Warkworth to Wellsford

Catchment Sediment Modelling

Technical Report

July 2019

QUALITY ASSURANCE

Prepared By

Jacobs GHD Joint Venture in association with Ridley Dunphy Environmental Ltd. Prepared subject to the terms of the Professional Services Contract between the Client and GHD Jacobs Joint Venture for the Route Protection and Consenting of the Warkworth to Wellsford Project.

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GLOSSARY AND DEFINED TERMS

Refer to the Water Assessment Report for a master glossary and defined terms table.

TABLE OF CONTENTS

1	**INTRODUCTION**	**1**
1.1	Project background	1
1.2	Project features	3
1.3	Purpose and structure of this report	5
1.4	Overview and context of the catchment sediment models	7
2	**INDICATIVE CONSTRUCTION DESIGN**	**9**
2.1	Indicative construction programme	9
2.2	Indicative earthwork areas	9
2.3	Erosion and sediment control	13
3	**MAHURANGI HARBOUR SEDIMENT LOAD ASSESSMENT**	**15**
3.1	Introduction	15
3.2	Study area	17
3.3	Previous studies	18
3.4	Applicability of P-Wk BNZ/GLEAMS model	18
3.5	Mahurangi catchment sediment model results	20
4	**KAIPARA HARBOUR SEDIMENT LOAD ASSESSMENT**	**30**
4.1	Introduction	30
4.2	Study area	30
4.3	Previous studies	32
4.4	Kaipara Harbour Model Overview	32
4.5	Hydrological model development	35
4.6	Sediment model development	55
4.7	Kaipara catchment pre-development sediment model outputs	68
4.8	Scenario modelling of Project construction	71
4.9	Construction model results	79
5	**FOREST HARVESTING**	**99**
5.1	Introduction	99
5.2	Matariki Forest – Hōteo River	99
5.3	Redwood Forest – Mahurangi River	102
6	**REFERENCES**	**105**
APPENDIX A	**MAHURANGI RIVER SEDIMENT MODEL**	**109**
APPENDIX B	**LITERATURE REVIEW: KAIPARA HARBOUR SEDIMENT STUDIES**	**113**
APPENDIX C	**PROJECT SOIL INVESTIGATIONS**	**120**
APPENDIX D	**COMPARISON OF DAILY RAINFALL**	**122**
APPENDIX E	**KAIPARA HARBOUR MODEL CALIBRATION AND VALIDATION FLOW DURATION CURVES**	**124**

APPENDIX F FORESTRY HARVESTING 127

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1 INTRODUCTION

1.1 Project background

The NZ Transport Agency (Transport Agency) is lodging a Notice of Requirement (NoR) and applications for resource consent (collectively referred to as "the Application") for the Warkworth to Wellsford Project (the Project).

The Project involves the construction, operation and maintenance of a new four lane state highway. The route is approximately 26km long. The Project commences at the interface with the Pūhoi to Warkworth project (P-Wk) near Woodcocks Road. It passes to the west of the existing State Highway 1 (SH1) alignment near The Dome, before crossing SH1 just south of the Hōteo River. North of the Hōteo River the Project passes to the east of Wellsford and Te Hana, bypassing these centres. The Project ties into the existing SH1 to the north of Te Hana near Maeneene Road. The proposed designation boundary and Indicative Alignment are shown in Figure 1 below.

For description purposes the Project has been divided into the following sections (as shown in Figure 1). These sections also reflect the indicative construction programme and sequencing.

a) Southern Section: From the southern extent of the Project at Warkworth to the northern tunnel portal.

b) Central Section: From the northern tunnel portal to the Hōteo River (southern abutment.

c) Northern Section: From the Hōteo River (northern abutment) to the northern tie in with existing SH1 near Maeneene Road.

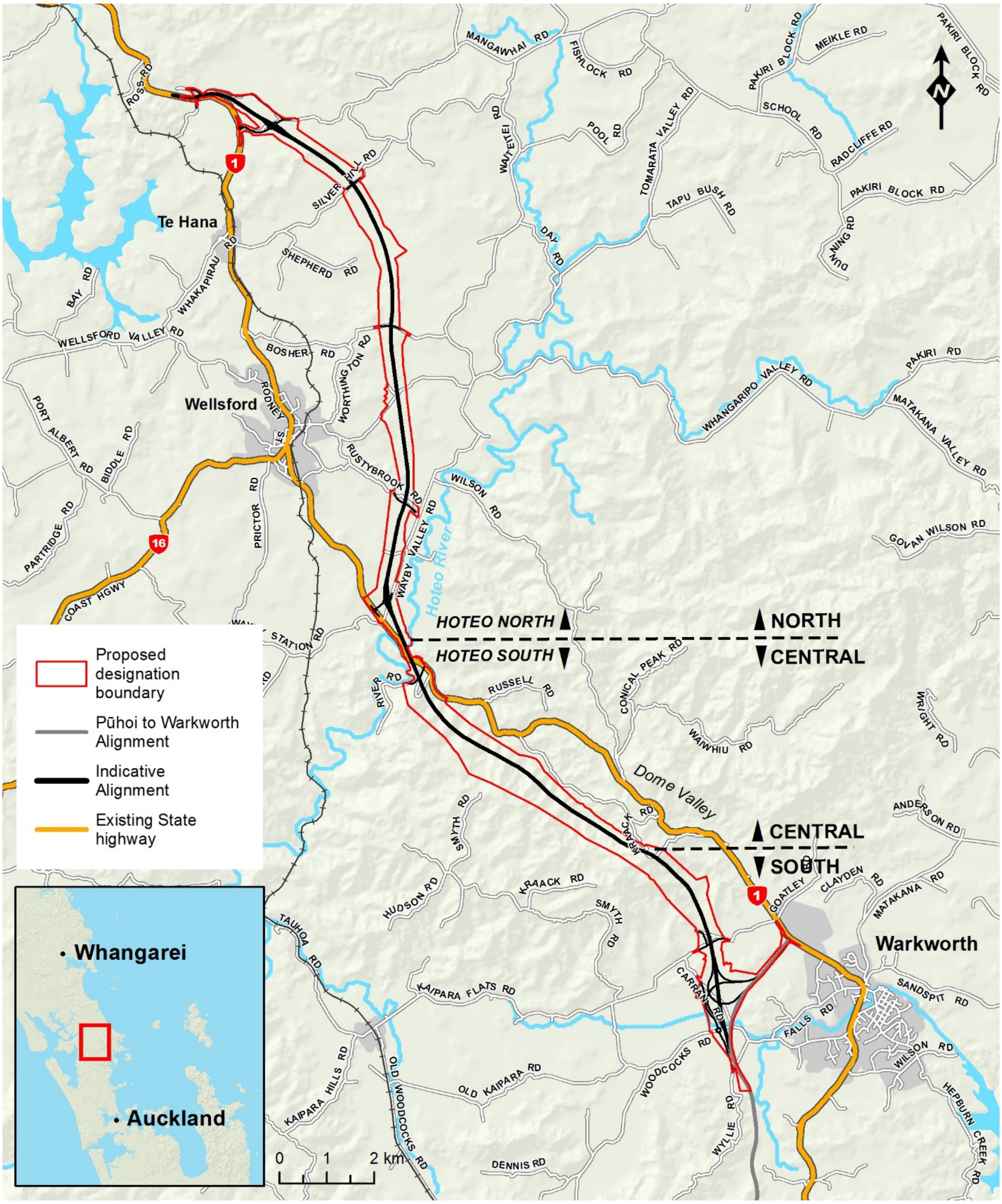

Figure 1 - Project Sections and Indicative Alignment

The proposed designation boundary and freshwater catchments relevant to the Project are shown in Figure 2 below.

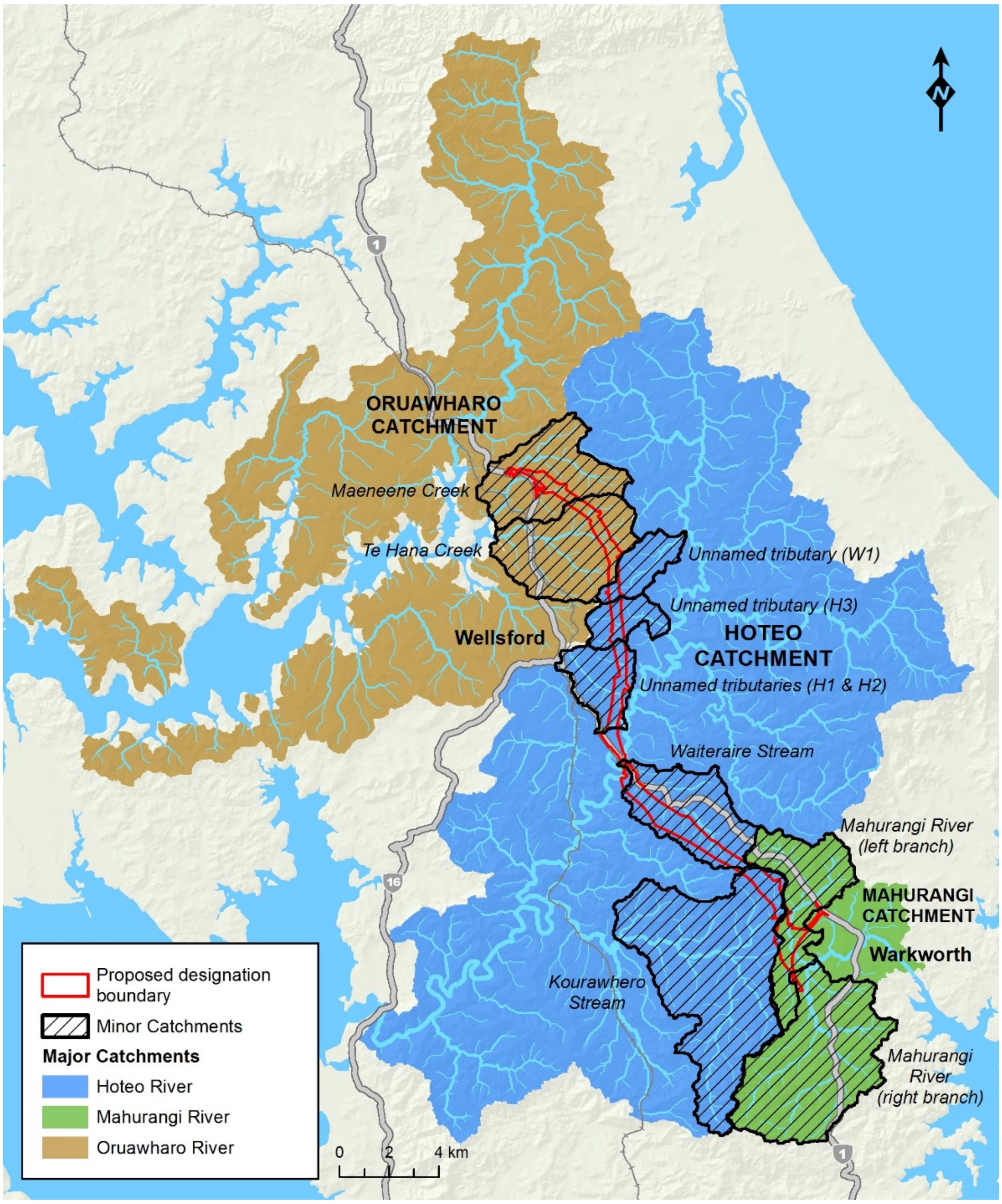

Figure 2 – Proposed designation boundary and freshwater catchments

1.2 Project features

The key features of the Project, based on the Indicative Alignment, are as follows:

a) A new four lane dual carriageway state highway, offline from the existing State Highway 1, with the potential for crawler lanes on the steeper grades.

b) Three interchanges as follows:

   i. Warkworth Interchange, to tie-in with the Pūhoi to Warkworth section of state highway and provide a connection to the northern outskirts of Warkworth.

   ii. Wellsford Interchange, located at Wayby Valley Road to provide access to Wellsford and eastern communities including Tomarata and Mangawhai.

iii. Te Hana Interchange, located at Mangawhai Road to provide access to Te Hana, Wellsford and communities including Port Albert, Tomarata and Mangawhai.

c) Twin bore tunnels under Kraack Road, each serving one direction, which are approximately 850 metres long and approximately 180 metres below ground level at the deepest point.

d) A series of steep cut and fills through the forestry area to the west of the existing SH1 within the Dome Valley and other areas of cut and fill along the remainder of the Project.

e) A viaduct (or twin bridge structures) approximately 485 metres long, to span over the existing SH1 and the Hōteo River.

f) A tie in to existing SH1 in the vicinity of Maeneene Road, including a bridge over Maeneene Stream.

g) Changes to local roads:

   i. Maintaining local road connections through grade separation (where one road is over or under the other). The Indicative Alignment passes over Woodcocks Road, Wayby Valley Road, Whangaripo Valley Road, Mangawhai Road and Maeneene Road. The Indicative Alignment passes under Kaipara Flats Road, Rustybrook Road, Farmers Lime Road and Silver Hill Road.

   ii. Realignment of sections of Wyllie Road, Carran Road, Kaipara Flats Road, Phillips Road, Wayby Valley Road, Mangawhai Road, Vipond Road, Maeneene Road and Waimanu Road.

   iii. Closing sections of Phillips Road, Robertson Road, Vipond Road and unformed roads affected by the Project.

h) Associated works including bridges, culverts, drainage, stormwater treatment systems, soil disposal sites, signage, lighting at interchanges, landscaping, realignment of access points to local roads, and maintenance facilities.

i) Construction activities, including construction yards, lay down areas for storage of materials and establishment of construction access and haul roads.

A full description of the Project including its current design, construction and operation is provided in Section 4: Description of the Project and Section 5: Construction and Operation of the AEE contained in Volume 1 and shown on the Drawings in Volume 3.

The Indicative Alignment is a preliminary alignment for a state highway that could be constructed within the proposed designation boundary. The assessment within this Catchment Sediment Modelling report provides inputs into the assessment of the effects of the Indicative Alignment, and also considers the sensitivity to effects if the alignment shifts within the proposed designation boundary when the design is finalised.

The final alignment for the Project (including the detailed design and location of associated works including bridges, culverts, stormwater management systems, soil disposal sites, signage, lighting at interchanges, landscaping, realignment of access points to local roads, and maintenance facilities), will be refined and confirmed at the detailed design stage.

1.3 Purpose and structure of this report

This Catchment Sediment Modelling technical report (this Report) forms part of a suite of water related design and technical reports prepared for the Ara Tūhono – Pūhoi to Wellsford - Warkworth to Wellsford section (the Project).

These reports are listed below with a short description of each:

- **Water Assessment Report (WAR) –** This report contains a summary of the work carried out and assessment of water related effects associated with construction and operation of the Project.
- **Construction Water Management Design technical report–** This report contains indicative details of the proposed construction methodology, proposed erosion and sediment controls (ESCs), and other construction phase mitigation measures recommended to reduce and erosion and sediment laden stormwater discharges from entering the receiving environment during construction.
- **Operational Water Design technical report** – This report contains details of the operational stormwater management and other operational phase mitigation by design.
- **Existing Water Quality technical report** – This report summarises water quality monitoring carried out by Auckland Council and for the Project.
- **Catchment Sediment Modelling technical report (this report)** – Sediment models have been developed to predict changes in sediment and water quality within receiving watercourses associated with the Project. This report summarises the modelling methodology and results.
- **Operational Water - Road Runoff technical report** – An assessment has been carried out to predict changes to water quality in relation to the Project and pollutants.
- **Flood Modelling technical report** – A model has been developed to predict any changes to flood risk associated with the Project. This report summarises any changes.
- **Hydrological technical report** – Catchment analysis has been developed to predict catchment wide hydrological changes associated with the Project. This report summarises predicted changes to the hydrological environment.

This purpose of this report is to estimate the construction sediment yield increases that would be delivered to the freshwater and marine environments during the Project construction phase due to earthworks utilising a modelling approach. This report informs the Water Assessment Report and the Assessment of Effects on the Environment (AEE). Figure 3 below summarises the relationship between each of the water related technical and assessment reports and the AEE.

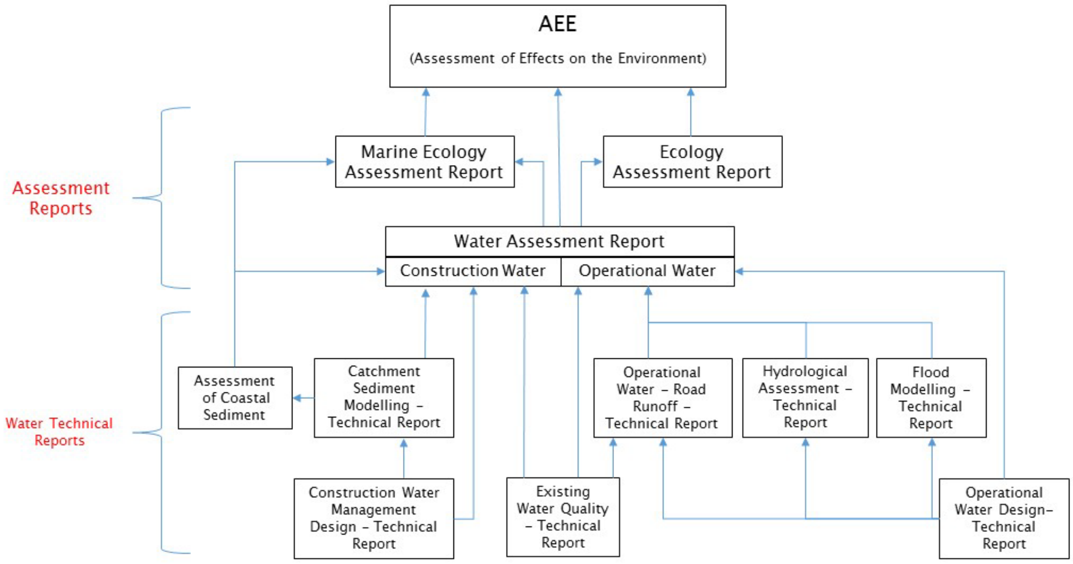

Figure 3 – Catchment Sediment Modelling technical report – relationship to other reports

The structure of this Report is as follows:

- **Section 1 (this section)** – The purpose and the content of this report.
- **Section 2** – Describes the indicative construction design, including the construction programme, indicative earthwork areas and erosion and sediment controls.
- **Section 3** – Sets out the context, methodology and results of the assessment of construction sediment yields within the Mahurangi River catchment, and the predicted changes to sediment loads delivered to the Mahurangi Harbour.
- **Section 4** – Sets out the context, methodology and results of the modelled construction sediment loads within the Hōteo and Oruawharo River catchments, and the predicted changes to construction sediment yields within the Hōteo and Oruawharo catchments, and the predicted changes to sediment loads delivered to the Kaipara Harbour.
- **Section 5** – Assesses the potential increases in sediment yield that could occur due to the harvesting of plantation forests located within the Hōt eo and Mahurangi River catchments.

1.4 Overview and context of the catchment sediment models

The construction of the Project has the potential to increase sedimentation within the receiving environment due to earthworks associated with construction activities (including extensive areas of cut and fill). An increase in sedimentation within a catchment draining to the Mahurangi and Kaipara Harbours has the potential to result in increased sediment delivery to the Kaipara Harbour.

Given that the harbours are sensitive to sediment, an integrated modelling approach was adopted to predict Project-related sediment loads associated with the road construction to assess the potential impact to the harbours. The model considers spatial and temporal variability in catchment hydrological processes and simulates the existing sediment budget through sediment generation and transport processes. The model is then used to assess the effectiveness of erosion and sediment controls under differing high flow events during road construction associated with the Project.

The river catchments that are potentially affected by the Project drain into two coastal waterbodies, the southern Kaipara Harbour and the Mahurangi Harbour.

This report documents the catchment-scale daily time-step sediment model that has been constructed and calibrated for all catchments draining to the southern Kaipara Harbour, including the Oruawharo River, using the eWater Source software (Welsh et al, 2012). The model provides estimates of sediment loads for input into biophysical models of the Kaipara Harbour.

This report also documents an assessment of predicted changes to sediment load in the Mahurangi River and Mahurangi Harbour associated with the Project. This assessment is based upon the results of an existing sediment model for the catchment. The Mahurangi Harbour was previously modelled as part of the Pūhoi to Warkworth (P-Wk) project. This report summarises the modelling conducted for the P-Wk project and includes an assessment of the predicted changes arising from the Project to sediment load within the Mahurangi River catchment and sedimentation within the Mahurangi Harbour.

The model linkages are shown in Figure 4.

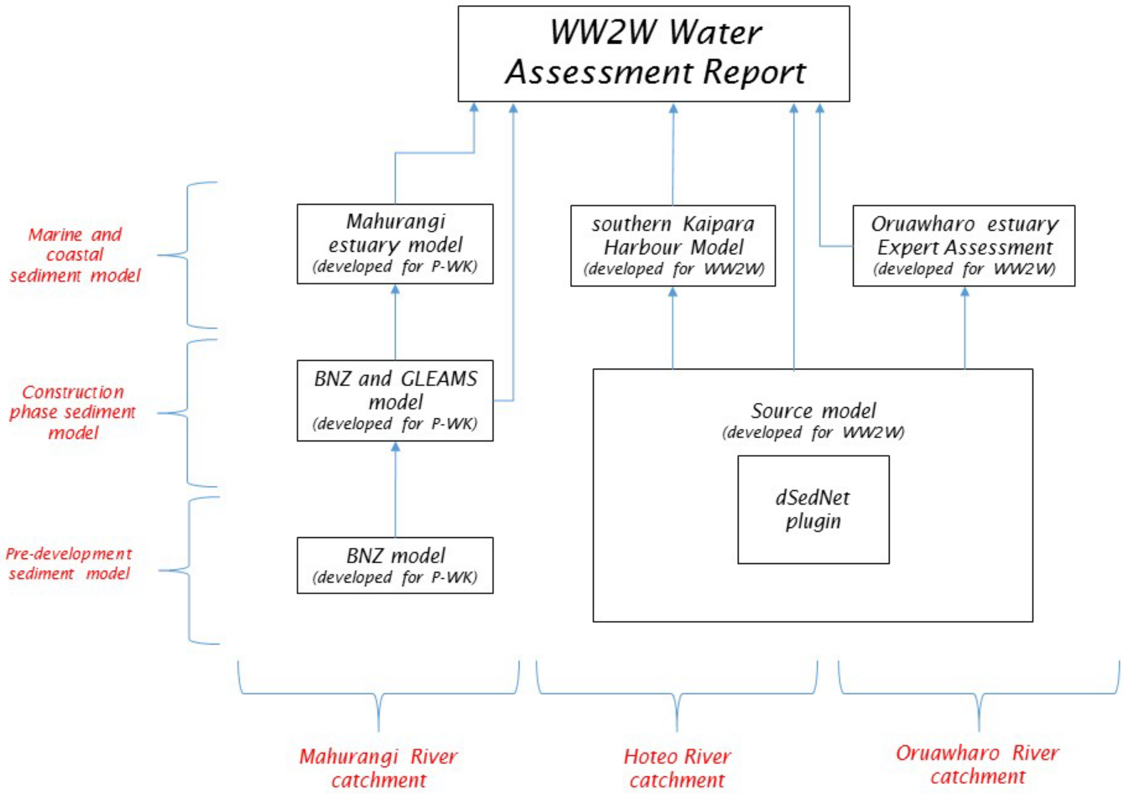

Figure 4 - Sediment model linkages

2 INDICATIVE CONSTRUCTION DESIGN

The indicative construction design is described in Section 5 of the AEE. The elements of the indicative construction design relevant to this report are construction sequencing, earthwork areas, and construction water management design. These elements are all detailed in the Construction Water Management Design - Technical Report.

2.1 Indicative construction programme

The Project has an Indicative construction programme of approximately 7 years. This comprises approximately one year of enabling works early construction activities (referred to as "Year 0"), and an estimated 6-year bulk earthwork construction period. This timeframe is only an estimate, based upon the Indicative Alignment and the construction methodology outlined in the Project Assessment of Effects on the Environment (AEE).

2.2 Indicative earthwork areas

The total earthworks area for the Project is estimated to be 310ha. The construction area is split into three main catchments with these catchments also forming the basis of the assessment within the WAR. Within the Hōteo River catchment (which involves the largest construction area) the construction areas have been further split into six indicative operational areas (Table 1), these are shown on Figure 5 to Figure 8. This approach has been adopted to inform the overall assessment; the Hōteo Operational Areas are split based upon key construction features such as bridges and tunnels.

Table 1 – Indicative earthwork areas

Catchment	Operation	Subcatchment(s)	Total earthworks area (ha)
Mahurangi River	-	Mahurangi River (right branch and left branch)	43.3
Hōteo River	Operation 1	Kourawhero Stream	23.7
	Operation 2	Waiteraire Stream	42.6
	Operation 3	Waiteraire Stream	27.0
	Operation 4	Waiteraire Stream and Hōteo River	21.8
	Operation 5	Hōteo River including unnamed tributaries	68.7
	Operation 6	Unnamed tributaries of Hōteo River	19.6
Oruawharo	-	Te Hana Creek & Maeneene Creek	63.3

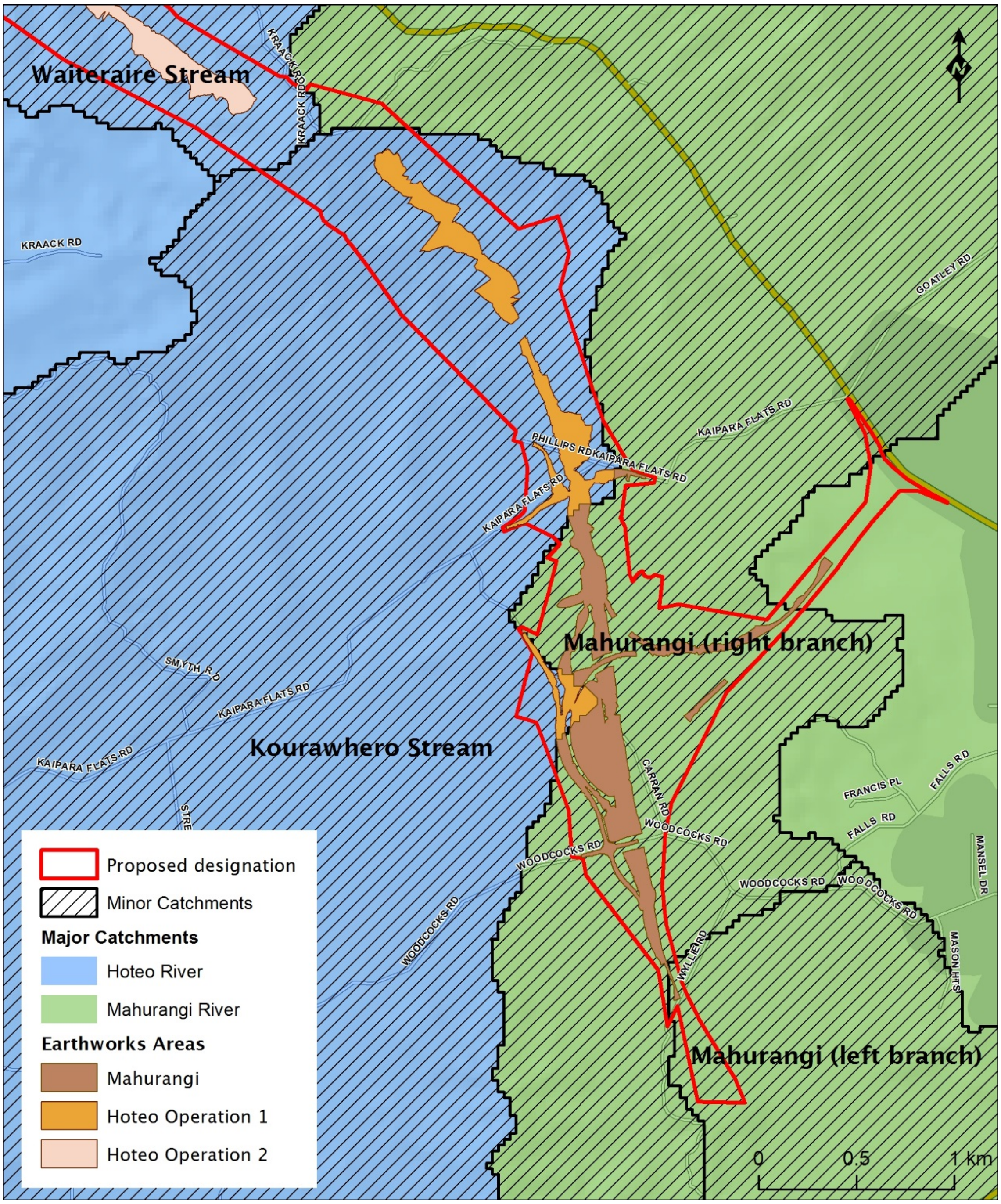

Figure 5 - Indicative earthwork areas – Mahurangi and Hōteo Operation 1 (Kourawhero Stream)

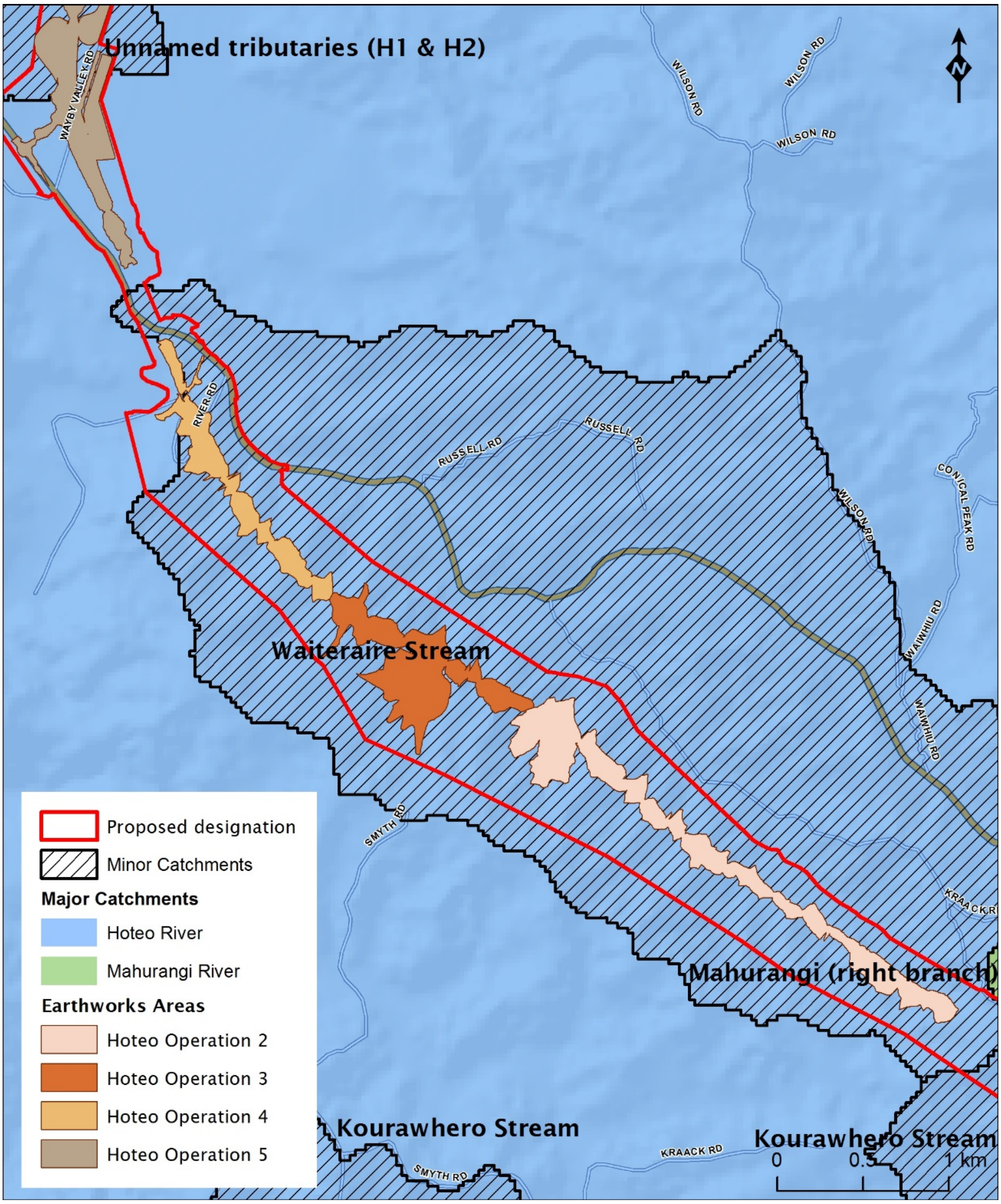

Figure 6 - Indicative earthwork areas – Hōteo Operation 2-4 (Waiteraire Stream)

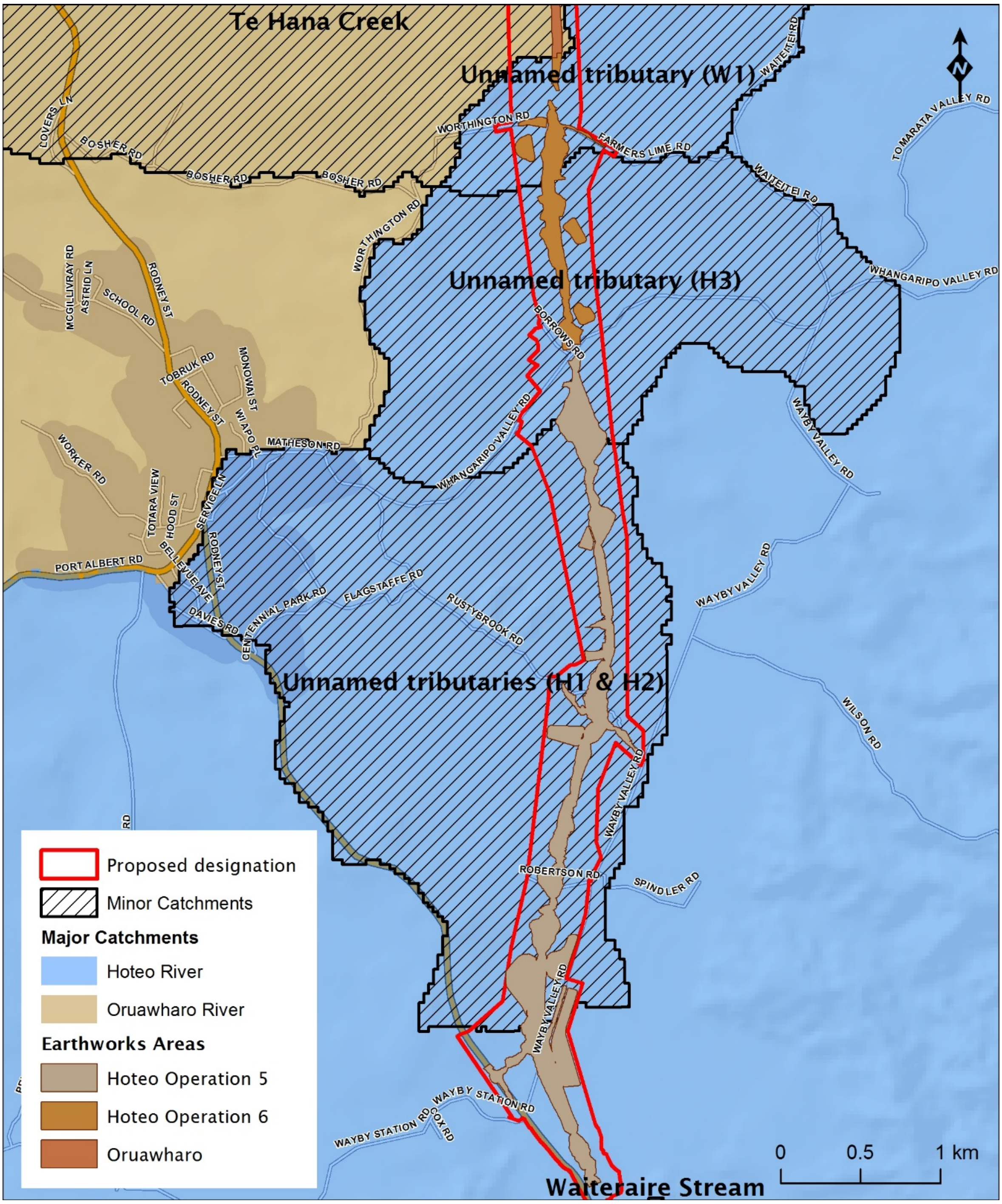

Figure 7 - Indicative earthwork areas – Hōteo Operation 5-6 (Unnamed Hōteo tributaries)

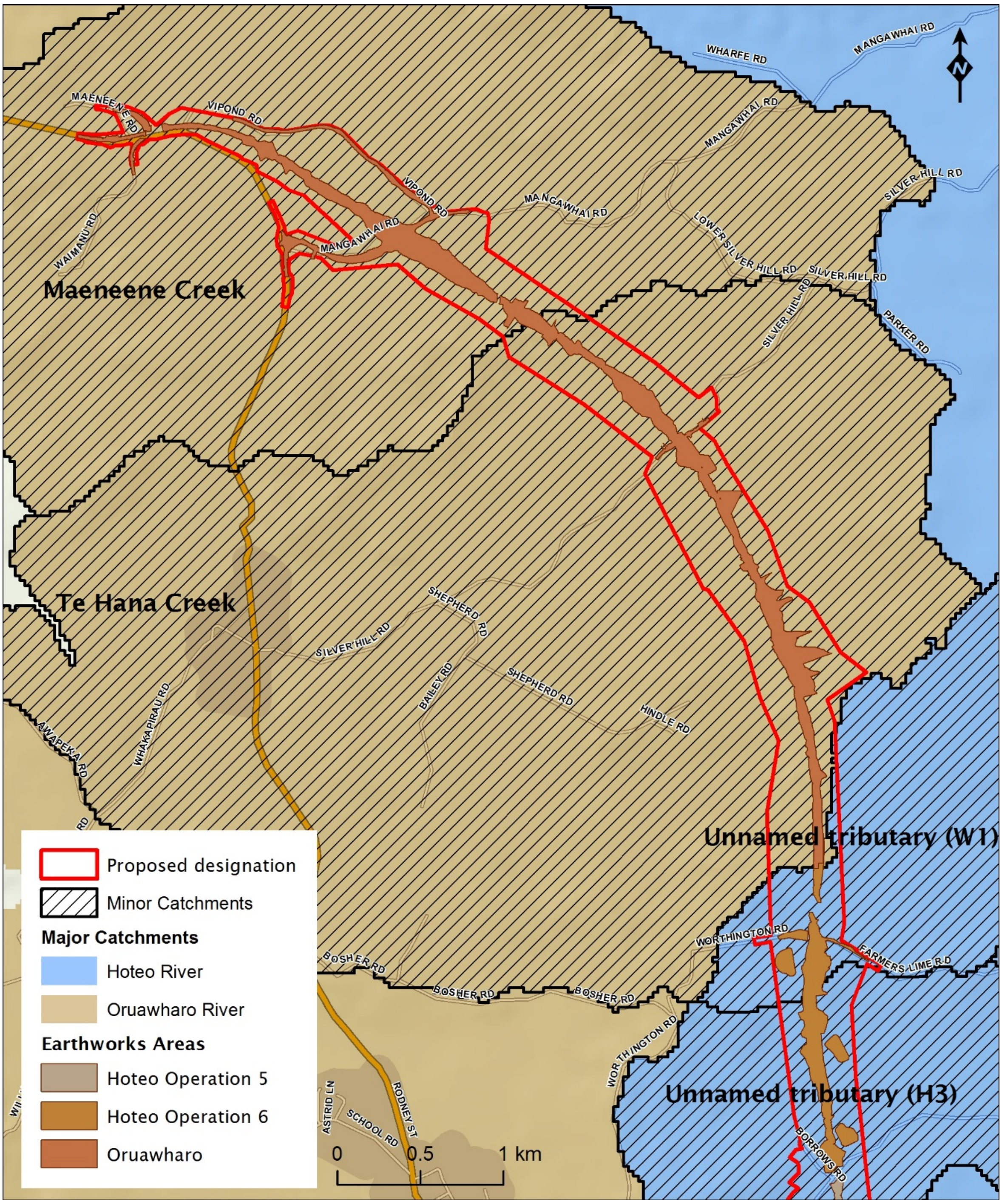

Figure 8 - Indicative earthwork areas – Oruawharo

2.3 Erosion and sediment control

During construction it is standard good practice to apply erosion and sediment control measures. For the Project several sediment control options are available, including super-silt fences (SSF), chemically-treated sediment retention ponds (SRP) and decanting earth bunds (DEB). Table 2 states the sediment yield reduction factors that these sediment control measures provide at different Annual Recurrence Intervals (ARI) rainfall events. These sediment yield reduction factors have been applied for the Project and were also utilised for the P-Wk project through the consenting process.

Table 2 – Sediment yield reduction factors for erosion and sediment control options for different ARI events (Harper et al, 2013)

Option	Yield reduction factor (%)		
	2-year ARI	10-year ARI	50-year ARI
Sediment retention pond	95%	85%	65%
Super-silt fence	80%	65%	50%
Decanting earth bund	90%	80%	60%

3 MAHURANGI HARBOUR SEDIMENT LOAD ASSESSMENT

3.1 Introduction

The assessment of sediment load delivery to the Mahurangi Harbour associated with the Project is based upon an existing sediment model for the estuary that was developed for the P-Wk project.

In 2013 NIWA was contracted by the Further North Alliance (the Transport Agency's contracted consenting consortium) to provide an assessment of sediment loads associated with the construction of the P-Wk project. The model is documented in the P-Wk Water Assessment Factual Report 3: Estimates of Construction Sediment Loads using the GLEAMS model (Harper et al, 2013). The report includes an assessment of:

- catchment background sediment loads; and
- construction phase sediment loads.

The hydrological sediment model developed by NIWA for the P-Wk assessment was based on the Basin New Zealand (BNZ) modelling study (Stroud & Cooper, 1997), which was used to estimate catchment background loads. NIWA then developed a Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) Hill-slope process model for two specified focus areas to analyse construction sediment loads, as shown on Figure 9.

