest variability in rates and quantities which is common across many or all scheme components. It largely presumes that the adopted design is feasible for the project. As many items allowed for in the Contingency are real costs, but are just not individually identified, the Contingency is added to the base cost estimates to cover a range of possible scenarios.

A second allowance of +/-15% on cost is provided (Table 30) that allows for the uncertainty associated with the feasibility of the design concept. The impact of this uncertainty is then shown in terms of the cost to users (Table 31). The uncertainty provided for with this allowance can be specific to a single component or group of components but are unlikely to be common across the entire scheme. Future investigations will almost certainly change and refine the design concept as it is advanced, verified and optimised with subsequent positive or negative impact on cost. Hence this is shown as upper and lower limits on cost expectation. The key areas where cost uncertainties could arise are discussed in **Section 7.6**, and as such are key areas of focus for subsequent project investigations.

7.1 Kaipara Large Storage Scenario

Capital costs for the large storage scenario in the Kaipara Area is dominated by the pipe network (53%) followed by storage costs (28%). This reflects the long conveyance length required to supply water from [redacted] located near the northern extent of the commend area, all the way down through the command area to reach the southernmost extent. It also reflects the low reservoir costs associated with high storage efficiencies.

A cost breakdown of scheme components is provided in **Table 24**.

Table 24. Kaipara Large Storage Scenario, capital cost breakdown.

Components	Sub Component	Type	Amount	Unit	Cost ($000)	Total ($000)
Intakes	[redacted]	Flow	520	L/s	[redacted]	
						[redacted]
Pump Stations	Distribution, High Pressure	Capacity	2,354	kW	[redacted]	
	Distribution, Low Pressure	Capacity	1,143	kW	[redacted]	
	Distribution, Localised	Capacity	103	kW	[redacted]	

[3] Bottom-up pricing involve accumulating the cost from each component to arrive at a total and is typically more accurate than top-down pricing, which involves assignment of a higher-level estimate based on experience and judgement.

Components	Sub Component	Type	Amount	Unit	Cost ($000)	Total ($000)
	Storage Refill	Capacity	567	kW	[redacted]	
						[redacted]
Reservoirs	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
						[redacted]
Piping	160 mm Dia	Length	3,170	m	[redacted]	
	200 mm Dia	Length	3,230	m	[redacted]	
	2500 mm Dia	Length	5,710	m	[redacted]	
	315 mm Dia	Length	3,700	m	[redacted]	
	355 mm Dia	Length	10,740	m	[redacted]	
	400 mm Dia	Length	9,020	m	[redacted]	
	450 mm Dia	Length	5,140	m	[redacted]	
	500 mm Dia	Length	4,130	m	[redacted]	
	560 mm Dia	Length	2,600	m	[redacted]	
	630 mm Dia	Length	18,430	m	[redacted]	
	700 mm Dia	Length	6,000	m	[redacted]	
	750 mm Dia	Length	260	m	[redacted]	
	Structures, fittings and property off-takes			10%	[redacted]	
						[redacted]
Transmission						[redacted]
Sub Total						[redacted]
Des, Constr, Cont						[redacted]
P&G						[redacted]
Total ($000s)						[redacted]

7.2 Kaipara Distributed Scenario

Capital costs for the distributed storage scenario in the Kaipara Area is again dominated by the pipe network (46%) followed closely by storage costs (41%). The relative (and absolute) increase in reservoir costs compared to the large storage scenario arises from the loss of economies of scale moving from one to four storages, and associated duplication of costs (i.e. four spillways, four flood diversions etc.).

A cost breakdown of scheme components is provided in **Table 25**.

Table 25. Kaipara Distributed Storage Scenario, capital cost breakdown.

Components	Sub Component	Type	Amount	Unit	Cost ($000)	Total ($000)
Intakes	[redacted]	Flow	520	L/s	[redacted]	
						[redacted]
Pump Stations	Distribution, High Pressure	Capacity	2,394	kW	[redacted]	
	Distribution, Low Pressure	Capacity	162	kW	[redacted]	
	Distribution, Localised	Capacity	103	kW	[redacted]	

Components	Sub Component	Type	Amount	Unit	Cost ($000)	Total ($000)
	Storage Refill	Capacity	567	kW	[redacted]	
						[redacted]
Reservoirs	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
						[redacted]
Piping*	110mm Dia	Length	390	m	[redacted]	
	160mm Dia	Length	7,760	m	[redacted]	
	200mm Dia	Length	3,510	m	[redacted]	
	250mm Dia	Length	16,310	m	[redacted]	
	300mm Dia	Length	9,340	m	[redacted]	
	400mm Dia	Length	9,030	m	[redacted]	
	450mm Dia	Length	24,990	m	[redacted]	
	500mm Dia	Length	260	m	[redacted]	
	600mm Dia	Length	15,410	m	[redacted]	
	Structures, fittings and property off-takes			10%	[redacted]	
						[redacted]
Transmission						[redacted]
Sub Total						[redacted]
Des, Constr, Cont						[redacted]
P&G						[redacted]
Total ($000s)						[redacted]

7.3 Mid-North Large Storage Scenario

Capital costs for the large storage scenario in the Mid-North Area is dominated by storage costs (46%) followed by pipe network costs (40%). This is primarily due to lower storage efficiencies in the Mid-North inducing higher relative storage costs.

A cost breakdown of scheme components is provided in **Table 26**.

Table 26. Mid-North Large Storage scenario, capital cost breakdown.