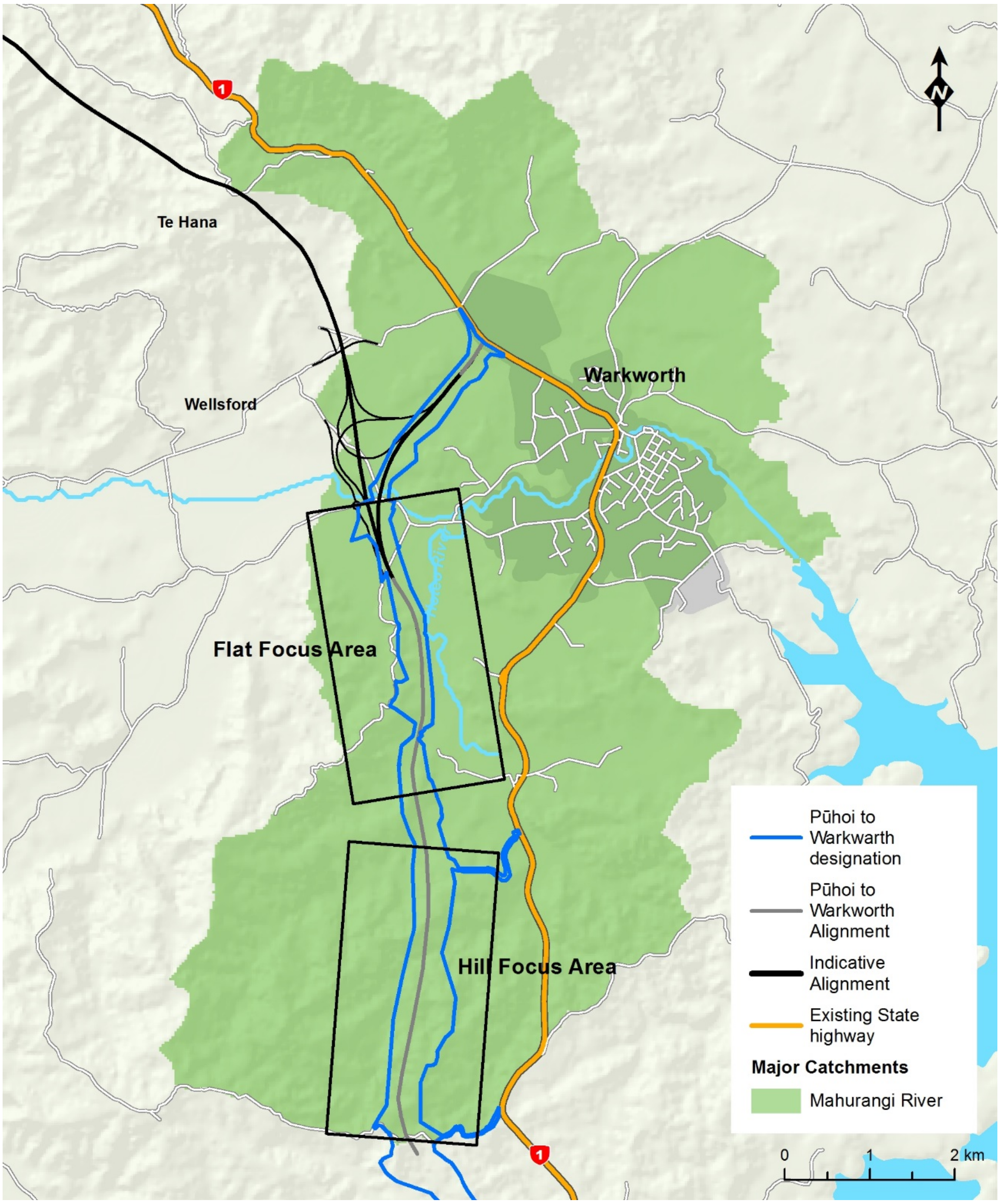

Figure 9 – P-Wk Project - GLEAMS focus areas (Further North, 2013)

The southern part of the Project is within the Mahurangi River catchment immediately to the north of the study area used for the GLEAMS modelling conducted by NIWA as part of the P-Wk project, as shown on Figure 10. We consider these previously modelled areas are sufficiently similar to the part of the Project in the Mahurangi Harbour catchment to support conclusions on Project sediment generation and yield estimates, as discussed in the following sections.

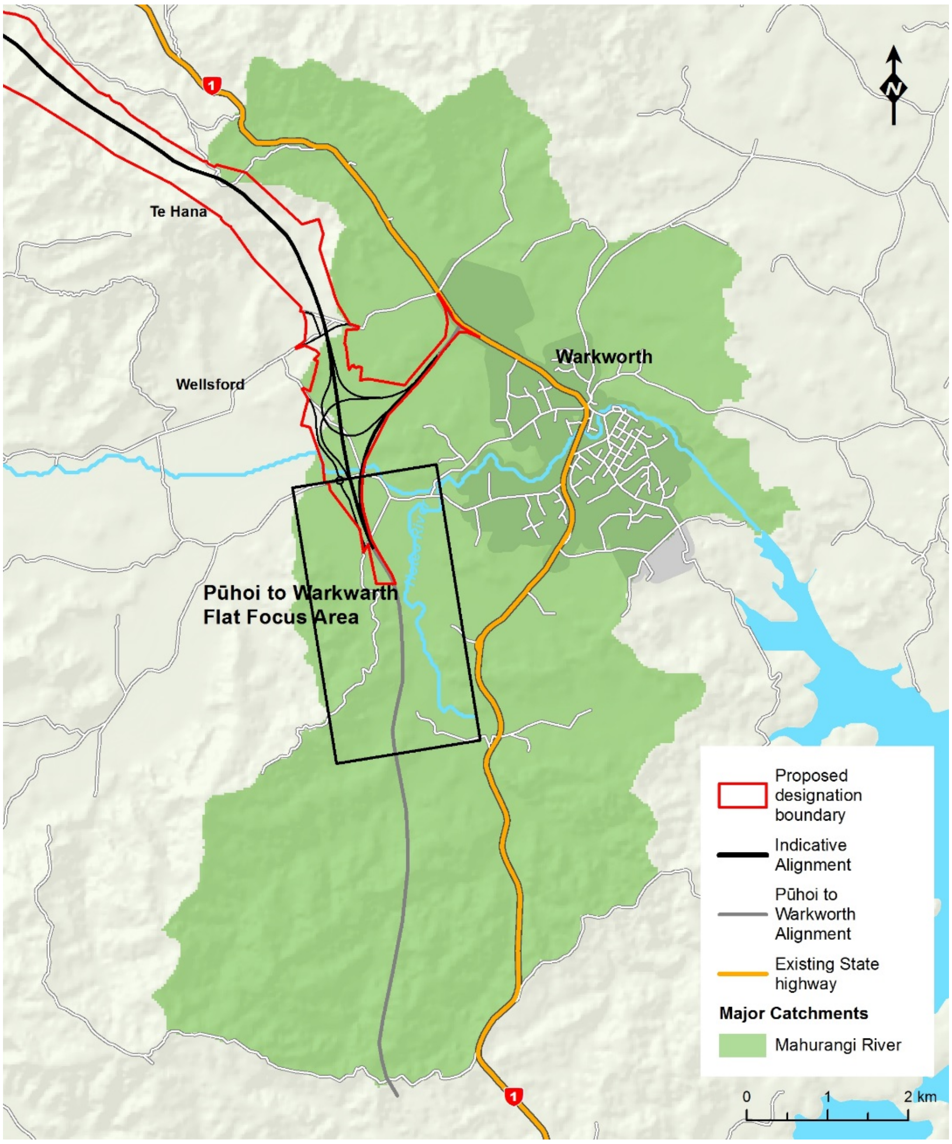

Figure 10 – Project Indicative Alignment within Mahurangi catchment including P-Wk "Flats" focus area

3.2 Study area

The study area within the Mahurangi Catchment assessment for the Project includes the entire Mahurangi River catchment including the Mahurangi Harbour, as shown in Figure 10.

The Mahurangi River has two main branches, the right and left branches. The Mahurangi River (Right Branch) originates in the south of the catchment and flows in a northerly direction. The Mahurangi River (Left Branch) originates in the north of the catchment in Dome Valley and flows in a southerly direction. The branches meet to the west of Warkworth, prior to flowing through Warkworth and discharging to Mahurangi Harbour.

The upper reaches of the Mahurangi River (North and South Branches) are steep, and the land use is generally forested. The area in the lower reaches around Warkworth is generally flat and is pasture and cropland. Warkworth is a large urban area which is wholly within the

Mahurangi River catchment. The river immediately upstream of the Mahurangi Harbour is estuarine.

The Mahurangi Harbour is a long estuary flowing southwards from Warkworth. There are many small bays and estuaries along the sides of the estuary with two larger arms to the south. Many of the small bays and upper estuaries dry during the tidal cycle and are comprised of soft muddy fine sediment.

Water within the river catchment supports aquatic habitats and fisheries and is used for irrigation and livestock watering. The water within the harbour supports aquatic habitats and fisheries.

The Mahurangi River previously provided drinking water for the town of Warkworth, however, Watercare have confirmed a change from surface water to groundwater abstraction occurring at the end of 2018.

3.3 Previous studies

The *P-Wk Water Assessment Factual Report 3: Estimates of Construction Sediment Loads using the GLEAMS Model* provided an overview of previous NIWA studies in and around the Mahurangi Harbour catchment. Due to the similar study area, these previous studies are also of relevance to the Project and are listed below:

- A 1990 modelling study of long-term sediment loads delivered to the Mahurangi Harbour conducted by NIWA for the then Auckland Regional Council (ARC).
- A 2007 field study undertaken to evaluate the performance of chemically-treated sediment retention ponds, conducted by NIWA for the ARC.

A summary of each report is contained in Appendix A. The 1990 assessment was used to generate estimates of catchment background loads and to form the basis of assessments of particle size distributions and sediment delivery to receiving waterbodies used within the BNZ/GLEAMS model. The 2007 study was used to inform the performance of sediment retention points applied in the model.

3.4 Applicability of P-Wk BNZ/GLEAMS model

The Project earthworks area in the Mahurangi catchment is similar to the P-Wk “Flats” focus area, relating to hydrology, slope, and soils, as summarised in Table 3. In addition, similar erosion and sediment controls will be employed through construction. As such we are confident that the “Flats” focus area studied for P-Wk, would have similar sediment yield processes as the earthworks area that will be constructed as part of the Project in the Mahurangi catchment.

Table 3 – Comparison of characteristics of all P-Wk modelled areas, the P-Wk 'Flats focus area' and Project indicative earthwork area within Mahurangi River catchment

	Mahurangi River P-Wk modelled area[A]	P-Wk 'Flats' focus area	Project indicative earthworks
River catchment	Mahurangi River (left branch and right branch)		
2 ARI event rainfall[B]	113mm	103mm	105mm
Existing land use[C]	Pasture & forestry	Pasture	Pasture & forestry
Slope (DEM)[D]	Flat to steep (0-30°)	Flat to rolling (0-20°)	Flat or undulating (0-13°)
Soils[E]	Clay, Clay loam	Clay, Clay loam	Clay, sand
Geology[F]	Pakiri Formation	Alluvium and Pakiri Formation	Alluvium and Pakiri Formation
Approximate length[G,H]	7.01km	3.76km	2.5km (mainline)
Approximate earthwork area[G,H]	89.9ha	35.7ha	43.3ha
Peak active earthwork area[G,H]	109.3ha	35.7ha	43.3ha

Data sources

A – Modelled areas are P-Wk "Flats" and "Hills" focus area, which comprise majority of total earthworks (101ha) within the Mahurangi River catchment.
B – Rainfall data from NIWA High Intensity Rainfall Systems (HIRDS) v3 (https://hirds.niwa.co.nz/) for 2-year ARI 24h duration
C – Land use derived from LCDB v4
D – Slope obtained from Digital Elevation Model (DEM) GIS layer
E – Derived from FSL New Zealand Soil Classification GIS layer
F – Obtained from Hydrogeology Assessment Report for P-Wk and Project
G – Data regarding P-Wk construction obtained from the P-Wk sediment report (Harper et al, 2013) unless noted otherwise
H – Project construction data obtained from Project team

The Mahurangi Harbour modelling, undertaken for the P-Wk assessment, used the "Flats" peak earthworks area of 21.5ha and the "Hills" peak earthworks area of 41ha as the peak scenario to calculate the peak event sediment yields using the GLEAMS model. This project proposes a maximum total open area of 43.3 ha and therefore, the increase in sediment yields delivered to the Mahurangi River for the Project is significantly smaller than would be expected to be generated by the P-Wk project.

The background sediment loads modelled for the Mahurangi Catchment were based on the calibrated BNZ/GLEAMS model and include the wider catchment prior to the year 2013. The background loads used for P-Wk are appropriate for the timeframe of the Project.

The BNZ/GLEAMS model does not consider the large scale plantation forest logging which is currently programmed to occur prior to the Project. Estimated Sediment yields from forestry are discussed in Section 5 of this report.

3.4.1 Construction timeframe

For the conceptual construction sequencing for the Mahurangi catchment, the majority of earthworks for the Project are assumed through the constructability assessment to occur in years 1-3, although the overall construction programme is approximately 7 years. The peak active earthworks are conservatively assumed to occur across all three years.

The P-Wk project modelling work addressed two different construction scenarios - a 5-year and 10-year construction period. The 5-year P-Wk construction period is most closely comparable to the Project as the bulk earthworks are estimated to occur during a 6-year period. Therefore, the results from the 5-year modelling work from P2W have been used for this report.

3.4.2 Earthwork area

The P-Wk project involved earthworks within the Mahurangi River catchment. For the purpose of that assessment the catchment was split between 'hills' and 'flats' areas (as focus areas) according to terrain with the consent process (through a Board of Inquiry) confirming the sediment yield potential of this flats focus area, in addition to the hills focus area. This was then reflected in consent conditions for P-Wk whereby open area limits of 21.5ha for "flats" and 41ha of "hills" earthworks could be exposed at any one time within the Mahurangi catchment to ensure the level of effect was acceptable. It was further confirmed through the P-Wk consenting process that due to the different sediment generating potential of "flats" vs "hills" that this 21.5ha and 41ha was the equivalent of 109.3ha of "flats" earthworks, with no corresponding "hills" earthworks occurring.

The Indicative Alignment is adjacent to, and has similar topography, geology and rainfall, to the 'Flats Focus area' at Perry Road and Carran Road and is assessed as having the same potential for sediment generation and yield on a per hectare basis.

The total area of earthworks within the Mahurangi catchment is 43.3ha for the Project, with a peak area of active earthworks of 43.3ha. This peak earthwork area has been set to achieve the Project programme. Therefore, the peak earthwork area of the Project is significantly less (2.5 times) than the currently consented 109.3ha for the P-Wk project. This also corresponds to a significantly smaller sediment load for the Project earthworks within the Mahurangi catchment than consented for the P-Wk project, as discussed in the following sections.

3.5 Mahurangi catchment sediment model results

This section presents a summary of the Mahurangi River catchment "*Estimates of Construction Sediment Loads 2013*" report for the P-Wk Notice of Requirement (Harper et al, 2013).

The data presented is based on the BNZ/GLEAMS model carried out by NIWA for the P-Wk project. For the reasons given in section 3.4 above, we do not consider it necessary to rerun this model as part of the assessment.

3.5.1 Pre-development scenario results

Methods

The modelling methods used to estimate sediment loads delivered to the Mahurangi Harbour were based on the previous NIWA studies of the Mahurangi Harbour. The BNZ model was used, which gives a 20-year time series (1976-1995) of daily sediment loads and associated runoff from individual sub-catchments (assumes no change in land cover). The

BNZ model was then used by NIWA as the background load in the GLEAMS model, which also incorporated the construction area of the P-Wk project (discussed further in Appendix A).

This Project and the P-Wk project use the BNZ/GLEAMS modelling study of the Mahurangi Harbour (Harper et al, 2013) to determine runoff and sediment load estimates for Mahurangi River sub-catchments. The model includes a 20-year time-series of daily runoff and sediment load estimates. For each sub-catchment the daily sediment loads were analysed to determine mean annual loads and event-based loads delivered to the harbour.

The daily event sediment loads were calculated for both the pre-development scenario and the construction scenario by carrying out a statistical analysis of the daily sediment load outputs, by fitting a Generalized Extreme Value (GEV) distribution to the annual maximum series.

Pre-development scenario load estimates

The P-Wk model estimated the mean annual sediment loads and associated runoff volume for each sub-catchment and at selected stream assessment sites in the Mahurangi River. The Mahurangi River was assessed at the river mouth and at two freshwater sites: the right branch of the Mahurangi River at the Forestry Headquarters (AC-FHQ) and the Mahurangi River main stem at the confluence of the left and right branches (MW). The results in Table 4 are the pre-development scenario loads. The P-Wk model estimated event daily sediment loads for each subcatchment and at selected stream assessment sites in the Mahurangi River (Table 5).

Table 4 – Estimated mean annual sediment load and runoff (Harper et al, 2013)

Location type	Location	Area (ha)	Load (T)	Runoff ($10^3 m^3$)
Selected stream sites	Mahurangi River - AC-FHQ	-	1,101	1,258
	Mahurangi River - MW	-	6,316	11,647
Sub-catchment delivery to Mahurangi Harbour	Mahurangi River outlet	5,825	12,193	24,459
	Total Mahurangi Harbour	11,675	45,931	53,988

Table 5 – Estimated daily sediment loads delivered to the Mahurangi Harbour and at selected stream sites in the Mahurangi River (Harper et al, 2013)

Location type	Location	ARI	Estimated daily sediment load (T)
Selected stream sites	Mahurangi River - AC-FHQ	2-year	226
		10-year	646
		50-year	1,652
	Mahurangi River - MW	2-year	1,296
		10-year	3,704
		50-year	9,481
Sub-catchment delivery to Mahurangi Harbour	Mahurangi River outlet	2-year	2,502
		10-year	7,152
		50-year	18,304
	Total Mahurangi Harbour	2-year	9,425
		10-year	28,938
		50-year	68,945

3.5.2 GLEAMS (P-Wk) construction scenario load results

Methods

The P-Wk assessment estimated mean annual sediment loads and ARI daily loads for the construction stage with and without treatment by erosion and sediment control measures (Section 2.3), for changing land-cover specified across the 5-year construction scenario, and for the maximum area of open earthworks in any one month.

The P-Wk BNZ/GLEAMS construction stage model has expected and worst case scenario outputs, which were calculated for the untreated options:

- The expected scenario outputs are 50-year time-series of daily sediment loads for the pre-development land-cover for each year of the proposed construction periods. These consider the land use and the size of rainfall events expected to occur when the earthworks are open, which are generally the summer months.
- The worst case model is a 50-year ARI time series of the maximum area of exposed earthworks in any one month. This scenario assumes that the earthworks remain open during all months of the year. A 50-year ARI storm is unlikely to occur during the 7-year construction period (refer to Section 6.1 of the WAR) and is very unlikely to coincide with the peak active area due to winter work limits.

The treated scenario modified the untreated daily time-series by applying the appropriate load reduction factors for the erosion and sediment control measures. For each modelled scenario NIWA calculated the mean annual sediment loads across the 50-year time period. The 2, 10 and 50 year ARI daily sediment loads were calculated by extracting the maximum daily load from the 50 years for a maximum series then fitting a generalized extreme values (GEV) statistical distribution to estimate the event frequency distribution and find the design event magnitude.

P-Wk construction load estimates

This section summarises the P-Wk construction load estimates, presented as the mean annual load and ARI daily sediments, both with and without treatment by erosion and sediment control measures (Table 6 to Table 8).

For the construction scenario the Fraction of Sediment Delivered to the Coast (FSDC) was set to 1 on the assumption that the full construction sediment yield is delivered to the catchment outlet. This is considered a reasonable assumption because the construction sediment is likely to be dominated by relatively finer soil particles compared to the background load, because the construction load will have passed through sediment retention devices, which will intercept the larger particles more readily than the fine particles.

The results are shown in Table 6, comparing the mean annual sediment yield for the "Flats" focus area and the total modelled P-Wk area ("Flats" and "Hills"). Table 7 shows the increase in load at the Mahurangi River mouth, which incorporates the additional load from the P-Wk "Flats" focus area and total earthworks area.

The ARI daily sediment yields for the fixed land-cover corresponding to the maximum area of exposed earthworks in the Mahurangi River is given in Table 8 for the "flats" focus area, as well as for the total P-WK area ("Flats" and "Hills").

Table 6 – Mean annual sediment yield (T) for the P-Wk "Flats" and "Hills" focus areas corresponding to the 'P-Wk project' changing land-cover during the 5-year construction period (Harper et al, 2013) adopted for Project

Year	P-Wk 'Flats' focus area yield (tonnes/year)							P-Wk "Hills" focus area yield (tonnes/year)						
	Pre-development	Untreated			Treated			Pre-development	Untreated			Treated		
		Yield (T)	Increase (T)	Increase (%)	Yield (T)	Increase (T)	Increase (%)		Yield (T)	Increase (T)	Increase (%)	Yield (T)	Increase (T)	Increase (%)
Year 1	435	833	398	91 %	472	37	9%	478	1066	588	123%	563	85	18%
Year 2	435	1,659	1,224	281%	532	97	22%	478	3,101	2,623	549%	853	375	78%
Year 3	435	1,487	1,052	242%	533	98	23%	478	6,555	6,077	1,271%	1,413	935	196%
Year 4	435	1,650	1,215	279%	560	125	29%	478	8,770	8,292	1,735%	1,953	1,475	309%
Year 5	435	483	48	11%	483	48	11%	478	2594	2,116	443%	1,598	1,120	234%
5-year total	2,175	6,113	3,937	181%	2,581	406	19%	2,390	22,086	19,696	824%	6,380	3,990	167%
Mean annual	435	1,223	787	181%	516	81	19%	478	4,417	3,939	824%	1,276	798	167%

Table 7 – Mean annual sediment load (T) for the Mahurangi River corresponding to the 'P-Wk project' changing land-cover during the 5-year construction period (Harper et al, 2013) adopted for Project

Year	Mahurangi Pre-development load	Mahurangi River outlet - "Flats" focus area only						Mahurangi River outlet - "Flats" and "Hills"					
		Untreated			Treated			Untreated			Treated		
		Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)
Year 1	12,193	12,591	398	3%	12,230	37	0.3%	13,179	986	8%	12,315	122	1.0%
Year 2	12,193	13,417	1,224	10%	12,290	97	0.8%	16,040	3,847	32%	12,666	472	3.9%
Year 3	12,193	13,245	1,052	9%	12,291	98	0.8%	19,322	7,129	58%	13,226	1,033	8.5%
Year 4	12,193	13,408	1,215	10%	12,318	125	1.0%	21,700	9,507	78%	13,793	1,600	13.1%
Year 5	12,193	12,241	48	0%	12,241	48	0.4%	14,357	2,164	18%	13,361	1,168	9.6%
5-year total	60,965	64,902	3,937	6%	61,371	406	0.7%	84,598	23,633	39%	65,361	4,396	7.2%
Mean annual	12,193	12,980	787	6%	12,274	81	0.7%	16,920	4,726	39%	13,072	879	7.2%

Table 8 – Daily sediment yield (T) for the P-Wk 'flats' focus area, and the daily sediment load (T) for the Mahurangi River (P-Wk "flats" focus area only and all P-Wk earthworks) corresponding to ARIs of 2, 10 and 50 years - Maximum area of exposed earthworks for 5-year construction scenario (Harper et al, 2013)

Location	Daily event ARI	Pre-development event load (T)	Construction (untreated) event loads			Construction (treated) event loads		
			Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)
P-Wk "flats" focus area event yields	2-year	106	685	579	546%	135	28	26%
	10-year	270	1,486	1,216	450%	472	202	75%
	50-year	579	2,742	2,163	374%	1,528	949	164%
Mahurangi River catchment outlet ("flats" focus area only)	2-year	2,502	3,081	579	23%	2,531	28	1.2%
	10-year	7,152	8,368	1,216	17%	7,354	202	2.8%
	50-year	18,304	20,467	2,163	12%	19,254	949	5.2%
Mahurangi River catchment outlet ("flats" and "Hills")	2-year	2,502	5,323	2,821	113%	2,826	324	13%
	10-year	7,152	13,050	5,898	82%	8,249	1,097	15%
	50-year	18,304	28,775	10,471	57%	21,844	3,540	19%

The P-Wk construction sediment yield of 4,396 tonnes across the 5-year construction period, including both the "hills" and "flats" areas, is considered an accepted sediment load. The effects of the construction of the P-Wk project were considered to be acceptable to the Mahurangi Harbour.

Given that the Project has a considerably smaller earthworks area, and therefore considerably smaller sediment load, the load is considered to be acceptable. As estimate of the Project sediment load increases is undertaken below.

3.5.3 Project construction load estimates

The outputs of the BNZ/GLEAMS model have been assessed to calculate the sediment yields associated with construction within the Mahurangi River catchment.

The Project construction area is very similar in physical characteristics (soils, slopes, landuse, rainfall) to the P-Wk "flats" focus area, as discussed in section 3.4. The construction erosion and sediment control measures are very similar to the P-Wk project, with similar structural and non-structural devices and treatment methods applied.

Mean annual loads

It is assumed that the increase in construction sediment yields on a per hectare basis are applicable between the two projects. The peak earthwork area for the P-Wk "flats" focus area is 21.5ha with a mean annual sediment yield of 560 tonnes in year 4 of the construction period, excluding the earthworks and corresponding sediment yield from "hills" focus areas. The construction sediment yield increase is estimated as 18.0 tonnes/ha for earthwork area.

Table 9 – Mean annual sediment yields (treated) for Project in the Mahurangi River catchment, based upon the P-Wk "flats" focus area

<table>
<tr><th colspan="2"></th><th>P-Wk 'Flats' focus area</th><th>Indicative Project earthwork area</th></tr>
<tr><td colspan="2">Total earthwork area</td><td>35.7ha</td><td>43.3ha</td></tr>
<tr><td colspan="2">Peak active earthwork area</td><td>21.5ha</td><td>43.3ha</td></tr>
<tr><td rowspan="4">Mean annual sediment yields (treated)</td><td>Pre-development</td><td>435 tonnes</td><td>-</td></tr>
<tr><td>Peak active earthworks</td><td>560 tonnes</td><td>-</td></tr>
<tr><td rowspan="2">Peak earthwork increase</td><td colspan="2">5.8 tonnes/ha</td></tr>
<tr><td>125 tonnes</td><td>252 tonnes[1]</td></tr>
<tr><td colspan="4">Notes:
1- Calculated using the P-Wk "flats" sediment yields</td></tr>
</table>

This assessment calculates the Project construction sediment load increase, and assumes that that the sediment yield increase from the peak year of the Project would be approximately twice the sediment yield for the P-Wk "flats" focus area during the peak year, given that it is approximately twice the area.

The potential mean annual sediment yield from the Project peak earthworks area can therefore be estimated as 250 tonnes/year, based on the assumption that the Project earthworks area has the same increase in sediment yield per hectare as for the P-Wk "Flats" focus area.

The Project peak earthworks occur during years 1-3 of the Project, therefore for this assessment this peak yield increase will be applied for the years 1-3 of the Project. Based on these peak yield assumptions, a yield per hectare based assessment of mean annual yields for the Project has been carried out, using the above P-Wk assumptions. An assessment of mean annual sediment yield for the Project is contained in Table 10.

In addition to assessing the peak annual sediment yield, the enabling works and early construction activities have also been included as Year 0. The enabling works include activities such as vegetation clearance, relocation of utilities and site investigations. Early construction activities include site establishment, construction of access roads and haul roads, trial embankment and provision of initial erosion and sediment control measures.

These activities will be defined and planned at the detailed design stage, and therefore the exact extent or location is not known. However, it is assumed that the earthworks required for the enabling works and site establishment could comprise as much as 10-15% of the total earthwork area within the Mahurangi catchment (43.3 ha). To conservatively assess the potential load associated with this, a 15% earthworks area has been assumed of 6.5ha, utilising the same increase in construction yield as for the P-Wk "flats" focus area. The results have been included in Table 10. An assessment of mean annual sediment load for the Mahurangi River for the Project is contained in Table 11.

Table 10 – Estimate of mean annual sediment yield (T) for the Project for the changing land-cover during the 7-year indicative construction programme, adapted from GLEAMS sediment yields per hectare

Year	Project construction yield increase (tonnes/year)				
	Construction area (ha)	Untreated		Treated	
		T/ha	T	T/ha	T
Year 0	6.5	56.5	367	5.8	38
Year 1	43.3		2,447		252
Year 2	43.3		2,447		252
Year 3	43.3		2,447		252
Year 4	0		0		0
Year 5	0		0		0
Year 6	0		0		0

Table 11 – Estimate of mean annual sediment load (T) for the Project for the changing land-cover during the 7-year indicative construction programme

Year	Mahurangi River outlet load (tonnes/year) for Project earthworks						
	Pre-development load (T)	Untreated			Treated		
		Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)
Year 0	12,193	12,560	367	3%	12,231	38	0.3%
Year 1	12,193	14,623	2,447	20%	12,443	252	2.1%
Year 2	12,193	14,623	2,447	20%	12,443	252	2.1%
Year 3	12,193	14,623	2,447	20%	12,443	252	2.1%
Year 4	12,193	12,193	0	0%	12,193	0	0.0%
Year 5	12,193	12,193	0	0%	12,193	0	0.0%
Year 6	12,193	12,193	0	0%	12,193	0	0.0%
5-year total	85,351	93,059	7,708	9%	86,144	793	0.9%
Mean annual	12,193	13,294	1,101	9%	12,306	113	0.9%

This assessment of mean annual sediment loads (Table 11) estimates an additional 793 tonnes of sediment to be delivered to the Mahurangi River and estuary across the indicative 7-year construction programme of the Project. This is significantly less (18%) of the P-Wk total sediment load increase of 4,396 tonnes.

Daily event sediment loads

A similar assessment of the daily ARI sediment loads for the Project has been carried out utilising the P-Wk GLEAMS sediment yields per hectare. The potential daily event sediment loads for the fixed land-cover scenario corresponding to the peak exposed earthworks (43.3ha) in the Mahurangi River is given in Table 12.

As noted above, the peak earthwork area for the Project is 43.3ha, which is approximately twice as large as the peak earthworks area for the P-Wk "flats" focus area (21.5ha).

Based on this, the Project peak earthwork daily sediment loads have been calculated by assuming that the increase in daily event sediment yields for the Project would be approximately twice that of the P-Wk "flats" focus area construction sediment yields. This assessment excludes the earthworks and corresponding sediment yield from "hills" focus areas.

Table 12 – High level assessment of daily sediment load (T) for the Project earthworks area and Mahurangi River corresponding to ARIs of 2, 10 and 50 years - peak area of exposed earthworks (summer year 1-3)

Location	Daily event ARI	Pre-development event load (T)	Construction (untreated) event loads			Construction (treated) event loads		
			Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)
Project peak earthworks daily event yields	2-year	-	-	1,166	-	-	56	-
	10-year	-	-	2,449	-	-	407	-
	50-year	-	-	4,356	-	-	1,911	-
Mahurangi River (Project peak earthworks)	2-year	2,502	3,081	1,166	47%	2,558	56	2%
	10-year	7,152	8,368	2,449	34%	7,559	407	6%
	50-year	18,304	20,467	4,356	24%	20,215	1,911	10%

This assessment of daily event sediment loads for 2, 10 and 50 year ARI storms (Table 12) occurring during the peak earthworks of the Project estimates that for the 2-year ARI event an additional 56 tonnes of sediment could be delivered to the Mahurangi catchment, that is significantly less (17%) of the increase in load associated with the P-Wk project. For the 10-year and 50-year ARI events an additional 407 tonnes and an additional 1,911 tonnes of sediment respectively could be delivered to the Mahurangi catchment. This is significantly less than the event load increases for the P-Wk Project which estimate 1,097 tonnes and 3,540 tonnes for the 10 and 50-year ARI events respectively.

Summary of Sediment Loads in Relation to P2W

The P-Wk project was approved through the Board of Inquiry, confirming that the predicted level of effect to the Mahurangi River from sediment loads generated through construction was acceptable.

An assessment of the potential sediment yields generated through the construction of the Project have found that the yields are considerably less than for P-Wk. The estimated increase in sediment load (mean annual load assessment) in the Mahurangi River due to the Project construction is estimated to be 793 tonnes across the indicative 7-year construction programme of the Project. This is significantly less (18%) of the P-Wk total sediment load increase of 4,396 tonnes. The Project has also assessed the potential increase in daily sediment load in the Mahurangi River that would occur with a range of storm events occurring during peak earthworks. The daily loads associated with the Project are significantly less (17-54%) of the P-Wk daily event loads.

4 KAIPARA HARBOUR SEDIMENT LOAD ASSESSMENT

4.1 Introduction

Catchment-scale sediment generation and transport modelling was undertaken to estimate sedimentation within the Kaipara Harbour from contributing catchments during road construction, and to assess the effectiveness of the erosion and sediment control that has been proposed for the Project. The model considers spatial and temporal variability in catchment hydrological processes and the resulting loads in sediment.

4.2 Study area

The model study area incorporates all catchments that drain into the Southern Kaipara Harbour and Oruawharo River including six large river catchments; that is the Hōteo River, the Hakaru River; Araparera River; the Makarau River; Kaukapakapa River; and the Kaipara River. The study area modelled subcatchments, including major rivers and some smaller streams, is shown in Figure 11. Unshaded areas are small catchments draining to Kaipara Harbour, and these were modelled as part of the assessment.

Generally, the land use across the study area is rural and mainly comprises forests and grassland pasture. The forests are located in the hills and upper reaches of catchments across the study area and are generally a mixture of indigenous forests and harvested exotic forests. The flatter lowland areas generally comprise grasslands, shrubs and some limited areas of crops. There are three main urban areas within the study area: Wellsford, located to the north partially within the Hōteo River catchment, and Helensville and Kumeu to the south, both located within the Kaipara River catchment. There are also several smaller urban areas dotted across the study area. There are additionally areas of natural wetlands including mangrove located around the Kaipara Harbour.

The topography varies across the study areas. Generally, the land nearer to the Harbour is flat, including both the Okakuhura Peninsula and the Te Korowai-o-Te-Tonga Peninsula. Catchments to the south of the study area are also generally flat or gently rolling, including the Kaipara River, the Kaukapakapa River and the Makarau River, with some hills in the upper reaches. The Hōteo River is steepest in the upper to middle reaches, as the river passes through the Dome Valley hills, and is flatter in the lower reaches.

The rivers within the catchments are subject to several different uses, including drinking water, irrigation, livestock water supply, and contact recreation.

The Kaipara Harbour is a complex drowned-valley enclosed estuary on the west coast of the Northland Peninsula (Gibbs et al, 2012). The harbour is composed of intertidal flat and shallow sub-tidal habitats, with deep channels following historic rivers. Sand barriers form north and south heads as well as tidal deltas, beach and dune systems. The harbour is an important natural fishery for snapper, is used as a commercial oyster fishery and other aquaculture and supports rich and varied aquatic habitats. The harbour receives runoff from a catchment of approximately 6,400 km^2, with the model study area covering 24%

(approximately 1,520 km^2) of this total catchment. The Wairoa River accounts for 63% of the Kaipara Harbour catchment; this is not modelled as it is considered too remote from the Project.

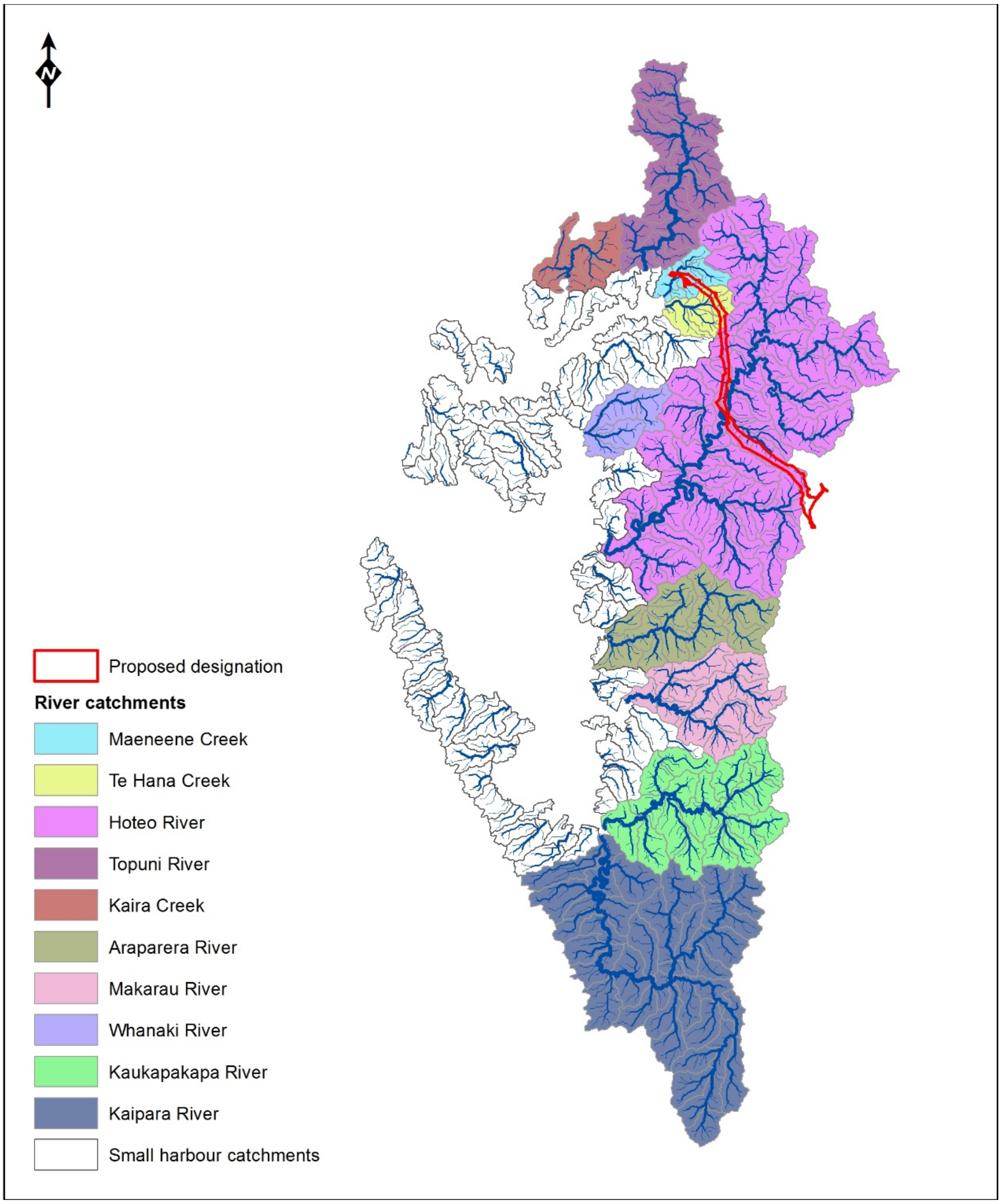

Figure 11 – Study area catchments. Unshaded areas are small catchments draining to Kaipara Harbour

4.3 Previous studies

A literature review was undertaken for relevant studies associated with sediment within the study area river catchments and Kaipara Harbour. The literature review identified the following relevant studies, which are listed with their applicability to the Project modelling:

- A study reporting sediment yields for ten sediment monitored catchments across Auckland, conducted by Auckland Council in 2013 (Curran-Cournane et al, 2013) reports sediment yields at three catchments flowing to the Kaipara Harbour. Data from this study have been used to calibrate the catchment sediment model.
- A review of environmental information available for the Hōteo River Catchment (Hart & Scott, 2014) contains information on erosion triggers and riparian vegetation. This study has been used as input data for the catchment sediment model development.
- A study of soil erosion across the whole Northland region using SedNetNZ (Mueller & Dymond, 2015), which has been used to inform the calculation of overland flow erosion rates and streambank erosion rates within the catchment sediment model.
- A study investigating the sources of sediment entering the Kaipara Harbour and the subsequent dispersion of those sediments within the harbour system, conducted by NIWA in 2012 (Gibbs et al, 2012) has been used to inform the harbour model.
- A study measuring bank erosion and deposition across five rivers in the Kaipara Harbour catchment, carried out by Landcare Research in 2013 (Spikermann et al, 2015). The data from this study have been used to calibrate the catchment sediment model.

A summary of each of these studies is provided in Appendix B.

4.4 Kaipara Harbour Model Overview

The eWater SOURCE software (Welsh et al, 2012) has been adopted as the Project sediment modelling platform. SOURCE is a semi-distributed catchment modelling framework. It conceptualises a range of catchment processes using subcatchments, which are composed of Functional Units (FU) that represent areas of similar hydrology and sediment generation. FUs are typically characterised through land use or soil types. Daily rainfall-runoff modelling, calibrated using spatially-distributed historical climate data, enables the representation of spatial and temporal variability in runoff and sediment generation from different land uses across the catchment.

The general process for developing a catchment model using SOURCE is illustrated in Figure 12. These steps shown are discussed in further detail in the following sections.