Components	Sub Component	Type	Amount	Unit	Cost ($000)	Total ($000)
Intakes	For [redacted]	Flow	635	L/s	[redacted]	
						[redacted]
Pumpstations	Distribution, High Pressure	Capacity	1,400	kW	[redacted]	
	Distribution, Low Pressure	Capacity	0	kW	[redacted]	
	Distribution, Localised	Capacity	175	kW	[redacted]	
	Storage Refill	Capacity	200	kW	[redacted]	
						[redacted]

Components	Sub Component	Type	Amount	Unit	Cost ($000)	Total ($000)
Reservoirs	MN-16	Vol	3.5	Mm^3	[redacted]	
	MN-02	Vol	4.0	Mm^3	[redacted]	
						[redacted]
Piping*	160mm Dia	Length	4,170	m	[redacted]	
	180mm Dia	Length	690	m	[redacted]	
	200mm Dia	Length	1,840	m	[redacted]	
	2250mm Dia	Length	8,060	m	[redacted]	
	280mm Dia	Length	16,490	m	[redacted]	
	315mm Dia	Length	2,770	m	[redacted]	
	355mm Dia	Length	6,460	m	[redacted]	
	400mm Dia	Length	4,860	m	[redacted]	
	560mm Dia	Length	13,740	m	[redacted]	
	Structures, fittings and property off-takes			10%	[redacted]	
						[redacted]
Transmission						[redacted]
Sub Total						[redacted]
Des, Constr, Cont						[redacted]
P&G						[redacted]
Total ($000s)						[redacted]

7.4 Mid-North Distributed Scenario

Capital costs for the distributed storage scenario in the Mid-North Area is dominated by storage costs (65%) followed by pipe network costs (18%). This is due to a combination of more storages and the lower storage efficiencies in the Mid-North. The distribution of storages reduces relative and absolute costs associated with the pipe network.

A cost breakdown of scheme components is provided in **Table 27**.

Table 27. Mid-North Distributed Storage scenario, capital cost breakdown

Components	Sub Component	Type	Amount	Unit	Cost ($000)	Total ($000)
Intakes	[redacted], Small stream intakes	Flow	450	l/s	[redacted]	
	[redacted]	Flow	450	l/s	[redacted]	
	[redacted] from [redacted]	Flow	450	l/s	[redacted]	
	[redacted]	Flow	570	l/s	[redacted]	
						[redacted]
Pump Stations	Distribution, High Pressure	Capacity	1,296	kW	[redacted]	
	Distribution, Low Pressure	Capacity	0	kW	[redacted]	
	Distribution, Localised	Capacity	102	kW	[redacted]	
	Storage Refill	Capacity	1,913	kW	[redacted]	
						[redacted]

Components	Sub Component	Type	Amount	Unit	Cost ($000)	Total ($000)
Reservoirs	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
						[redacted]
Piping*	100mm Dia	Length	9,000	m	[redacted]	
	160mm Dia	Length	5,750	m	[redacted]	
	200mm Dia	Length	5,610	m	[redacted]	
	250mm Dia	Length	14,530	m	[redacted]	
	300mm Dia	Length	3,950	m	[redacted]	
	350mm Dia	Length	1,330	m	[redacted]	
	400mm Dia	Length	180	m	[redacted]	
	550mm Dia	Length	11,430	m	[redacted]	
	Structures, fittings and property off-takes			10%	[redacted]	
						[redacted]
Transmission						[redacted]
Sub Total						[redacted]
Des, Constr, Cont						[redacted]
P&G						[redacted]
Total ($000s)						[redacted]

7.5 Mid-North Distributed Storage Scenario Incorporating Lake Omapere

A cost breakdown of scheme components is provided in **Table 27**.

Table 28. Mid-North Distributed Storage scenario Incorporating Lake Omapare, capital cost breakdown

Components	Sub Component	Type	Amount	Unit	Cost ($000)	Total ($000)
Intakes	[redacted]	Flow	390	l/s	[redacted]	
	[redacted]	Flow	500	l/s	[redacted]	
	[redacted]	Flow	450	l/s	[redacted]	
	[redacted]	Flow	170	l/s	[redacted]	
	[redacted]	Flow	220	l/s	[redacted]	
						[redacted]
Pump Stations	Distribution, High Pressure	Capacity	1,595	kW	[redacted]	

Components	Sub Component	Type	Amount	Unit	Cost ($000)	Total ($000)
	Distribution, Low Pressure	Capacity	0	kW	[redacted]	
	Distribution, Localised	Capacity	102	kW	[redacted]	
	Storage Refill	Capacity	0	kW	[redacted]	
						[redacted]
Reservoirs	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
	[redacted]	Vol	[redacted]	Mm^3	[redacted]	
						[redacted]
Piping*	100mm Dia	Length	9,080	m	[redacted]	
	160mm Dia	Length	9,350	m	[redacted]	
	200mm Dia	Length	5,830	m	[redacted]	
	250mm Dia	Length	3,580	m	[redacted]	
	300mm Dia	Length	8,410	m	[redacted]	
	400mm Dia	Length	2,850	m	[redacted]	
	500mm Dia	Length	2,460	m	[redacted]	
	550mm Dia	Length	5,130	m	[redacted]	
	Structures, fittings and property off-takes			10%	[redacted]	
						[redacted]
Transmission						[redacted]
[redacted]						[redacted]
Sub Total						[redacted]
Des, Constr, Cont						[redacted]
P&G						[redacted]
Total ($000s)						[redacted]

[redacted]

7.6 Scenario Costings Comparison

The costing developed for the scheme concepts are presented in **Table 29**. Superior storage efficiency for the reservoirs in the Kaipara area is evident in the lower portion of dam related costs compared to the Mid-north. In comparison, pipe network costs in the Mid-North are less as the scheme layouts are more compact in terms of storage proximity to demand.

Table 29. Comparative summary of scheme costs.

Components	Kaipara ($)		Mid-North ($)		
	Large Storage	Distributed Storage	Large Storage	Distributed Storage	Distributed Storage (Lake Omapere)
Intakes	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Pump-stations	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Reservoirs	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Components	Kaipara ($)		Mid-North ($)		
	Large Storage	Distributed Storage	Large Storage	Distributed Storage	Distributed Storage (Lake Omapere)
Piping	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Transmission	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]					[redacted]
Sub Total ($000s)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Design, Supervision, Contingency	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Provisional and General	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total ($000s)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Cost Uncertainty (+/-15%)					
Expected Lower Limit	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Expected Upper Limit	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

As would be anticipated the scheme based on [redacted] large storages has a lower overall capital cost due to the economies of scale associated with dam construction and associated storage. There is however limited opportunity in the Large Storage scenario to progressively develop the schemes over time.