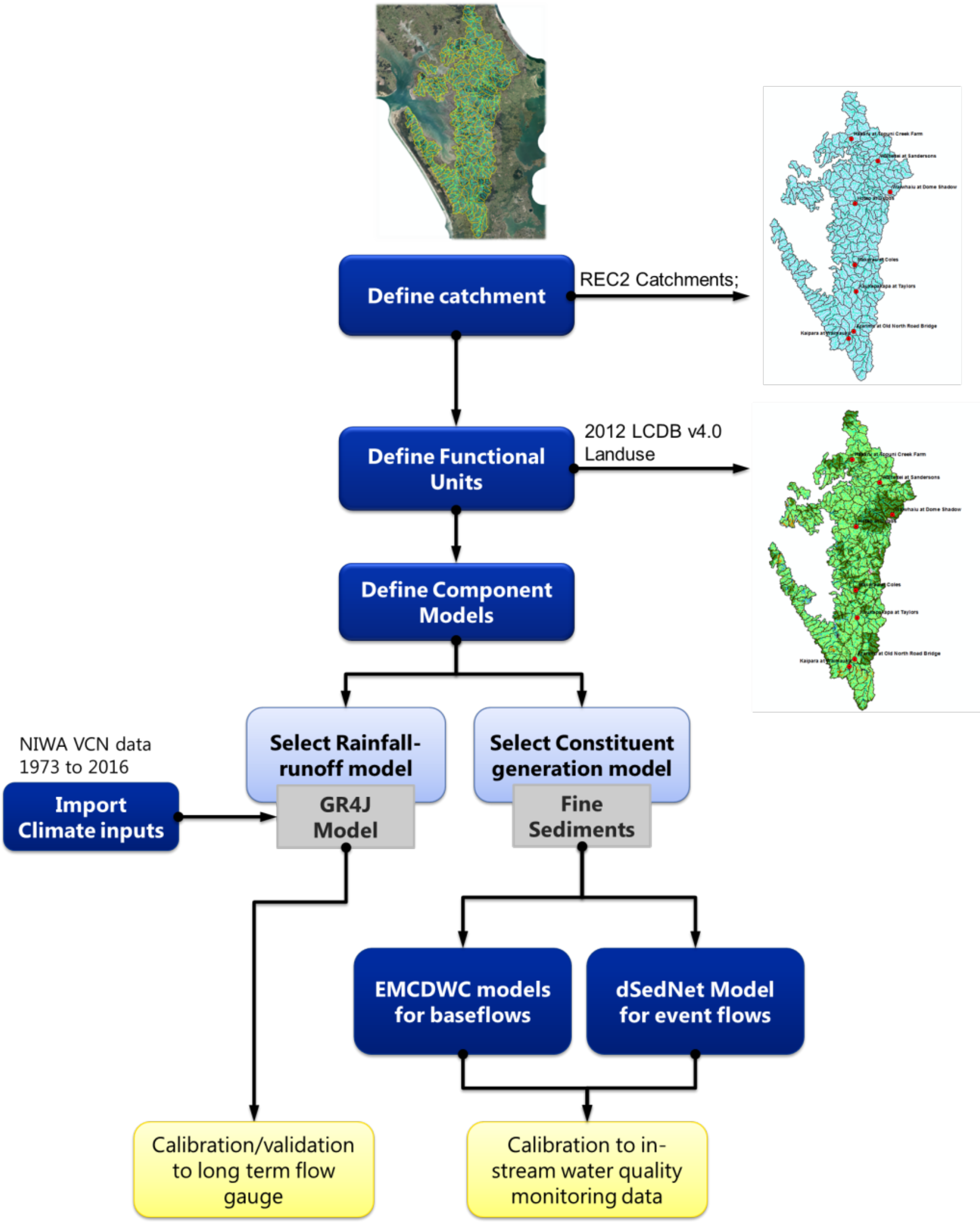

Figure 12 - Source catchment sediment model development process

SOURCE uses the Daily SedNet (dSedNet) plugin (Freebairn et al, 2015) to simulate surficial erosion. The dSedNet plugin was developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and was adopted to capture hillslope sources of sediment erosion at a finer temporal resolution. DSedNet is a time-stepping spatially-distributed sediment budget model for predicting daily sediment loads in river basins and is based on a node-link representation of a river system network. The plugin uses the Revised Universal Soil Loss Equation (RUSLE) approach to estimate surficial erosion rates.

The dSedNet plugin requires a spatial raster input of the combined KLSC (i.e., K × L × S × C) factors (as mean annual rates), these are defined in Section 4.6.1. The R factor is calculated on a daily-timestep by the model, based on spatially gridded, daily rainfall data. The resulting erosion rates is essentially derived as a disaggregation of the mean annual rates by daily rainfall (via the R factor) and runoff to generate a daily sediment load. The dSedNet sediment generation models are assigned to FUs, and their outputs for fine and/or coarse sediment are transported through the node-link network, where in-stream deposition can occur, to the catchment outlet.

DSedNet is a stand-alone module that has been evaluated in the Burdekin basin in tropical Australia, as part of the Queensland Government's REEF Plan for the Great Barrier Reef (Wilkinson et al, 2013). The modelling approach is well described in Wilkinson et al. (2014). The SOURCE software and dSedNet plugin have been used within New Zealand by Greater Wellington Regional Council (by Jacobs) and Bay of Plenty Regional Council (by Williamsons Water Advisory).

The eWater SOURCE software, utilising the daily SedNet (dSedNet) plugin, has been chosen as the Project modelling platform for the Kaipara Harbour catchment for the following reasons:

- there is an existing SedNetNZ model (Mueller & Dymond, 2015) for the Kaipara catchment from which data can be taken to inform the dSedNet model configuration;
- dSedNet is similar to GLEAMS, in that it is based on RUSLE and uses a daily time-step, which was used as a component of the P-Wk project assessment of effects; and
- the ability of dSedNet to predict daily changes in sediment loads utilising the SedNetNZ parameterisation, as explained below.

SedNet is a time-averaged GIS model that estimates mean annual sediment budgets for river catchments and is based on erosion risk in different areas of land as well as mean annual rainfall. The main outputs are mean annual sediment loads in each stream link throughout the river network. SedNetNZ was developed through the development of estimate erosion rates for New Zealand. Daily SedNet uses erosion rates, however calculates a daily sediment budget based on a daily rainfall/runoff. As such the dSedNet model is an improvement on the existing SedNetNZ model as it simulates daily variation and can estimate sediment loads associated with large storms.

The GLEAMS model has been used in previous road construction effects studies, as noted in Section 3. The GLEAMS model is a daily time-step model that estimates sediment loads in a catchment based upon different land use, soils and precipitation. As such the GLEAMS model has similar functionality as the SOURCE dSedNet model, however the dSedNet incorporates SedNetNZ parameterisation and therefore is more relevant to this study of the Kaipara Harbour (due to the existing SedNetNZ model for the harbour). Consequently, the dSedNet model is appropriate to model the sediment implications of the Project in this catchment.

The dSedNet model was reviewed by NIWA (Hughes, 2017, pers comms.) to review the applicability of the model and methodology of the assessment. NIWA confirmed that the dSedNet model is applicable for this assessment and approved the final methodology and assessment.

4.5 Hydrological model development

4.5.1 Data collation

The data required for developing the model for the Southern Kaipara Harbour and Oruawharo River catchments are given in Table 13. Data were generally sourced from Auckland Council (AC), Northland Regional Council (NRC), NIWA and the Ministry for the Environment (MfE).

Table 13 – Data requirements for the catchment model

Data required for Source catchment model	Data source
River Environment Classification (REC) v2.0 database to derive subcatchment boundaries and node-link network	NIWA
2012 Land Cover Database (LCDB v4.0) for land use descriptions and extents	MfE
VCN gridded daily rainfall and potential evapotranspiration (PET) data at a 5km scale	NIWA
Rainfall gauged data	NIWA
Daily flow from stream flow gauging stations	AC, NRC, NIWA
Sediment and turbidity data for fresh water	AC, NIWA

4.5.2 Subcatchment boundaries and node-link network

Subcatchment boundaries for catchments that drain into the Southern Kaipara Harbour and the Oruawharo River were derived from the River Environment Classification (REC) v2.0 database. A subcatchment area of between 5 km^2 and 10 km^2 was adopted for the rainfall-runoff modelling to sufficiently capture event sediment loads and flows, particularly along the indicative road alignment. The node-link network was configured within the SOURCE software based on the REC2 river network to represent the direction of drainage between subcatchments to the Harbours. The resulting subcatchment delineation and node-link network is illustrated in Figure 13.

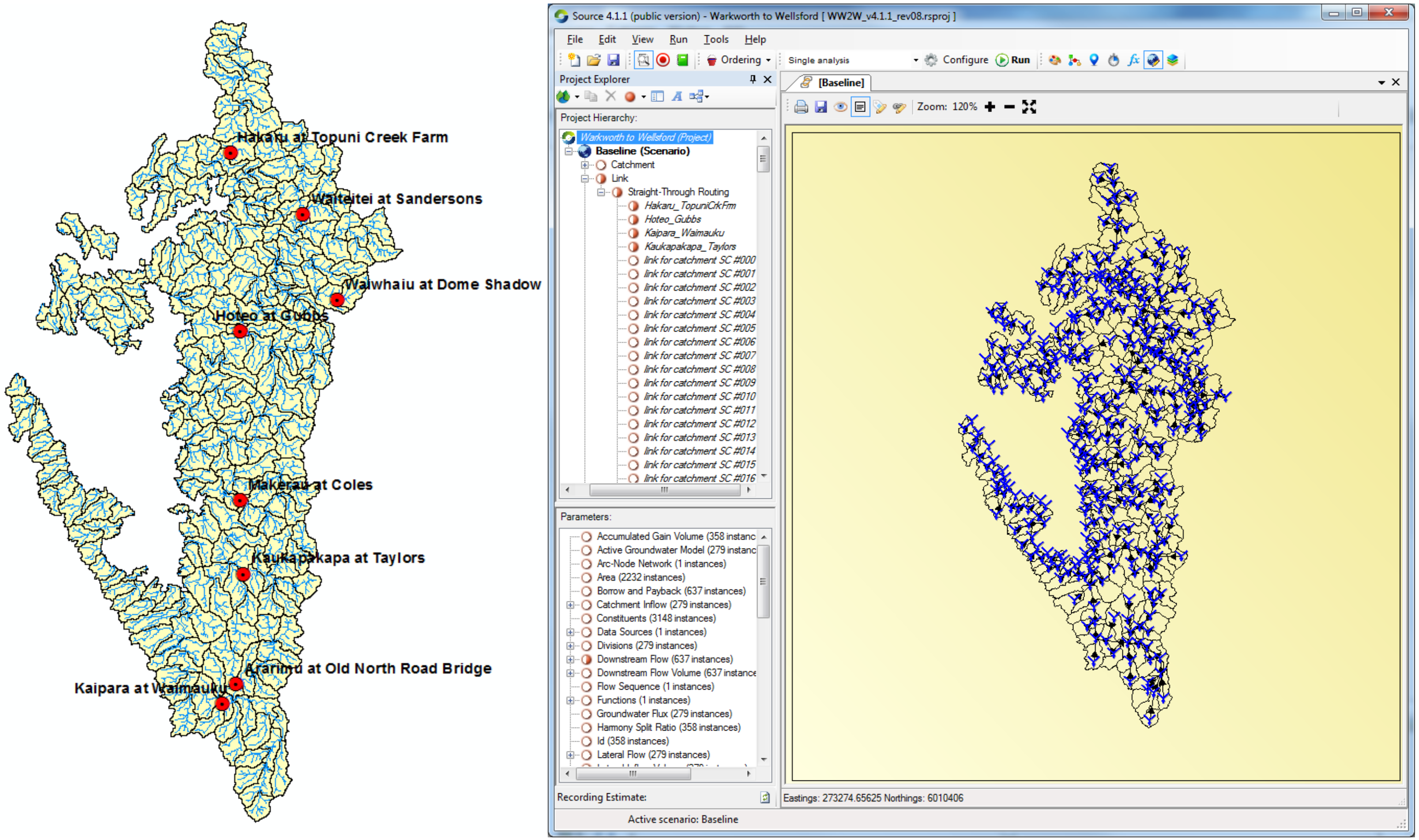

Figure 13 – Subcatchments and node-link network (blue connectors and arrows) structure in the Source model representing catchments (red circles are flow gauges)

4.5.3 Functional units (Land use)

Figure 14 illustrates the land use FUs defined in the Source Model. The FU ASCII grid used in the model is 15m x 15m resolution.

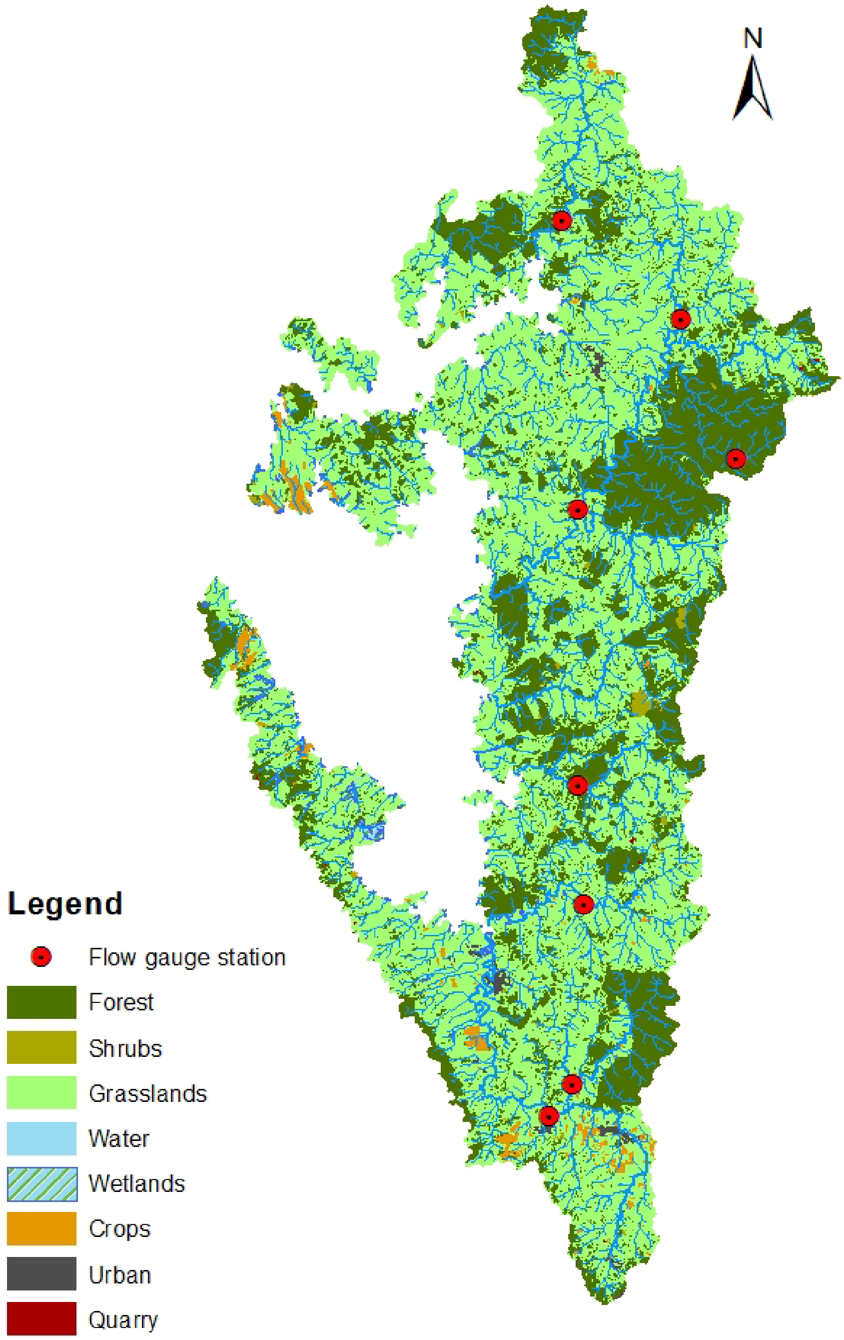

Figure 14 - Land use categories adopted for rainfall-runoff calibration

FUs within subcatchments were defined for the study area based on the land use descriptions in the 2012 Land Cover database (LCDB v4.0). For rainfall-runoff modelling, the primary purpose of the land use layer is to separate areas of the catchment that are likely to have appreciably different runoff generation responses. The land use categories adopted are:

- areas of forest (forest);
- areas of shrubs (shrubs)
- cleared agricultural grasslands (grasslands);
- natural wetlands (wetlands);
- areas of open water (water);
- irrigated horticultural areas (crops);
- impervious urban areas (urban); and
- low-pervious quarries (quarries).

4.5.4 Rainfall-runoff model

The purpose of the rainfall-runoff model is to model the catchment's response to rainfall. The rainfall-runoff model takes climatic inputs (rainfall and evapotranspiration) and transforms these into runoff through representation of multiple flow pathways (i.e. quick flow and baseflow). These flow pathways are characterised by its parameters, determined through parameter calibration. The GR4J (Perrin et al, 2003) rainfall-runoff model was adopted based on its strong performance in numerous settings around the world (see Perrin et al, 2003; Vaze et al, 2011) and its parsimony in terms of parameters.

The structure of GR4J is illustrated in Figure 15. GR4J operates by assuming that rainfall can be discharged to two stores (a production store (x_1) and a routing store (x_3)) or routed overland. Water stored in the routing store is partitioned into quick and slow flow components, which are routed by a unit hydrograph for each partition, the time base of which is controlled by parameter x_4. Water can also be exchanged (gained or lost) from a conceptual groundwater store, which is represented by x_2. A description of each of the GR4J parameters is provided in Table 14, with the typical parameter ranges.

Table 14 – GR4J model parameters

Parameter	Description	Units	Range
x_1	Capacity of the production soil (SMA) store	mm	1-1500
x_2	Water exchange coefficient	mm	-10.0–5.0
x_3	Capacity of the routing store	mm	1-500
x_4	Time parameter for unit hydrographs	days	0.5-4.0
k	Baseflow filter – parameter given by recession constant	none	0-1
C	Baseflow filter – shape parameter	none	0-1

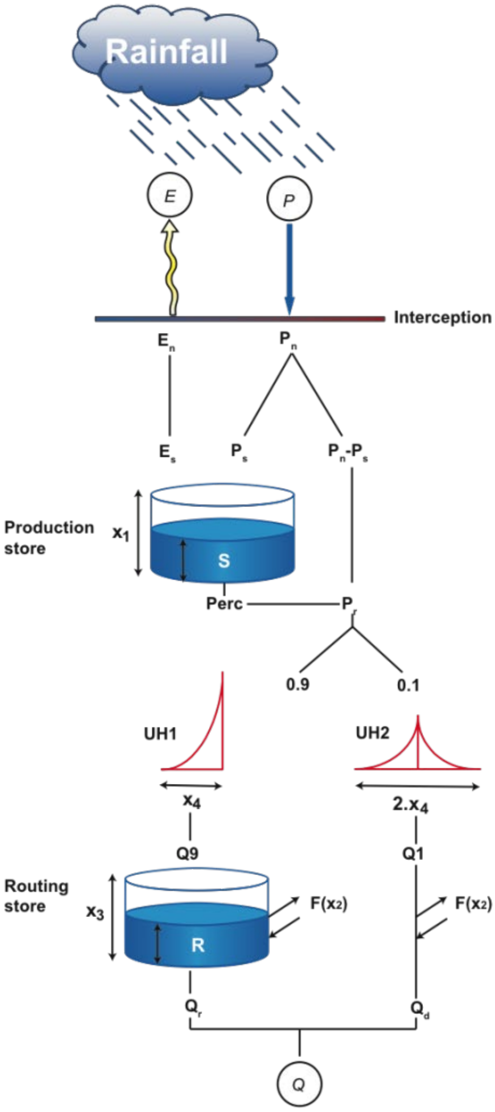

Figure 15 - GR4J model schematic (eWater, 2015)

4.5.5 Climate inputs

Spatially gridded rainfall and potential evapotranspiration (PET) data at 5 km x 5 km resolution was obtained from NIWA's Virtual Climate Station Network (VCSN) and reformatted into ASCII grids for input to the Source model. The SOURCE model then calculates the spatial average daily rainfall and PET from the VCSN grids for each subcatchment.

To assess the appropriateness of using rainfall data from the VCSN for modelling flows for the model, VCSN data was checked against selected long-term rain gauge data. Long-term rain gauge data is available for seven locations in the vicinity of the model catchments; a summary of the data is contained in Table 15, and the location of the rain gauges are shown in Figure 16. Daily VCSN data was obtained for the period 1937-2016 for several grids over the model catchment area.

Table 15 – Long-term rain gauge data

Rainfall Station	Owner	River catchment	Available data
Hakaru at Topuni Creek Farm	NRC	Hakaru River	16/9/2011- 20/4/2016
Hakaru at Tara	NRC	Adjacent to Hakaru River	1/11/2013-26/4/2016
Makarau at Folded Hills Farm	AC	Makarau River	19/02/2003-16/11/2016
Hōteo at Oldfields	AC	Hōteo River	13/8/1978-30/12/2016*
Ararimu Rain at Zanders	AC	Kaipara River	1/1/2003-29/4/2016
Kumeu at Maddrens Weir	AC	Kaipara River	24/9/2001-30/12/2016
Kaipara Heads at Wallers	AC	Kaipara Harbour	6/3/1999-14/7/2015
Notes: *Gaps in rainfall record			

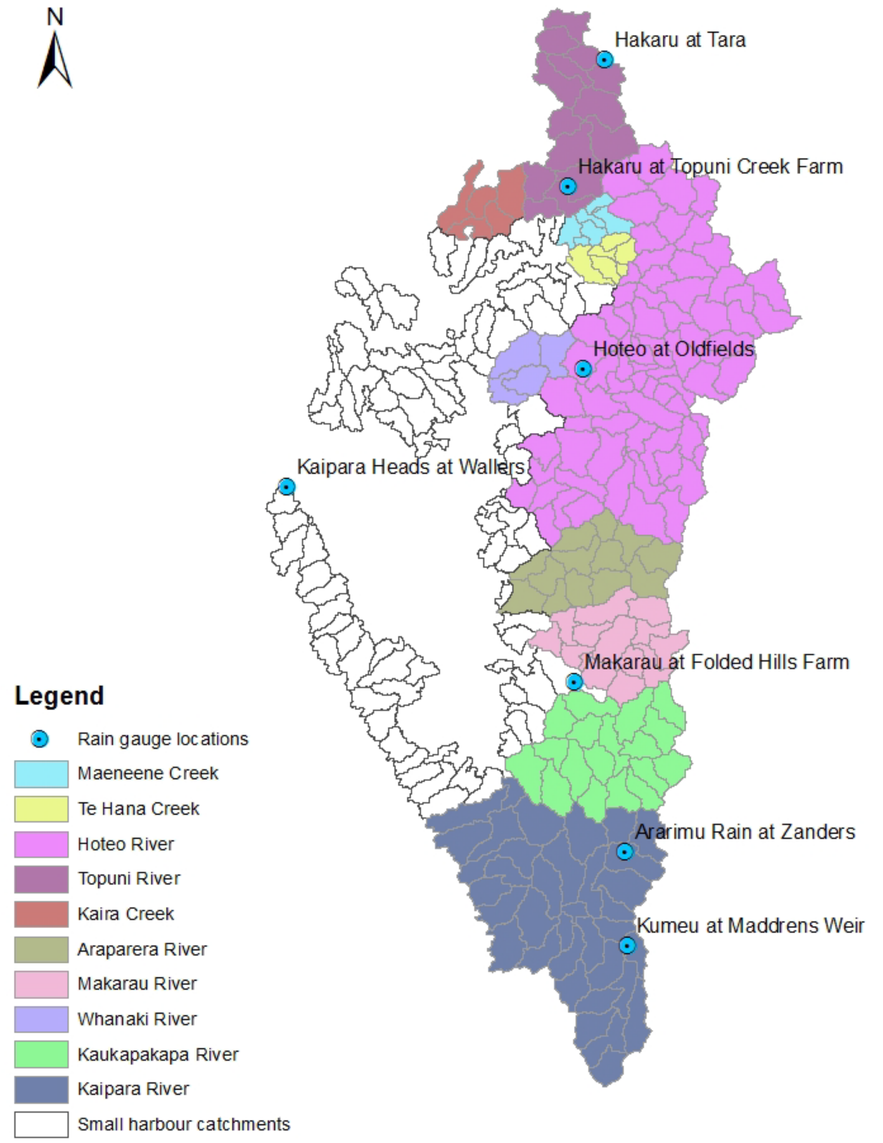

Figure 16 - Location of rainfall gauges within the Project catchments

Rainfall totals

Table 16 contains a comparison of the rainfall totals over the full period of overlapping records. This compares the rainfall station data to the daily average VCSN rainfall taken from the SOURCE Model for the corresponding catchment. The observed rainfall gauge records include gaps due to equipment malfunction, these time periods have not been included in the rainfall totals.

Table 16 – Comparison of rainfall totals between rain gauges and VCSN

Rainfall Station	Time period	Total rainfall (mm)		
		Gauged	VCSN	Difference
Hakaru at Topuni Creek	16/9/2011-20/4/2016	5,476	5491	0.3%
Hakaru at Tara	1/11/2013-26/4/2016	3,103	2,750	11.4%
Makarau at Folded Hills	19/02/2003-16/11/2016	18,045	18,895	4.7%
Hōteo at Oldfields	13/8/1978-30/12/2016*	51,497	58,134	12.9%
Ararimu Rain at Zanders	1/1/2003-29/4/2016	17,101	17,125	0.1%
Kumeu at Maddrens Weir	24/9/2001-30/12/2016	20,284	19,479	4.0%
Kaipara Heads at Wallers	6/3/1999-14/7/2015	17,581	19,595	11.5%
Notes: *Totals do not include VCSN rainfall during gaps in rainfall record				

The rainfall totals were accurate for a number of sites. For the sites Hakaru at Topuni Creek Farm, Makarau at Folded Hills Farm, Ararimu at Zanders and Kumeu at Maddrens Weir there is less than 5% difference between the gauged and VCSN data. The rainfall totals were moderately accurate for three sites: Hakaru at Tara, Hōteo at Oldfields and Kaipara Heads at Wallers, with rainfall totals between 11-16% differences to observed.

Daily rainfall

A comparison of daily rainfall totals has been carried out for each rainfall gauge. The respective means of the VCSN and observed daily rainfall totals across the entire record of each catchment were compared. Generally, the VCSN mean daily value is similar to the observed mean. The mean difference in rainfall was also compared for the highest 10% of rainfall days for each catchment. Generally, the VCSN underestimates these high rainfall events. The differences in daily means for each gauge are given below.

- **Hakaru at Topuni Creek** – The mean difference in daily rainfall totals across the entire record is 0.01mm (VCSN is higher). The mean difference for the highest 168 rainfall days (10%) is -3.9 mm (17%) for the VCSN compared with observed (VCSN lower).
- **Hakaru at Tara –** The mean difference in daily rainfall totals across the entire record is -0.04 mm, with the VCSN predicting lower rainfall. The mean difference for the highest 91 rainfall days (10%) is -5.2 mm, or 22% (VCSN lower).
- **Makarau at Folded Hill Farm** - The mean difference in daily rainfall totals across the entire record is 0.17 mm, with the VCSN predicting higher rainfall. The mean

difference for the highest 502 rainfall days (10%) is -3.1mm, or the VCSN predicting 14% lower rainfall.

- **The Hōteo at Oldfields** - The mean difference in daily rainfall totals across the entire record is 0.48 mm, with the VCSN predicting 13% higher rainfall. The mean difference for the highest 1402 rainfall days (10%) is -2.4 mm, or 10% (VCSN lower).
- **The Ararimu at Zanders** - The mean difference in daily rainfall totals across the entire record is 0.0mm, therefore the VCSN shows a very good comparison. The mean difference for the highest 487 rainfall days (10%) is -3.9 mm, or 17% (VCSN lower).
- **The Kumeu at Maddrens** - The mean difference in daily rainfall totals across the entire record is -0.14 mm, with VCSN predicting a lower mean rainfall. The mean difference for the highest 558 rainfall days (10%) is -4.6 mm, or 20% (VCSN lower).
- **The Kaipara Head at Wallers** - The VCSN grid does not cover the location of the rain gauge, and therefore the VCSN compared is the grid to the south of the rain gauge. The mean difference in daily rainfall totals across the entire record is 0.33 mm, with VCSN predicting a higher mean rainfall. The mean difference for the highest 598 rainfall days (10%) is -2.4 mm, or 12% (VCSN lower).

Inspection of the rainfall totals indicates that this error in the VSCN is likely due to timing of the rainfall event. For example, the VSCN may predict rainfall before midnight when it actually occurred after midnight, so it is recorded on a different day. As shown by Figure 31 to Figure 37 in Appendix D, when the rainfall totals are compared on a 3-day rolling average basis, the VSCN totals are more similar to the observed gauge totals (as indicated by the 1:1 line) for the majority of the sites. Therefore, considering that the sediment modelling is being conducted on a daily basis, the error in rainfall timing in the VCSN data should have negligible impact to the model outputs.

The only exception to this is Hakaru at Tara, at this gauge the totals are still substantially different across the three day rolling average. This is likely due to the location of the gauge in the hilly upper reaches and the short duration of the record. Given that this site is not located in close proximity to the Project, the effect on the model accuracy is considered negligible.

4.5.6 Abstractions

Details of all surface water abstractions within the study area were obtained from Auckland Council and Northland Regional Council. There are few consented abstractions in the catchments of the rivers and streams modelled, and majority of abstractions are small (<150 m^3/day), used for irrigation, farm and domestic use (Table 17).

Table 17 – Large (>150m^3/day) surface water abstractions within study area

Catchment	Council	ID	Owner	Source	Use	Max daily take (m^3)
Kaipara River	AC	20785	Watercare Services Limited	River	Town water supply	2100
	AC	25161		Dam		700
	AC	25168		Dam		700

Catchment	Council	ID	Owner	Source	Use	Max daily take (m^3)
	AC	25169		Dam		700
Hōteo River	AC	36246	Watercare Services Limited	River	Town water supply	1300
Hakaru River	NRC	AUT.007286.04.03	Brooklands Irrigation Scheme	Dam	Irrigation	4320
	NRC	AUT.007286.03.03		Dam	Irrigation	6048
	NRC	AUT.007286.06.01		Dam	Irrigation	1200

There are no records of historical daily or monthly water abstraction volumes available for any of these abstractions. For some of the abstractions a yearly take is recorded, however this information is not consistent across all years and is not available for all consented abstractions. Additionally, the consents generally do not have maximum consented daily volume (aside from the larger abstractions identified in Table 17) or instantaneous flow limits.

Due to the lack of information available relating to the operation of the consented abstractions there is limited scope to simulate abstractions within the Source model without creating a series of broad assumptions, introducing unnecessary uncertainty into the model. Therefore, abstractions are not modelled explicitly, however any large impacts of the abstractions on flows are implicit within in the streamflow record and are reflected in the model through calibration to streamflow data. In addition, given that there are few abstractions occurring in the catchment the effect on model reliability is negligible.

4.5.7 Streamflow data for calibration

There are eight flow gauge sites available for hydrological calibration across the study area (Table 18 and see Figure 17 for locations). The flow data for the gauging locations were obtained from Auckland Council, Northland Regional Council and NIWA. Generally, the information was received as 15 minute or hourly flow data. The data for all gauging sites was quality checked and aggregated into average daily flows for use in flow calibration.

Generally, all flow gauge sites had good quality data. However, Makarau at Coles was observed to have very high peak flows compared with the catchment size. Following further consultation, NIWA stated that this data is based on water level converted to flow rate, and the high flow rating curve has been derived using slope areas rather than gauged flows. NIWA recommended that flows above the mean annual maximum should be used with caution, therefore these peak flows have been excluded from the calibration.

Table 18 – Flow gauge site information

Rainfall Station	Owner	River catchment	Upstream area	Data record	Significant data gaps*
Hakaru at Topuni Creek Farm	NRC	Hakaru River	81.8km²	17/10/2011-10/3/2016	N/A
Waiteitei at Sandersons	AC	Waiteitei River/ Hōteo River	80.6km²	21/02/1996-2/2/2017	Jun-Jul 2001
Waiwhiu at Dome Valley	NIWA	Waiwhiu Stream/ Hōteo River	8.5km²	23/11/1967 -16/3/2017	Jan-Feb 1971; Mar-Jun 1972; May-Jun 1985
Hōteo at Gubbs	AC	Hōteo River	268km²	4/8/1977-24/1/2017	Mar-May 1979
Makarau at Coles	NIWA	Makarau River	53.7km²	1/4/1989-20/4/2017	N/A
Kaukapakapa at Taylors	AC	Kaukapakapa River	61.9km²	4/7/1994-10/1/2017	Feb-March 1997; Feb 1998-Jul 2002
Ararimu at Old North Road	AC	Ararimu Stream/ Kaipara River	66.8km²	15/12/1983-25/1/2017	Mar 1984-Jan 1985; May 1986-Oct 1990; Jul-Aug 1992; Jun-Jul 1995
Kaipara at Waimauku	AC	Kaipara River	155.4km²	6/10/1978-3/6/2016	N/A
*Data gaps greater than one month, other smaller data gaps exist within records					

4.5.8 Flow calibration

Flow gauge calibration catchments

The flow gauge locations and corresponding calibration catchments are illustrated in Figure 17.

The Hōteo River catchment has three flow gauges within the wider catchment all of which have long flow records. Therefore, the climate variability within this catchment is well represented in the observed record. The two flow gauges in the upper reaches of the catchment (Waiteitei at Sandersons and Waiwhiu at Dome Valley), were used to calibrate the catchments upstream of the gauges. The Hōteo River catchments downstream of these gauges were calibrated using the Hōteo at Gubbs flow gauge.

The Kaipara River catchment has two flow gauges, which both have long flow records, capturing the climate variability within the Kaipara River catchment. Ararimu at Old North Road is on the Ararimu Stream, upstream of the confluence with the Kaipara River. Downstream of the confluence is the Kaipara at Waimauku gauge (i.e., the upstream catchment of this gauge includes the Ararimu Stream). Ararimu at Old North Road was used to calibrated Ararimu Stream, while Kaipara at Waimauku was used to calibrate the rest of the Kaipara catchment.

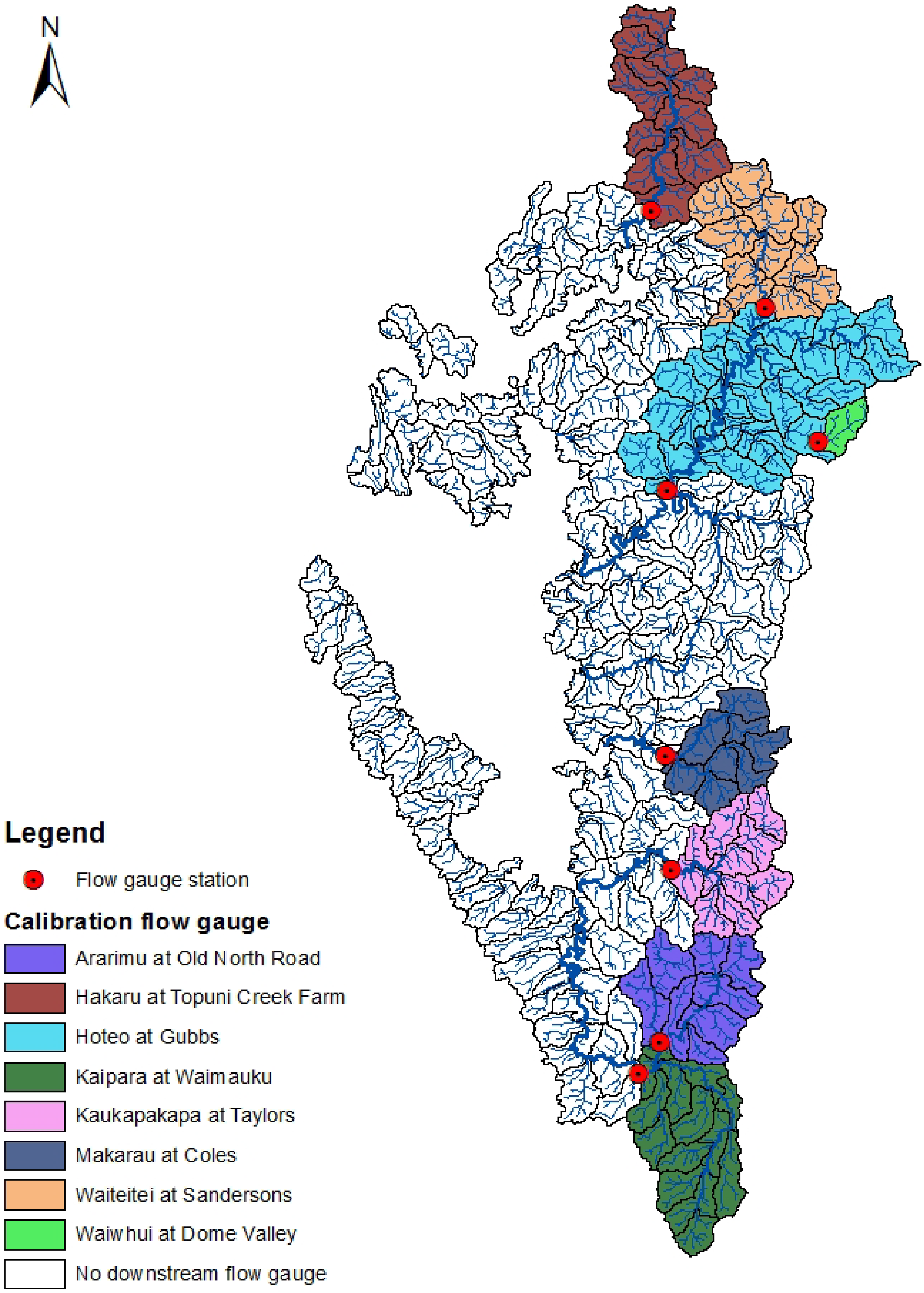

Figure 17 – Calibration catchments associated with each flow gauge – catchment colours correspond to the associated flow gauge

The Kaukapakapa River catchment has one flow gauge, which has a moderate length flow record. This gauge is located along the main channel in the middle reaches of the river. The Hakaru River catchment has one flow gauge, located in the lower reaches of that catchment.

The Makarau River catchment has one flow gauge located along the main channel in the middle to lower reaches of the river.

Land use changes 1996 - 2012

A review of the land use from 1996 to 2012 within the catchments upstream of key flow gauges has been carried out, as detailed in Table 19. Generally, there was very little change in land use between 1996 and 2012. The change in the catchments land use (per land use type) varies between 0.36% for the Hakaru catchment to a maximum change of 4.97% in the Hōteo catchment.

Generally, land use changes are associated with plantation forestry, with grasslands becoming exotic forests for harvesting (as occurred within the Hōteo catchment and the Makarau catchments). Only two catchments have an increase in urban area, the Ararimu catchment and the Kaipara catchment; however, the change is less than 0.5% of the catchment. Given that the majority of all catchments are rural it is unlikely that there has been a considerable change in land use since the 1970s. As such it is considered that there is no likely significant change in the land use across the available flow records.

Table 19 – Land use changes between 1996 and 2012 taken from the land use database

Rainfall Station	Calibration area	Year	Land use							
			Crops	Forest	Grasslands	Quarry	Shrubs	Urban	Water	Wetlands
Hakaru at Topuni Creek Farm	81.8km^2	1996	1.32%	28.89%	69.32%	0.01%	0.00%	0.00%	0.40%	0.06%
		2001	1.32%	28.93%	69.28%	0.01%	0.00%	0.00%	0.40%	0.06%
		2008	1.08%	28.85%	69.60%	0.01%	0.00%	0.00%	0.40%	0.06%
		2012	1.08%	28.81%	69.64%	0.01%	0.00%	0.00%	0.40%	0.06%
		Change	**0.24%**	**0.12%**	**0.36%**	-	-	-	-	-
Waiteitei at Sandersons	79.5km^2	1996	0.10%	13.07%	86.59%	0.00%	0.00%	0.01%	0.23%	0.00%
		2001	0.10%	13.57%	86.09%	0.00%	0.00%	0.01%	0.23%	0.00%
		2008	0.28%	13.61%	85.87%	0.00%	0.00%	0.01%	0.23%	0.00%
		2012	0.28%	13.61%	85.87%	0.00%	0.00%	0.01%	0.23%	0.00%
		Change	**0.18%**	**0.54%**	**0.72%**	-	-	-	-	-
Waiwhiu at Dome Valley	8.5km^2	1996	0.00%	99.65%	0.07%	0.00%	0.00%	0.28%	0.00%	0.00%
		2001	0.00%	99.65%	0.07%	0.00%	0.00%	0.28%	0.00%	0.00%
		2008	0.00%	99.65%	0.07%	0.00%	0.00%	0.28%	0.00%	0.00%
		2012	0.00%	99.65%	0.07%	0.00%	0.00%	0.28%	0.00%	0.00%
		Change	-	-	-	-	-	-	-	-
Hōteo at Gubbs	184.6km^2	1996	0.00%	49.90%	49.22%	0.11%	0.43%	0.30%	0.03%	0.01%
		2001	0.08%	54.62%	44.56%	0.11%	0.28%	0.30%	0.03%	0.01%
		2008	0.08%	54.87%	44.36%	0.11%	0.24%	0.30%	0.03%	0.01%
		2012	0.08%	54.77%	44.26%	0.12%	0.43%	0.30%	0.03%	0.01%
		Change	**0.08%**	**4.97%**	**4.96%**	**0.01%**	**0.19%**	-	-	-
Makarau at Coles	49.2km^2	1996	0.00%	32.66%	66.41%	0.14%	0.80%	0.00%	0.00%	0.00%
		2001	0.00%	35.41%	63.65%	0.14%	0.80%	0.00%	0.00%	0.00%
		2008	0.00%	35.68%	63.42%	0.14%	0.76%	0.00%	0.00%	0.00%
		2012	0.00%	35.84%	63.25%	0.14%	0.78%	0.00%	0.00%	0.00%
		Change	-	**3.18%**	**3.16%**	-	**0.04%**	-	-	-
Kaukapakapa at Taylors	62.3km^2	1996	0.67%	18.64%	79.84%	0.16%	0.46%	0.15%	0.08%	0.00%
		2001	0.67%	19.38%	78.79%	0.16%	0.77%	0.15%	0.08%	0.00%
		2008	0.67%	19.70%	78.48%	0.16%	0.77%	0.15%	0.08%	0.00%
		2012	0.62%	19.34%	78.97%	0.16%	0.68%	0.15%	0.08%	0.00%

Rainfall Station	Calibration area	Year	Land use							
			Crops	Forest	Grasslands	Quarry	Shrubs	Urban	Water	Wetlands
		Change	**0.05%**	**1.06%**	**1.36%**	-	**0.31%**	-	-	-
Ararimu at Old North Road	70.3km²	1996	0.63%	54.17%	44.94%	0.00%	0.17%	0.08%	0.00%	0.01%
		2001	0.63%	55.23%	43.73%	0.00%	0.27%	0.12%	0.00%	0.01%
		2008	0.81%	55.53%	43.39%	0.00%	0.13%	0.12%	0.00%	0.01%
		2012	0.81%	55.46%	43.28%	0.00%	0.32%	0.12%	0.00%	0.01%
		Change	**0.18%**	**1.36%**	**1.66%**	-	**0.19%**	**0.04%**	-	-
Kaipara at Waimauku	85.0km²	1996	6.46%	14.81%	75.87%	0.03%	0.47%	2.34%	0.03%	0.00%
		2001	6.46%	15.38%	75.47%	0.03%	0.22%	2.42%	0.03%	0.00%
		2008	6.75%	15.24%	74.94%	0.03%	0.40%	2.60%	0.03%	0.00%
		2012	6.75%	14.98%	75.15%	0.03%	0.38%	2.68%	0.03%	0.00%
		Change	**0.29%**	**0.57%**	**0.93%**	-	**0.25%**	**0.34%**	-	-

Calibration and validation timing

Given that there has not been a significant change in land use across the flow gauge catchments, the entire flow record for each site has been used for calibration and validation.