This highlights the value in undertaking a bookends approach. The difference in cost is modest in the Kaipara suggesting that the lower risk Distributed Storage scheme is more representative of the optimal solution. In the Mid-North, however, it is highly likely that the optimum design solution will lie between the two bookends drawing on the most cost-effective components from each.

Furthermore, while not currently undertaken, a Net Present Value analysis would likely indicate that the discounted costs of the distributed schemes over an evaluation period of say 30 years or greater, would likely render the cost of the distributed schemes as more favourable. This is discussed further in report **Volume 4 – Analysis and Recommendations**.

Table 30 summarises the costs for each command area on a per hectare basis. Also provided is the expected range in cost per hectare once the provision of +/- 15% uncertainty is applied.

Table 30. Summary of scheme costs per hectare in each command area.

Supply Area (Ha)	Kaipara ($)		Mid North ($)		
	Large Storage	Distributed Storage	Large Storage	Distributed Storage	Distributed Storage (Lake Omapere)
Farm	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Canopy	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Cost ($/ha)					
Farm: mid-point	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
range	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Canopy[4]: mid-point	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
range	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[4] Assuming 70% canopy cover density

7.7 Sensitivity Analysis

Sensitivity analysis has been undertaken across the main scheme components based on the pre-feasibility design. This does not consider uncertainties that might measurably impact on the design of a particular scheme component, and hence cost of that component, rather it is undertaken to:

- test the adequacy of contingency provisions;
- provide a relative comparison between main scheme components in terms of impact on cost; and
- highlight obvious areas, both in terms of risk and opportunity, for focus in future stages.

The following figures illustrate the high and low limits for cost sensitivity as well as indicating the overall contingency provision. All figures show that the contingency provision is comfortable, sufficient to cover the largest sensitivity range. As would be expected, piping and dam costs dominate cost sensitivity.

Cost sensitivity for the four scheme concepts are presented in **Figure 19** to **Figure 22**.

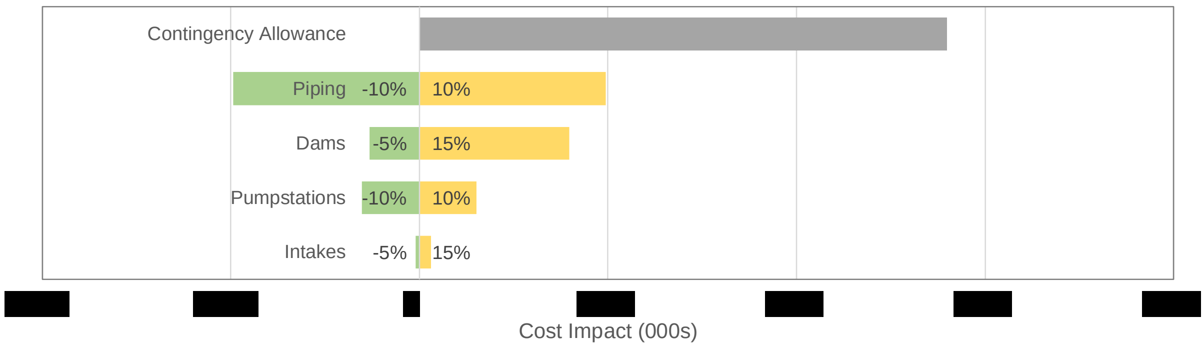

Figure 19. Cost sensitivity, Kaipara – Large Storage scenario.

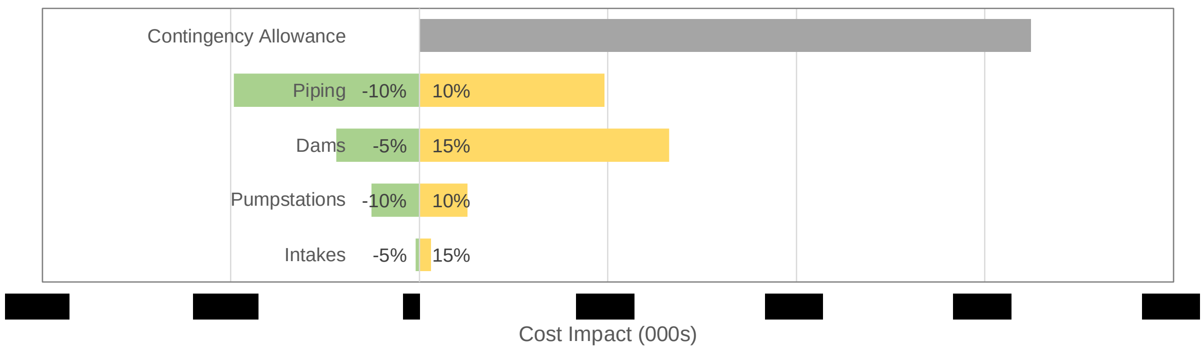

Figure 20. Cost sensitivity, Kaipara – Distributed Storage scenario.

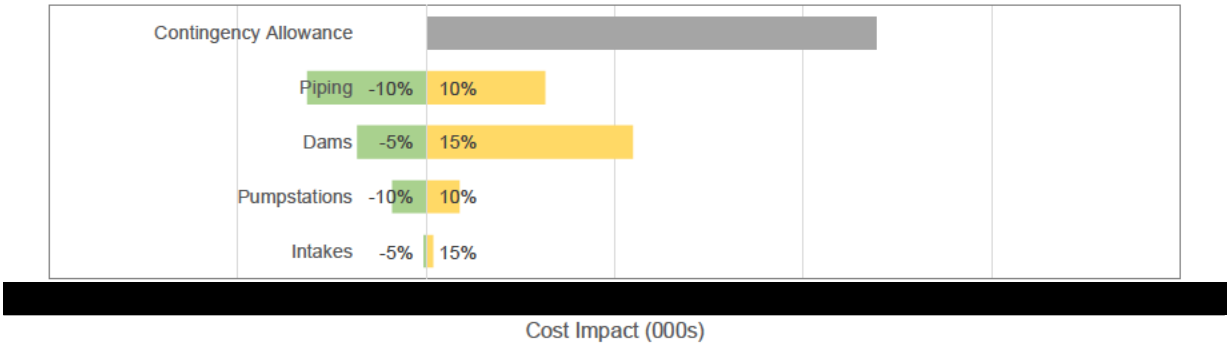

Figure 21. Cost sensitivity, Mid North – Large Storage scenario.