For the majority of sites, the flow records for each gauge were split into warm-up periods (a time for the model to warm up to typical running conditions for the system), calibration and validation periods, details of these are contained in Table 20. The Hakaru River catchment has a short flow record of approximately 4.3 years. Due to the short length of the flow record the data was not split for calibration and validation periods. Instead, this location was calibrated against the full flow record.

Table 20 – Study area flow calibration timings

Catchment	Gauge site	Warm up	Calibration	Validation
Hōteo River	Waiteitei at Sandersons	6.2 years 1/1/1990–21/2/1996	11.8 years 22/2/1996-30/12/2008	8 years 31/12/2008-30/12/2016
	Waiwhiu at Dome Valley	4 years 1/1/1973–31/12/1976	24 years 1/1/1977–30/12/2001	14 years 31/12/2001–30/12/2016
	Hōteo at Gubbs	4.6 years 1/1/1973-4/8/1977	23.4 years 5/8/1977-30/12/2001	14 years 31/12/2001-30/12/2016
Kaipara River	Ararimu at Old North Road	5.8 years 1/1/1995–10/10/1990	12.8 years[1] 11/10/1990-30/12/2008	7.5 years 31/12/2008-3/6/2016
	Kaipara at Waimauku	4.8 years 1/1/1974–6/10/1978	22.2 years 6/10/1978–30/12/2001	14 years 31/12/2001–30/12/2016
Kaukapakapa River	Kaukapakapa at Taylors	4.6 years 1/1/1990–4/7/1994	10.8 years[2] 5/7/1994-30/12/2010	6 years 31/12/2010-30/12/2016
Hakaru River	Hakaru at Topuni	4.8 years 1/1/2007–17/10/2011	4.4 years 18/10/2011-10/3/2016	N/a
Makarau River	Makarau at Coles	4.3 years 1/1/1985-31/3/1989	16.7 years 1/4/1989-30/12/2006	10 years 31/12/2006-20/12/2016

Notes:
1 - Taking into account 4.3 month data gap May 1986 – Oct 1990
2 - Taking into account 4 year data gap between Feb 1998 – Jul 2002

Flow calibration methods

The rainfall-runoff model parameters were calibrated to represent different land use hydrological properties. Each of the sites were calibrated using the SOURCE automated calibration tool. The Shuffled Complex Evolution algorithm was used to undertake a global search for the optimum set of parameters. The resulting parameter set was then used as the initial parameter for a local search algorithm (Rosenbrock). A Nash-Sutcliffe Efficiency (NSE) daily and log flow duration curve objective function was used, in order to achieve a good fit to baseflows, weighted towards NSE to obtain a good fit to peak flows. Once a good calibration was achieved the flood frequency was assessed and, where necessary, further manual calibration was used to better match peak flows in some catchments.

The calibration of the Kaukapakapa catchment was different to the method detailed above. Initially the automated calibration tool was used with the NSE daily and log flow duration curve objective function using a variety of NSE weightings from 60-85%; however, there was difficulty in producing satisfactory results for the validation period. Therefore, the metaparameter values from the adjacent catchment Ararimu at Old North Road calibration were applied to the Kaukapakapa catchment. Ararimu catchment is immediately south of the Kaukapakapa catchment and it shares similar climate and slope characteristics. This produced an acceptable model fit for both the calibration and validation periods. These values were then manually adjusted to better match peak flows. These approaches are summarised in Table 21, below.

Table 21 – Source calibration tool set-up

Gauge site	Automatic calibration		Manual calibration?
	Objective function	NSE weighting	
Waiteitei at Sandersons	NSE daily and log flow duration	85%	Yes
Waiwhiu at Dome Valley	NSE daily and log flow duration	85%	Yes
Hōteo at Gubbs	NSE daily and log flow duration	85%	No
Ararimu at Old North Road	NSE daily and log flow duration	80%	No
Kaipara at Waimauku	NSE daily and log flow duration	75%	No
Kaukapakapa at Taylors	N/A	N/A	Yes
Hakaru at Topuni	NSE daily and log flow duration	70%	No
Makarau at Coles	NSE and bias penalty	N/A	Yes

Flow calibration evaluation

The simulated catchment flows at the eight flow gauge locations were assessed for performance against observed and gauged data using a number of statistical analyses, listed below. The results of the calibration are discussed in the following section.

- Comparison of daily flows using summary statistics:
  - the Nash-Sutcliff Efficiency (NSE) statistic (Equation 1) (used as a measure of goodness-of-fit, where 0 is poor and 1 is a perfect fit to observed data);

$$E = 1 - \frac{\sum_{t=1}^{T}(Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T}(Q_o^t - \overline{Q_0})^2}$$

Equation 1

  - percent bias (PBIAS) (% difference between modelled and gauged mean daily flow); and
  - the mean annual flow (MAF) and 7-day mean annual low flow (MALF).
- Comparison of the flow duration curves.
- Comparisons of annual maxima at key ARI, as an evaluation of simulated peak flows.

SUMMARY STATISTICS

Moriasi et al. (2007) suggests values for general performance ratings for statistical analysis of the streamflow simulations for NSE and percent bias, as given in Table 22.

Table 22 - Moriasi et al. (2007) General performance ratings for recommended statistics

Performance rating	NSE	Percent bias
Very good	0.75 < NSE ≤ 1.00	PBIAS < ±10
Good	0.65 < NSE ≤ 0.75	±10 ≤ PBIAS < ±15
Satisfactory	0.5 < NSE ≤ 0.65	±15 ≤ PBIAS < ±25
Unsatisfactory	NSE ≤ 0.50	PBIAS ≥ ±25%

Comparisons between NSE and PBIAS for the calibration sites (Table 23) demonstrates that for all flow gauges at least a satisfactory rating has been achieved, with many sites achieving good or very good ratings. The Hōteo River catchment is the only gauged catchment that is crossed by the Project. The Project is upstream of the Hōteo at Gubbs gauge and the catchments impacted by the road are calibrated against this gauge. Therefore, the Hōteo at Gubbs is the most important calibration location. This gauge achieved a very good calibration for all statistics.

Table 23 – Summary of flow calibration summary statistics at gauging locations

Location	Record	Statistics	Calibration		Validation		Performance
Hakaru at Topuni Creek Farm	17/10/2011–10/3/2016	NSE daily	0.68		-		Good
		% Bias	-2%		-		Very good
		MAF (m^3/s)	683[1]	667[2]	-	-	-
		MALF (m^3/s)	0.23[1]	0.22[2]	-	-	-
Waiteitei at Sandersons	21/02/1996–2/2/2017	NSE daily	0.83		0.74		Good
		% Bias	11%		17%		Satisfactory
		MAF (m^3/s)	671[1]	745[2]	550[1]	644[2]	-
		MALF (m^3/s)	0.17[1]	0.13[2]	0.12[1]	0.10[2]	-
Waiwhiu at Dome Valley	23/11/1967–16/3/2017	NSE daily	0.63		0.61		Satisfactory
		% Bias	15%		5%		Good
		MAF (m^3/s)	94[1]	109[2]	93[1]	98[2]	-
		MALF (m^3/s)	0.02[1]	0.01[2]	0.03[1]	0.01[2]	-
Hōteo at Gubbs	4/8/1977-24/1/2017	NSE daily	0.88		0.86		Very good
		% Bias	7%		-2%		Very good
		MAF (m^3/s)	2,138[1]	2,284[2]	2,130[1]	2,080[2]	-
		MALF (m^3/s)	0.39[1]	0.36[2]	0.54[1]	0.38[2]	-
Makarau at Coles	1/4/1989–20/4/2017	NSE daily	0.62		0.56		Satisfactory
		% Bias	0%		-7%		Very good
		MAF (m^3/s)	389[1]	391[2]	418[1]	390[2]	-
		MALF (m^3/s)	0.09[1]	0.04[2]	0.08[1]	0.03[2]	-
Kaukapakapa at Taylors	4/7/1994–10/1/2017	NSE daily	0.65		0.71		Good
		% Bias	3%		5%		Very good
		MAF (m^3/s)	503[1]	398[2]	383[1]	400[2]	-
		MALF (m^3/s)	0.04[1]	0.03[2]	0.02[1]	0.02[2]	-
Ararimu at Old North Road	15/12/1983–25/1/2017	NSE daily	0.86		0.84		Very good
		% Bias	-3%		-11%		Good
		MAF (m^3/s)	394[1]	402[2]	451[1]	403[2]	-
		MALF (m^3/s)	0.09[1]	0.06[2]	0.05[1]	0.05[2]	-
Kaipara at Waimauku	6/10/1978–3/6/2016	NSE daily	0.91		0.85		Very good
		% Bias	2%		-11%		Good
		MAF (m^3/s)	1,043[1]	1,071[2]	1,121[1]	1,008[2]	-

Location	Record	Statistics	Calibration		Validation		Performance
		MALF (m^3/s)	0.26[1]	0.19[2]	0.11[1]	0.11[2]	-

Notes:
1 – Gauged MAF/MALF
2 – Modelled MAF/MALF

FLOW DURATION CURVES

The observed and modelled flow duration curves (FDCs) for both calibration and validation periods are shown in Figure 38 to Figure 45 in Appendix F. Goodness-of-fit between modelled and observed FDCs is assessed using the NSE statistic (Table 24).

Table 24 – Summary of flow duration curve NSE ratings

Gauging location	Gauged record	Calibration FDC NSE	Validation FDC NSE	Performance
Hakaru at Topuni Creek	17/10/2011-10/3/2016	0.88	-	Very good
Waiteitei at Sandersons	21/02/1996-2/2/2017	0.996	0.98	Very good
Waiwhiu at Dome Valley	23/11/1967-16/3/2017	0.94	0.86	Very good
Hōteo at Gubbs	4/8/1977-24/1/2017	0.99	0.996	Very good
Makarau at Coles	1/4/1989-20/4/2017	0.59	0.69	Satisfactory
Kaukapakapa at Taylors	4/7/1994-10/1/2017	0.93	0.94	Very good
Ararimu at Old North Road	15/12/1983-25/1/2017	0.99	0.998	Very good
Kaipara at Waimauku	6/10/1978-3/6/2016	0.97	0.90	Very good

The data indicates that the majority of sites have a very good calibration for the flood duration curves, with only the Makarau River having a satisfactory calibration.

FLOOD FREQUENCY ANALYSIS

The simulation of peak flow events was a key focus of the calibration process, as the assessment of sediment loads will be driven by peak flow events within the catchment. Underestimation of low flows is acceptable in this context.

Flood frequency analysis (FFA) was used to determine if the rainfall runoff model was able to replicate the flooding response of the catchment. FFA was undertaken on the observed and modelled annual maximum series for all gauge locations (using daily mean flows).

An annual maximum series for each gauge was extracted for the full period of record forming the observed annual maximum series, the flow period for each gauging site is contained in Table 25. Annual maximum series for the entire modelled period were extracted for both sites. It was not possible to undertake FFA for Hakaru at Topuni Creek Farm as the flow record is too short to analyse.

FFA was undertaken by fitting either a Generalised Extreme Value (GEV) distribution or Gumbel distribution using a higher order L-moments (LH moments) technique (for a description of LH moments see Kuczera and Franks, 2015). Results in Table 25 shows that the SOURCE model is able to replicate the flood quantiles calculated from the observed series for the majority of sites. The two exceptions are discussed below:

- **Makarau at Coles** - The SOURCE model is unable to achieve the peaks in the observed record with differences of approximately 56% for ARIs. NIWA has stated that the flow-stage curve is potentially inaccurate for higher flows, and as such flows above the mean annual maximum should be used with caution. Therefore, it is considered that the observed ARIs are likely to be incorrect and the Makarau site can be excluded from this calibration.
- **Waiwhiu at Dome Valley** – The SOURCE model is unable to achieve the peaks in the observed flow record, with differences of approximately 33% of flows for ARI events. The catchment at this location is small, only 8.5 km^2 and in a hilly location. Given that the downstream location Hōteo at Gubbs achieved a good calibration, it is considered that the Hōteo catchment is reasonably calibrated for peak flows.

Based on the analysis the SOURCE model is suitably reproducing peaks flows for sediment transport modelling.

Table 25 – Comparison of observed[1] and modelled[2] flood frequency estimates for gauge locations for key Annual Recurrence Intervals (ARIs).

Flow calibration location	Flow record	Estimate	Daily mean flow (m^3/s) at ARIs				
			2 yr	5 yr	10 yr	20 yr	50 yr
Waiteitei at Sandersons	21/02/1996–2/2/2017	OBS	48.9	65.6	79.2	92.3	109.2
		Model	40.5	54.7	66.3	77.4	91.7
Waiwhiu at Dome Valley	23/11/1967–16/3/2017	OBS	7.5	10	12	14	16.5
		Model	5.6	7.2	8.5	9.7	11.3
Hōteo at Gubbs	4/8/1977-24/1/2017	OBS	123.4	165.6	200	232.8	275.5
		Model	114.9	154.2	186.1	216.7	256.4
Makarau at Coles	1/4/1989–20/4/2017	OBS	108.3	100.7	89	78.7	66.6
		Model	49.3	44.7	38.6	33.8	28.9
Kaukapakapa at Taylors	4/7/1994–10/1/2017	OBS	31.6	42	50.5	58.7	69.2
		Model	29.9	38.9	46.2	53.2	62.2
Ararimu at Old North Road	15/12/1983–25/1/2017	OBS	19.7	26.7	32.4	37.9	45
		Model	19.4	26.3	32.2	38.3	46.6
Kaipara at Waimauku	6/10/1978–3/6/2016	OBS	43.9	62.5	81.5	103.7	139.8
		Model	46.2	62.3	76.8	92.1	114

1 - Observed record is for the length of the flow record
2 - Model record is for entire model run of 1973-2016

4.5.9 Rainfall-runoff parameter regionalisation

The final values for the GR4J parameters for each land use are contained in Table 26. Rainfall runoff parameters obtained from the flow calibration of the flow gauges are regionalised across ungauged catchments as illustrated in Figure 18. The k and C baseflow separation parameters do not affect the calibration and have been left as default values.

Table 26 – GR4J model calibration parameter values

Gauging location	Land use	GR4J parameter values					
		k	C	x_1	x_2	x_3	x_4
Hakaru River at Topuni Creek Farm	Crops	0.950	0.150	1.000	-0.500	1.000	2.017
	Forest			69.911	-2.907	17.7	1.861
	Grasslands			59.381	1.923	29.773	1.816
	Quarry			67.516	1.324	21.722	1.932
Waiteitei at Sandersons	Urban	0.950	0.150	10.000	-0.806	16.957	0.669
	Crops			500.000	-5.000	1.000	1.628
	Forest			1000.000	-10.000	6.864	4.000
	Grasslands			138.171	1.068	29.747	1.804
Waiwhiu at Dome Valley	Forest	0.950	0.150	40.000	0.644	30.000	1.296
	Grasslands			1.000	5.000	1.000	0.500
	Urban			1.000	5.000	1.000	0.500
Hōteo at Gubbs	Shrubs	0.950	0.150	1.000	5.000	215.180	2.037
	Crops			1.000	5.000	215.180	2.037
	Forest			322.399	-0.707	131.120	1.956
	Grasslands			20.642	-2.983	29.480	2.358
	Quarry			1.000	5.000	78.369	2.000
	Urban			2.255	1.000	20.000	1.000
Makarau River at Coles	Quarry	0.950	0.150	67.980	-0.695	73.922	1.000
	Grasslands			81.596	-1.532	32.201	1.324
	Forest			1.000	-3.102	40.902	1.271
	Shrubs			1.000	-3.102	40.902	1.271
Kaukapakapa at Taylors	Crops	0.950	0.150	35.810	2.185	500.000	2.249
	Shrubs			35.810	2.185	500.000	2.249
	Grasslands			40.000	-3.870	35.182	1.855
	Urban			3.430	0.332	14.230	0.983
	Quarry			3.430	0.332	14.230	0.983
	Forest			200.000	-0.336	68.714	1.512
Ararimu at Old North Road	Crops	0.950	0.150	35.810	2.185	500.000	2.249
	Shrubs			35.810	2.185	500.000	2.249
	Grasslands			50.000	-3.870	35.182	1.855
	Urban			3.430	0.332	14.230	0.983
	Forest			330.681	-0.336	68.714	1.512
Kaipara River at Waimauku	Crops	0.950	0.150	1.000	-0.021	52.297	2.026
	Forest			155.097	-0.021	52.297	2.026
	Grasslands			155.097	-0.515	52.297	2.026
	Quarry			22.364	0.010	35.810	1.566
	Shrubs			155.097	-0.021	52.297	2.026
	Urban			22.364	0.010	35.810	1.566

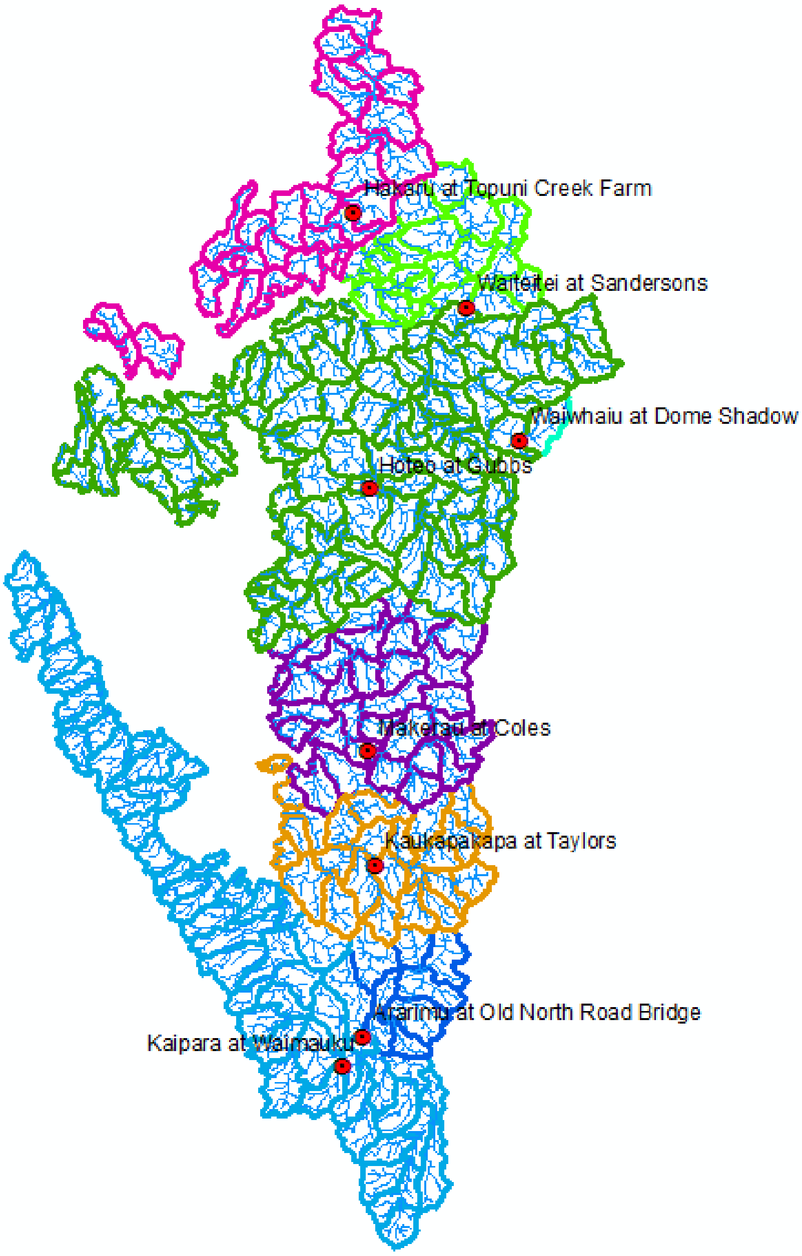

Figure 18 - Regionalisation of calibrated rainfall-runoff model parameters to ungauged catchments

4.6 Sediment model development

4.6.1 Sediment constituent models

There are many different sources of sediment generation possible within a river catchment. These include surficial (hillslope) erosion, streambank erosion, landslide erosion, gully erosion and earthflow erosion. To identify the different potential sources of erosion across the Kaipara Harbour catchments, the NZEEM and NZLRI Erosion Rates GIS layers were reviewed for erosion risks by sources across the catchment. The erosion risk and types are shown in Figure 19.

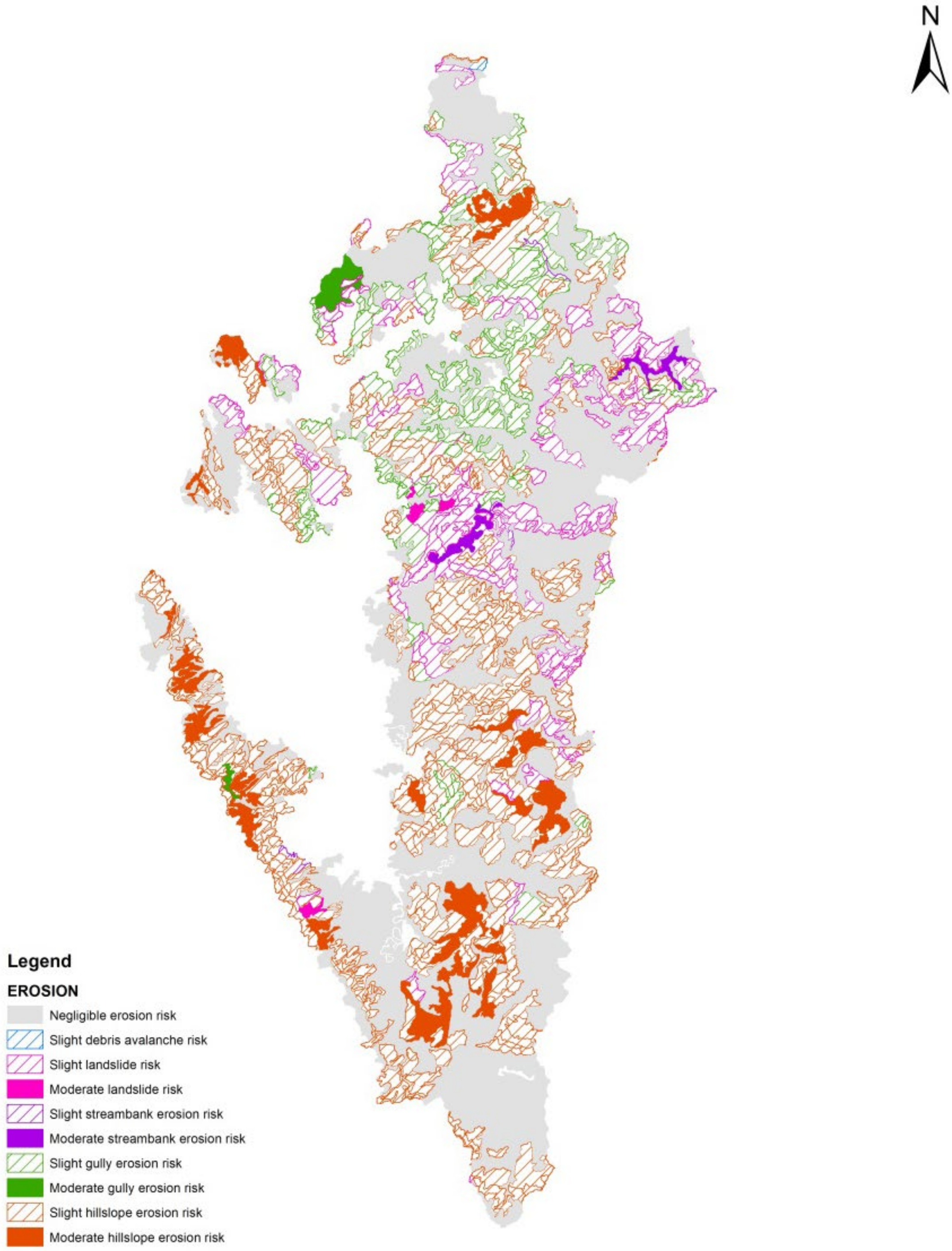

Figure 19 - NZEEM main erosion risk across study area

The landslide risk includes debris avalanches and soil slips, the gully erosion includes gully and tunnel gully erosion, while hillslope erosion includes sheet erosion and wind erosion.

These erosion layers show that the main erosion types within the Hōteo River catchment, and the wider Kaipara Harbour catchment, are hillslope and streambank erosion. The erosion risk from landslides, gully and earthflow erosion is generally either negligible or slight. Therefore, the dSedNet model has only included modelled sediment from hillslope and streambank erosion sources.

Surficial (Hillslope) erosion generation model

Surficial erosion is simulated using the Source dSedNet plugin. The dSedNet hillslope module implements a spatially distributed from of the Revised Universal Soil Loss Equation (RUSLE), which predicts surficial erosion according to:

$$E = R \times K \times S \times L \times C \times P \times E$$

Equation 2

where E is the soil erosion per unit area (t/ha/year);
R is the rainfall erosivity (EI30) (MG.mm/ha.h.day);
K is the soil erodibility (t.ha.h/ha.MJ.mm);
S is slope Steepness (dimensionless);
L is slope length (dimensionless);
C is cover management factor (dimensionless);
P is the practice factor (conservation measures) (dimensionless); and
E is the sediment treatment devices efficiency factor (dimensionless).

The product of the K, L, S, and C factors are imported into dSedNet as a raster grid (15 m resolution). The P factor is related to farm management techniques (contouring, terracing etc.); because there is negligible arable farmland (cropland) in the Project catchments, the P factor is assumed to be equal to 1 for all scenarios. The E factor is the efficiency of sediment treatment devices and controls (Section 4.8.2), for the pre-development scenario these do not exist and are input as being equal to 1.

KLSC GRID

K factor

We have approximated K factor values based on soil texture following the NZUSLE approach described in Dymond (2010) and Dymond (2016). Dymond (2010) differentiates K factors based on soil texture:

- sand 0.05
- clay 0.20
- loam 0.25
- silt 0.35

We have applied the K-factor values above to the NZLRI soils GIS layer (S-map is currently unavailable for the Project catchments), with Silt Loam given a value of 0.30, and stony sandy loam or sandy loam a value of 0.20. The class 'Town' is assumed to be loam (0.25). Following Renard et al. (1997), the K factor values from Dymond (2010) have been converted to SI units (multiplied by 0.1317).

The soil types defined in the NZLRI soils GIS layer have been compared to the observed PSDs from boreholes across the Project area and found that the soil type (silty clay and silt) correspond to the observed PSDs (Appendix C).

LS Factor

The LS factor encompasses the slope length (L) factor and the slope steepness (S) factor. We have adopted the GIS-ready approach of Moore & Burch (1986) and Moore & Wilson (1992):

$$LS = \left(\frac{A_S}{22.13}\right)^{0.4} \times \left(\frac{\sin\theta}{0.0896}\right)^{1.3}$$

Equation 3

where LS is the combined length and slope factors,
A_s is the specific catchment area,
θ is the slope angle.

Equation 3 accounts for two-dimensional accumulated flow and avoids limitations that follow from the implicit division of the landscape into hillslopes required for the one-dimensional RUSLE method (Moore & Wilson, 1992). Equation 5 has been calculated using the national 15 m resolution DEM developed by the Otago University School of Surveying. A_s is calculated for each cell as the number of upstream contributing cells multiplied by the cell resolution. An upper limit of 20 cells (300 m equivalent) (Renard et al, 1997), and a lower limit of 1 cell (15 m) were specified. Slope angle is calculated from the same DEM.

C factor

C factor values have been mapped to the model FUs as in Table 27.

Table 27 – C factor mapped to functional units (metric units)

Functional Unit	C factor
Crops	0.01
Forest	0.005
Grasslands	0.01
Quarry	0.01
Shrubs	0.005
Urban	0.005
Water	0
Wetlands	0

These C factor values have been adapted from NZUSLE, which applies the following (Dymond et al. 2016):

- 0.005 for plantation forest, native forest, and scrub;
- 0.01 for pasture, urban areas;
- 1.0 for bare earth.

Preliminary application of the above C factor values indicates that a value of 0.01 for urban areas results in an over-estimation of urban erosion when compared to the Auckland Regional Council Contaminant Load Model (CLM) and is an order of magnitude greater than that adopted elsewhere; Lu et al. (2003) use a C-factor of 0.001 for urban areas in Australia. We have instead adopted a value of 0.005.

For the baseline scenario all areas of plantation forestry are considered to be forested and no forest harvesting is included explicitly within the baseline model. It is noted that these baseline loads are unlikely to occur in practice during the indicative construction period as harvesting of the large plantation forest, owned and managed by Rayonier Matariki Forests (RMF), within the Hōteo River catchment (Section 5) is likely to occur prior to and during the construction. Therefore, it is expected that the background loads within the Hōteo River will be higher during construction than the modelled baseline loads beacausesediment levels will be temporarily elevated due to the harvesting activity.

The baseline model reflects the long-term background load of the catchment and given that the majority of the assessment is relating to the mean annual sediment load, it provides an effective benchmark to assess the Project against.

The potential increases in sediment load associated with the forest harvesting is discussed separately in Section 5.

SEDIMENT DELIVERY RATIO

A sediment delivery ratio for surficial erosion is applied to estimate the mass of eroded sediment reaching the stream network. In New Zealand, an SDR of 0.5 is generally accepted (ARC, 2014). Internationally, an SDR based on watershed size is widely used because of its simplicity (Lim et al, 2005). A power function was derived from data for 300 watersheds to develop a generalized SDR curve by the American Society of Civil Engineers (Vanoni, 1975, reported in Lim et al, 2005):

$$SDR = 0.4724\, A^{-0.125}$$

Equation 4

Where *A* is watershed area (km^2).

Equation 4 has been applied to the model subcatchments, with calculated SDR ranges between 0.42 and 1.0, and a mean of 0.56.

RAINFALL EROSIVITY FACTOR

The rainfall erosivity factor (R) is calculated within SOURCE for each day using NIWA VCSN input data as:

$$EI30 = \propto \times \left(1 + \eta \times TimeOfYearFactor\right) \times R^{\beta}, when\ R > R_0$$

Equation 5

where EI30 is daily rainfall erosivity (MJ.mm/ha.h);
R is daily rainfall amount (mm);
R0 is the threshold rainfall amount (mm);
η is time of year scaling factor;
Time of Year Factor determines the peak intensity;

β is an erosion scaling factor; and
α is a calculated constant – utilised as a calibration factor.

As far as reasonably possible, the model applied the default values, however some values were altered during calibration and some were based upon literature values, as summarised in Table 28.

Table 28 – Hillslope dSedNet rainfall erosivity factor variables

Variable	Value	Justification
R_0	0.025	Based on Hōteo River report (Hart & Scott, 2014) values of 25 – 50 mm erosion threshold
β	1.69	Based upon best calibration of the Hōteo River for peak flows
α	0.1	Based upon best calibration of the Hōteo River for high flows
η	0.7	Based on Hōteo River calibration sites to show monthly variation in flows.
TimeOfYearFactor	240	Based on Hōteo River flow data, which indicates a peak in sediment load in winter. Justified by the Hōteo River report (Hart & Scott, 2014) which states that erosion reduces to 50 mm trigger value in the summer months.

Streambank erosion generation model

The streambank erosion is related to high flows and is included within the model as an event mean concentration and a dry weather concentration attributed to the quickflow and slowflow generated from the rainfall-runoff model respectively. The annual streambank erosion rate was calculated for each catchment following methodology derived from the SedNetNZ modelling of soil erosion in Northland (Mueller & Dymond, 2015). This was done following the steps below.

- The REC river lengths were obtained using GIS for each subcatchment. For each subcatchment these river lengths were then grouped into stream orders (2 - 5).
- The modelled downstream flow for each source catchment was extracted, and the mean discharge ($\bar{q}$ and Q_{mean}) was calculated for each subcatchment (highest stream order).
- The mean discharge was calculated for each stream order within each catchment, based on observed differences (1/5 of the higher order).
- The observed flow data was reviewed to derive the relationship between the mean discharge and mean flood, giving values of a=20.02 and b=1. Based on this, the mean annual floods (Q_f) were derived for each subcatchment.
- The bank heights and bank migration rates were derived for each subcatchment based on the equations contained in Mueller & Dymond (2015). The rate of streambank erosion per unit channel length was then derived for each subcatchment and stream order.
- The maximum potential annual streambank erosion (tonnes) in each subcatchment was then calculated by totalling the product of the rate of erosion for each stream order by the river length, following the equation in Mueller & Dymond (2015).

- The maximum potential annual streambank erosion was then reduced based upon the calculated riparian proportion related to each land use. The amount of streambank erosion was reduced by 80% where a riparian buffer/stock exclusion exists (Dymond et al, 2014). This calculated the actual annual streambank erosion (tonnes).
- A dry weather concentration of 10 mg/l was included for all subcatchments based upon observed minimum concentrations within the Hōteo River. The remaining streambank erosion for each subcatchment was then applied in the model as an event mean concentration, which was calculated by dividing the remaining actual annual streambank erosion by the average annual quickflow.

The riparian proportion for each land use was estimated based on literature values. The Hōteo River report (Hart & Scott, 2014) contains values for the percentage of the streambank which has a riparian zone for each Hōteo subcatchment (i.e. Waiwhiu, Waiteitei) as shown in Table 29. The riparian proportion for each land use (Table 30) was estimated iteratively by comparing the literature values for riparian percentage for each subcatchment against a calculated riparian percentage, which was calculated as a product of functional unit stream length and an estimated riparian proportion) against these literature values (Table 30).

Table 29 –Stream riparian proportions comparison to Hōteo River Catchment environment and socio-economic review (Hart & Scott, 2014)

Hōteo subcatchment	Literature riparian %	Calculated riparian %	REC Stream length (m)	Calculated riparian length (m)
Waiteitei Stream	56	56	57,203	32,175
Whangaripo	60	70	33,871	23,693
Waiwhiu Stream	96	93	32,947	30,757
Hōteo Central	77	76	58,063	44,137
Wayby	40	55	17,885	9,796
Hōteo Gorge	66	75	19,272	14,448
Kourawhero Stream	68	71	61,222	43,450
Hōteo Lower	63	61	45,596	27,856

Table 30 – Hillslope dSedNet filter model – stream riparian proportions

Functional unit	Stream Riparian Proportion
Crops	0.8
Forest	0.95
Grasslands	0.5
Quarry	0
Shrubs	0.95
Urban	0
Water	0
Wetlands	0.5

Sediment filter models – streambank erosion

Within the dSedNet model, streambank sediment is removed from the river channel through the application of a load-based sediment delivery ratio filter model. This model is applied separately for each catchment and functional unit.

The filter removes sediment load annually based upon the stream length. The stream length for each functional unit was calculated from the REC stream lengths for each subcatchment (stream order 2 - 5) multiplied by the percentage of each land use within each subcatchment.

The filter model has been applied as a calibration factor for low flows and operates as accretion along stream lengths. The model was calibrated against observed values and applies a removal factor based upon the length of stream within each unit, the filter removes up to 1.5 tonnes/km/year of sediment, which is a small proportion of the streambank sediment generation.

There is no filter applied to the hillslope erosion model, this was calibrated using the calibration factor.

4.6.2 Sediment data analysis

Auckland Council has provided sediment data for seven sites within the Kaipara Harbour catchment, however data supplied is variable for each station. Table 31 summarises the available sediment information which includes turbidity, total suspended sediment (TSS) and suspended sediment concentration (SSC) data.

Table 31 – Water quality station site information (NIWA and Auckland Council)

Catchment	Station	Data	Data record	Description
Hōteo River catchment	Hōteo at Gubbs	Continuous turbidity	Mar 1996; Feb-Apr 1997	15 minute, short record, unreliable
			Oct 2011–Dec 2016	5-minute continuous record. Gap Aug–Oct 2016
		TSS	Jun 2010–Jun 2015	Automatic event triggered sampling, to calculate event yields
		SSC	Jun 2010–Jul 2016	
		Turbidity	Feb 1989-Sep 2016	Monthly water quality sampling
	Waiteitei at Sandersons	Continuous turbidity	Mar–Apr 1997	15-minute, short record, unreliable
			Oct 2011-Nov 2016	5-minute continuous record
		TSS	Dec 2011-Sep 2014	Automatic event triggered sampling to calculate event yields
		SSC	Sep 2012-Sep 2014	
Makarau River	Makarau at Railway	Turbidity	Jan 2009-Jan 2017	Monthly water quality sampling
		TSS		
		Turbidity	Jul 2010-Oct 2014	

Catchment	Station	Data	Data record	Description
Kaukapakapa River	Kaukapakapa at Taylors	TSS	Jul 2010-Dec 2014	Automatic event triggered sampling, to calculate event yields
		SSC	Jul 2010-Oct 2016	
Kaipara River catchment	Riverhead at Ararimu	Turbidity	Jan 2009-Jan 2017	Monthly water quality sampling
		TSS		
	Kumeu at Weza	Turbidity	Aug 1993-Jan 2017	Monthly water quality sampling
		TSS		
	Kaipara at Waimauku	Continuous turbidity	May 1998; May 1999; Jan-Feb 2001	15-minute, short record, unreliable
		TSS	Jul 2010–Dec 2014	Automatic event triggered sampling, to calculate event yields
		SSC	Jul 2010–Oct 2016	

Generally, the amount of data was limited to monthly water quality sampling of TSS and turbidity, peak event sampling of SSC and locations with a reliable continuous turbidity record. The dSedNet model was primarily calibrated against two continuous turbidity records within the Hōteo River catchment (Hōteo at Gubbs and Waiteitei at Sandersons)[1] given that the Hōteo River is key to the Project assessment.

The NIWA turbidity data for Hōteo at Gubbs and Waiteitei at Sandersons was converted to a TSS (mg/l) using a field turbidity-TSS relationship provided by NIWA (Hughes, 2017). This relationship was derived by NIWA in a recent study into suspended sediment and visual clarity (Hughes et al, 2016). The field turbidity-TSS relationships provided are based upon the NIWA sampling regime, shown in Figure 20.

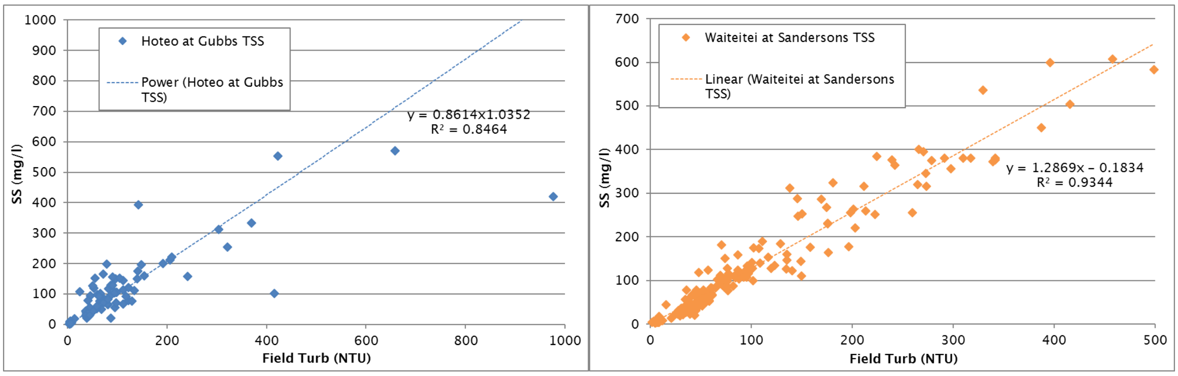

Figure 20 - NIWA derived relationships between field turbidity and total suspended sediment at Hōteo at Gubbs and Waiteitei at Sandersons

This conversion resulted in a continuous 5-minute suspended sediment concentration for both sites for approximately five years (with some data gaps). This was converted to a continuous sediment load (mg/time step) by multiplying the 5-minute suspended sediment concentration by the observed flow converted to 5-minute interval sediment loads. The time

1 Following the calibration of the model we were made aware that NIWA have a third calibration site on the Hoteo River at Waiwhiu. This data was not provided by NIWA or Aucklaend council prior to the calibration taking place.

step between each record was calculated in seconds and multiplied by the sediment load (mg/s), and then this was aggregated by day to calculate the daily sediment load (kg/day).

The resulting sediment load (kg/day) was compared to the recorded event loads supplied by Auckland Council; these were found to be a satisfactory representation of the event sediment loads.

4.6.3 Sediment calibration

The sediment modules for hillslope and streambank erosion were calibrated initially against the Hōteo River catchment using daily TSS load. The modelled sediment yield for the Hōteo River catchment was calculated and checked against the Hōteo catchment sediment yields calculated in the Auckland Council sediment yields report (Curran-Cournane et al, 2013).

Daily calculated TSS yields calibration – Hōteo River catchment

Sediment calibration focused on the Waiteitei stream at Sandersons and the Hōteo River at Gubbs where good quality data was available. The model was calibrated against the observed data for a number of metrics, including the total load, monthly loads and peak daily load (Table 32 and Figure 21).

Table 32 – Hōteo Catchment load statistics and comparisons (October 2011-December 2016)

Statistic	Hōteo at Gubbs		Waiteitei at Sandersons	
	Observed	Modelled	Observed	Modelled
Total load (tonnes)	51,390	68,334	10,166	10,987
Mean annual load (t/yr)	10,532	14,005	2,329	2,517
Load % difference	-	+33%	-	+8%
Daily statistics				
Peak daily load (tonnes)	4,090	4,144	1,190	833
Mean (daily) (tonnes)	28.9	38.4	6.4	6.9
Median (daily) (tonnes)	1.28	1.95	0.19	0.42
90th percentile (daily) (tonnes)	0.11	0.18	0.03	0.03
5th percentile (daily) (tonnes)	91.3	163.8	11.7	25.7
PBIAS (daily)	-	+33%	-	+8%
Percentile NSE	-	0.99	-	0.91
Monthly statistics				
Mean (monthly) (tonnes)	30.5	39.5	6.2	6.7
Median (monthly) (tonnes)	3.9	14.0	0.6	2.1
90th percentile (monthly) (tonnes)	0.55	0.56	0.10	0.09
5th percentile (monthly) (tonnes)	159.6	161.5	38.6	29.6
PBIAS (monthly)	-	29%	-	8%
NSE (monthly)	-	0.67	-	0.31

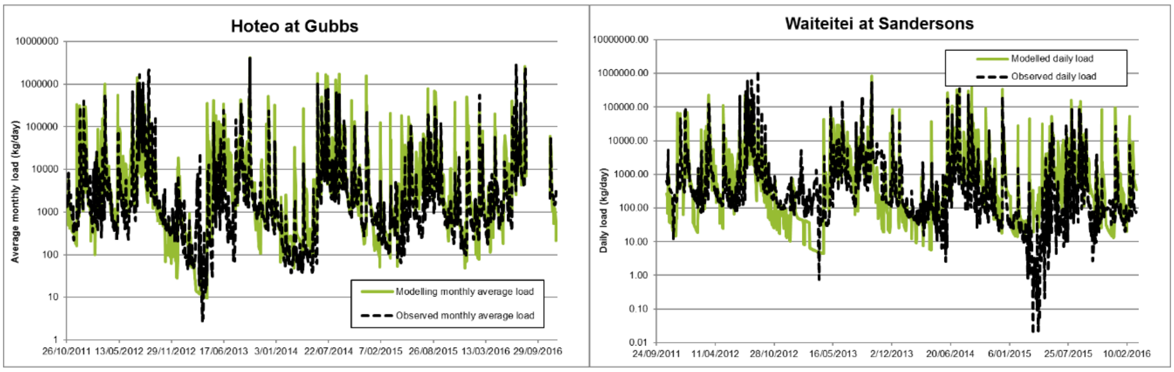

Figure 21 - Hōteo catchment daily load (kg/day) on a log scale – comparison of observed and modelled loads

The data was also plotted to compare the percentile yields (Figure 22), and a 5-day rolling average was created to compare the sediment through time (Figure 23). Additionally, the monthly averages were compared using statistical analysis.

The calibration results indicate that the model slightly overestimated the mean load, however shows a good representation of the peak and minimum sediment loads. The statistics show that the sites are calibrated well against the observed values; the monthly bias error is 15-29%, and a monthly NSE of 0.67 for Hōteo at Gubbs, indicating a good calibration (Moriasi et al, 2007). Generally, the calibration is better at Hōteo at Gubbs than at Waiteitei at Sandersons, this is likely due to the better flow calibration.

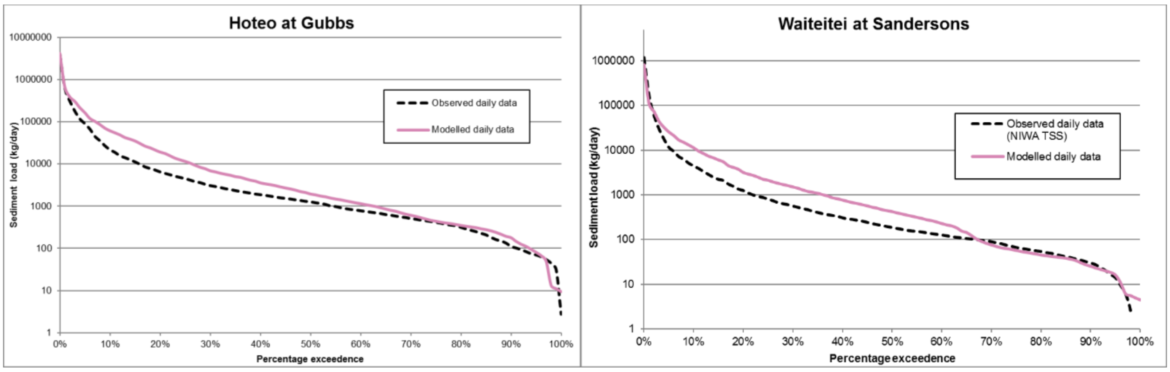

Figure 22 - Hōteo catchment sediment percentiles – comparison of observed and modelled loads

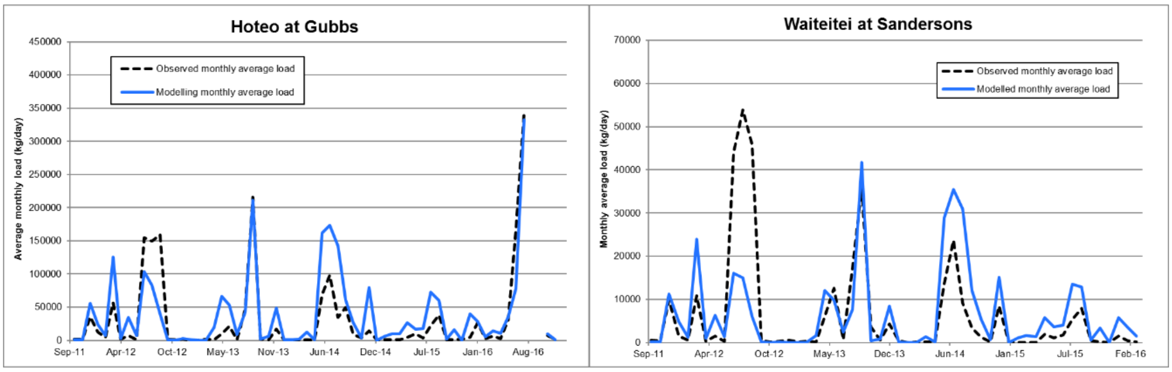

Figure 23 - Hōteo catchment monthly mean load (kg/day) – comparison of observed and modelled loads

The modelled annual sediment load for each calibration site is shown in Figure 24, the modelled load at the Hōteo River mouth has also been included to show scale.

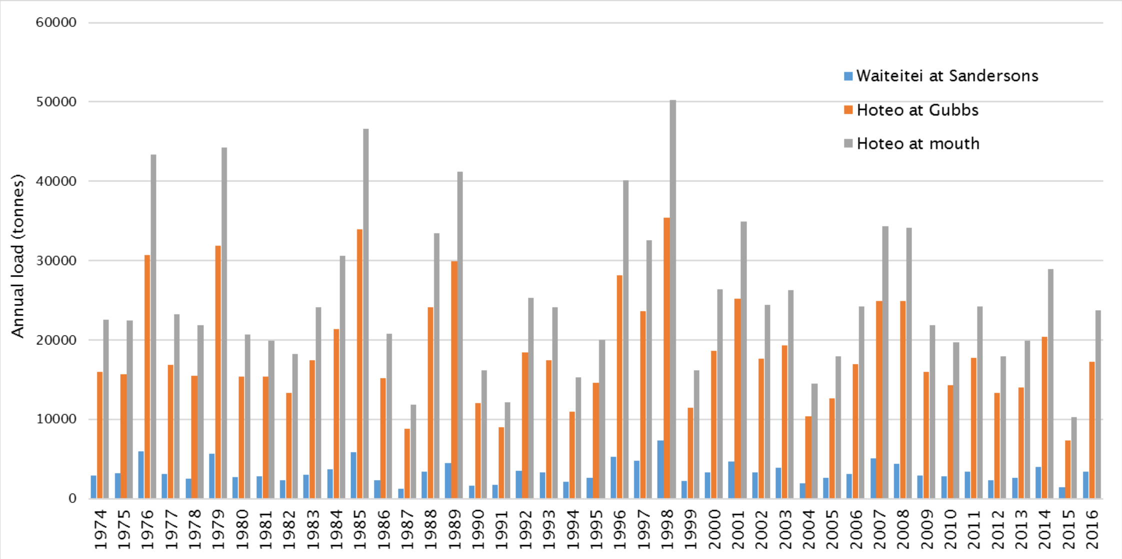

Figure 24 – Modelled annual sediment loads

Annual sediment yield verification

The performance of the model was assessed against the observed values contained in the Auckland Council sediment yield report (Curran-Cournane et al. 2013) for the Hōteo, Kaukapakapa and Kaipara Rivers as a model verification exercise. The Auckland Council sediment yields are based on 1-2.6 years of data; therefore, these values were compared over the same time period (Table 33).

Table 33 – Comparison of modelled and observed sediment loads of Auckland catchments (Curran-Cournane *et* al. 2013)

Statistic	Hōteo at Gubbs		Kaukapakapa at Taylors		Kaipara at Waimauku	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Time period	May 2010–Dec 2012		May 2010–Dec 2012		Jan 2012–Dec 2012	
Total load (t)	51,748	47,848	12,194	5,823	5,259	3,905
Mean annual load (t)	19,903	18,403	4,690	2,240	5,259	3,905
Specific yield (t/km^2/yr)	74.3	67.5	76	36	32.3	25.1
Yield trend (kg/day)	55.5	50.4	11	6.1	21	15.6
Bias error	-8%		-52%		-26%	

Based upon this information, the model performance is good for Hōteo at Gubbs and Kaipara and is satisfactory for Kaukapakapa. It should be noted that the observed data is in a large part based upon a rating curve that does not consider seasonal variation as described within the Hōteo at Gubbs Environment Review (Hart & Scott, 2014). Therefore, based upon limitations in methodology it is considered that the model performs well in simulating catchment sediment mean annual loads.

Relative proportions of erosion

The relative proportion of modelled surficial and streambank erosion sources for each calibration site is shown in Figure 25 and Figure 26. The mean annual of these sediment sources is summarised in Table 34.

Table 34 – Relative proportions of erosion

Site	Mean annual sediment load (tonnes)	Mean annual proportion	
		Hillslope erosion	Streambank erosion
Waiteitei at Sandersons	3,371	51%	49%
Hōteo at Gubbs	18,449	51%	49%
Hōteo at mouth	25,600	59%	41%

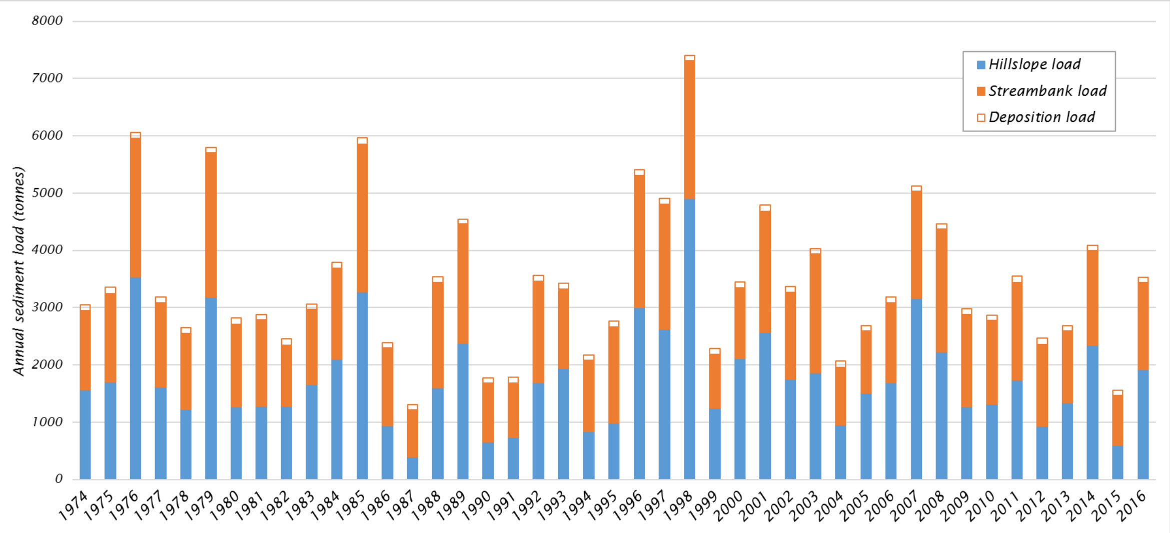

Figure 25 – Waiteitei at Sandersons modelled sediment load

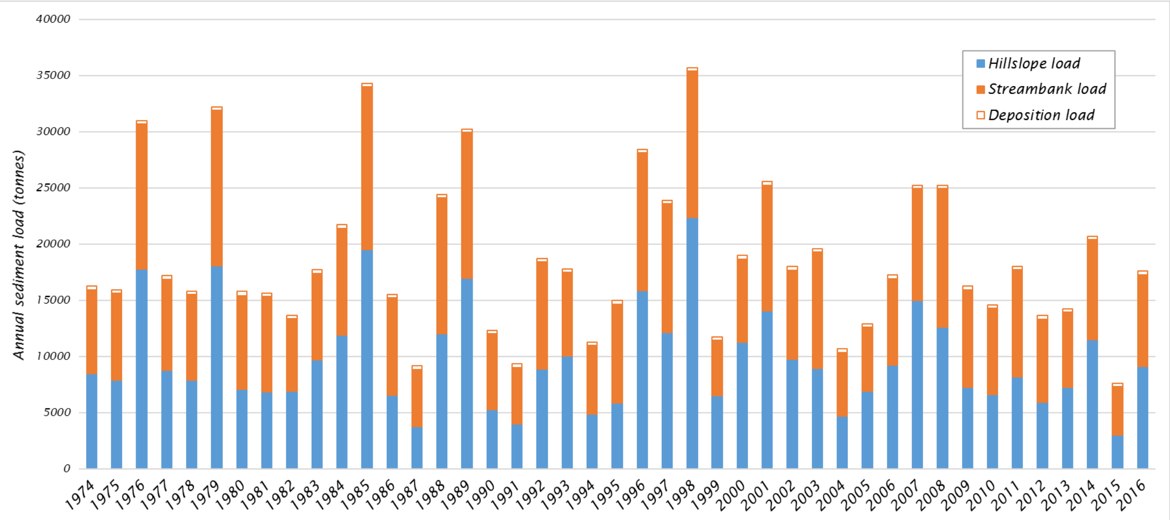

Figure 26 – Hōteo at Gubbs modelled sediment load

4.7 Kaipara catchment pre-development sediment model outputs

The model produces a 34-year time-series (1974-2016) of daily runoff, sediment loads and sediment concentration at multiple points throughout the modelled catchments. The reporting points are river mouths, NIWA water quality monitoring locations, and the site-specific monitoring locations (as identified in *Water Quality – Technical Report*). A map of these locations is shown in Figure 27.

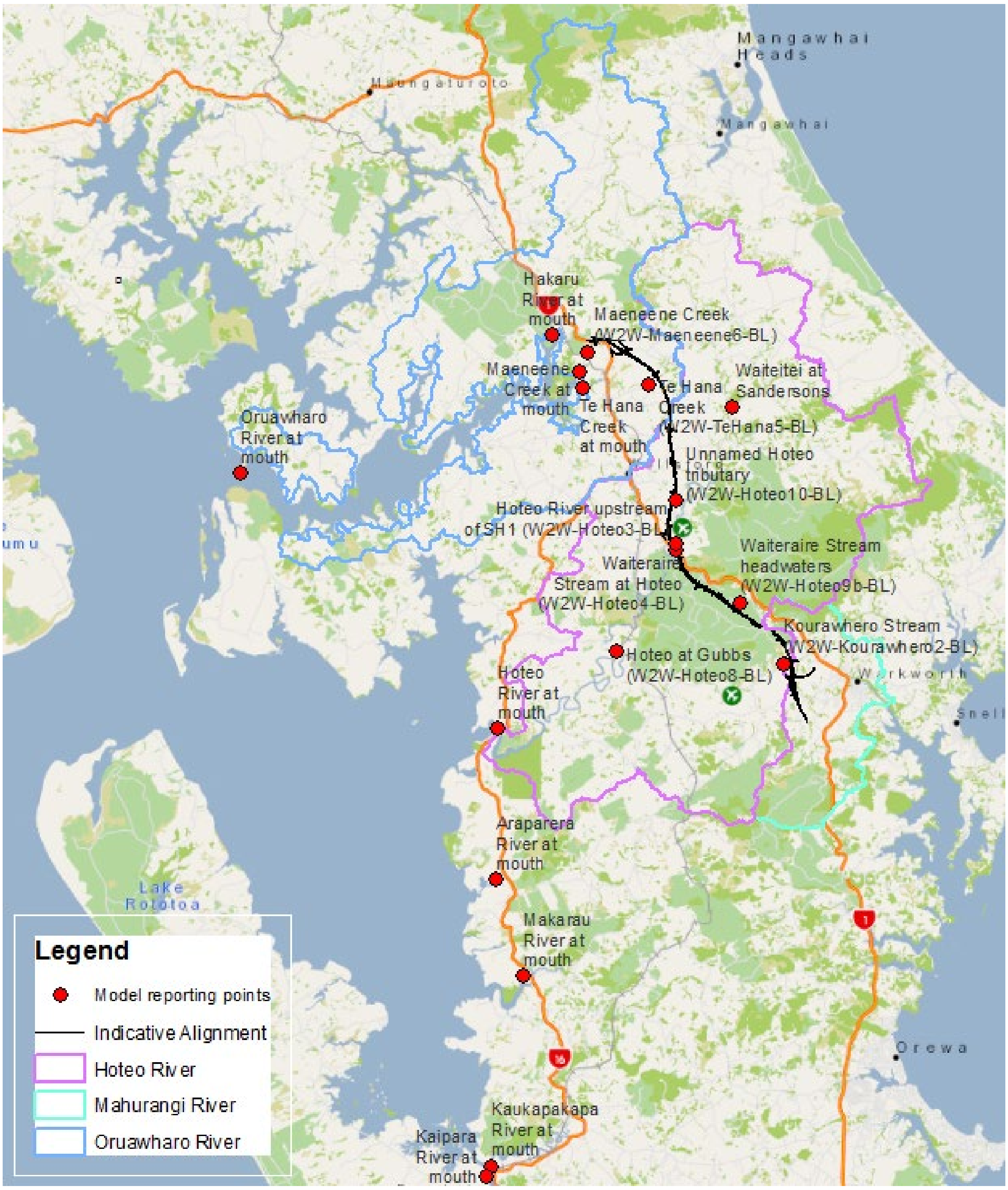

Figure 27 – Approximate locations of model reporting points

The background mean annual sediment loads are reported for each significant river draining to the southern part of the Kaipara Harbour in Table 35. The mean annual sediment loads for the Hōteo River reporting points is contained in Table 36, and for the Oruawharo River reporting points in Table 37.

In addition, event-based loads were calculated for subcatchments with return periods of 2, 10 and 50 year ARIs. These were calculated by performing a frequency analysis on the annual maximum series of daily sediment loads, for each reporting point, in a similar manner as for flows reported in Section 4.5.8. The pre-development scenario ARIs are shown in Table 38 to Table 40.

4.7.1 Pre-development mean annual loads

Table 35 – Estimated mean annual sediment load and runoff delivered to the Kaipara Harbour at Hōteo River and to the estuarine Oruawharo River for pre-development scenario

River catchment	Area (ha)	Mean Annual Load (T)	Mean Annual Runoff (10^3 m^3)
Hōteo River mouth	39,816	25,600	276,516
Oruawharo River terrestrial inputs	26,660	9,284	198,442
Hakaru River at mouth	9,828	4,391	82,339
Araparera River at mouth	7,749	4,106	49,373
Makarau River at mouth	7,468	4,305	50,704
Kaukapakapa River at mouth	11,920	4,250	60,768
Kaipara River at mouth	26,627	16,465	149,183

Table 36 – Estimated mean annual sediment load and runoff within the Hōteo River sub-catchments for pre-development scenario

Hōteo sub-catchment	Reporting point	Area (ha)	Mean annual load (T)	Mean annual runoff (10^3 m^3)
Waiteitei Stream	Waiteitei at Sandersons	7,743	3,371	59,595
Unnamed pasture tributary	Unnamed pasture tributary (Hōteo 10)	227	78	1,501
Waiteraire Stream	Forested headwater (Hōteo 9)	236	119	1,732
	Confluence with Hōteo (Hōteo 4)	1,446	678	10,651
Kourawhero Stream	Headwater (Kourawhero2)	184	69	1,302
Hōteo River	Upstream of SH1 (Hōteo 3)	19,645	12,308	144,710
	Hōteo at Gubbs	26,756	18,449	192,120
	Hōteo River mouth	39,816	25,600	276,516

Table 37 – Estimated mean annual sediment load and runoff within the estuarine Oruawharo River sub-catchments for pre-development scenario

Oruawharo sub-catchment	Reporting point	Area (ha)	Mean annual load (T)	Mean annual runoff (10^3 m^3)
Te Hana Creek	Tributary (TeHana5)	286	67	2,345
	Te Hana mouth	1,743	1,175	14,480
Maeneene Creek	Downstream of SH1 (Maeneene6)	1,188	319	8,363
	Maeneene mouth	1,558	537	9,971
Hakaru River	Hakaru mouth	9,828	4,391	69,118
Oruawharo River	Oruawharo River terrestrial inputs	26,660	9,284	198,442

4.7.2 Pre-development daily event sediment loads

Table 38 – Estimated daily sediment loads delivered to the Kaipara Harbour at Hōteo River and Oruawharo River for ARIs of 2, 10 and 50 years for pre-development scenario

River outlet	50-year ARI (T)	10-year ARI (T)	2-year ARI (T)
Hōteo River mouth	10,912	7,130	3,715
Oruawharo River terrestrial inputs	4,425	2,860	1,405
Hakaru River at mouth	1,952	1,226	577
Araparera River at mouth	408	734	1,020
Makarau River at mouth	1,684	1,238	703
Kaukapakapa River at mouth	1,346	939	516
Kaipara River at mouth	3,070	2,061	1,118

Table 39 – Estimated daily sediment loads within the Hōteo River sub-catchments for ARIs of 2, 10 and 50 years for pre-development scenario

Hōteo sub-catchment	Location	2-year ARI (T)	10-year ARI (T)	50-year ARI (T)
Waiteitei Stream	Waiteitei at Sandersons	1,441	925	449
Unnamed tributary	Unnamed pasture tributary (Hōteo 10)	37	26	14
Waiteraire Stream	Forested headwater (Hōteo 9)	81	51	27
	Confluence with Hōteo River (Hōteo 4)	421	270	140
Kourawhero Stream	Headwater (Kourawhero2)	48	30	16
Hōteo River	Upstream of SH1 (Hōteo 3)	5,194	3,264	1,643
	Hōteo at Gubbs	7,147	4,578	2,329
	Hōteo River mouth	10,912	7,130	3,715

Table 40 – Estimated daily sediment loads within the estuarine Oruawharo River sub-catchments for ARIs of 2, 10 and 50 years

Oruawharo sub-catchment	Location	2-year ARI (T)	10-year ARI (T)	50-year ARI (T)
Te Hana Creek	Te Hana Creek tributary (TeHana5)	15	29	44
	Te Hana Creek at mouth	332	225	118
Maeneene Creek	Maeneene Creek downstream of SH1 (Maeneene6)	199	129	65
	Maeneene Creek at mouth	271	174	87
Oruawharo River	Oruawharo River terrestrial inputs	4,425	2,860	1,405

4.8 Scenario modelling of Project construction

4.8.1 Earthwork areas

The total area of land to be subject to earthworks to construct the Project Indicative Alignment is estimated to be 310 ha. The indicative construction area has been split into the three main catchment areas, and within the Hōteo River catchment this has further been split into 6 operational areas (Table 1). The assumed changing landuse (summer earthworks areas for each year) across the indicative 7-year construction programme are shown in Table 41.

Table 41 – Assumed peak active earthwork areas during 7-year indicative construction programme by construction area

Catchment	Construction area	Total earthwork area (ha)	Peak active summer earthworks (ha)						
			Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6
Mahurangi River	Mahurangi	43.3	6.5	43.3	43.3	43.3	0.0	0.0	0.0
Hōteo River	Operation 1	23.7	3.6	23.7	23.7	0.0	0.0	0.0	0.0
	Operation 2	42.6	6.4	30.0	30.0	30.0	0.0	0.0	0.0
	Operation 3	27.0	4.1	21.3	21.3	0.0	0.0	0.0	0.0
	Operation 4	21.8	3.3	0.0	0.0	21.8	21.8	21.8	0.0
	Operation 5	68.7	10.3	0.0	0.0	23.2	35.0	35.0	55.2
	Operation 6	19.6	2.9	0.0	0.0	0.0	18.2	18.2	19.8
	Hōteo total	203.4	30.5	75.0	75.0	75.0	75.0	75.0	75.0
Oruawharo River	Oruawharo	63.3	9.5	25.0	25.0	25.0	25.0	25.0	0.0

For the 6-years of bulk earthworks, for the summer months the full area of open earthworks in that year is assumed to be open. In the winter months it is assumed through the constructability assessment that 20% of the previous summer area will remain open, with mulching and stabilisation occurring across the other 80% for three months. Year 0 is the year of enabling works and early construction activities, the exact extent of these works is not known at this time and will be detailed during the detailed design stage. It is likely that these works will be approximately 10-15% of the total earthworks, therefore this assessment has conservatively assumed 15% of the total earthworks are open during this year.

The peak active earthworks within the Hōteo River catchment are estimated to be 75 ha, which is based upon achieving the construction programme within the 6-year bulk earthwork timeframe. This peak earthwork area may occur each summer throughout the construction programme, and as such the model has allowed for 75 ha to be open within the Hōteo River catchment each year. It is known that in practice the erosion and sediment management activities will include undertaking progressive stabilisation throughout the summer, and therefore the assumption of 75 ha open each year is considered conservative in terms of open area and associated sediment yields.

Although each summer models 75 ha open area, the peak sediment yield occurs during years 1 and 2. This is due to the assumption that construction is mainly occurring within the Waiteraire catchment during these years, which is a steep catchment and a higher risk area.

The peak active earthworks within the Oruawharo catchment is 25 ha of earthworks, which is also based upon achieving the construction programme. The model estimates that each year of the construction programme will be the same for the Oruawharo catchment. As above, this is also a conservative assumption given that progressive stabilisation will be applied within this catchment.

4.8.2 Erosion and sediment control

The modelled sediment and erosion control reduction factors as applied to the catchment sediment model for the construction scenarios are summarised below:

- For the entire bulk earthwork period (6-years), 10% of the area is assumed to be treated with super silt fences (SSF) and the remaining 90% treated by sediment retention ponds (SRP) or decanting earth bunds (DEB) (Table 42). The majority of construction areas are assumed to be treated by SSFs and SRPs. However, Hōteo Operations 2-4 (Waiteraire Stream), where the area is very steep, it is unlikely that there will be enough space to create SRPs for full treatment and therefore, DEBs have been included in the scenarios as the treatment device.
- For the majority of the Project Indicative Alignment it is possible to site the SRPs and DEBs outside of the floodplain extent. However, the Hōteo River floodplain is extensive in the Hōteo Operation 5 construction area, and it is unlikely that all SRPs in this area could be situated outside of the 20-year floodplain extent. To model this 25% of Hōteo Operation 5 has been modelled as untreated for the 20 year ARI event with the other 75% modelled as incorporating the 50 year ARI event treatment efficiencies of SRPs.
- Within each construction area, there may be areas of open earthworks, stabilised grass areas, and in winter also mulched areas. The exact location of earthworks within the construction areas are not known, therefore to apply the earthwork areas an area weighting has been applied. The ‘open’ area ratio is total area open earthworks per year in each area divided by the entire area.

Table 43 gives the treatment device sediment reduction efficiency factors for each ARI event period applied in the construction scenarios and are expressed as an E factor. These values are based on the ESC efficiency of controls for treatment devices found for the Long Bay[2] development (2011-2012) and were used for P-Wk.

Table 42 – Treatment device percentages applied for construction areas

Construction area	Treatment device weighting		
	SSF	EDB	SRP
Mahurangi	10%	-	90%
Hōteo Operation 1	10%	-	90%
Hōteo Operation 2-4	10%	90%	-
Hōteo Operation 5-6	10%	-	90%
Oruawharo	10%	-	90%

Table 43 – E factor sediment yield reductions for construction areas for different ARI events

Construction area state	E factor		
	2-year ARI	10-year ARI	50-year ARI
'Closed' areas	1.0	1.0	1.0
'Open' areas treated by SRP	0.05	0.15	0.35
'Open' areas treated by SSF	0.20	0.35	0.50

4.8.3 Construction earthworks scenario configuration

The construction scenarios were developed for the Project based upon a 7-year total construction period with 6-years of bulk earthworks. The changing landuse (earthworks) across the 6-year bulk earthworks was modelled across the 34-year historical rainfall record for multiple earthwork scenarios, including modelling summer (October-April) and winter (May – September) earthwork scenarios across the 6-years, using the earthwork area assumptions outlined in Section 4.8.1.

The construction model comprised several different scenarios. The model included changing land-cover scenarios for summer and winter periods for each year of construction (year 1-6 summer and winter scenarios), and each was run for four different treatment reduction options. The construction scenario matrix is shown in Table 44.

2 Long Bay development is a residential development on the Auckland North Shore that was subject to many years of cut to fill earthworks activity.

Table 44 – Construction scenarios matrix

Year	Season	Treatment efficiencies			
		2 ARI	10 ARI	50 ARI	No treatment
Year 1 & year 2	Summer	Yr1Yr2S2	Yr1Yr2S10	Yr1Yr2S50	Yr1Yr2SNoT
	Winter	Yr1Yr2W2	Yr1Yr2W10	Yr1Yr2W50	Yr1Yr2WNoT
Year 3	Summer	Yr3S2	Yr3S10	Yr3S50	Yr3SNoT
	Winter	Yr3W2	Yr3W10	Yr3W50	Yr3WNoT
Year 4 & year 5	Summer	Yr4Yr5S2	Yr4Yr5S10	Yr4Yr5S50	Yr4Yr5SNoT
	Winter	Yr4Yr5W2	Yr4Yr5W10	Yr4Yr5W50	Yr4Yr5WNoT
Year 6	Summer	Yr6S2	Yr6S10	Yr6S50	Yr6SNoT
	Winter	Yr6W2	Yr6W10	Yr6W50	Yr6WNoT

The construction sequencing has divided the total earthworks into eight areas (Table 41): one earthworks area in the Mahurangi River catchment, six (operation) areas within the Hōteo River catchment, and one earthworks area in the Oruawharo catchment. Details of the construction sequencing are detailed in the *Construction Water Management Design - Technical Report*.

The construction-phase sediment loads were estimated by modifying the pre-development SOURCE model to include the construction earthworks scenarios. These modelled construction scenarios were created by changing the land-cover, slope and sediment treatment in the KLSC raster input to the SOURCE model as follows:

Land Cover (C) Factor

The Project Indicative Alignment construction areas in the pre-development land-cover were generally grassland or forest. For the construction this was changed to either exposed soil, mulched or grassland. This was determined by the construction staging and *Construction Water Management Design - Technical Report*.

The C factor values vary for the different construction areas within each area:

- 0.01 is applied to the unworked and stabilised areas which are assumed to have been cleared, this equates to pasture.
- 1.0 is applied for all 'open' areas, which is the value applied for bare earth.
- 0.15 is applied for the mulched areas, which are partially stabilised.

These values are based upon the GLEAMS approach carried out in the P-Wk project (Basher et al, 2016).

The exact areas within each construction area (cuts and fills) to be worked each year is not known at this stage in the project, therefore a spatially weighted approach has been adopted across each construction area.

The construction scenarios assume no change to landuse outside of the indicative earthworks footprint, including within the designation footprint, as this model is assessing the changes associated only with the Project earthworks and construction. It is assumed that all areas of RMF plantation forest within the proposed designation boundary will be harvested prior to construction as part of the plantation forestry owners harvesting programme. The harvesting of these areas prior to construction will change the background sediment load over that period. This harvesting will be undertaken as part of the forest activity, and as such does not form part of the enabling works. The baseline assessment assumes that all plantation forest areas are forested prior to and during construction. This is because the baseline assessment reflects the long-term sediment load rather than temporal changes in land cover that may occur with forest harvest. Therefore the construction scenarios include no change to landuse within the proposed designation outside of the indicative earthworks footprint; ie; the plantation forest areas remain intact. The potential changes to background sediment load that may occur due to forest harvesting are addressed in Section 5 and Appendix F.

Soil Type and soil erodibility (K) factor

The construction scenario assumed that the active earthwork areas will be soil and remain the same soil type as the pre-development scenario model (NZLRI soils).

For the construction scenarios it has been conservatively assumed that the active areas will be soil and remain the same as the pre-development scenario model, which is the K-factor values from the NZLRI soils GIS layer. The NZRLI soil particle size was compared against the bore hole soil data, and the particle size at depth collected for the Project and representative data reported for the P-Wk project.

The geology of the Indicative Alignment has been reviewed by the geotechnical team, and a review of PSD of boreholes within corresponding geological units for the P-Wk Project. The Project's geotechnical team have found that the K NZRLI soil particle size is comparable to borehole soil data. The geotechnical team advised that using the same particle size for cuts as existing (surface) soil was a reasonable assumption (Appendix C). There are some areas that have large cuts, namely, Hōteo Operations 2-4, which will likely have reduced erodibility with depth due to the presence of low slaking rock at depth. We acknowledge that the erodibility will reduce with depth of cutting, however this has not been able to be quantified within the model. This means that in the Waiteraire catchment the results are conservative in these areas.

Slope Length (L) and Slope Steepness (S) Factors

The slopes of the construction areas were modelled with the initial slope of the land as a reasonable representation of the slopes during construction. A comparison of initial and final slopes found that the slopes are generally similar for both cases, however the initial slope is steeper for the Waiteraire catchment, therefore this slope was used as a conservative assumption.

Sediment treatment device efficiency (E) factor

The sediment treatment devices discussed in Section 4.8.2 are implemented for each scenario via the E factor for the 2-year ARI, 10-year ARI and 50-year ARI events, as a representation of the efficiency of the devices at each return period. An additional scenario was run for each season of construction; this has no sediment treatment applied.

The selection criteria for treatment device reduction factors (Table 42) were assumed to be 6 years and 20 year ARI daily event loads. That is, for daily loads less than the 6 year ARI event sediment load the 5 year ARI load reduction factor was applied; for daily loads between the 6 year ARI event load and 20 year event load the 10 year ARI load reduction factor was applied; and for daily loads greater than the 20 year ARI event load the 50 year reduction factor was applied. The GLEAMS model applied 6 years and 30 years as the selection criteria for the sediment treatment efficiencies, our use of 20 years is therefore more conservative.

Rainfall erosivity (R) factor

The R factor is calculated within the model, the set up applied for the pre-development model was retained for the construction scenarios.

Sediment Delivery Ratio

A sediment delivery ratio for surficial erosion is applied to estimate the mass of eroded sediment reaching the stream network. The calculated SDR ranges between 0.42 and 1.0 for the Project catchments, with a mean of 0.56. The sediment delivery ratio has been changed to 1 for construction areas that are open and mulched to represent the increased sediment delivery ratio to watercourses.

Streambank erosion model

The pre-development scenario streambank erosion generation and filter models have been applied for the construction phase scenarios. Although the Project will include some in-stream works, these will be too discrete to be captured in a robust manner in the SOURCE model which operates at a catchment scale. Sediment changes associated with in-stream activities are discussed in the *Water Assessment Report* on a case by case basis.

4.8.4 Construction model outputs

Multiple construction scenarios have been modelled to calculate the estimated increases in sediment yields associated with the Project. These were analysed to calculate two construction outputs, described in detail below:

- Changing land-cover specified across the 7-year indicative construction programme, with modelled scenarios for the 6-year bulk earthworks based upon the Project sequencing, which outputs mean annual sediment loads; and
- Peak active area outputs based on the maximum active area informed by the sequencing which outputs event loads.

Construction scenario loads are compared to pre-development (background) sediment loads, reported for each sub-catchment outlet as both mean annual loads and event-based loads associated with 2, 10 and 50-year ARIs (as documented in Section 4.7).

7-year changing land-use output

The 7-year changing land use outputs report the mean annual sediment load and daily event loads for each construction year, incorporating the changing earthworks for summer and winter, with and without the ESC measures. The mean annual loads reported as part of this output averages the 34-year daily time series output from the model.

The peak active area output

The peak active area outputs report the event loads for the peak active area (summer) of earthworks at each reporting point. This output reports the resulting loads with and without the ESC measures.

The event loads reported assume that the large rainfall events occur during the peak earthworks, and therefore assumes that these rare large rainfall events are occurring during the summer months, as such this is a conservative output.

Historical 7-year “wet weather” output

The historical 7-year “wet weather” output reports the construction sediment load for a 7-year period spanning the years 1997 to 2003. This includes two storm events larger than the 20-year ARI storm event and several more typical events with less than 10 years ARI (Figure 28). The output incorporates the changing earthworks for each year: 1998 corresponds to Year 1 and 1999 to year two, and so on, and incorporates winter work reductions and ESC measures. This output has been included to provide a realistic assessment of the potential increase in sediment load that could occur during consecutive “wet weather” years with large storms, with and without ESC measures.

The selection of the 1997-2003 7-year period is based on analysis of the 34-year historical pre-development daily sediment load. The largest annual sediment load for each year was ranked for a given ARI, indicating the largest storm that occurred each year (Figure 28). This relates to the historical rainfall, given that a large sediment events are driven by a large rainfall events within the model.

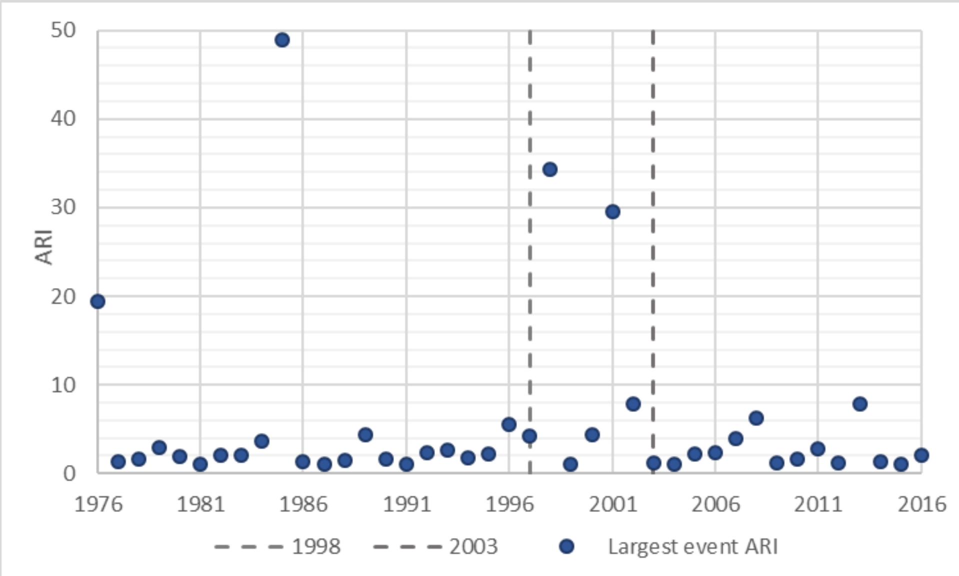

Figure 28 – The largest sediment event in each year for the Hōteo River at mouth, calculated from frequency analysis of the baseline daily sediment yields

This is a reasonable and conservative assumption as it assumes that a number of significant rainfall events will occur during construction, generating a potentially large sediment yield and associated load.

4.8.5 Exclusions

This Kaipara Harbour model estimates the increases in daily sediment load to the receiving water environment associated with the changing land use and earthworks areas. The construction of the Project also has the potential to result in increase to sediment load within receiving watercourses from:

- land clearance and forest harvesting;
- dewatering of the tunnel and excavations; and
- instream works.

These activities have not been modelled as part of this assessment, however the effects have been assessed in the Water Assessment Report.

Forest harvesting has not been modelled as part of the effects assessment given that the harvesting forms part of a forest activity and is not a Project activity. Additionally, there is some uncertainty relating to the harvesting timeframe and methods associated with harvesting activities. An assessment of potential changes to sediment load associated with forest harvesting is included in Section 5, and effects are assessed in the *Water Assessment Report*.

The dewatering of the tunnel and other excavations has not been modelled as dewatering of groundwater is not related to rainfall or surface water.

Instream works are not modelled as instream works occur over a small area, and the sediment generation is dependent upon the type of activities, the methodology applied and the ESC measures. The streambank erosion is therefore the same as for the pre-development scenario. The effect of instream works is assessed in the *Water Assessment Report*.

4.9 Construction model results

4.9.1 7-year changing land-cover output

Mean annual loads

Table 45 to Table 51 summarise the mean annual sediment loads for the 7-year changing land-cover output, both with and without sediment control treatment. The 6-year bulk earthworks scenario were modelled based upon the construction scenario earthwork areas and are included as years 1-6.

Year 0 is an estimate of the potential increase in sediment load for enabling works and early construction activities. The location, extent and timing of these enabling works is not known, therefore we have conservatively assumed that these will be approximately 15% of the total earthworks area. The loads associated with year 0 are based upon a high-level assessment using sediment yields within each catchment (i.e. assuming 15% of the area is open and estimating a load equal to 15% open based on outputs from the model).