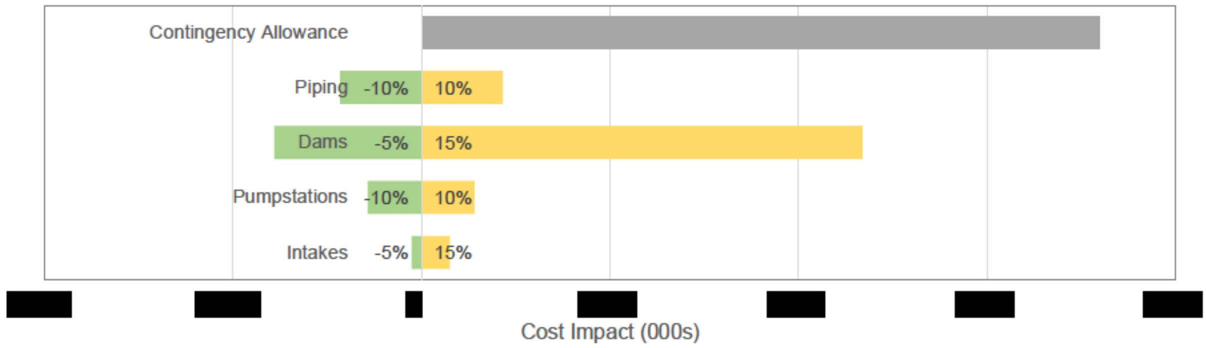

Figure 22. Cost sensitivity, Mid North – Distributed Storage scenario.

[redacted]

Figure 23. Cost sensitivity, Mid North – Distributed Storage (Lake Omapere) scenario.

8. Operational Costs

Operational costs have been developed and separated into two components; operations and maintenance, and energy related costs. Costs shown are for the fully developed scheme. It is envisaged that approximately 50% of the operations and maintenance costs will be fixed irrespective of uptake, with the remainder broadly proportional to uptake. Energy costs will be broadly proportional to uptake.

No allowances were made for:

- the cost of financing;
- any costs related to land lease or easements; and
- costs associated with access to water beyond typical costs associated with resource consents.

8.1 Operations and Maintenance

Costs associated with scheme operations, other than energy have been developed based on comparable costs from other distributed infrastructure schemes. These include both physical (operational cost and maintenance) and non-physical (human resources, administration, etc),

These indicate a range between [redacted] of total capital cost. The range largely reflects the breakdown of component types that make up the scheme. Schemes dominated by large civil components are toward the lower end of the range, while those with significant mechanical and electrical components toward the upper end of the range.

To allow for the breakdown of different component types, operation and maintenance costs have been developed based on varying rates by component type (**Table 31**).

Table 31. Summary of adopted operation and maintenance rates.

Component Type	O&M Rate as % of Capital Cost
Civil	[redacted]
Mechanical & Electrical	[redacted]
Other	[redacted]

8.2 Energy and Connection Costs

Energy costs have been developed based on energy use by pump-stations but also include fixed costs arising from connection charges at each pump-station to the local lines-companies. Connection charges are taken from the local lines companies published rates for uninterrupted large industrial/pump connections.

Energy costs are based on rates published by MBIE (2018) adjusted by CPI to estimate rates as at Dec 2019.

The costs adopted for connection energy are presented in **Table 32**. No allowance was made for on-farm energy demand.

[5] The upper limit o[redacted] is understood to contain some financing costs which is not normally incorporated directly in to O&M estimates.

Table 32. Summary of adopted energy costs.

Charge	Unit	Northpower (Kaipara)	Top Energy (Mid-North)
Daily Fixed	$/Day	1.200	27.610
Variable / kWh	$/kWh	0.107	0.089
Energy	$/kWh	0.147	0.147

8.3 Summary of Operation and Maintenance.

Operational and maintenance costs are summarised in **Table 33**. The Kaipara is dominated by energy costs due to the high elevation of much of the demand area relative to storage sites. This partially arises from the adoption of the default design criteria of supplying pressurised water directly to the lower 75% (by elevation) of area in each zone. The remaining (highest elevation) 25% uses localised pressurisation. It is likely that during subsequent design stages, an optimised balance between scheme pressurisation and localised pressurisation can be achieved. The comparably high energy use does however highlight the potential for incorporating local renewable energy generation to offset operational costs.

In comparison, the Mid-north requires less pumping as many of the storages are closer in elevation to the demand areas. There are however still locations where significant energy use occurs that could logically utilise renewable energy generation as an operational cost offset.

Table 33. Summary of operation and maintenance costs.

Supply Area (Ha)	Kaipara ($)		Mid North ($)		
	Large Storage	Distributed Storage	Large Storage	Distributed Storage	Distributed Storage (Lake Omapere)
Operation & Maintenance Costs ($000s per annum)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Energy Costs including connection charges ($000s per annum)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total Operational Costs (000s per annum)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Cost per Hectare					
Farm ($/ha per annum)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Canopy ($/ha per annum)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

9. Cost of Land Access

The construction of scheme components, in particular reservoirs and the associated inundation from lake filling, will result in land needing to be acquired in most instances. Access, and or acquisition, of land will have a cost associated with it and needs to be allowed for within the overall development costings.

The value of the land may vary considerably, depending on several factors both in terms of financial metrics such as productive capacity, and non-financial metrics such as environmental heritage, cultural or family values.

Table 34 illustrates the land area likely to be inundated for each reservoir assuming a nominal 20 m riparian buffer.

Table 34 - Reservoir Footprints

Storage Name	Area (ha)	Parcels Affected
[redacted]	[redacted]	12
[redacted]	[redacted]	9
[redacted]	[redacted]	8
[redacted]	[redacted]	7
[redacted]	[redacted]	4
[redacted]	[redacted]	2
[redacted]	[redacted]	3
[redacted]	[redacted]	10
[redacted]	[redacted]	5
[redacted]	[redacted]	6
[redacted]	[redacted]	1
[redacted]	[redacted]	5
[redacted]	[redacted]	8
[redacted]	[redacted]	11

It should be noted that, in many instances the parcels outlined in **Table 34** are in common ownership, resulting in a lesser number in landowners to engage with.