Table 45 – Mean annual sediment load (T) discharged to the Kaipara Harbour from the Hōteo River corresponding to changing land-cover (earthworks) during the 7-year indicative construction programme

Year	Hōteo River mouth						
	Pre-development load (T)	Construction (untreated)			Construction (treated)		
		Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)
0	25,600	26,387	787	3.1%	25,692	92	0.4%
1	25,600	28,445	2,845	11.1%	25,941	341	1.3%
2	25,600	28,445	2,845	11.1%	25,941	341	1.3%
3	25,600	27,714	2,114	8.3%	25,877	277	1.1%
4	25,600	26,756	1,155	4.5%	25,761	161	0.6%
5	25,600	26,756	1,155	4.5%	25,761	161	0.6%
6	25,600	26,140	540	2.1%	25,688	87	0.3%
Total	179,202	190,642	11,440	6.4%	180,661	1,459	0.8%
Mean annual	25,600	27,235	1,634	6.4%	25,809	208	0.8%

Table 46 – Mean annual sediment load (T) discharged to the estuarine Oruawharo River corresponding to changing land-cover (earthworks) during the 7-year indicative construction programme

Year	Oruawharo River terrestrial inputs						
	Pre-development load (T)	Construction (untreated)			Construction (treated)		
		Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)
0	9,284	9,364	80	0.9%	9,291	7	0.1%
1	9,284	9,494	210	2.3%	9,302	18	0.2%
2	9,284	9,494	210	2.3%	9,302	18	0.2%
3	9,284	9,494	210	2.3%	9,302	18	0.2%
4	9,284	9,500	216	2.3%	9,302	18	0.2%
5	9,284	9,500	216	2.3%	9,302	18	0.2%
6	9,284	9,292	8	0.1%	9,287	2	0.0%
Total	64,990	66,140	1,150	1.8%	65,088	98	0.2%
Mean annual	9,284	9,449	164	1.8%	9,298	14	0.2%

Table 47 – Mean annual sediment load (T) within the Kourawhero Stream and Waiteraire Stream (Hōteo River) corresponding to changing land-cover (earthworks) during the 7-year indicative construction programme

Year	Kourawhero Stream - headwater (Kourawhero2)							Waiteraire stream – forested headwater (Hōteo 9)							Waiteraire stream - confluence with Hōteo (Hōteo 4)						
		Construction (untreated)			Construction (treated)				Construction (untreated)			Construction (treated)				Construction (untreated)			Construction (treated)		
	Pre-development load (T)	Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)	Pre-development load (T)	Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)	Pre-development load (T)	Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)
0	69	148	79	115%	75	6	9%	119	227	108	90.9%	132	14	12%	678	1,271	593	87.4%	755	76	11%
1	69	596	527	764%	112	43	63%	119	625	507	427%	183	65	55%	678	2,978	2,299	339%	974	296	44%
2	69	596	527	764%	112	43	63%	119	625	507	427%	183	65	55%	678	2,978	2,299	339%	974	296	44%
3	69	75	6	8%	75	6	8%	119	625	507	427%	183	65	54%	678	2,580	1,901	280%	930	251	37%
4	69	75	6	8%	75	6	8%	119	126	8	6%	126	8	6%	678	1,381	703	104%	794	115	17%
5	69	75	6	8%	75	6	8%	119	126	8	6%	126	8	6%	678	1,381	703	104%	794	115	17%
6	69	75	6	8%	75	6	8%	119	126	8	6%	126	8	6%	678	718	40	6%	718	40	6%
Total	482	1,637	1,155	239%	598	116	24%	831	2,482	1,651	199%	1,061	231	28%	4,749	13,288	8,539	180%	5,938	1,189	25%
Mean annual	69	234	165	239%	85	17	24%	119	355	236	199%	152	33	28%	678	1,898	1,220	180%	848	170	25%

Table 48 – Mean annual sediment load (T) in the unnamed pasture tributary (H2) of the Hōteo River and Waiteitei Stream corresponding to changing land-cover (earthworks) during the 7-year construction period

Year	Unnamed pasture tributary (Hōteo 10)							Waiteitei Stream - at Sandersons						
	Pre-development load (T)	Construction (untreated)			Construction (treated)			Pre-development load (T)	Construction (untreated)			Construction (treated)		
		Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)		Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)
0	78	104	27	34%	80	2	3%	3,371	3,384	13	0.4%	3,372	1	0.0%
1	78	78	0	0%	78	0	0%	3,371	3,371	0	0%	3,371	0	0.0%
2	78	78	0	0%	78	0	0%	3,371	3,371	0	0%	3,371	0	0.0%
3	78	137	59	76%	83	5	6%	3,371	3,371	0	0%	3,371	0	0.0%
4	78	168	91	116%	85	7	10%	3,371	3,450	79	2%	3,376	5	0.2%
5	78	168	91	116%	85	7	10%	3,371	3,450	79	2%	3,376	5	0.2%
6	78	223	145	187%	90	12	15%	3,371	3,456	85	2%	3,377	6	0.2%
Total	544	957	413	76%	579	34	6%	23,597	23,852	255	1.1%	23,613	16	0.1%
Mean annual	78	137	59	76%	83	5	6%	3,371	3,407	36	1.1%	3,373	2	0.1%

Table 49 – Mean annual sediment load (T) within the Hōteo River corresponding to changing land-cover (earthworks) during the 7-year indicative construction programme

Year	Hōteo River upstream of SH1 (Hōteo 3)							Hōteo River at Gubbs						
	Pre-development load (T)	Construction (untreated)			Construction (treated)			Pre-development load (T)	Construction (untreated)			Construction (treated)		
		Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)		Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)
0	12,308	12,396	88	1%	12,315	7	0.1%	18,449	19,157	708	4%	18,535	86	0.5%
1	12,308	12,308	0	0%	12308	0	0.0%	18,449	20,749	2,300	12%	18,744	294	1.6%
2	12,308	12,308	0	0%	12308	0	0.0%	18,449	20,749	2,300	12%	18,744	294	1.6%
3	12,308	12,428	120	1%	12318	10	0.1%	18,449	20,557	2,108	11%	18,719	270	1.5%
4	12,308	12,666	358	3%	12337	29	0.2%	18,449	19,599	1,149	6%	18,604	154	0.8%
5	12,308	12,666	358	3%	12337	29	0.2%	18,449	19,599	1,149	6%	18,604	154	0.8%
6	12,308	12,791	483	4%	12348	40	0.3%	18,449	18,983	534	3%	18,530	81	0.4%
Total	86,156	87,564	1,407	2%	86,272	116	0.1%	129,144	139,393	10,249	8%	130,479	1,335	1.0%
Mean annual	12,308	12,509	201	2%	12,325	17	0.1%	18,449	19,913	1,464	8%	18,640	191	1.0%

Table 50 – Mean annual sediment load (T) within the Te Hana Creek (Oruawharo River) corresponding to changing land-cover during the 7-year indicative construction programme including summer (100% construction area open) and winter extents (20% construction area open)

Year	Te Hana Creek - tributary (TeHana5)							Te Hana Creek - at mouth						
	Pre-development load (T)	Construction (untreated)			Construction (treated)			Pre-development load (T)	Construction (untreated)			Construction (treated)		
		Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)		Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)
0	67	89	23	34.2%	68	2	3%	1,175	1,224	49	4.2%	1,178	4	0.3%
1	67	126	60	90%	71	5	7%	1,175	1,303	128	11%	1,184	10	0.8%
2	67	126	60	90%	71	5	7%	1,175	1,303	128	11%	1,184	10	0.8%
3	67	126	60	90%	71	5	7%	1,175	1,303	128	11%	1,184	10	0.8%
4	67	126	60	90%	71	5	7%	1,175	1,309	134	11%	1,185	10	0.8%
5	67	126	60	90%	71	5	7%	1,175	1,309	134	11%	1,185	10	0.8%
6	67	67	0	0%	67	0	0%	1,175	1,181	6	1%	1,175	0	0.0%
Total	466	788	322	69.0%	492	26	6%	8,222	8,931	709	8.6%	8,275	53	0.6%
Mean annual	67	113	46	69.0%	70	4	6%	1,175	1,276	101	8.6%	1,182	8	0.6%

Table 51 – Mean annual sediment load (T) within the Maeneene Creek (Oruawharo River) corresponding to changing land-cover during the 7-year indicative construction programme including summer (100% construction area open) and winter extents (20% construction area open)

Year	Maeneene Creek - downstream of SH1 (Maeneene6)							Maeneene Creek - at mouth						
	Pre-development load (T)	Construction (untreated)			Construction (treated)			Pre-development load (T)	Construction (untreated)			Construction (treated)		
		Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)		Load (T)	Increase (T)	Increase (%)	Load (T)	Increase (T)	Increase (%)
0	319	349	30	9.4%	321	3	0.8%	537	567	31	5.7%	539	3	0.5%
1	319	398	79	24.8%	325	7	2.1%	537	617	80	15.0%	543	7	1.3%
2	319	398	79	24.8%	325	7	2.1%	537	617	80	15.0%	543	7	1.3%
3	319	398	79	24.8%	325	7	2.1%	537	617	80	15.0%	543	7	1.3%
4	319	398	79	24.8%	325	7	2.1%	537	617	80	15.0%	543	7	1.3%
5	319	398	79	24.8%	325	7	2.1%	537	617	80	15.0%	543	7	1.3%
6	319	319	1	0.2%	319	1	0.2%	537	537	1	0.1%	537	1	0.1%
Total	2,231	2,657	426	19.1%	2,267	36	1.6%	3,756	4,189	433	11.5%	3,792	37	1.0%
Mean annual	319	380	61	19.1%	324	5	1.6%	537	598	62	11.5%	542	5	1.0%

Daily event sediment loads

Across the 6-year bulk earthwork period the landcover (earthworks) change each year, with summer and winter areas modelled. Winter earthwork reductions are applied, therefore across the 6-year bulk earthwork period there are twelve “earthwork seasons”. For each of these seasons there are two scenarios, that is with and without ESC, therefore there are a total of 24 modelled construction scenarios.

Table 52 to Table 62 summarise the ARI daily event sediment loads reflecting the changing land-cover (earthworks) for each modelled construction scenario across the the 6-year bulk earthwork period. These tables include both the summer and winter loads for each event ARI, that correspond to each modelled construction scenario, with and without treatment by sediment control devices. The numbers reflect the potential load that could occur were a storm to occur during an earthwork season and are not cumulative across each year or across the 6-year bulk earthworks period. Generally, these large events are more likely to occur during the winter months when earthworks are reduced in area.

Table 52 – Daily event loads (T) discharged to the Kaipara Harbour from the Hōteo river catchment corresponding to changing land-cover (earthworks) during the 6-year bulk earthworks for ARIs of 2, 10 and 50 years

Model scenario			Hōteo River mouth event loads (T)								
			50-year ARI			10-year ARI			2-year ARI		
			Load	Increase		Load	Increase		Load	Increase	
Pre-development			10,912	-	-	7,130	-	-	3,715	-	-
Year 1	*No ESC*	*Summer*	*15,545*	*4,632*	*42%*	*9,583*	*2,453*	*34%*	*5,041*	*1,326*	*36%*
		Winter	*12,027*	*1,115*	*10%*	*7,721*	*591*	*8%*	*4,034*	*320*	*9%*
	With ESC	Summer	12,776	1,863	17%	7,642	512	7%	3,854	139	4%
		Winter	11,403	491	4%	7,263	133	2%	3,754	40	1%
Year 2	*No ESC*	*Summer*	*15,545*	*4,632*	*42%*	*9,583*	*2,453*	*34%*	*5,041*	*1,326*	*36%*
		Winter	*12,027*	*1,115*	*10%*	*7,721*	*591*	*8%*	*4,034*	*320*	*9%*
	With ESC	Summer	12,776	1,863	17%	7,642	512	7%	3,854	139	4%
		Winter	11,403	491	4%	7,263	133	2%	3,754	40	1%
Year 3	*No ESC*	*Summer*	*14,211*	*3,299*	*30%*	*8,952*	*1,822*	*26%*	*4,737*	*1,022*	*28%*
		Winter	*11,723*	*810*	*7%*	*7,577*	*447*	*6%*	*3,966*	*251*	*7%*
	With ESC	Summer	12,296	1,383	13%	7,526	396	6%	3,830	115	3%
		Winter	11,266	354	3%	7,237	107	2%	3,750	35	1%
Year 4	*No ESC*	*Summer*	*12,623*	*1,710*	*16%*	*8,144*	*1,014*	*14%*	*4,302*	*587*	*16%*
		Winter	*11,347*	*435*	*4%*	*7,386*	*256*	*4%*	*3,863*	*148*	*4%*
	With ESC	Summer	11,649	737	7%	7,347	217	3%	3,780	65	2%
		Winter	11,115	202	2%	7,196	66	1%	3,738	23	1%
Year 5	*No ESC*	*Summer*	*12,623*	*1,710*	*16%*	*8,144*	*1,014*	*14%*	*4,302*	*587*	*16%*
		Winter	*11,347*	*435*	*4%*	*7,386*	*256*	*4%*	*3,863*	*148*	*4%*
	With ESC	Summer	11,649	737	7%	7,347	217	3%	3,780	65	2%
		Winter	11,115	202	2%	7,196	66	1%	3,738	23	1%
		Summer	*11,652*	*740*	*7%*	*7,614*	*484*	*7%*	*3,992*	*277*	*7%*

Model scenario			Hōteo River mouth event loads (T)								
			50-year ARI			10-year ARI			2-year ARI		
			Load	Increase		Load	Increase		Load	Increase	
Year 6	*No ESC*	*Winter*	*11,117*	*204*	*2%*	*7,261*	*130*	*2%*	*3,789*	*74*	*2%*
	With ESC	Summer	11,271	358	3%	7,230	100	1%	3,744	29	1%
		Winter	11,026	113	1%	7,169	39	1%	3,730	15	0%

Table 53 – Daily event loads (T) discharged to the estuarine Oruawharo river catchment corresponding to changing land-cover (earthworks) during the 6-year bulk earthworks for ARIs of 2, 10 and 50 years

Model scenario			Terrestrial inputs to Oruawharo River								
			50-year ARI			10-year ARI			2-year ARI		
			Load	Increase		Load	Increase		Load	Increase	
Pre-development			4,425	-	-	2,860	-	-	1,405	-	-
Year 1	*No ESC*	*Summer*	*4,724*	*+299*	*7%*	*3,069*	*+210*	*7%*	*1,513*	*+108*	*8%*
		Winter	*4,498*	*+73*	*2%*	*2,911*	*+51*	*2%*	*1,432*	*+27*	*2%*
	With ESC	Summer	4,535	+110	2%	2,896	+37	1%	1,413	+8	1%
		Winter	4,453	+28	1%	2,869	+10	0%	1,407	+2	0%
Year 2	*No ESC*	*Summer*	*4,724*	*+299*	*7%*	*3,069*	*+210*	*7%*	*1,513*	*+108*	*8%*
		Winter	*4,498*	*+73*	*2%*	*2,911*	*+51*	*2%*	*1,432*	*+27*	*2%*
	With ESC	Summer	4,535	+110	2%	2,896	+37	1%	1,413	+8	1%
		Winter	4,453	+28	1%	2,869	+10	0%	1,407	+2	0%
Year 3	*No ESC*	*Summer*	*4,724*	*+299*	*7%*	*3,069*	*+210*	*7%*	*1,513*	*+108*	*8%*
		Winter	*4,498*	*+73*	*2%*	*2,911*	*+51*	*2%*	*1,432*	*+27*	*2%*
	With ESC	Summer	4,535	+110	2%	2,896	+37	1%	1,413	+8	1%
		Winter	4,453	+28	1%	2,869	+10	0%	1,407	+2	0%
Year 4	*No ESC*	*Summer*	*4,732*	*+307*	*7%*	*3,074*	*+215*	*8%*	*1,516*	*+111*	*8%*
		Winter	*4,500*	*+75*	*2%*	*2,912*	*+53*	*2%*	*1,432*	*+27*	*2%*
	With ESC	Summer	4,538	+113	3%	2,897	+37	1%	1,413	+8	1%
		Winter	4,453	+29	1%	2,869	+10	0%	1,407	+2	0%
Year 5	*No ESC*	*Summer*	*4,732*	*+307*	*7%*	*3,074*	*+215*	*8%*	*1,516*	*+111*	*8%*
		Winter	*4,500*	*+75*	*2%*	*2,912*	*+53*	*2%*	*1,432*	*+27*	*2%*
	With ESC	Summer	4,538	+113	3%	2,897	+37	1%	1,413	+8	1%
		Winter	4,453	+29	1%	2,869	+10	0%	1,407	+2	0%
Year 6	*No ESC*	*Summer*	*4,435*	*+10*	*0%*	*2,866*	*+6*	*0%*	*1,409*	*+4*	*0%*
		Winter	*4,428*	*+3*	*0%*	*2,862*	*+2*	*0%*	*1,406*	*+1*	*0%*
	With ESC	Summer	4,429	+4	0%	2,861	+2	0%	1,406	+1	0%
		Winter	4,427	+2	0%	2,861	+1	0%	1,405	+1	0%

Table 54 – Daily event loads and increases (T) in Kourawhero Stream (Hōteo tributary) for changing land-cover (earthworks) during the 6-year bulk earthworks (with and without treatment) for ARIs of 2, 10 and 50 years

Model scenario			Kourawhero Stream (Kourawhero2)								
			50-year ARI			10-year ARI			2-year ARI		
			Load	Increase		Load	Increase		Load	Increase	
Pre-development			49	-	-	30	-	-	16	-	-
Year 1	*No ESC*	*Summer*	*844*	*794*	*1613%*	*521*	*491*	*1613%*	*270*	*255*	*1613%*
		Winter	*236*	*187*	*380%*	*146*	*115*	*380%*	*76*	*60*	*380%*
	With ESC	Summer	341	292	592%	115	85	279%	33	17	110%
		Winter	120	71	143%	52	21	71%	21	5	32%
Year 2	*No ESC*	*Summer*	*844*	*794*	*1613%*	*521*	*491*	*1613%*	*270*	*255*	*1613%*
		Winter	*236*	*187*	*380%*	*146*	*115*	*380%*	*76*	*60*	*380%*
	With ESC	Summer	341	292	592%	115	85	279%	33	17	110%
		Winter	120	71	143%	52	21	71%	21	5	32%
Year 3	*No ESC*	*Summer*	*53*	*4*	*8%*	*33*	*2*	*8%*	*17*	*1*	*8%*
		Winter	*53*	*4*	*8%*	*33*	*2*	*8%*	*17*	*1*	*8%*
	With ESC	Summer	53	4	8%	33	2	8%	17	1	8%
		Winter	53	4	8%	33	2	8%	17	1	8%
Year 4	*No ESC*	*Summer*	*53*	*4*	*8%*	*33*	*2*	*8%*	*17*	*1*	*8%*
		Winter	*53*	*4*	*8%*	*33*	*2*	*8%*	*17*	*1*	*8%*
	With ESC	Summer	53	4	8%	33	2	8%	17	1	8%
		Winter	53	4	8%	33	2	8%	17	1	8%
Year 5	*No ESC*	*Summer*	*53*	*4*	*8%*	*33*	*2*	*8%*	*17*	*1*	*8%*
		Winter	*53*	*4*	*8%*	*33*	*2*	*8%*	*17*	*1*	*8%*
	With ESC	Summer	53	4	8%	33	2	8%	17	1	8%
		Winter	53	4	8%	33	2	8%	17	1	8%
Year 6	*No ESC*	*Summer*	*53*	*4*	*8%*	*33*	*2*	*8%*	*17*	*1*	*8%*
		Winter	*53*	*4*	*8%*	*33*	*2*	*8%*	*17*	*1*	*8%*
	With ESC	Summer	53	4	8%	33	2	8%	17	1	8%
		Winter	53	4	8%	33	2	8%	17	1	8%

Table 55 – Daily event loads and increases (T) in Waiteraire Stream (Hōteo tributary) for changing land-cover (earthworks) during the 6-year bulk earthworks (with and without treatment) for ARIs of 2, 10 and 50 years

Model scenario			Waiteraire Stream headwaters (Hōteo 9)									Waiteraire Stream at confluence (Hōteo 4)								
			50-year ARI			10-year ARI			2-year ARI			50-year ARI			10-year ARI			2-year ARI		
			Load	Increase		Load	Increase		Load	Increase		Load	Increase		Load	Increase		Load	Increase	
Pre-development			81	-	-	51	-	-	27	-	-	421	-	-	270	-	-	140	-	-
Year 1	*No ESC*	*Summer*	*809*	*728*	*896%*	*512*	*460*	*896%*	*265*	*238*	*896%*	*3,718*	*3,297*	*783%*	*2,288*	*2,018*	*747%*	*1,217*	*1,077*	*768%*
		Winter	*259*	*177*	*218%*	*164*	*112*	*218%*	*85*	*58*	*218%*	*1,219*	*798*	*189%*	*759*	*488*	*181%*	*401*	*261*	*186%*
	With ESC	Summer	381	300	369%	151	100	195%	53	27	101%	1,779	1,358	322%	709	439	162%	262	121	87%
		Winter	160	79	97%	77	26	51%	34	7	28%	778	357	85%	385	114	42%	175	34	24%
Year 2	*No ESC*	*Summer*	*809*	*728*	*896%*	*512*	*460*	*896%*	*265*	*238*	*896%*	*3,718*	*3,297*	*783%*	*2,288*	*2,018*	*747%*	*1,217*	*1,077*	*768%*
		Winter	*259*	*177*	*218%*	*164*	*112*	*218%*	*85*	*58*	*218%*	*1,219*	*798*	*189%*	*759*	*488*	*181%*	*401*	*261*	*186%*
	With ESC	Summer	381	300	369%	151	100	195%	53	27	101%	1,779	1,358	322%	709	439	162%	262	121	87%
		Winter	160	79	97%	77	26	51%	34	7	28%	778	357	85%	385	114	42%	175	34	24%
Year 3	*No ESC*	*Summer*	*809*	*728*	*896%*	*512*	*460*	*896%*	*265*	*238*	*897%*	*3,106*	*2,685*	*637%*	*1,960*	*1,690*	*625%*	*1,034*	*893*	*637%*
		Winter	*259*	*177*	*219%*	*164*	*112*	*219%*	*85*	*58*	*219%*	*1,078*	*657*	*156%*	*684*	*413*	*153%*	*359*	*218*	*156%*
	With ESC	Summer	381	300	369%	151	100	195%	53	27	101%	1,531	1,110	263%	641	371	137%	243	103	73%
		Winter	156	75	92%	77	26	51%	34	7	28%	703	282	67%	370	99	37%	171	30	22%
Year 4	*No ESC*	*Summer*	*86*	*5*	*6%*	*55*	*3*	*7%*	*28*	*2*	*7%*	*1,346*	*924*	*219%*	*915*	*645*	*239%*	*473*	*332*	*237%*
		Winter	*86*	*5*	*6%*	*55*	*3*	*7%*	*28*	*2*	*7%*	*660*	*239*	*57%*	*436*	*165*	*61%*	*226*	*85*	*61%*
	With ESC	Summer	86	5	6%	55	3	7%	28	2	7%	814	393	93%	420	150	55%	184	43	31%
		Winter	86	5	6%	55	3	7%	28	2	7%	534	113	27%	318	48	18%	157	17	12%
Year 5	*No ESC*	*Summer*	*86*	*5*	*6%*	*55*	*3*	*7%*	*28*	*2*	*7%*	*1,346*	*924*	*219%*	*915*	*645*	*239%*	*473*	*332*	*237%*
		Winter	*86*	*5*	*6%*	*55*	*3*	*7%*	*28*	*2*	*7%*	*660*	*239*	*57%*	*436*	*165*	*61%*	*226*	*85*	*61%*
	With ESC	Summer	86	5	6%	55	3	7%	28	2	7%	814	393	93%	420	150	55%	184	43	31%
		Winter	86	5	6%	55	3	7%	28	2	7%	534	113	27%	318	48	18%	157	17	12%
Year 6	*No ESC*	*Summer*	*86*	*5*	*6%*	*55*	*3*	*7%*	*28*	*2*	*7%*	*448*	*27*	*6%*	*287*	*17*	*6%*	*149*	*9*	*6%*
		Winter	*86*	*5*	*6%*	*55*	*3*	*7%*	*28*	*2*	*7%*	*448*	*27*	*6%*	*287*	*17*	*6%*	*149*	*9*	*6%*
	With ESC	Summer	86	5	6%	55	3	7%	28	2	7%	448	27	6%	287	17	6%	149	9	6%
		Winter	86	5	6%	55	3	7%	28	2	7%	448	27	6%	287	17	6%	149	9	6%

Table 56 – Daily event loads and increases (T) in Hōteo tributaries for changing land-cover (earthworks) during the 6-year bulk earthworks (with and without treatment) for ARIs of 2, 10 and 50 years

Model scenario			Unnamed tributary (Hōteo 10)									Waiteitei Stream - at Sandersons								
			50-year ARI			10-year ARI			2-year ARI			50-year ARI			10-year ARI			2-year ARI		
			Load	Increase		Load	Increase		Load	Increase		Load	Increase		Load	Increase		Load	Increase	
Pre-development			37	-	-	26	-	-	14	-	-	1,441	-	-	925	-	-	449	-	-
Year 1	*No ESC*	*Summer*	*37*	*-*	*0%*	*26*	*-*	*0%*	*14*	*-*	*0%*	*1,441*	*-*	*0%*	*924*	*-*	*0%*	*449*	*-*	*0%*
		Winter	*37*	*-*	*0%*	*26*	*-*	*0%*	*14*	*-*	*0%*	*1,441*	*-*	*0%*	*924*	*-*	*0%*	*449*	*-*	*0%*
	With ESC	Summer	37	-	0%	26	-	0%	14	-	0%	1,441	-	0%	924	-	0%	449	-	0%
		Winter	37	-	0%	26	-	0%	14	-	0%	1,441	-	0%	924	-	0%	449	-	0%
Year 2	*No ESC*	*Summer*	*37*	*-*	*0%*	*26*	*-*	*0%*	*14*	*-*	*0%*	*1,441*	*-*	*0%*	*924*	*-*	*0%*	*449*	*-*	*0%*
		Winter	*37*	*-*	*0%*	*26*	*-*	*0%*	*14*	*-*	*0%*	*1,441*	*-*	*0%*	*924*	*-*	*0%*	*449*	*-*	*0%*
	With ESC	Summer	37	-	0%	26	-	0%	14	-	0%	1,441	-	0%	924	-	0%	449	-	0%
		Winter	37	-	0%	26	-	0%	14	-	0%	1,441	-	0%	924	-	0%	449	-	0%
Year 3	*No ESC*	*Summer*	*116*	*-*	*0%*	*83*	*-*	*0%*	*43*	*-*	*0%*	*1,441*	*-*	*0%*	*924*	*-*	*0%*	*449*	*-*	*0%*
		Winter	*56*	*-*	*0%*	*40*	*-*	*0%*	*21*	*-*	*0%*	*1,441*	*-*	*0%*	*924*	*-*	*0%*	*449*	*-*	*0%*
	With ESC	Summer	78	-	0%	36	-	0%	16	-	0%	1,441	-	0%	924	-	0%	449	-	0%
		Winter	47	-	0%	29	-	0%	15	-	0%	1,441	-	0%	924	-	0%	449	-	0%
Year 4	*No ESC*	*Summer*	*158*	*122*	*260%*	*113*	*87*	*300%*	*58*	*44*	*304%*	*1,571*	*130*	*9%*	*997*	*72*	*8%*	*486*	*37*	*8%*
		Winter	*66*	*29*	*19%*	*47*	*21*	*19%*	*25*	*11*	*18%*	*1,472*	*31*	*2%*	*942*	*17*	*2%*	*458*	*9*	*2%*
	With ESC	Summer	99	62	94%	41	15	31%	17	3	12%	1,488	47	3%	937	12	1%	452	2	0%
		Winter	52	15	15%	30	4	9%	15	1	4%	1,452	11	1%	927	3	0%	450	0	0%
Year 5	*No ESC*	*Summer*	*158*	*122*	*234%*	*113*	*87*	*288%*	*58*	*44*	*299%*	*1,571*	*130*	*9%*	*997*	*72*	*8%*	*486*	*37*	*8%*
		Winter	*66*	*29*	*19%*	*47*	*21*	*19%*	*25*	*11*	*18%*	*1,472*	*31*	*2%*	*942*	*17*	*2%*	*458*	*9*	*2%*
	With ESC	Summer	99	62	94%	41	15	31%	17	3	12%	1,488	47	3%	937	12	1%	452	2	0%
		Winter	52	15	15%	30	4	9%	15	1	4%	1,452	11	1%	927	3	0%	450	0	0%
Year 6	*No ESC*	*Summer*	*233*	*196*	*377%*	*166*	*140*	*464%*	*85*	*71*	*481%*	*1,581*	*140*	*10%*	*1,002*	*78*	*8%*	*489*	*40*	*9%*
		Winter	*84*	*47*	*20%*	*60*	*33*	*20%*	*31*	*17*	*20%*	*1,475*	*33*	*2%*	*943*	*19*	*2%*	*459*	*9*	*2%*
	With ESC	Summer	137	100	120%	50	24	40%	19	5	15%	1,492	51	3%	937	13	1%	452	2	1%
		Winter	61	24	18%	32	6	12%	15	1	6%	1,453	12	1%	927	3	0%	450	0	0%

Table 57 – Daily event loads and increases (T) in the Hōteo River for changing land-cover (earthwork) during the 6-year bulk earthworks (with and without treatment) for ARIs of 2, 10 and 50 years

Model scenario			Hōteo River at SH1 (Hōteo 3)									Hōteo River at Gubbs								
			50-year ARI			10-year ARI			2-year ARI			50-year ARI			10-year ARI			2-year ARI		
			Load	Increase		Load	Increase		Load	Increase		Load	Increase		Load	Increase		Load	Increase	
Pre-development			5,194	-	-	3,264	-	-	1,643	-	-	7,147	-	-	4,578	-	-	2,329	-	-
Year 1	*No ESC*	*Summer*	*5,194*	*-*	*0%*	*3,264*	*-*	*0%*	*1,643*	*-*	*0%*	*10,614*	*3,467*	*49%*	*6,612*	*2,034*	*44%*	*3,788*	*1,459*	*63%*
		Winter	*5,194*	*-*	*0%*	*3,264*	*-*	*0%*	*1,643*	*-*	*0%*	*7,986*	*839*	*12%*	*5,070*	*492*	*11%*	*2,682*	*353*	*15%*
	With ESC	Summer	5,194	-	0%	3,264	-	0%	1,643	-	0%	8,575	1,428	20%	5,020	442	10%	2,493	165	7%
		Winter	5,194	-	0%	3,264	-	0%	1,643	-	0%	7,522	375	5%	4,693	115	3%	2,375	47	2%
Year 2	*No ESC*	*Summer*	*5,194*	*-*	*0%*	*3,264*	*-*	*0%*	*1,643*	*-*	*0%*	*10,614*	*3,467*	*49%*	*6,612*	*2,034*	*44%*	*3,788*	*1,459*	*63%*
		Winter	*5,194*	*-*	*0%*	*3,264*	*-*	*0%*	*1,643*	*-*	*0%*	*7,986*	*839*	*12%*	*5,070*	*492*	*11%*	*2,682*	*353*	*15%*
	With ESC	Summer	5,194	-	0%	3,264	-	0%	1,643	-	0%	8,575	1,428	20%	5,020	442	10%	2,493	165	7%
		Winter	5,194	-	0%	3,264	-	0%	1,643	-	0%	7,522	375	5%	4,693	115	3%	2,375	47	2%
Year 3	*No ESC*	*Summer*	*5,352*	*158*	*3%*	*3,378*	*114*	*3%*	*1,705*	*63*	*4%*	*10,284*	*3,138*	*44%*	*6,414*	*1,836*	*40%*	*3,635*	*1,306*	*56%*
		Winter	*5,232*	*38*	*1%*	*3,292*	*28*	*1%*	*1,658*	*15*	*1%*	*7,914*	*767*	*11%*	*5,027*	*449*	*10%*	*2,648*	*319*	*14%*
	With ESC	Summer	5,275	81	2%	3,284	20	1%	1,647	4	0%	8,460	1,313	18%	4,976	398	9%	2,476	147	6%
		Winter	5,214	19	0%	3,269	5	0%	1,644	1	0%	7,479	332	5%	4,684	106	2%	2,372	43	2%
Year 4	*No ESC*	*Summer*	*5,694*	*500*	*10%*	*3,610*	*346*	*11%*	*1,830*	*187*	*11%*	*8,772*	*1,625*	*23%*	*5,533*	*956*	*21%*	*2,996*	*667*	*29%*
		Winter	*5,315*	*120*	*2%*	*3,348*	*83*	*3%*	*1,688*	*45*	*3%*	*7,556*	*409*	*6%*	*4,819*	*241*	*5%*	*2,497*	*168*	*7%*
	With ESC	Summer	5,413	219	4%	3,325	60	2%	1,656	13	1%	7,844	697	10%	4,782	205	4%	2,403	74	3%
		Winter	5,247	53	1%	3,279	15	0%	1,646	3	0%	7,335	188	3%	4,639	62	1%	2,356	27	1%
Year 5	*No ESC*	*Summer*	*5,694*	*500*	*10%*	*3,610*	*346*	*11%*	*1,830*	*187*	*11%*	*8,772*	*1,625*	*23%*	*5,533*	*956*	*21%*	*2,996*	*667*	*29%*
		Winter	*5,315*	*120*	*2%*	*3,348*	*83*	*3%*	*1,688*	*45*	*3%*	*7,556*	*409*	*6%*	*4,819*	*241*	*5%*	*2,497*	*168*	*7%*
	With ESC	Summer	5,413	219	4%	3,325	60	2%	1,656	13	1%	7,844	697	10%	4,782	205	4%	2,403	74	3%
		Winter	5,247	53	1%	3,279	15	0%	1,646	3	0%	7,335	188	3%	4,639	62	1%	2,356	27	1%
Year 6	*No ESC*	*Summer*	*5,863*	*669*	*13%*	*3,731*	*467*	*14%*	*1,896*	*254*	*15%*	*7,847*	*700*	*10%*	*4,996*	*418*	*9%*	*2,619*	*290*	*12%*
		Winter	*5,354*	*160*	*3%*	*3,376*	*112*	*3%*	*1,703*	*61*	*4%*	*7,337*	*190*	*3%*	*4,691*	*113*	*2%*	*2,408*	*79*	*3%*
	With ESC	Summer	5,497	303	6%	3,346	81	2%	1,660	18	1%	7,483	337	5%	4,665	87	2%	2,361	32	1%
		Winter	5,267	73	1%	3,284	20	1%	1,647	5	0%	7,250	103	1%	4,612	34	1%	2,346	17	1%

Table 58 – Daily event loads and increases (T) within the Te Hana Creek for changing land-cover (earthworks) during the 6-year bulk earthworks (with and without treatment) for ARIs of 2, 10 and 50 years

Model scenario			Te Hana Creek tributary (TeHana5)									Te Hana Creek at mouth								
			50-year ARI			10-year ARI			2-year ARI			50-year ARI			10-year ARI			2-year ARI		
			Load	Increase		Load	Increase		Load	Increase		Load	Increase		Load	Increase		Load	Increase	
Pre-development			44	-	-	29	-	-	15	-	-	332	-	-	225	-	-	118	-	-
Year 1	*No ESC*	*Summer*	131	87	199%	87	58	199%	44	29	199%	511	179	54%	368	143	63%	181	63	54%
		Winter	65	21	48%	43	14	48%	22	7	48%	375	43	13%	260	35	15%	133	15	13%
	With ESC	Summer	76	32	73%	39	10	35%	17	2	14%	397	66	20%	249	24	11%	122	4	4%
		Winter	51	8	18%	32	2	9%	15	1	4%	348	16	5%	231	6	3%	119	1	1%
Year 2	*No ESC*	*Summer*	131	87	199%	87	58	199%	44	29	199%	511	179	54%	368	143	63%	181	63	54%
		Winter	65	21	48%	43	14	48%	22	7	48%	375	43	13%	260	35	15%	133	15	13%
	With ESC	Summer	76	32	73%	39	10	35%	17	2	14%	397	66	20%	249	24	11%	122	4	4%
		Winter	51	8	18%	32	2	9%	15	1	4%	348	16	5%	231	6	3%	119	1	1%
Year 3	*No ESC*	*Summer*	131	87	199%	87	58	199%	44	29	199%	511	179	54%	368	143	63%	181	63	54%
		Winter	65	21	48%	43	14	48%	22	7	48%	375	43	13%	260	35	15%	133	15	13%
	With ESC	Summer	76	32	73%	39	10	35%	17	2	14%	397	66	20%	249	24	11%	122	4	4%
		Winter	51	8	18%	32	2	9%	15	1	4%	348	16	5%	231	6	3%	119	1	1%
Year 4	*No ESC*	*Summer*	131	87	199%	87	58	199%	44	29	199%	518	186	56%	374	149	66%	184	66	56%
		Winter	65	21	48%	43	14	48%	22	7	48%	377	45	14%	261	36	16%	134	16	14%
	With ESC	Summer	76	32	73%	39	10	35%	17	2	14%	400	68	21%	250	25	11%	122	4	4%
		Winter	51	8	18%	32	2	9%	15	1	4%	348	17	5%	231	6	3%	119	1	1%
Year 5	*No ESC*	*Summer*	131	87	199%	87	58	199%	44	29	199%	518	186	56%	374	149	66%	184	66	56%
		Winter	65	21	48%	43	14	48%	22	7	48%	377	45	14%	261	36	16%	134	16	14%
	With ESC	Summer	76	32	73%	39	10	35%	17	2	14%	400	68	21%	250	25	11%	122	4	4%
		Winter	51	8	18%	32	2	9%	15	1	4%	348	17	5%	231	6	3%	119	1	1%
Year 6	*No ESC*	*Summer*	44	0	0%	29	0	0%	15	0	0%	339	7	2%	231	6	3%	121	3	2%
		Winter	44	0	0%	29	0	0%	15	0	0%	334	2	1%	226	1	1%	119	1	1%
	With ESC	Summer	44	0	0%	29	0	0%	15	0	0%	334	3	1%	226	1	0%	118	0	0%
		Winter	44	0	0%	29	0	0%	15	0	0%	332	1	0%	225	0	0%	118	0	0%

Table 59 – Daily event loads and increases (T) within the Maeneene Creek for changing land-cover (earthworks) during the 7-year indicative construction programme (with and without treatment) for ARIs of 2, 10 and 50 years

Model scenario			Maeneene Creek at SH1 (Maeneene 6)									Maeneene Creek at mouth								
			50-year ARI			10-year ARI			2-year ARI			50-year ARI			10-year ARI			2-year ARI		
			Load	Increase		Load	Increase		Load	Increase		Load	Increase		Load	Increase		Load	Increase	
Pre-development			199	-	-	129	-	-	65	-	-	271	-	-	174	-	-	87	-	-
Year 1	*No ESC*	*Summer*	323	124	62%	209	80	62%	105	40	62%	398	127	47%	258	83	48%	128	41	47%
		Winter	230	30	15%	148	19	15%	75	10	15%	301	31	11%	195	20	12%	97	10	11%
	With ESC	Summer	245	46	23%	143	14	11%	68	3	4%	317	47	17%	189	15	8%	90	3	3%
		Winter	211	11	6%	133	4	3%	66	1	1%	282	12	4%	178	4	2%	87	1	1%
Year 2	*No ESC*	*Summer*	323	124	62%	209	80	62%	105	40	62%	398	127	47%	258	83	48%	128	41	47%
		Winter	230	30	15%	148	19	15%	75	10	15%	301	31	11%	195	20	12%	97	10	11%
	With ESC	Summer	245	46	23%	143	14	11%	68	3	4%	317	47	17%	189	15	8%	90	3	3%
		Winter	211	11	6%	133	4	3%	66	1	1%	282	12	4%	178	4	2%	87	1	1%
Year 3	*No ESC*	*Summer*	323	124	62%	209	80	62%	105	40	62%	398	127	47%	258	83	48%	128	41	47%
		Winter	230	30	15%	148	19	15%	75	10	15%	301	31	11%	195	20	12%	97	10	11%
	With ESC	Summer	245	46	23%	143	14	11%	68	3	4%	317	47	17%	189	15	8%	90	3	3%
		Winter	211	11	6%	133	4	3%	66	1	1%	282	12	4%	178	4	2%	87	1	1%
Year 4	*No ESC*	*Summer*	323	124	62%	209	80	62%	105	40	62%	398	127	47%	258	83	48%	128	41	47%
		Winter	230	30	15%	148	19	15%	75	10	15%	301	31	11%	195	20	12%	97	10	11%
	With ESC	Summer	245	46	23%	143	14	11%	68	3	4%	317	47	17%	189	15	8%	90	3	3%
		Winter	211	11	6%	133	4	3%	66	1	1%	282	12	4%	178	4	2%	87	1	1%
Year 5	*No ESC*	*Summer*	323	124	62%	209	80	62%	105	40	62%	398	127	47%	258	83	48%	128	41	47%
		Winter	230	30	15%	148	19	15%	75	10	15%	301	31	11%	195	20	12%	97	10	11%
	With ESC	Summer	245	46	23%	143	14	11%	68	3	4%	317	47	17%	189	15	8%	90	3	3%
		Winter	211	11	6%	133	4	3%	66	1	1%	282	12	4%	178	4	2%	87	1	1%
Year 6	*No ESC*	*Summer*	200	0	0%	129	0	0%	65	0	0%	271	0	0%	175	0	0%	87	0	0%
		Winter	200	0	0%	129	0	0%	65	0	0%	271	0	0%	175	0	0%	87	0	0%
	With ESC	Summer	200	0	0%	129	0	0%	65	0	0%	271	0	0%	175	0	0%	87	0	0%
		Winter	200	0	0%	129	0	0%	65	0	0%	271	0	0%	175	0	0%	87	0	0%

4.9.2 Peak active area outputs

Daily event loads

Table 60 to Table 62 below summarise the ARI daily sediment loads reflecting the fixed-cover associated with the indicative peak active earthworks area throughout the 7-year indicative construction programme.

For the Hōteo River catchment the peak summer active area is 75ha and is based upon achieving the indicative construction programme which includes a bulk earthworks period of 6 years. The modelling assumes that the maximum 75ha active area occurs each year of bulk earthworks, therefore the peak load occurs in Years 1 and 2, when construction is occurring within the Waiteraire catchment which has steep slopes. The catchments to the north of the Hōteo River crossing have the peak sediment load occurring during year 6 of bulk earthworks.

For the Oruawharo River catchment the peak active earthworks area is 25ha and is based upon a potential maximum active area scenario. For the purpose of modelling the peak sediment load occurs each summer during years 1-5 of bulk earthworks.

Table 60 – Daily event loads and increases (T) discharged to the Kaipara Harbour from the Hōteo and Oruawharo river catchments corresponding to peak summer earthworks (fixed landcover) for ARIs of 2, 10 and 50 years

Location	Daily event ARI	Pre-development event load (T)	*Construction (untreated) event loads*			Construction (treated) event loads		
			Load (T)	*Increase (T)*	*Increase (%)*	Load (T)	Increase (T)	Increase (%)
Hōteo River mouth	2-year	3,715	*5,041*	*1,326*	*36%*	3,854	139	4%
	10-year	7,130	*9,583*	*2,453*	*34%*	7,642	512	7%
	50-year	10,912	*15,545*	*4,633*	*42%*	12,776	1,864	17%
Oruawharo River terrestrial inputs	2-year	1,405	*1,566*	*161*	*11.5%*	1,416	11	0.8%
	10-year	2,860	*3,169*	*309*	*10.8%*	2,914	54	1.9%
	50-year	4,425	*4,869*	*444*	*10.0%*	4,588	164	3.7%

Table 61 – Daily event loads (T) in the Hōteo River and tributaries corresponding to maximum area of exposed earthworks (fixed landcover) for ARIs of 2, 10 and 50 years

Sub-catchment	Reporting point	Daily event ARI	Pre-development event load (T)	*Construction (untreated) event loads*			Construction (treated) daily loads		
				Load (T)	*Increase (T)*	*Increase (%)*	Load (T)	Increase (T)	Increase (%)
Kourawhero Stream	Headwater[1] (Kourawhero2)	2-year	16	*270*	*254*	*1591%*	33	17	107%
		10-year	30	*521*	*491*	*1637%*	115	85	284%
		50-year	49	*844*	*795*	*1622%*	341	292	596%
Waiteraire Stream	Forested headwater[1] (Hōteo 9b)	2-year	27	*265*	*238*	*880%*	53	26	98%
		10-year	51	*512*	*461*	*903%*	151	100	197%
		50-year	81	*809*	*728*	*899%*	381	300	370%
	Confluence with Hōteo [1] (Hōteo 4)	2-year	140	*1,217*	*1,077*	*770%*	262	122	87%
		10-year	270	*2,288*	*2,018*	*748%*	709	439	163%
		50-year	421	*3,718*	*3,297*	*783%*	1,779	1,358	323%
Unnamed pasture tributary	Unnamed tributary[2] (H2) (Hōteo 10)	2-year	14	*85*	*71*	*508%*	19	5	34%
		10-year	26	*166*	*140*	*539%*	50	24	94%
		50-year	37	*233*	*196*	*529%*	137	100	270%
Waiteitei Stream	Waiteitei at Sandersons[1]	2-year	449	*489*	*40*	*9%*	452	3	1%
		10-year	925	*1,002*	*77*	*8%*	937	12	1%
		50-year	1,441	*1,581*	*140*	*10%*	1,492	51	4%
Hōteo River	Upstream of SH1[2] (Hōteo 3)	2-year	1,643	*1,896*	*253*	*15%*	1,660	17	1%
		10-year	3,264	*3,731*	*467*	*14%*	3,346	82	3%
		50-year	5,194	*5,863*	*669*	*13%*	5,497	303	6%
	Hōteo at Gubbs[1]	2-year	2,329	*3,788*	*1,459*	*63%*	2,493	164	7%
		10-year	4,578	*6,612*	*2,034*	*44%*	5,020	442	10%
		50-year	7,147	*10,614*	*3,467*	*49%*	8,575	1,428	20%
	Hōteo River mouth[1]	2-year	3,715	*5,041*	*1,326*	*36%*	3,854	139	4%
		10-year	7,130	*9,583*	*2,453*	*34%*	7,642	512	7%
		50-year	10,912	*15,545*	*4,633*	*42%*	12,776	1,864	17%

Notes:

1 – Peak earthworks is estimated to occur during the summer of year 1 and year 2

2 – Peak earthworks are estimated to occur during the summer of year 6

Table 62 – Daily event loads (T) in the estuarine Oruawharo River and tributaries corresponding to maximum area of exposed earthworks (fixed landcover) for ARIs of 2, 10 and 50 years

Sub-catchment	Reporting point	Daily event ARI	Pre-development event load (T)	Construction (untreated) event loads			Construction (treated) daily loads		
				Load (T)	*Increase (T)*	*Increase (%)*	Load (T)	Increase (T)	Increase (%)
Te Hana Creek	Tributary[3] (TeHana5)	2-year	15	*44*	*29*	*195%*	17	2	12%
		10-year	29	*87*	*58*	*200%*	39	10	35%
		50-year	44	*131*	*87*	*197%*	76	32	72%
	Te Hana Creek at mouth[3]	2-year	118	*181*	*63*	*54%*	122	4	4%
		10-year	225	*368*	*143*	*63%*	249	24	11%
		50-year	332	*511*	*179*	*54%*	397	65	20%
Maeneene Creek	Downstream of SH1[3] (Maeneene6)	2-year	65	*105*	*40*	*62%*	68	3	4%
		10-year	129	*209*	*80*	*62%*	143	14	11%
		50-year	199	*323*	*124*	*63%*	245	46	23%
	Maeneene Creek at mouth[3]	2-year	87	*128*	*41*	*47%*	90	3	3%
		10-year	174	*258*	*84*	*48%*	189	15	9%
		50-year	271	*398*	*127*	*47%*	317	46	17%
Oruawharo River	Oruawharo River terrestrial inputs[3]	2-year	1,405	*1,513*	*108*	*8%*	1,413	8	1%
		10-year	2,860	*3,069*	*209*	*7%*	2,896	36	1%
		50-year	4,425	*4,724*	*299*	*7%*	4,535	110	2%

3 – Peak earthworks are estimated to occur during the summer of year 1 to year 5

4.9.3 Historical 7-year "wet weather" output

The construction model outputs detailed above provide two different estimates of sediment load associated with earthworks, that is:

- The mean annual load, which averages the 34-year annual loads; and
- The daily event loads, which looks at daily storm events for the 2, 10 and 50 year ARI events.

The mean annual load is a useful output as it is comparable to other methods such as USLE and RUSLE in estimating the mean annual load and change. The daily event load outputs provide the increases associated with specific storms, although these storms (such as the 50 year ARI event) may be unlikely to occur during the construction period.

Given that the construction period is 7-years including 6-years of bulk earthworks, the likelihood of a large storm occurring is considered low. As per Section 6.1.1 of the WAR, during a 6 year bulk earthworks programme there is a 100% probability of a 1 year ARI event occurring and a 70% probability of a 5 year ARI event occurring. For the 20 year and 50 year ARI events the probability of occurrence are 26% and 11% respectively. It is not possible to predict the actual rainfall events that will occur during construction, however it is important to assess a realistic future scenario.

The mean annual load (7-year changing landuse output) alone may underestimate the increase in sediment associated with the Project were a large storm to occur. On the other hand, consideration of increases in load due to the large storm events will significantly overestimate the load as the probability of these events occurring each year is low.

Therefore, to further examine and assess the potential future sediment load associated with the Project earthworks a 7-year rainfall period was chosen from the historical rainfall record to use as a reasonable representation of rainfall with significant peak storm events. The years chosen are 1997-2003, which are very wet years with two storms larger than the 30 year ARI event occurring within the rainfall record. The baseline sediment load record was analysed to calculate the magnitude of ARI events with statistical analysis (Section 4.5.8), and a period of 7-years was chosen that included two large storms. The storms that occur include a 34.3 ARI sediment event in 1998, and a 29.5 ARI sediment event in 2001, as well as a number of other smaller storms.

The output incorporates the changing earthworks for each year, incorporating winter work reductions and ESC measures as carried out for the 7-year changing landcover output. However, for the 7-year changing output the 40 year rainfall period was used to calculate the mean annual sediment load, while the 7-years was chosen for this output.

For the construction, the year 1998 corresponds to Year 1 and 1999 to year two, and so on. Table 63 and Table 64 summarise the annual sediment loads for the historical 7-year construction period output at the Hōteo and Oruawharo river mouths, and gives the increase in loads under construction scenarios with sediment and erosion controls.

Table 63 – Sediment load (T) discharged to the Kaipara Harbour from the Hōteo River for the historical years 1997-2003, comparing the annual sediment load

Historic year	Hōteo River mouth				
	Historic (pre-development) annual load (T)	Construction (treated) annual load			
		Year	Load (T)	Increase (T)	Increase (%)
1997	32,546	0	32,676	130	0.4%
1998	50,268	1	50,939	671	1.3%
1999	16,122	2	16,406	284	1.8%
2000	26,381	3	26,697	315	1.2%
2001	34,943	4	35,255	312	0.9%
2002	24,419	5	24,547	128	0.5%
2003	26,247	6	26,324	77	0.3%
Total	178,381	-	180,167	1,786	1.0%

Table 64 – Sediment load (T) discharged to the estuarine Oruawharo River for the historical years 1998-2003, comparing the annual sediment load

Historic year	Oruawharo River terrestrial inputs				
	Historic (pre-development) annual load (T)	Construction (treated)			
		Year	Load (T)	Increase (T)	Increase (%)
1997	14,276	0	14,287	11	0.1%
1998	20,909	1	20,968	60	0.3%
1999	6,601	2	6,616	15	0.2%
2000	8,177	3	8,195	19	0.2%
2001	11,462	4	11,485	23	0.2%
2002	8,706	5	8,716	10	0.1%
2003	11,346	6	11,349	2	0.0%
Total	67,201	-	67,329	128	0.2%

5 FOREST HARVESTING

5.1 Introduction

There are two exotic forests located upstream, within the same catchments as the Project:

- the Rayonier Matariki Forests (RMF) own a 48.3 km^2 plantation forest located in the Hōteo River catchment; and
- the Redwood Forest has approximately 16.3 km^2 of plantation forestry within the Mahurangi River catchment.

These forests are likely to reach maturity around the same time as the Project construction phase and harvested prior to and during construction of the Project. For the purposes of this Project it is assumed that:

- The majority of the RMF plantation will be harvested prior to construction and all of the plantation forestry within the proposed designation boundary will be harvested prior to construction. Some of the Matariki Forest outside of the proposed designation boundary may be harvested during construction or after construction.

- The Redwood Forest harvesting plan is not known; it is assumed that the Redwood Forest may be harvested prior to, during or soon after construction of the Project. There is no Redwood forest within the proposed designation boundary.

The harvesting of plantation forests results in increased sediment load in downstream rivers and streams. This will therefore change the background sediment load of these catchments and may also result in cumulative impacts in downstream receiving environments.

We have carried out a literature review to understand the effects that forestry harvesting and recovery could have on sediment loads in the Project receiving streams, rivers and harbours. This literature review is detailed in Appendix F, with a summary presented in this section.

5.2 Matariki Forest – Hōteo River

Rayonier Matariki Forests (RMF) are the owners of a large plantation pine forest in the Dome Valley area (48.3 km^2), referred to as Matariki Forest within this assessment, located on the steep slopes of the Dome ridges in the Hōteo River catchment. This forest is located in the east of the catchment, associated with the sub-catchments of Waiwhiu Stream, Hōteo Central (specifically Waiteraire Stream and Awatere Stream), Kourawhero Stream and a small area within the Mahurangi catchment (see Figure 29). Matariki Forests have provided a plan showing the total areas of plantation forestry, this is shown in Figure 29.

The Matariki Forest is almost exclusively on areas of high elevation, with steep slopes and thus are more connected to the river network. The geology is a sedimentary formation of sandstone and siltstone or mudstone, with soils of clays or clay loams.

Based on the indicative harvest plans provided by RMF, the plantation forest is due to be harvested prior to and during Project construction in 2021-2035+. The plantation forest within the proposed designation boundary is assumed to be harvested prior to the start of the Project, and it is expected that the majority of the forest outside the designation will also be harvested.

RMF (correspondence, 2018) have provided an indicative harvesting plan for the Hōteo catchment. This indicates that 4,830 ha of forest would be harvested over 16-years, with up to 630ha of forest harvested each year. The likely harvesting sequencing for the East Forest and the West Forest are shown in Appendix F.

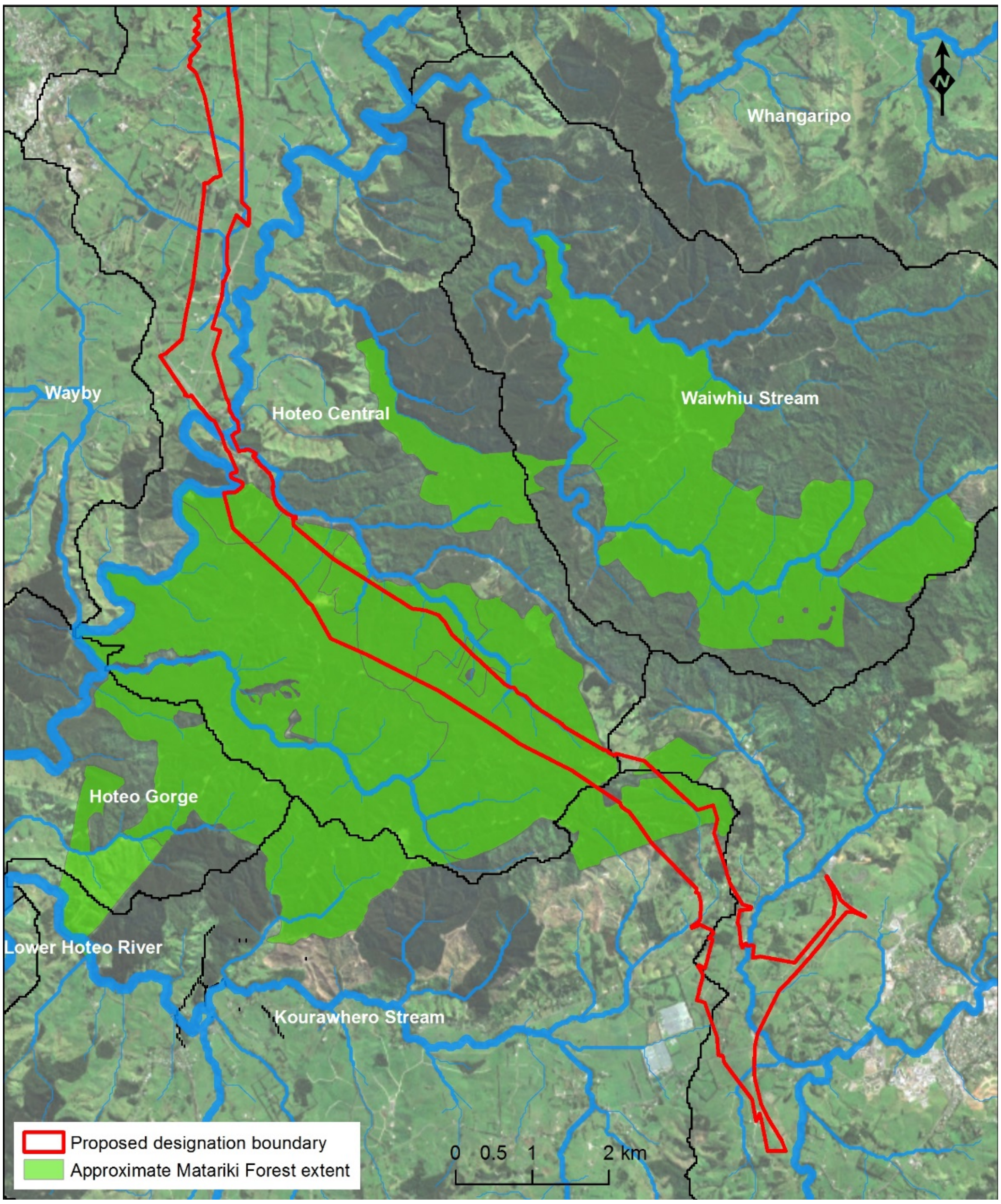

Figure 29 – Approximate extent of the Matariki Forest

The pre-harvesting mean annual sediment yield has been calculated for the Hōteo River, based upon the reporting point Project-Hōteo 9b-BL, located in the upper reaches of the

Waiteraire Stream. The model estimates a pre-harvesting mean annual yield of 50 t/km²/year. The estimated logging and post-harvesting yields come from the Pakuratahi forest study (Fahey et al. 2003; Eyles & Fahey, 2006) described in Appendix F, due to the similarities in topography and geology.

As confirmed by Matariki (correspondence, 2018), the Matariki Forest is a second-generation forest with existing forestry roads and tracks, so no major track building is required to facilitate harvesting. The forest will be harvested in accordance with the National Environmental Standard (NES) for plantation forestry. Based upon this the harvesting, sediment yields have been selected, shown in Table 65.

Table 65 – Estimated sediment yields for harvesting of Matariki forest

Harvesting stage		Sediment yield (t/km²/yr)	Notes
Pre-harvesting		50	Source hydrological input
Post-harvesting	*Track building*	*270*	*Pakuratahi study – not used*
	Logging	134	Pakuratahi study
	1-year post harvesting	99	Pakuratahi study
	2-year post harvesting	99	Pakuratahi study (no 2nd year data)
	3-year post harvesting	50	Based on literature review

Based upon correspondence with Matariki Forest, the harvesting is currently planned to take place over 16 years, with a harvesting plan provided (Appendix F). Following harvesting there will be a two year recovery time. A high level assessment into a likely annual sediment yields that could occur during harvesting and during recovery is contained in Appendix F, this is also summarised below in Table 66.

Table 66 – Estimated annual sediment yields for 16-year harvesting of Matariki Forest, logging and recovery period (based on likely sediment yield from literature review and Matariki Forest indicative harvesting plan)

Year	Harvesting phase	Pre-harvesting annual sediment yield (T)	Harvesting annual sediment yield estimate (T)	
			Total	Change
1 (2021)	Logging	2,415	2,456	41
2 (2022)	Logging & recovery	2,415	2,621	206
3 (2023)		2,415	2,643	228
4 (2024)		2,415	2,740	324
5 (2025)		2,415	2,682	267
6 (2026)		2,415	2,830	414
7 (2027)		2,415	2,907	492
8 (2028)		2,415	3,006	591
9 (2029)		2,415	3,271	855
10 (2030)		2,415	3,315	900
11 (2031)		2,415	3,150	735
12 (2032)		2,415	3,007	592

Year	Harvesting phase	Pre-harvesting annual sediment yield (T)	Harvesting annual sediment yield estimate (T)	
			Total	Change
13 (2033)		2,415	2,979	564
14 (2034)		2,415	2,961	545
15 (2035)		2,415	3,122	707
16 (2036)		2,415	3,116	700
17 (2037)	Recovery	2,415	2,845	429
18 (2038)		2,415	2,616	201
Total		43,475	52,266	8,792
Mean annual		2,415	3,267	549

This high level assessment indicates that harvesting of the Matariki Forest could result in an additional 8,792 tonnes of sediment entering the Hōteo River, or a mean annual increase of 549 tonnes, with a peak increase of 900 tonnes based on the indicative harvesting plan provided by Matariki Forest. The modelling undertaken as part of this report for the Hōteo River indicates that the background mean annual sediment load at the mouth of the Hōteo River is 25,600 tonnes. This indicates that the forest harvesting could increase the sediment load within the Hōteo River annually by an average of 2.1%.

The total increase in sediment load due to harvesting (8,792 tonnes) is significantly larger than the modelled increase in sediment load to the Hōteo River mouth from the 7-year indicative construction programme of the Project, and more than double the mean annual increase in load predicted for the Project. The construction of the Project is estimated to result in a total increase of 1,459 tonnes of sediment to the Hōteo River, or a mean annual sediment load increase of 208 tonnes/year (0.8% increase).

The NES (discussed in Appendix F) requires ESC measures to be adopted during harvesting. As such the sediment loads generated by harvesting the Matariki Forest may be less than recorded in the previous studies. However, even considering some conservative assumptions made in the estimate of the forest harvesting yield, the sediment load associated with forest harvesting is assessed to have a significantly larger increase in sediment loads on the Hōteo River and the Kaipara Harbour than the Project.

As stated at the beginning of this section, it is assumed that all of the Matariki Forest within the proposed designation boundary will be harvested prior to the start of construction and the current harvest plans show the majority of the area outside the designation will also be harvested prior to construction. The current harvest plan therefore indicates some harvesting outside of the proposed designation boundary may occur concurrently with the Project construction period.

5.3 Redwood Forest – Mahurangi River

Redwood Forest is a large plantation pine forest located towards the south of the Mahurangi River catchment to the west of Pohuehue, as shown on Figure 30. The Redwood Forest is in the sub-catchment of the Mahurangi River (right branch). There is approximately 16.25 km^2 of the Redwood Forest within the Mahurangi Catchment. The Redwood Forest is also likely to reach maturity around the same time as the Project construction phase.

In 1998, NIWA undertook a study for Auckland Regional Council (now Auckland Council) estimating the increased sediment load that may be discharged to the Mahurangi Harbour when the Redwood Forest is harvested (Oldman, Stroud, & Cummings, 1998). This study is highly conservative; therefore, we have disregarded this study in assessing the potential sediment load to the Mahurangi River (Appendix F).

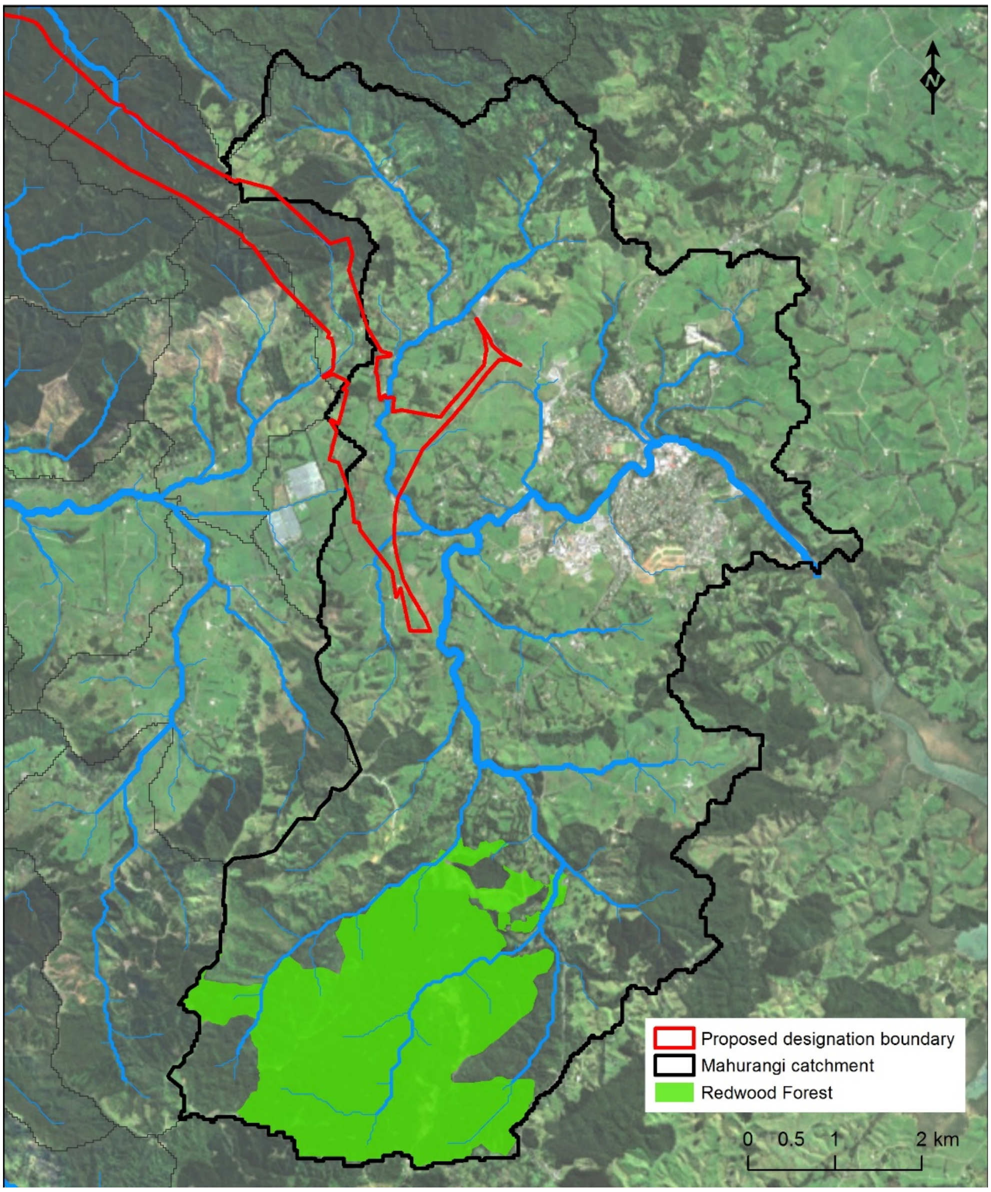

Figure 30 – Approximate extent of the Redwood Forest

A high level assessment of the potential sediment load delivery to the Mahurangi Catchment has been undertaken using values from the literature review (Appendix F). There are no details available relating to the harvesting plan for the 1,625 ha Redwood Forest. Therefore, based on the information provided by Matariki Forests, and given that the Redwoods Forest is approximately one third of the size of the Matariki Forest, it was assumed that it would be harvested over a period of 6 years.

The estimated pre-logging yields come from an existing study carried out in the Redwood Forest (Hicks et al, 2009) relating to sediment yields (as identified in Appendix F). This study does not include post-harvesting sediment yields; therefore, this has been estimated and reported in Table 67.

Table 67 – Estimated mean annual sediment yields for harvesting of Redwood forest

Harvesting stage		Sediment yield ($t/km^2/yr$)	Notes
Pre-harvesting		180	Redwood forest study
Harvesting and Post-harvesting	Logging	280	Redwood forest study
	1-year post harvesting	230	Estimated from Redwood study
	2-year post harvesting	230	Estimated from Redwood study
	3-year post harvesting	180	Estimated from Redwood study

A high level assessment into likely annual sediment yields that could occur during harvesting is contained in Appendix F, this is also given below for a 6-year harvesting period.

Table 68 – High level estimate of annual sediment yields for 6-year harvesting of Redwood Forest through an 8-year logging and recovery period (based on likely sediment yield identified from literature review)

Year	Harvesting phase	Pre-harvesting annual sediment load (T)	Harvesting annual sediment load estimate (T)	
			Total	Change
1	Logging	2,925	3,200	270
2	Logging & recover	2,925	3,330	410
3		2,925	3,470	540
4		2,925	3,470	540
5		2,925	3,470	540
6		2,925	3,470	540
7	Recovery	2,925	3,200	270
8		2,925	3,060	140
Total		23,400	26,650	3,250
Mean annual		2,925	3,330	410

This high level assessment, shown in Table 68, indicates that harvesting of the Redwood Forest could result in an additional 3,250 tonnes of sediment entering the Mahurangi River, or a mean annual increase of between 410 tonnes. The modelling undertaken as part of this report indicates that the mean annual sediment load at the mouth of the Mahurangi River is 12,190 tonnes. This indicates that the harvesting could increase the sediment load within the Mahurangi River by an average of 3.4% across the harvesting period.

This is greater than the modelled increase in sediment load to the Mahurangi River mouth during the construction of the Project. The construction of the Project is estimated to result in a total increase of 790 tonnes of sediment to the Mahurangi River, or a mean annual sediment load increase of 110 tonnes/year (0.9% increase).

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APPENDIX A MAHURANGI RIVER SEDIMENT MODEL

A.1 LITERATURE REVIEW FOR THE MAHURANGI RIVER SEDIMENT MODEL

A.1.1 MODELLING OF LONG-TERM SEDIMENT LOADS TO THE MAHURANGI HARBOUR

ARC commissioned NIWA to undertake a modelling study of long-term sediment loads delivered to Mahurangi Harbour (Stroud & Cooper, 1997). This study was carried out to increase the ARC knowledge base and to provide management strategies around sediment and other water quality risks.

The Basin New Zealand (BNZ) model was used to model the Mahurangi Harbour. A long-term climate record of 1976-1995, comprised of daily rainfall, temperature and solar radiation data, was input to the gridded model. The model used this data to determine daily estimates of runoff volume and associated sediment yields per unit area, as well as nutrient yields per unit area (nitrogen and phosphorus). The daily sediment and nutrient yields from each grid cell are spatially distributed by the BNZ model and routed via the drainage network to sub-catchment outlets. Sediment removal via riparian and stream channel deposition is also simulated within the model.

The BNZ model sediment outputs were tested against observed flow and suspended sediment concentrations (1994-1995) at three catchment outlets and showed a good agreement with the measured data.

The BNZ modelled background loads project, along with the construction loads calculated using GLEAMS, were used to inform the water quality and ecological assessments for the P-Wk project. For the Project the catchment sediment loads, and harbour modelling developed for P-Wk is being used to inform the Warkworth to Wellsford water quality and ecological assessments.

A.2.2 ALPURT SEDIMENT POND STUDY

ARC commissioned a field study to evaluate the effectiveness of Polyaluminium Chloride (PAC) treatment to improve the removal of sediment from earthworks runoff in a sediment retention pond (Moores & Pattinson, 2008). The field programme comprised of hydrological monitoring and the collection of water samples at the ALPURT B2 motorway construction site near Orewa, north of Auckland to evaluate the effectiveness of the PAC treatment.

The ALPURT B2 motorway construction site was located in the Nukumea Stream catchment, approximately 4km south of the southern boundary of the Pūhoi River catchment. The construction site had an earthworks area of 4.4 ha which drained approximately equally to two retention ponds. The outflows of these ponds were monitored through the installation of a rainfall gauge, weirs, water level records and automatic water samplers. The inflow to one pond was treated with PAC by a rainfall activated dosing system while the second pond water was not treated.

The study looked at water samples for seven storm events (March to December 2007), these were samples collected at the shared pond inlet and at the two outlets. The samples were analysed for concentrations of total suspended solids and particle size distribution. The results were considered applicable to the P-Wk project construction scenarios due to the proximity of the ALPURT B2 site and the Pūhoi to Warkworth project, which includes the area of construction within the Mahurangi catchment being constructed for the Warkworth to Wellsford Project. (Harper et al, 2013, and representative of the PSDs for the treated and untreated sediment loads modelled in GLEAMS (Section A.2.4).

A.2 HYDROLOGICAL MODEL DEVELOPMENT

A.2.1 INTRODUCTION

The hydrological sediment model developed by NIWA for the P-Wk assessment was based on the BNZ modelling study (Stroud & Cooper, 1997), which was used to estimate catchment background loads. NIWA then developed a Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) Hill-slope process model for two specified focus areas to revise the pre-development scenario and analyse construction sediment loads (Harper et al, 2013).

These models remain valid for the Mahurangi River catchment for the current Project. This section summarises the hydrological model applied.

A.2.2 GLEAMS MODEL

GLEAMS is a physically-based model developed for continuous simulation of surface runoff and sediment losses on a field-scale. GLEAMS is a grid-based model which defines a hill-slope response to each grid cell by combining climate, land-cover, soil type, slope information and hydrological parameters. GLEAMS then applies a long-term climate record to these individual grid cells to output a long-term series of daily sediment loads per unit area of each cell type.

The sediment loads can be estimated for an entire catchment by aggregating the GLEAMS yields (Harper et al, 2013). Within the P-Wk assessment the GLEAMS model had two different focus areas, which is the ‘Hills’ and ‘Flats’ areas. The Project corresponds to the ‘Flats’ focus area of the GLEAMS model.

A.2.3 MODEL INPUTS

TOPOGRAPHY

The 1997 BNZ model (Stroud & Cooper, 1997) applied a uniform slope across the entire model. However, within the GLEAMS model NIWA identified the existing topography by using LiDAR data, and classified the topography into different slope classes. The topography was assumed to remain unchanged during and following the construction period in the P-Wk assessment.

CLIMATE

The climate used by NIWA within the pre-development scenario assessment model was a 20-year time series (1976-1995) which was based upon the previous BNZ study (Stroud & Cooper, 1997). The input to the BNZ model is daily rainfall, temperature and solar radiation data. The construction-phase GLEAMS model applied a 50-year climate record (1963-2012) consisting of daily rainfall, monthly temperature, wind run and solar radiation. This data was drawn from stations in the Mahurangi River catchment.

LAND USE

The BNZ model assumed a uniform land use across the entire gridded area. Within the GLEAMS model, the existing land-cover was taken from the Land Cover Database (LCDB3) shapefile and included categories of farmland, forestry and native forest. Construction land-cover was defined within the GLEAMS model as either exposed soil, exposed rock, mulched or stabilised. NIWA modelled the mulched and stabilised land-covers with reduction factors of 85% and 93% respectively.

A.2.4 PARTICLE SIZE DISTRIBUTION AND SEDIMENTS

PARTICLE SIZE DISTRIBUTIONS

The particle size distribution (PSD) within the P-Wk assessment (Harper et al, 2013) was based on the ALPURT sediment pond study and other data sources. The assessment found that the particle size varied widely across the sources, likely due to differences in samples conditions, sampling methods and analytical methods.

In view of the wide variation in PSDs of the various samples, the 2013 P-Wk assessment adopted a relatively fine PSD on the assumption that it would represent a conservative approach for the assessment of effects. Based on that, the representative PSDs were largely derived from the borehole sample data and ALPURT study results. The recommended representative PSDs of sediment in untreated runoff from the P-Wk study are given in Table 69.

Table 69 – Recommended representative particle size distributions (proportion of total sediment load in each size class) (Harper et al, 2013)

Particle size class	Catchment background	Construction runoff		
		Untreated	Non-chemical treatment	Chemical treatment
Clay (<3.9 μm)	26%	26%	55%	60%
Silt (39-63.0 μm)	56%	56%	45%	40%
Sand (63.0 μm-2 mm)	18%	18%	0%	0%

The catchment background and untreated construction runoff PSDs were derived from three boreholes and the inflow runoff from the ALPURT sediment pond. The treated construction runoff PSDs were derived from the ALPURT study. Further details are contained in the P-Wk study.

FRACTION OF SEDIMENT DELIVERED TO THE COAST

The P-Wk study estimated the Fraction of Sediment Delivered to the Coast (FSDC), which is the fraction of sediment in the freshwater environment that is delivered to the coastal environment, also known as the Sediment Deliver Ratio (SDR). The BNZ study (Stroud & Cooper, 1997) was used to model the FSDC in each catchment; the FSDC of the Mahurangi River is estimated as 0.48.

The BNZ study estimates have not been validated by sampling, however are used in multiple studies of the Mahurangi River. Due to this the P-Wk assessment was undertaken with both the calculated FSDC of 0.48 and a steady state assessment (FSDC=1) to estimate the two extremes of the likely range.

APPENDIX B LITERATURE REVIEW: KAIPARA HARBOUR SEDIMENT STUDIES

B.1 STUDY OF SEDIMENT YIELDS FOR SEDIMENT MONITORED CATCHMENTS ACROSS AUCKLAND

A sediment monitoring plan was designed and established for Auckland Council in 2009 to satisfy the state of the environment requirement to report sediment yield. In 2013 a study was commissioned by Auckland Council to report the results up to 31 December 2012 (Curran-Cournane et al, 2013). The monitoring focusses on ten catchments across Auckland, which includes three catchments within the Kaipara Harbour model study area: Hōteo River (Hōteo at Gubbs), Kaipara River (Kaipara at Waimauku) and Kaukapakapa River (Kaukapakapa at Taylors). The sediment sampling sites were selected to be regionally representative and to represent different land use, geology, climate and slope. The catchment characteristics for the three catchments within the study area are shown in Table 70.

Table 70 – Shortened summary of catchment characteristics - Table 3 from Quantifying Catchment Sediment Yields in Auckland (Curran-Cournane et al. 2013)

Characteristic	Hōteo	Kaipara	Kaukapakapa
Catchment size	268km^2	163km^2	62km^2
Geology	Waitemata (77%) Mudstone (8%) Alluvium (8%) Limestone (6%) Greywacke (<1%)	Waitemata (45%) Alluvium (34%) Sand/sand dune (10%) Conglomerate (9%) Mudstone (2%)	Mudstone (33%) Waitemata (25%) Alluvium (23%) Conglomerate (16%) Limestone (3%)
Landcover	Pasture (56%) Exotic vegetation (23%) Indigenous veg. (21%) Other[1] (<0.5%)	Pasture (60%) Exotic veg. (23%) Indigenous veg. (10%) Other[1] (7%)	Pasture (60%) Exotic veg. (23%) Indigenous veg. (10%) Other[1] (7%)
Soil order	Ultic (75%) Recent (16%)	Ultic (43%) Allophanic (25%)	Ultic (74%) Allophanic (13%)
Slope	Moderately steep (44%)	Rolling (35%)	Rolling (39%)
Mean annual rainfall	1387 mm/yr	1278 mm/yr	1283 mm/yr
Mean annual runoff	659 mm/yr	567 mm/yr	651 mm/yr
Notes: [1]Other includes cropland, orchard, built up area, urban parkland, surface mine and lake/pond			

The Council sediment monitoring method used automatic water samplers set up at each site; these were triggered during storm events to collect samples from the river to capture storm sediment yields. These samplers were analysed at a laboratory for total suspended sediments, and in some cases for true suspended sediment concentrations.

The Auckland Council study used this data to calculate event sediment yields for each storm event over the study period. Where data gaps existed (due to equipment failure) the event yields were calculated based upon a derived relationship between the event yield and peak discharge. The sediment for each storm was then graphed to accumulate over the study period and derive sediment yield summaries for each catchment including Specific sediment yield, yield trend and specific yield trends.

The study found that the specific sediment yield range across catchments was relatively small (32-80 t/km^2/yr) when excluding sites with only one year of record. The specific yield trends for the catchments within the study area are given in Table 71.

Table 71 – Specific sediment yields of Auckland catchments - from Quantifying Catchment Sediment Yields in Auckland (Curran-Cournane et al, 2013)

Site (dominant land cover)	Specific sediment yield	Length of sediment record
Hōteo (pasture)	74.3 t/km^2/yr	2.6 years
Kaipara (pasture)	32.3 t/km^2/yr	1 year
Kaukapakapa (pasture)	75.8 t/km^2/yr	2.6 years

B.2 A REVIEW OF ENVIRONMENT INFORMATION FOR HŌTEO RIVER CATCHMENT

A review of environmental and socio-economic information was carried out by Landcare Research in 2014 on behalf of Auckland Council (Hart & Scott, 2014) for the Hōteo River catchment. The review was undertaken as the Hōteo River had been selected as a priority catchment primarily due to the threat posed by river sedimentation to the snapper breeding grounds within the Kaipara Harbour.

The Landcare review includes a significant amount of information regarding erosion processes and sources within the Hōteo River catchment. The review has identified that most erosion and subsequent sedimentation occurs during flood events via bank scouring and overland flow, with erosion occurring throughout the catchment (Hart & Scott, 2014). The review states that rainfall is the key driver of erosion processes, and rainfall events greater than 25 mm in the autumn, winter and spring, and events greater than 50 mm in late summer, are expected to result in erosion. The review has found that the key erosion process is streambank erosion and hillslope erosion occurring on steep land in the central and southern hills.

The study splits the Hōteo River catchments into subcatchments and provides hydrological and geological information for each subcatchment. One relevant table is a review of the riparian vegetation throughout the catchment, as reproduced below in Table 72. The review also presents recommendations for erosion and sediment management, including through the development of more comprehensive estimates of sediment yields and sources.

Table 72 – Hōteo catchment: Percentage stream length with riparian vegetation by subcatchments (Hart & Scott, 2014)

Subcatchment	Riparian vegetation	Subcatchment	Riparian vegetation
Waiteitei	56%	Waiwhiu	96%
Waitapu	53%	Hōteo Gorge	66%
Whangaripo	60%	Lower Hōteo	54%
Wayby	40%	Kourawhero	68%
Hōteo Central	77%	Total	63%

B.3 STUDY OF BANK EROSION AND ACCRETION IN FIVE RIVERS WITHIN KAIPARA HARBOUR CATCHMENT

Landcare Research carried out a study into river bank erosion in the Kaipara Catchment in Northland (Spikermann et al, 2015) to collect data to improve SedNetNZ. The study measured bank erosion across four rivers (Wairua, Mangakahia, Tangowahine, and Hōteo Rivers). The reaches studied were on average 11 km long. The study was conducted by reviewing historic mapping, aerial photography and LiDAR data to measure the height of river banks every two metres. This information was then used to calculate volumetric erosion and accretion rates.

The study indicates that within the Hōteo River catchment there are high rates of streambank erosion within the catchment, with the majority of erosion occurring downstream of river bends.

B.4 SEDNETNZ: MODELLING OF SOIL EROSION IN NORTHLAND

Landcare Research modelled erosion processes and estimated mean annual erosion rates across Northland using SedNetNZ. The report by Mueller & Dymond (2015) contains a summary of the methodology applied for each erosion process and also contains the resulting sediment loads.

SedNet is a GIS model designed as a spatially distributed, time-averaged annual model that routes sediment through a river network. The SedNet model accounts for deposition in water bodies and river reaches. The main outputs from the model are mean annual sediment loads in each stream link throughout the river network. The model is based on a full sediment budget and can be used to examine the proportionate contribution of sediment from specific areas of land use. The SedNet model was modified to suite application to New Zealand conditions (e.g. inclusion of earth slips and landslide erosion sources), hence SedNetNZ, which estimates erosion rates across New Zealand.

The Mueller & Dymond report documents simulated annual sediment yields for three sites within the Kaipara network as modelled with SedNetNZ (Table 73). These were compared with Auckland Council measured sediment yields (Curran-Cournane et al, 2013).