In the instance of Lake Omapere, a nomina[redacted] ha area to be acquired has been assumed. This is considered conservative as the value of the land is likely to be relatively low, and the area affected could be considerably reduced by incorporating embankments to protect potentially inundated land.

Table 35 assumes lower and upper land values of [redacted] per hectare respectively for comparative purposes for the scheme options.

Table 35. Indicative Cost of Land Acquisition

Scheme	Area (ha)	Land Value ($M)	
		Lower	Upper
Kaipara Main Storage	137	[redacted]	[redacted]
Kaipara Distributed Storage	279	[redacted]	[redacted]
Mid-North Main Storage	225	[redacted]	[redacted]
Mid-North Distributed Storage	185	[redacted]	[redacted]
Mid-North with Lake Omapere	260	[redacted]	[redacted]

Estimates in **Table 35** do not allow for the likes of professional and consenting costs which would be additional. It also does not allow for the formation of any easements which may be required for pipe routes when they cannot practically utilise publicly owned land.

For comparative purposes within this pre-feasibility work, it would be prudent to consider the upper value of **Table 35** above to allow for un accounted for elements without building in high degree of conservatism.

Further consider should be given to cost neutral outcomes for the scheme through strategic acquisition of land surrounding the potential reservoir sites through the creation of high value irrigated land, lifestyle blocks with lake views, etc.

10. Discussion

10.1 Lake Omapere

The scenario which considers the inclusion of Lake Omapere is quite different to the other two options as a significant portion of supply is sourced as an on-demand supply from a natural water body. While Lake Omapere could be considered simply as a storage, as a natural water body it is less likely that it can be utilised in a totally unconstrained manner. The man made in-scheme storages will be able to be actively and flexibly managed, within physical constraints, to meet user requirements. It is unlikely that such unfettered use of Lake Omapere will be similarly acceptable.

The scheme would need to be operated quite different, particularly regarding deficit management, reliability and certainty of supply. This is not to say that it won't deliver a comparative level of service, just with [redacted] held in "scheme" storage it may need to operate quite differently.

If this scenario is to be advanced, in subsequent stages, specific consideration will need to be given to the appropriate constraints on the use of Lake Omapere and what this means to the security of supply to the scheme. This may indicate a need for some additional in-scheme storage in order to manage security of supply, or potentially the ability to reduce the size of [redacted] which could have a positive impact from a dam safety perspective.

Currently only indicative costs have been included [redacted] for infrastructure associated with lake level management and aspects such as fish passage, flood management, stream bank erosion (for conveyance) and restoration works required to ensure the lake can be considered a reliable source of water.

Whilst these costs will need to be refined in subsequent stages, they are likely to be less than the difference in capital cost that currently exists between this option and the other two options which are between [redacted] and [redacted]

This option, even if not guaranteed, should be actively progressed as the opportunity is significant. This approach is supported by the conceptual distributed schemes provided herein this report which reflect the ability to initiate several man-made storages at project inception without precluding one or the other longer-term outcomes.

It should be also factored in that consideration of Lake Omapere, and supporting the restoration of it, is likely to place a key part in gaining social/cultural licence to progress the scheme as a whole.

10.2 Alternative Water Source for Distributed Kaipara Option

It was identified during the **Volume 2 - Water Resources Analysis** report that a significant volume of water flows across the Poutō Peninsula on an annual basis, albeit not enough to reliably supply the entire Kaipara Command Area. However, access to this flow is constrained by the ability to transfer water to reservoirs in the upper extents of the catchments. For example, even in an extreme dry year (e.g. with a 1 in 20-year recurrence interval), the annual flow volume of the [redacted] within the command area [redacted] is approximately [redacted] Mm^3.

High-level analysis of the flow regime for [redacted] demonstrated that if high flows were to be harvested and pumped to storage at a maximum rate of [redacted] m^3/s, approximately [redacted] Mm^3 could be transferred to storage during a dry year with a 1 in 20-year recurrence interval.

[redacted]

Pumping high flows upstream to the storage reservoirs from these creeks and drains on the Poutō Peninsula could provide an alternative source of water supply for the Kaipara distributed scenario. This option potentially defers the [redacted] and associated infrastructure to a later stage of development, or indefinitely, depending on scheme update and could potentially reduce scheme capital costs in the order of approximately [redacted].

10.3 Opportunities for Reducing Uncertainty

10.3.1 Flow Monitoring to Improve Catchment Yield Assessment

One of the key design considerations for reservoir location and size is the ability to supply (fill) the reservoirs from surrounding surface water sources.

All five conceptual design scenarios primarily rely upon high flow river takes, with only proportionally minor run of river takes being available.

Catchment flow models were developed for both command areas in the **Volume 2 – Water Resources Analysis** report, to provide an understanding of flow regimes and quantify the volumes of water available for harvesting. The catchment models were calibrated to available measured flow data. However, this was limited to sparse low flow spot gauging, particularly along the Poutō Peninsula.

For example, only three low flow gaugings have been collected from Aratapu Creek, while no gaugings are available along western Poutō Peninsula in the upper catchments where the proposed reservoirs are located. Therefore, a level of uncertainty exists in the high flow regime of these catchments, and hence ultimate ability to fill the proposed reservoirs.

Should the actual characteristics of the catchment vary significantly from the modelling, this could have a considerable impact upon the conceptual designs developed herein.

Both the Kaipara and Mid-North study areas would benefit from targeted flow monitoring for key sites to inform subsequent feasibility assessments.

10.3.2 Geotechnical Conditions

Specimen design for the dams have been based on the broad characteristics known or suspected to be present at the dam sites. These will vary between sites and across a given site. Three key examples are the depth of excavation required at a dam site to reach sound foundation material, whether additional foundation treatment (for liquefaction mitigation or seepage mitigation) is required, or whether leakage rates from the reservoirs are acceptable (and warrant synthetic lining).

This uncertainty will have a direct impact on the cost of any given reservoir (positive or negative). Potentially more importantly, for the distributed scenarios, may shift the distribution of storage across sites to those that have better characteristics. This could result in an overall improvement in cost, as a proportion of storage held at sites where cost increase could be shifted to sites where the cost decreases.

Geological mapping and site-specific investigations are required to reduce this uncertainty.

10.3.3 Pipe Network

The pre-feasibility design for the pipe network typically utilised existing corridors (e.g. roads) to where practical avoid private land. Subsequent discussion with landowners may identify opportunities to reduce conveyance lengths and associated costs. Any adjustments to the main storage sites that arise from future hydrology and dam investigations will also influence the pipe network layout and capacity.

At this time, it is anticipated that resolving uncertainties associated with the layout of pipe networks would largely confirm or have a slight positive impact on costs. Given this, and that it is a function of other future workstreams, further work in this area is not warranted until enhanced certainty around hydrology storage is available.

Refined scheme definition and landowner input is required to reduce this uncertainty.

10.3.4 Resource Consenting and Land Acquisition

Allowances for the likes of resource consent, environmental enhancement or mitigatory measures, land acquisition, legal fees have not been included at this pre-feasibility stage due to significant uncertainties that still exist.

10.3.5 Land Contamination

No assessment of land-contaminating activities has yet been implemented. The NES-CS[7] requires that an assessment of historic or current MfE HAIL[8] activities be done to assess health risk to workers and the public relevant to soil disturbance, if the land intended to be developed is more likely than not to have had HAIL activities present which may have caused soil contamination.

For these rural settings, the most likely types of HAIL activities to be present are farm dumps, sheep dips, storage and use of persistent pesticides (e.g. organochlorine, organophosphorus and organonitrogen pesticides), asbestos containing materials and/or lead from demolished or dilapidated older sheds, structures and dwellings, and historic importation of uncertified fill.

The uncertainty associated with the potential presence of contaminants could impact on the configuration and cost of specific components and in the worst case limit the ability to store water within the reservoirs.

A high-level Preliminary Site Investigation (PSI) should be carried out to assess whether any of the land to be developed is likely to have soil contamination issues present. The PSI involves desktop assessment and includes requests for contaminated land database, spills and compliance information held by Northland Regional Council (NRC), Far North District Council (FNDC) and Kaipara District Council (KDC); historic aerial reviews; request and review of relevant property files and discussion with landowners, if required. The outcomes of the PSI will inform any intrusive soil testing requirements in particular areas that may be contaminated.

If contamination is identified which exceeds regional background concentrations and/or relevant health-based soil contaminant standards, resource consents under the NES-CS will need to be sought from FNDC and/or KDC. Under these circumstances a Site Management Plan (SMP) for contaminated soils will need to be produced to meet consent requirements and to provide guidance to the civil works contractors regarding management or disposal of contaminated soils.

[7] Resource Management: National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health Regulations 2011.
[8] Ministry for the Environment, revised 2011. Hazardous Activities and Industries List.

11. Summary

Concept design of five potential irrigation scheme configurations, two in the Kaipara and three in the Mid-North, is presented which collectively represent the two reasonable, but extreme limits within which the final optimal design scenario is anticipated to sit. Broadly, the scheme configuration "bookends" comprise a Large Storage Scenario whereby much of the available water is stored from [redacted] reservoir, and a Distributed Storage Scenario, utilising several interlinked storages. Each configuration aims to capture and distribute the available water resources identified in **Volume 2: Water Resources Analysis** to the refined scheme areas from **Volume 1: Command Area Analysis and Refinement.**

Reservoir sites were selected from those outlined in the MCA process and volumes optimised using the SOURCE modelling framework. Geotechnical evaluation and dam failure consequence assessments were then undertaken to develop concept embankment dam designs. A recirculating network, linking sources to storages and storages to command area zones, was then modelled in EPANET to calculate pipe diameters and pressure ratings.

The five scheme configurations comprise:

1. Kaipara Large Storage [redacted]
2. Kaipara Distributed Storage: [redacted]
3. Mid-North Large Storage: [redacted]
4. Mid-North Distributed Storage [redacted]
5. Mid-North Distributed Storage Incorporating Lake Omapere: [redacted]

Optimisation testing indicates that the concept designs deliver a high level of reliability (>95%) to the command areas. Further analysis may demonstrate the ability for the scheme to supply a greater area, or alternatively the same area for less cost.

Capital costings were estimated for individual scheme components broken down into river and stream intakes, pump-stations, reservoirs, pipe networks and other allowances such as design, construction supervision, contingency, preliminary and general and uncertainty. Costings are based on fully piped and pressurised supply to 75% of the potential command area, with the remaining 25% requiring localised pressurisation the cost of which is also included.

Capital costs for the Kaipara are dominated by the pipe network followed by storage costs. This reflects the long conveyance length required to supply water from the north to the south, and the comparably low reservoir costs associated with high storage efficiencies. Storage costs are responsible for the difference in cost between the Distributed Scenario and Large Storage scenarios. Conversely, capital costs for the Mid-north are dominated by storage costs, particularly for the Distributed scenario. The Mid-North Distributed Storage Scenario Incorporating Lake Omapere is almost half the cost overall when compared to the other scenarios, illustrating the potential opportunities for utilising this as a reservoir source.

Operational costs have been estimated from a combination of operation and maintenance rates, and energy and connection costs. Operational costs are greater in the Kaipara compared to the Mid-North and are dominated by energy costs of pumping around the scheme. The Distributed Storage Scheme has greater operational costs compared to the Large Storage Scheme owing to greater number and frequency of pumping.

Table 36 provides a summary of the capital and operational costs for the schemes. Overall, within the envelop defined by the two "bookend" scenarios, options exist in both areas for comparable scheme in terms of cost per hectare.

Table 36. Comparative summary of scheme costs.

Components	Kaipara ($)		Mid-North ($)		
	Large Storage	Distributed Storage	Large Storage	Distributed Storage	Distributed Storage (Lake Omapere)
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
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[redacted]					[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
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Appendix B. Verification of Concept Dam Designs

The following presents a summary of preliminary calculations undertaken to support the proposed concept reservoir designs in terms of stability and hydrological considerations. Further and more detailed analysis is required once geotechnical site investigations are undertaken and preliminary design advanced.

B.1 Stability Modelling

A slope stability analysis was performed in Slide v8.0 to better understand how the concept designs may perform under typically expected loading conditions. Analysis was undertaken on the two conceptual designs illustrated in **Appendix A**, using assumed foundation conditions and geotechnical parameters. Note these ground models, along with the parameters adopted, will almost certainly change once geotechnical investigations are undertaken at the dam sites and designs are advanced.

The soil/material layers from the ground model are as follows:

Kaipara
- Fill embankment materials – 'Sand-Embankment'
- Synthetic geomembrane liner – 'Liner'
- Foundation materials – 'Sand-Foundation'

Mid-North
- Two types of fill embankment materials – 'Allochthon' and 'Volcanic'
- Foundation materials – 'Rock-Allochthon'
- Filter and rock riprap materials – 'Filter/Riprap'

Table 37. Adopted strength parameters.

Command Area	Unit	Y' (kN/m^3)	c' (kPa)	Φ' (°)	S_u (kPa)
Kaipara	Sand-Embankment	18	2	30	-
	Liner	Properties as above			-
	Rock-Allochthon	21	50	28	-
	Sand-Foundation	17	0	30	-
Mid-North	Filter/Riprap	17	0	32	-
	Allochthon	19	5	28	100
	Volcanic	18	2	30	100

NOTE: Liner is modelled as a thin (0.01m) soil layer.

Table 38. Adopted hydraulic parameters.

Command Area	Unit	Ysat (kN/m3)	k (m/s)	kv/kh	e	icritical
Kaipara	Sand-Embankment		1×10^{-6}	0.3		
	Liner		1×10^{-20}	0.3		
	Rock-Allochthon		1×10^{-8}	0.1		
	Sand-Foundation	21	1×10^{-4}	0.01	0.3	1.3
Mid-North	Filter/Riprap		1×10^{-4}	1.0		
	Allochthon	22	1×10^{-9} (u/s) 1×10^{-8} (d/s)	0.3	0.5	1.1
	Volcanic		1×10^{-8} (u/s) 1×10^{-5} (d/s)	0.3		

NOTE: Liner is modelled as a thin (0.01m) soil layer.

The scenarios modelled represent general loading conditions that the dams would be expected to accommodate over their design life. These include:

- Post-construction conditions while pore pressures are high
- Static conditions at high and low reservoir levels
- Fluctuating normal and extreme water levels resulting in transient pore pressure conditions within the embankment

Table 39. SLIDE modelling results.

Scenario	Slope or Location	FoS Target*	Mid-North (Allochthon Embankment)	Mid-North (Volcanic Embankment)	Kaipara
Post-Construction	Upstream	1.3	4.3	4.3	2.0
	Downstream	1.3	3.2	3.2	2.0
Steady-state seepage	Downstream	1.5	2.0	2.0	2.0
Steady-state seepage (during flood)	Downstream	1.3	2.0	2.0	2.0
Rapid Drawdown	Upstream	1.2 to 1.3	2.0	1.9	1.8
Heave/uplift	Downstream toe	1.5	2.7	2.6	2.6
Piping ($i_{critical}$ / $i_{modelled}$)	Across foundation	1.5	2.7	3.0	2.1

* Design stability requirements in accordance with NZSOLD Dam Safety Guidelines 2015

Results from the analysis indicate satisfactory performance for all scenarios modelled, which was expected given the reasonably conventional profiles adopted, i.e. up- and down-stream batters of 3H:1V and 5 m wide crest. These results will need to be checked and updated during future stages of work as the project progresses, site specific details are quantified, and designs advanced.

A seismic analysis is also normally performed for the operating basis earthquake (OBE) and Seismic Evaluation Earthquake (SEE). However, given the low seismic risk for Northland and uncertainties regarding foundation conditions, particularly in the Kaipara where liquefiable soils may be present, it is recommended that seismic stability analyses be performed once site specific geotechnical information becomes available.

B.2 Construction Diversion and Spillway Facilities

Two key elements of dam design are the diversion capabilities during construction and spillway capacity.

Stream diversions protect the working area during construction and are normally provided by an upstream embankment 'coffer' dam with conduit pipe. The conduit can also be incorporated into the final embankment design to serve as the inlet/outlet to the reservoir, for residual flow and potentially hydroelectric generation. Coffer dam heights and conduit diameters have been designed to accommodate a 50-year flood, with a check of the conduit size against maximum likely operational and residual flows to ensure it is not undersized. A 50-year flood is deemed an appropriate balance between risk and cost for a pre-feasibility level assessment. Subsequent stages will consider site specific flood management requirements and diversion sizing.

Service and emergency spillways are an essential component of dams, providing the ability for large storm events to bypass the structure without overtopping or damage. Design flood events for each reservoir are assigned based on their potential impact classification, and typically range from a 1,000-year flood for a Low PIC up to the Probable Maximum Flood (PMF) for High PIC dams.

High intensity rainfall data up to a 250-year storm for each reservoir site was obtained from NIWA's High Intensity Rainfall Design System (HIRDS[9]). The Kaipara area receives around 25% less rainfall and is much more consistent across sites compared to the Mid-North area – refer Figure below.

1,000-year and 10,000-year rainfall depths were approximated by extrapolating results from the HIRDS v4 database using a logarithmic line of best fit. The peak maximum precipitation (PMP) was calculated using the method outlined in "*Probable maximum precipitation in New Zealand for small areas and short durations"* (Thompson and Tomlinson, 1993) and "*A guide to probable maximum precipitation in New Zealand"* (Thompson and Tomlinson, 1995).

Inflows to each reservoir were estimated using the rational formula. A check of the inflows was made using HEC-HMS for one representative (average) catchment in each area. Outflows were then estimated via reservoir routing applying the simplified method presented in "*Preliminary Sizing of Detention Reservoirs to Reduce Peak Discharges"* (McEnroe, 1992). The routing procedure was undertaken on a range of storm durations between 10 mins and 120 hours to determine the critical storm duration in terms of outflow.

[9] https://www.niwa.co.nz/software/hirds

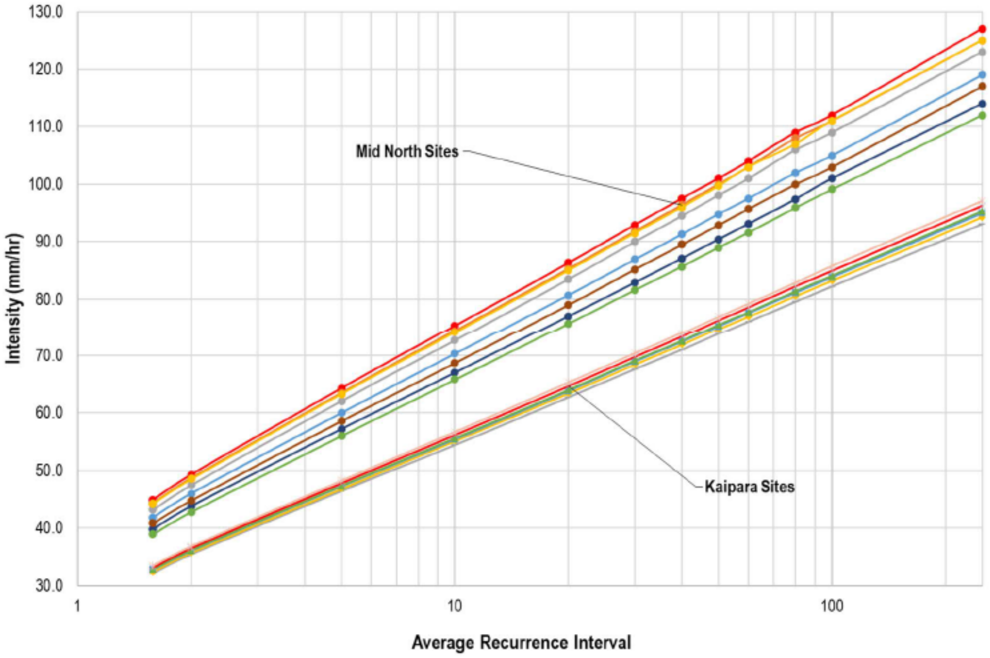

Figure 24. HIRDS rainfall data from reservoir sites.

Table 40. Catchment statistics.

Reservoir	Catchment Size (km²)	Mean Annual Flow (m³/s)	Runoff Coefficient	Elevation Range (m)	Average Slope (%)	Time of Concentration Tc (min)
Kaipara Reservoirs						
[redacted]	7.8	3.5	0.45	3-125	5%	30
[redacted]	6.4	3.1	0.45	4-124	4%	40
[redacted]	2.8	1.2	0.45	7-141	4%	40
[redacted]	2.2	1.7	0.45	4-140	6%	25
Mid-North Reservoirs						
[redacted]	12.3					
[redacted]	10.6					
[redacted]	0.3	1.77	0.65	138-176	3%	20
[redacted]	0.5	0.4	0.65	114-154	2%	30
[redacted]	3.1	4.0	0.60	188-353	7%	25
[redacted]	12.8	12.7	0.60	109-230	4%	60
[redacted]	1.0	2.6	0.65	232-301	10%	15
[redacted]	5.2	17	0.60	124-267	2%	75
[redacted]	3.2	4	0.60	137-381	7%	30

Table 41. Flood diversion results for 50-year flood.

Reservoir	Critical duration	Qin (m3/s)	Qout (m3/s)	Attenuation / routing	Coffer Dam height (m)	Conduit Size (m)
Kaipara Reservoirs						
[redacted]	6hrs	17.2	5.9	66%	4.0	1.2mΦ
[redacted]	6hrs	17.2	5.9	66%	4.0	1.2mΦ
[redacted]	6hrs	14.1	4.7	67%	2.5	1.3mΦ
[redacted]	6hrs	6.3	2.4	62%	2.0	1.0mΦ
[redacted]	6hrs	4.8	1.9	60%	1.0	0.53mΦ
Mid-North Reservoirs						
[redacted]					4.0	1.5mΦ
[redacted]					4.0	3x4m box
[redacted]	30min	5.5	2.8	49%	2.5	1.0mΦ
[redacted]	10min	15.5	11.5	26%	3.5	1.8mΦ
[redacted]	6hrs	16.3	8.3	49%	4.0	1.5mΦ
[redacted]	Detailed analysis warranted					
[redacted]	2hr	8.7	5.1	41%	3.5	1.2mΦ
[redacted]	2hr	38.5	18.9	51%	3.0	2.6mΦ
[redacted]	12hr	8.3	3.6	57%	3.2	1.2mΦ

Table 42. Spillway capacity design.

Reservoir	PIC	Design Storm	Critical duration	Qin (m^3/s)	Qout (m^3/s)	Attenuation / routing	Spillway Depth (m)	Spillway Width (m)
Kaipara Reservoirs								
[redacted]	High	PMF	2hrs	146.7	86.3	41%	2.0	50
[redacted]	High	PMF	6hrs	86.6	62.0	28%	2.0	40
[redacted]	High	PMF	6hrs	71.1	20.2	72%	2.0	15
[redacted]	Low	1,000-yr	12hrs	6.1	2.2	64%	2.0	10
[redacted]	High	PMF	6hrs	24.4	17.8	27%	2.0	10
Mid-North Reservoirs								
[redacted]	High	PMF					2.5	30
[redacted]	High	PMF	Detailed analysis warranted				3.0	100
[redacted]	Medium	10,000-yr	6hrs	2.9	1.8	38%	2.0	10
[redacted]	Low	1,000-yr	12hrs	2.4	1.2	50%	2.0	10
[redacted]	High	PMF	6hrs	70.3	69.3	1%	2.5	25
[redacted]	Medium	10,000-yr	Detailed analysis warranted				3.3	130
[redacted]	High	PMF	1hrs	37.8	30.3	20%	2.0	20
[redacted]	Low	1,000-yr	30min	115.2	59.5	48%	2.5	20
[redacted]	Low	1,000-yr	6hrs	12.5	5.9	53%	2.5	10

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