Table 73 – Comparison of measured sediment yields and loads with modelled sediment yields and loads (Mueller & Dymond, 2015)

Site	Area (km^2)	Measured Sediment		SedNetNZ Modelled sediment	
		Yield ($t/km^2/yr$)	Load (t/yr)	Yield ($t/km^2/yr$)	Load (t/yr)
Kaipara at Waimauku	163	32	5216	62	10065
Kaukapakapa at Taylors	62	76	4712	60	3719
Hōteo at Gubbs	268	74	19832	125	33366

The methodology used by SedNetNZ for erosion sources and depositions are summarised below:

- **Overland flow erosion** – This erosion type is modelled through the New Zealand Universal Loss Equation[3] (NZUSLE) which estimates erosion rates from sheetwash, rill and inter-rill processes at broad scales across New Zealand. This data is estimated and input to SedNetNZ as a 15 m resolution grid cell, estimating the values from climate, topographic, landcover and soil data as a raster. NZUSLE give the annual erosion rate (HE) in tonnes/km^2/year as a product of five factors:

$$HE = \propto \times P^2 \times K \times L \times S \times C$$

Equation 6

where α is a constant calibrated with published surficial erosion rates;
P is mean annual rainfall (mm) squared;
K is the soil erodibility factor;
L is slope length factor;
C is vegetation cover factor; and
S is the slope factor.

- **Shallow landslide erosion** – This erosion type is modelled based on the probability of landslide across a time-period, the amount of material in a typical landslide, and the percentage of this material that will be deposited in the channel. These factors are used to calculate the amount of eroded sediment (*LE*, tonnes/year) that reaches the stream link:

$$LE = SDR_L \times \frac{\overline{D} \times \rho_{ls} \times A \sum_{j=1}^{n} LD_j}{T}$$

Equation 7

where SDR_L is the sediment delivery ratio accounting for losses along the landslide runout path (based on field data and published literature);
$\overline{D}$ is the average depth of failure below the ground surface (~1m);
ρ_{ls} is the soil bulk density (~1.5t/m^3);
A is the total area of landslide in a watershed, calculated by summing cells with landside probability (*LD*) based on the slope; and
T is the period of landslide activity.

3 NZUSLE is a modified (simplified) version of the USLE equation developed specifically for New Zealand.

- **Gully erosion** – Gully erosion is calculated in the model from a gully density raster representing the lineal extent of gullies per unit area (km/km[2]). Gully erosion is limited to hill country and hilly steeplands on non-cohesive sandstone. The model assumed 100% sediment delivery to the channel, the sediment delivery to the channel (*GME*) is calculated through the equation:

$$GME = \frac{\rho \times \overline{A_g} \times \overline{GD}}{T}$$

Equation 8

where ρ is the soil bulk density (~1.5t/m^3);
$\overline{A_g}$ is the mean cross sectional area of gullies (based on field data);
$\overline{GD}$ is the gully density in square kilometres (based on terrain types); and
T is the period of landslide activity (100 years).

- **Earthflow erosion** – Earthflow erosion is a type of erosion where sediment is delivery to the valley bottom from the hillslopes via a slow moving is a conveyer system. Earthflows are dependent on geology and terrain and applied using the mapped distribution of earthflow prone erosion terrains, this is limited to hill country on crushed mudstone/argillite. Sediment delivery from earthflows (*EE*, tonnes/km[2]/year) is estimated through the following equation:

$$EE = \rho \times \overline{M_e} \times \overline{D_e} \times \overline{ED}$$

Equation 9

where ρ is the soil bulk density (~1.5t/m^3);
$\overline{M_e}$ is the mean speed of earthflows (~0.1m/yr);
$\overline{D_e}$ is the mean depth of earthflows (~3.0m); and
$\overline{ED}$ is the density of earthflows (~1024m/km^2).

- **Riverbank erosion** – Riverbank erosion occurs across all streams and is dependent upon the flow rate. In the model the river bank erosion is calculated as a product of stream length, bank migration rate, bank height, soil density, and a factor applied to account for accretion (factor obtained from correspondence with the authors of the report). The report states that the bank migration rate can be predicted from the annual flood discharge based on an observed relationship. The bank height is estimated from a regional relationship between bank height and mean discharge. Therefore, the bank erosion sediment delivery to the channel can be calculated from the following equations:

$$Streambank\ erosion = \rho \times \mathrm{BE} \times \mathrm{SL} \times 0.2$$

$$BE = \mathrm{H} \times \mathrm{M}$$

$$H = 2 + log_{10}Q_{mean}$$

$$M = 0.028 \times Q_f^{0.469}$$

$$Q_f = \mathrm{a} \times \bar{q}^b$$

Equation 10

where ρ is the soil bulk density (~1.5 t/m^3);

BE is the rate of erosion per unit channel length (m³/m/year);
SL is the stream length (m, REC layer stream orders 2-5);
0.2 is factor applied to the gross bank erosion to obtain net bank erosion, accounting for bank accretion and the recovery of stable bank form (Dymond et al, 2016);
H is the bank height (m);
M is the bank migration rate (m/year);
Q_{mean} is the mean discharge;
Q_f is the mean annual flood;
$\bar{q}$ is the measured mean discharge; and
a and *b* are constants derived from observed relationships in gauged subcatchments in the Kaipara Harbour catchment (a=30 and b=1).

- **Floodplain deposition** – Floodplain deposition (FD) was modelled separately for the Wairoa, Kaipara and Hōteo rivers. Floodplain deposition was calculated as a proportion of the total sediment load that overtops the banks during a flood event (discharge with return period of 1.5 years). The annual rate of floodplain deposition is estimated by dividing the total deposited sediment by the area of floodplain in the tributary catchment. Tributaries controlled by flood-control banks were modified by multiplying by a flood control factor.

B.5 STUDY INVESTIGATING THE SOURCES AND DISPERSION OF SEDIMENT WITHIN KAIPARA HARBOUR

A study by NIWA (Gibbs et al, 2012) investigates terrestrial sources and dispersion of sediments within Kaipara Harbour, in response to previous studies that identified increases in sedimentation within Kaipara Harbour were reducing water quality and biodiversity within the harbour.

The study describes the marine sands that compose the sand barriers, tidal deltas, beach and dune systems that define the harbour and contribute to the ecological qualities of the harbour. Land use changes have increased soil erosion in the 6,400 km² of land draining into the harbour; 63% of the erosion is from the Wairoa River catchment. The study notes that there is a lack of information available for the Kaipara Harbour with regards to sediment monitoring in catchments and the effects of increased catchment sediment runoff, which could affect the environmental quality in the harbour.

NIWA collected surface layer sediment samples over spring low tides from the southern and northern harbour systems. These samples were analysed to identify sediment sources through the use of compound-specific stable isotope (CCSI) techniques using the mixing model IsoSource. The model also used assessment of percent soil, sediment process assumptions and mapping tools to identify sediment sources in the harbour. The results indicate that the sediments within the main Kaipara Harbour include terrigenous sediments in addition to the marine sources.

The study analyses the sediment dispersion for each river system entering the Kaipara Harbour, a summary of this and the NIWA river flow estimates for each of the major sediment sources is given in Table 74.

Table 74 – Catchment sediment sources and dispersion in Kaipara Harbour (Gubbs et al, 2013)

River catchment	Site	Upstream area (km^2)	Mean annual (m^3/s)		Sediment dispersion
			flow	flood	
Wairoa	Mouth	3,554	88.5	3,716	Widely dispersed sediments, sediments found in northern Kaipara Harbour including northern river arms and in west of southern Kaipara Harbour.
Arapara	Mouth	72	1.5	53	Low proportions of sediment, along east of northern Kaipara Harbour
Otamatea	Mouth	37	0.65	40	Sediment confined to the south-east of the northern Kaipara Harbour
Oruawharo	Total	133	2.25	144	
Hōteo	Gubbs	270	4.35	181	High sediment load, dispersion pattern extends north and south across eastern sand flats of southern Kaipara Harbour
	Mouth	405	8.2	221	
Araparera	Mouth	69	1.5	38	No distinct sediment identified, similar to Kaipara / Kaukapakapa River sediments.
Makarau	Mouth	74	1.6	48	
Kaipara	Mouth	267	4.8	93	Joint local systems, main sediment south to southern Kaipara Harbour. Sediment extends north towards the harbour mouth.
Kaukapakapa	Mouth	120	2.4	64	

Therefore, within the southern Kaipara Harbour the main sediment source is the Kaipara and Kaukapakapa river system, as well as exports from the Hōteo towards the east of the Harbour. Additionally, there is sediment entering the southern Kaipara Harbour from the Wairoa River, which is not modelled as part of the assessment for this Project.

APPENDIX C PROJECT SOIL INVESTIGATIONS

C.1 DATA SOURCES

The following data sources were considered as part of the assessment of soil and PSDs for the background and construction sediment loads:

- Results provided by the Project team from particle size analysis of samples from five boreholes (BH1022, BH1017, BH1027, BH1013, BH1028) near the alignment. The PSD of these samples was determined by wet sieving and hydrometer analysis for particle sizes <63 µm.
- Results of PSD analysis of water samples taken from 10 stream and river sites near the Project. These samples were collected by the Jacobs team for the Project in conjunction with water quality sampling. At 10 sites 5 samples were taken between June to September 2017, with 2 of these samples obtained during wet weather. PSDs were determined by laser diffraction without the addition of a dispersant other than water, and minimum particle size was 10 µm.
- Data on the PSD of sediment in influent and effluent water samples collected as part of the ALPURT sediment pond study described in Section 2.3.3. This study informed the Pūhoi to Warkworth Project, and also provided treatment efficiencies assumed for the treatment devices for the Project.

The PSDs from these three data sources vary widely, with PSDs varying at each stream site for each monitoring visit, as well as varying from the borehole data. This is likely due to differences in sampling conditions, sampling methods and analytical methods.

C.2 BOREHOLE PSDS

PSD was calculated for five boreholes along the Indicative Alignment. Four of these were sampled in the surface soils, while another was surveyed at a depth of 1.5 m below ground level (bgl) however this depth was still within the soil profile. The resulting proportional PSDs are given in Table 75.

Table 75 – Project borehole soil PSDs

Particle size class	BH1013 (surface)	BH1017 (surface)	BH1022 (surface)	BH1027 (surface)	BH1028 (1.5 m bgl)
Clay (<3.9 µm)	48	8	48	75	46
Silt (3.9-63 µm)	29	8	29	21	45
Sand (62.5 µm - 2mm)	16	22	16	4	9
Gravel (>2 mm)	7	62	7	0	0

For three of these boreholes the PSD was found to be mostly silty clay or clayey silt (BH1013, BH1027, BH1028). The remaining two were sandy gravel, however these were taken from an area of active slip and as such are not representative of the surface soil PSD.

The borehole studies found that boreholes had soil to a depth of approximately 15 m in some places. The underlying rock was generally found to be of similar composition to the surface comprising mudstone and sandstone.

C.3 INSTREAM PSDS

PSD was calculated for 10 freshwater quality locations near the Indicative Alignment. Water samples were taken as a grab sample from streams during wet and dry weather conditions. NIWA carried out PSD analysis on the sediments within the grab samples.

The results vary considerably by location and depending upon flow condition, generally particle size was larger during wet weather monitoring, however that was not the case for all sites. As such the distributions indicate that PSDs vary temporally and by catchment. Mean PSDs for a number the locations were calculated, and are presented in Table 76 and Table 77.

Table 76 – Project borehole freshwater mean PSDs in Mahurangi and Oruawharo River tributaries

Particle size class	Mahurangi River (left branch) (Mahurangi1)	Mahurangi River (Mahurangi7)	Te Hana Creek (TeHana5)	Maeneene Creek (Maeneene6)
Clay (<3.9 µm)	0.0%	0.0%	0.0%	0.0%
Silt (3.9-63 µm)	64.9%	78.1%	54.7%	68.1%
Sand (62.5 µm - 2mm)	35.1%	21.9%	45.3%	31.9%
Gravel (>2 mm)	0.0%	0.0%	0.0%	0.0%

Table 77 – Project borehole freshwater mean PSDs in Hōteo River and tributaries

Particle size class	Kourawhero Stream headwater (Kourawhero2)	Waiteraire stream		Unnamed pasture tributary (Hōteo 10)	Hōteo River	
		at headwater (Hōteo 9)	at confluence (Hōteo 4)		Upstream of SH1 (Hōteo 3)	at Gubbs (Hōteo 8)
Clay (<3.9 µm)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Silt (3.9-63 µm)	60.4%	43.2%	48.3%	44.7%	46.1%	55.2%
Sand (62.5 µm - 2mm)	39.6%	56.8%	51.7%	55.3%	53.9%	44.8%
Gravel (>2 mm)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

The results did not detect any clay within any of the results, and instead found a large proportion of silts and sand. The NIWA laboratory stated that the particles were not crushed or broken up, and when shaken the particle size breaks down. As such it is likely that the higher particle size represents the material as it erodes, and it is likely that the particle size is smaller once it reaches the mouths of the rivers and receiving marine environments.

APPENDIX D COMPARISON OF DAILY RAINFALL

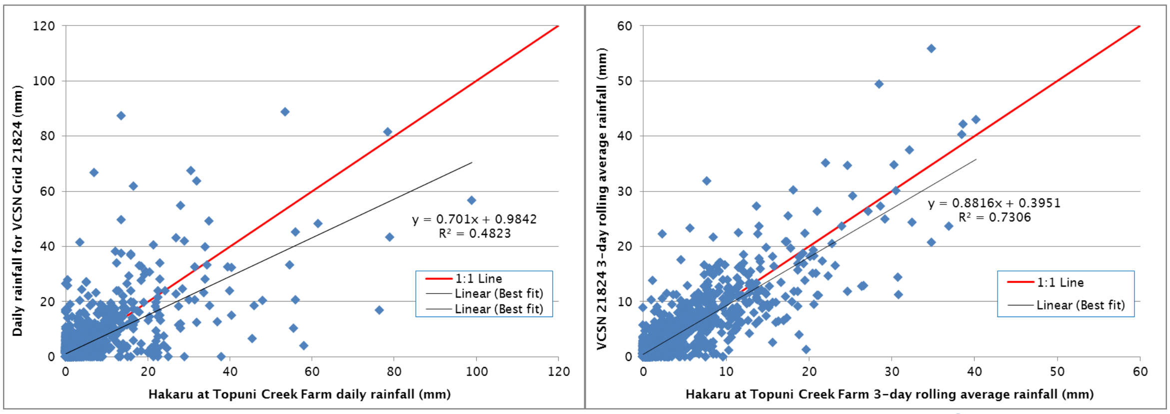

Figure 31 - Hakaru at Topuni Creek Farm daily and 3-day rolling average rainfall comparisons

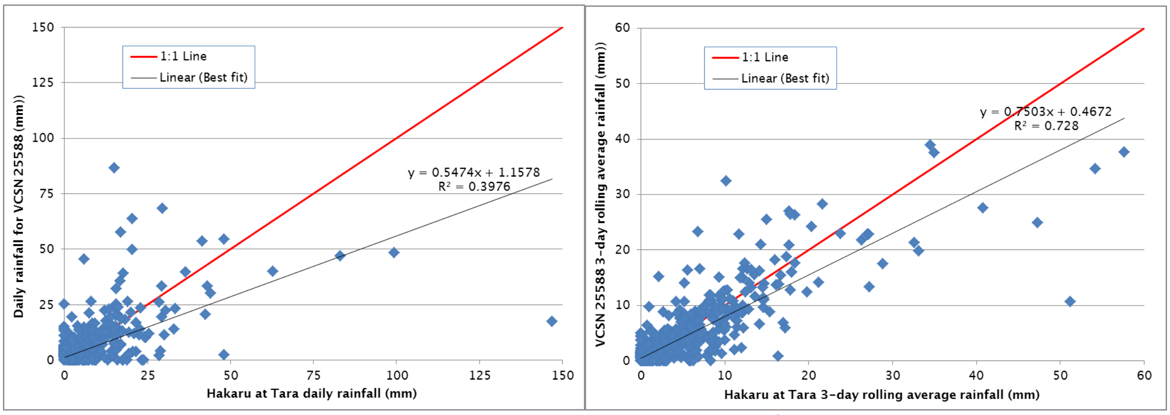

Figure 32 - Hakaru at Tara daily and 3-day rolling average rainfall comparisons

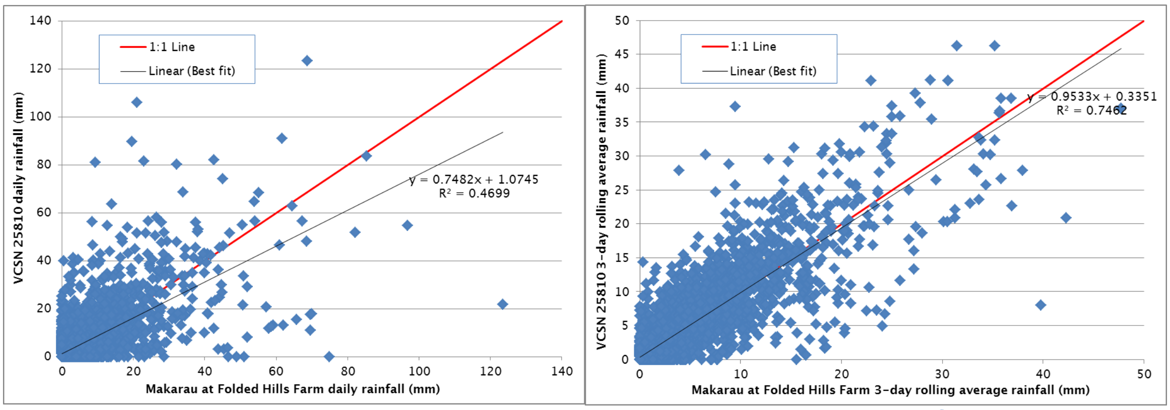

Figure 33 - Makarau at Folded Hill Farm daily and 3-day rolling average rainfall comparisons

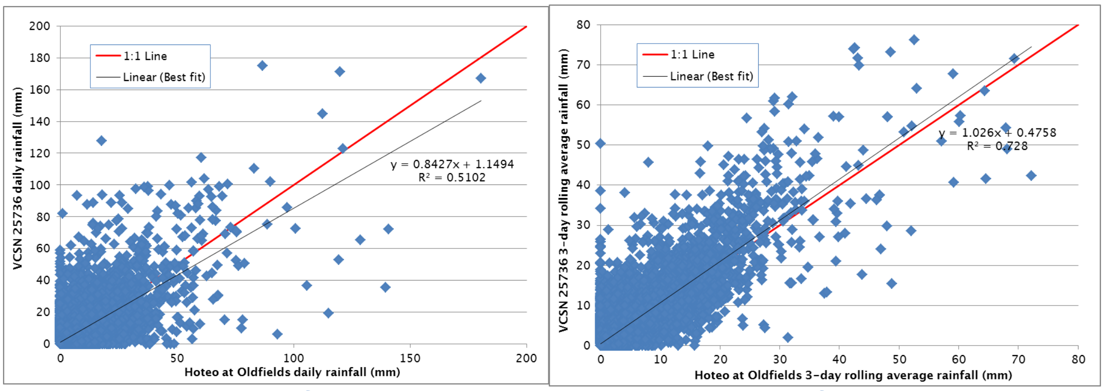

Figure 34 - Hōteo at Oldfields daily and 3-day rolling average rainfall comparisons

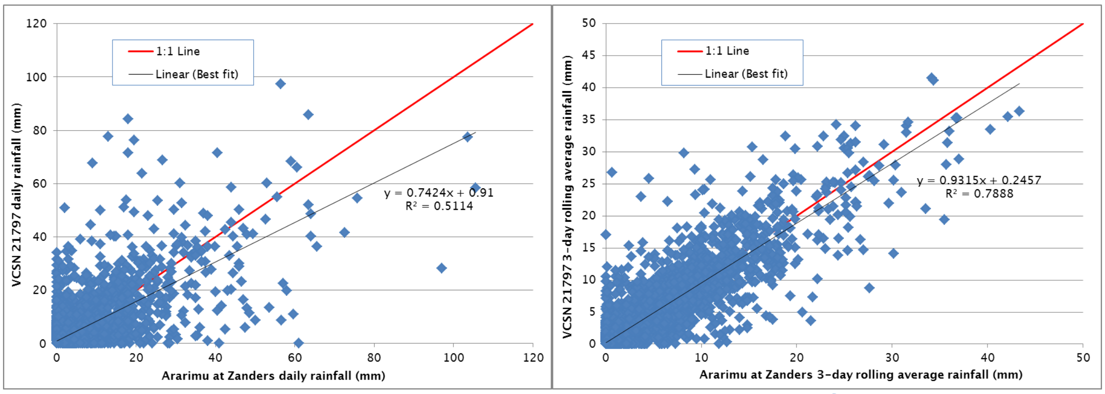

Figure 35 - Ararimu at Zanders daily and 3-day rolling average rainfall comparisons

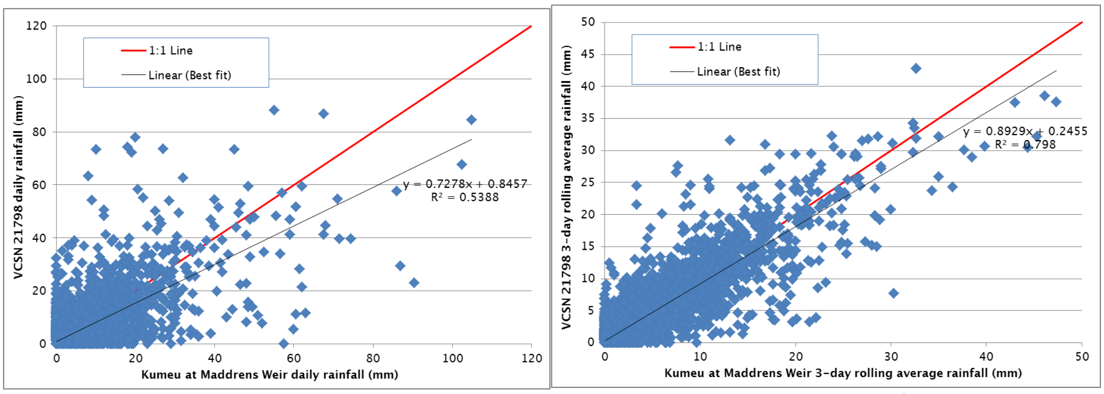

Figure 36 - Kumeu at Maddrens Weir daily and 3-day rolling average rainfall comparisons

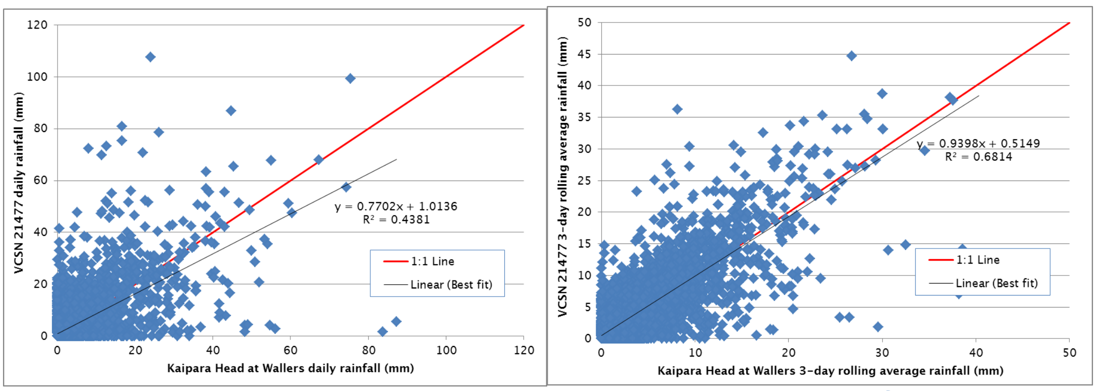

Figure 37 - Kaipara Head at Wallers daily and 3-day rolling average rainfall comparisons

APPENDIX E KAIPARA HARBOUR MODEL CALIBRATION AND VALIDATION FLOW DURATION CURVES

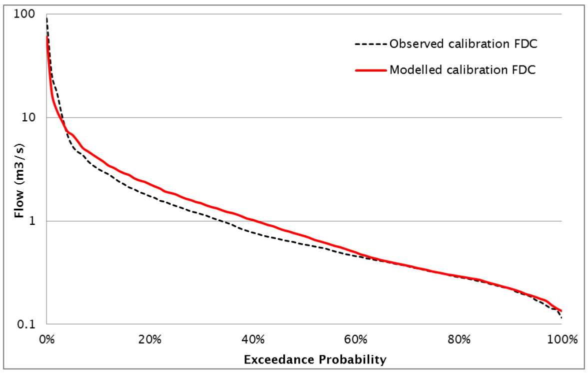

Figure 38 – Hakaru at Topuni Creek Farm calibration period flow duration curve

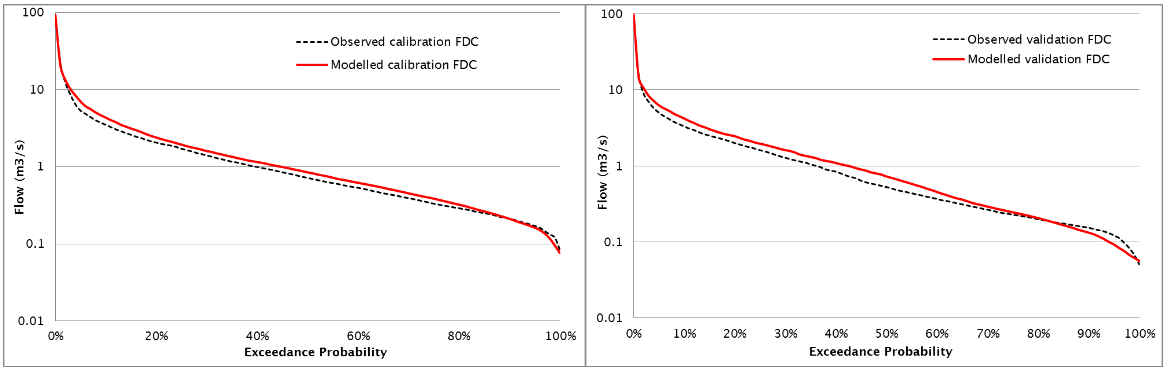

Figure 39 – Waiteitei at Sandersons calibration and validation flow duration curves

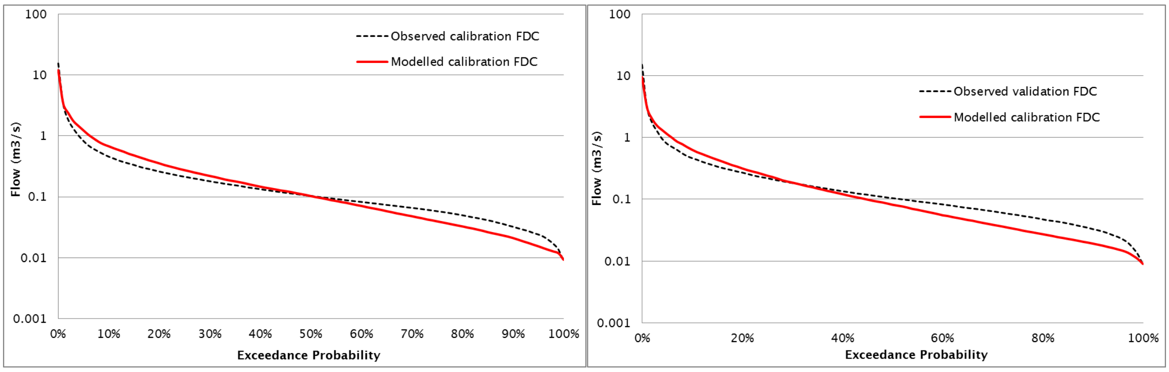

Figure 40 – Waiwhiu at Dome Valley calibration and validation flow duration curves

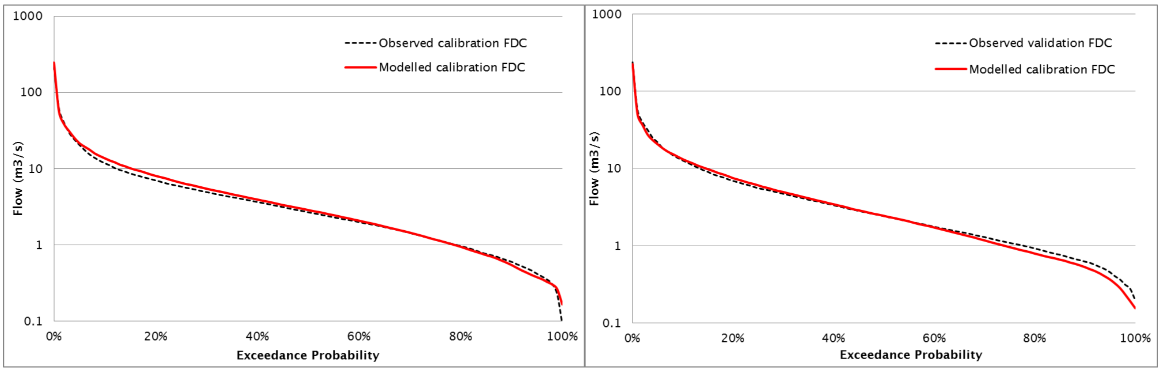

Figure 41 – Hōteo at Gubbs calibration and validation flow duration curves

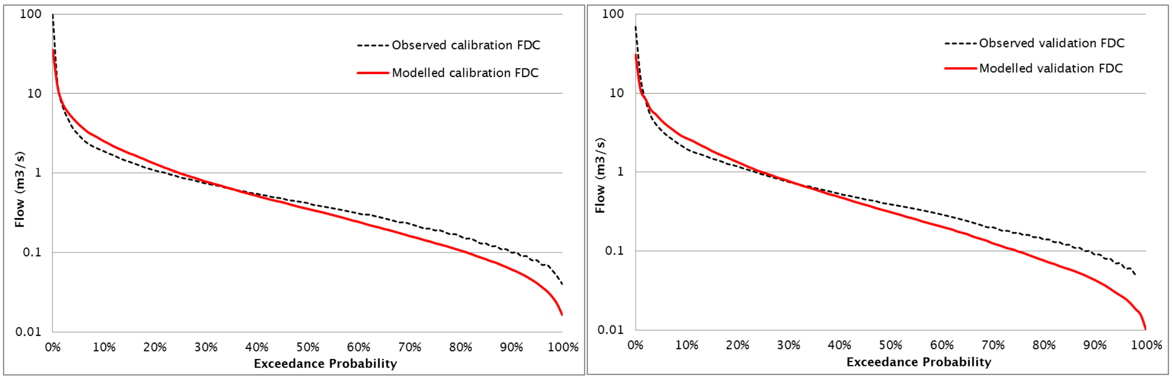

Figure 42 – Makarau at Coles calibration and validation flow duration curves

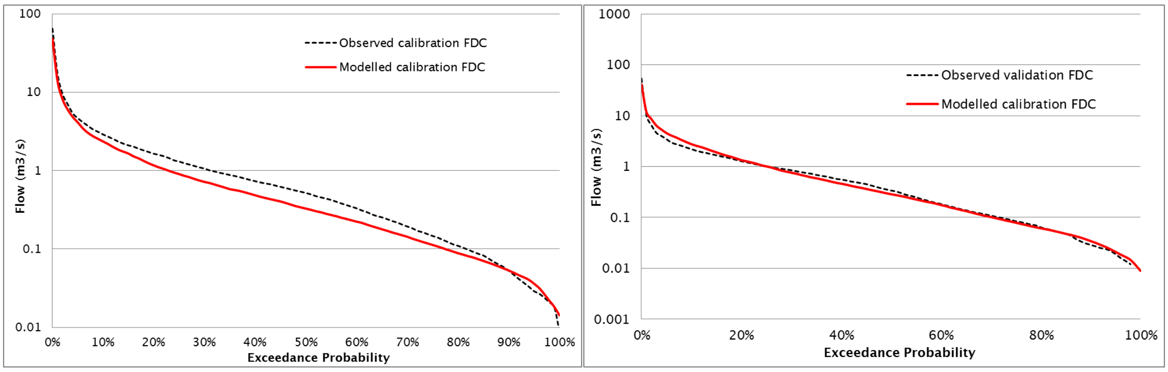

Figure 43 – Kaukapakapa at Taylors calibration and validation flow duration curves

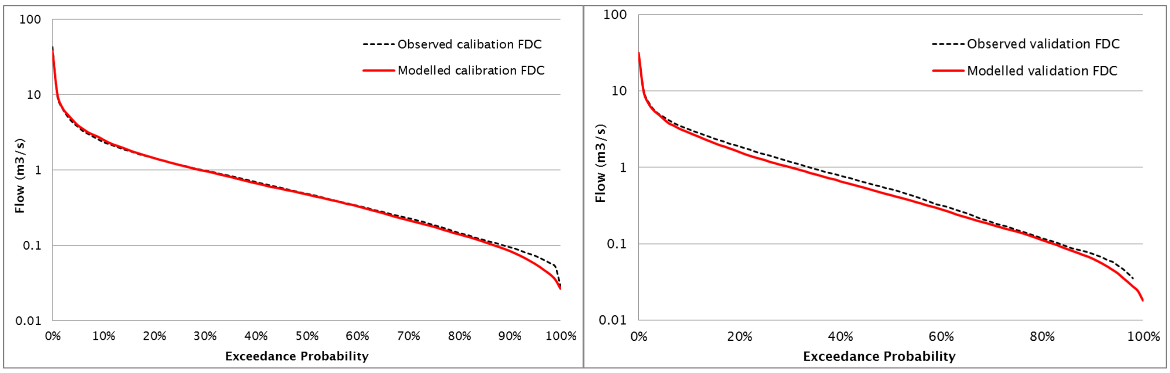

Figure 44 – Ararimu at Old North Road calibration and validation flow duration curves

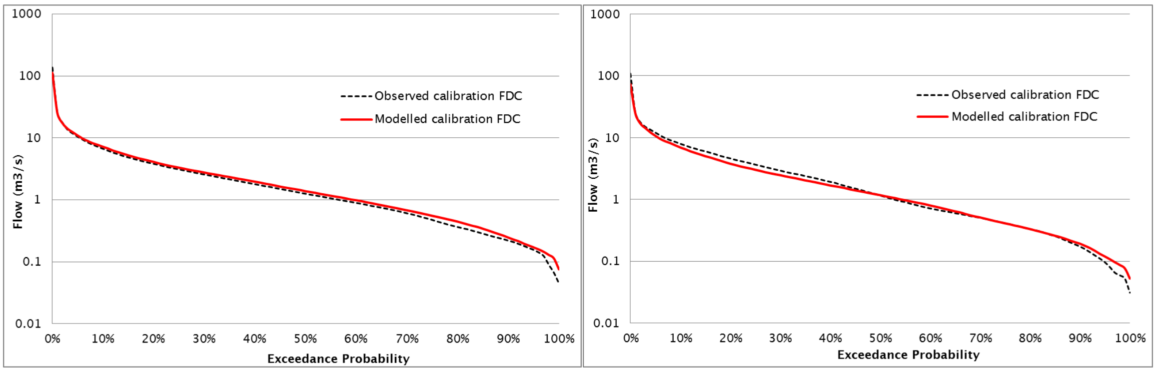

Figure 45 – Kaipara at Waimauku calibration and validation flow duration curves

APPENDIX F FORESTRY HARVESTING

F.1 INTRODUCTION

The Hōteo River catchment and Mahurangi River catchments have large plantation forests located within the catchments, that is the plantations managed by Rayonier Matariki Forests and the Redwood Forest respectively. The existing land use (2018) for over 48.3 km^2 of the Hōteo River catchment is exotic plantation forests, located to the east associated with the catchments of Waiwhiu Stream, Waiteraire Stream, Awatere Stream and a small area in the Kourawhero Stream catchment. The Redwood Forest is located in the southern part of the Mahurangi River catchment. These forests are likely to reach maturity around the same time as the Project construction phase.

Neither the GLEAMS nor the dSedNet models attempt to distinguish between different phases of forestry operations. The dSedNet model has been calibrated against the observed record of sediment loads, and therefore may implicitly include some effects of forest harvesting over the last 10 years, however most of calibration spans periods where the forest has been mature.

Although forestry harvesting operations were not modelled, there is the potential that large scale harvesting will occur prior to the Project, and as such the background sediment loads during the indicative construction programme may be different than that modelled. Therefore, this section aims to carry out a literature review to understand the effect that forestry harvesting, and recovery could have on sediment loads on receiving streams, rivers and harbours within the Project catchments.

F.2 LITERATURE REVIEW

F.2.1 SEDIMENT PROCESSES

Harvesting of plantation forests can result in increases in sediment load in downstream rivers and streams through on-site and off-site erosion processes. On-site erosion is generally due to several different sources:

- earthworks associated with harvesting operations such as road/track and landing construction (Phillips et al, 2005);
- soil becoming exposed due to harvesting and canopy removal (Kamarinas et al, 2016);
- creation of new flow and erosion pathways due to harvesting resulting in gullying and landslips (Fahey et al, 2003);
- ground disturbance due to dragging of trees and machinery movements (Basher & Hicks 2002);
- riparian vegetation removal resulting in increased streambank erosion on site (Basher & Hicks 2002); and
- dumping of slash and soils in flow pathways and watercourses resulting in erosion and sediment movements (Fahey et al, 2003).

The earthworks and soil left bare all have the potential to be washed into receiving watercourses during the next high precipitation event, resulting in considerable amounts of sediment and other materials entering the receiving stream (Kamarinas et al, 2016). The amount of generated sediment entering the stream is dependent upon the landscape and connectivity (Croke & Hairsine, 2006). A review into sediment delivery in managed forests indicates that one of the main issues with estimating harvesting sediment yields is associated with defining the sediment delivery ratio, due to complex patterns of sediment storage, remobilization and delivery within forest areas (Croke & Hairsine, 2006).

There is also potential for harvesting to increase sediment yields off-site. The removal of the forest canopy can result in increased overland flow volume due to reduced infiltration/evapotranspiration, and increased flow speed due to compaction and vegetation removal (Fahey, 1994). This can result in increased flow volume and speed within downstream watercourses up to 80% (Fahey, 1994), which can result in erosion of streambanks downstream. Additionally, any materials such as trees and slash entering streams has the potential to increased downstream streambank erosion due to damning of watercourses.

F.2.2 SEDIMENT YIELDS

A number of studies of sediment yields relating to forest harvesting in New Zealand were carried out from the 1970s to the 2000s. Generally, these studies were carried out over short time-periods (2-6 years). The resulting sediment yields are related to rainfall conditions, as well as the geology, slope and forestry practices. The resulting sediment yields from these sites is given in Table 79, further information on these studies is summarised below.

The majority of the sediment yields in Table 78 are reported from the 2005 study into sediment yields in the Coromandel Peninsula (Phillips et al, 2005). The study calculated the sediment yield following logging of a plantation forest catchment over a 30-month period and reviewed a number of other studies in New Zealand.

The Coromandel Peninsula forest study area is a 36-ha plantation forest (Whangapoua Forest) which has a geology of weathered volcanic rock and steep slopes. The study (Phillips et al, 2005) calculated a range of sediment yields for the forest throughout harvesting, including pre-harvesting, road construction, logging and post-harvest period, the results are contained inTable 79 – Estimated sediment yields for harvesting of Matariki forest Table 79. The study found that the sediment yield is highest during the road creation phase and remains high through harvesting and post-harvesting. The study did not occur at a time with any large rainfall events (Phillips et al, 2005).

The Coromandel Peninsula study also reviewed several other studies on forestry sediment yield in New Zealand. The studies referenced in Table 79 have been reviewed for more detail to add further information regarding harvesting practices and sediment yields where available, however there are gaps in the information available especially relating to rainfall events and catchment sizes.

The 2003 study into sediment yields from plantation forestry in Hawkes Bay (Fahey et al, 2003) contains details on Pakuratahi forest. The study finds that most of the increase in yields is from increased flows from road sidecast, landslides and channel bed scouring. The report found that one storm contributed over a quarter of the sediment yield over 29 months, which highlights the importance for storm events in generating large sediment loads.

An analysis of sediment yields within the Auckland Region was carried out in 2009 (Hicks et al. 2009) to analyse measurements of sediment storm yields at nine locations through the Auckland Region. One of the sites is the Redwood Forest in the southern Mahurangi River catchment, which was monitored pre-harvesting (2.7 years) and post-harvesting (1 year). The resulting sediment yields are given in Table 78, and show that the yield increases by approximately 40% post-harvesting. The pre-harvesting yield is higher than expected at this catchment, which may be due to the steep slopes and high rainfall in the catchment. This study is the nearest geographically to the Hōteo River catchment.

The review into sediment delivery in managed forests (Croke & Hairsine, 2006) has found that throughout the world the patterns of sediment delivery are the same. Therefore, a study in Canada by Kreutzweiser & Cappel (2001) has been reviewed to assist in estimating plantation forestry yields due to different types of selective forest harvesting. The study reviewed fine sediment accumulation in four small streams in forest watersheds utilising the following selective harvesting: selection-cut (40% canopy removal), shelterwood-cut (50% canopy removal), diameter limit cut (about 85% canopy removal) and undisturbed tolerant hardwood catchments. These were also compared to pre-harvested catchment affected by logging road activities; the results are summarised below:

- Road improvement resulted in the largest increase in sediment with mean bedload estimates more than 4000 times higher than pre-manipulation values. This remained high for 2 years.
- The 85% canopy removal resulted in significant increases of up to 1900 times the pre-harvest average, likely due to skidder activity creating flow paths in riparian areas.
- The shelterwood harvest area, where logging roads were not a factor, no measurable increases in sediment deposition were detected (Kreutzweiser & Cappel, 2001).

This literature review has found that the sediment yield resulting from forestry is dependent upon a number of factors including the rainfall, slope, geology, catchment connectivity, harvesting method including road development. The review has found that sediment generation is least when applying selective harvesting and avoiding road construction.

The increase in sediment load during the post-harvesting stage is between 48% (Hicks et al. 2009) and 4,000 times (Kreutzweiser & Cappel, 2001) higher than pre-harvesting sediment loads. These values show the high variability in harvesting sediment yields. The maximum recorded sediment yield for post-harvesting in New Zealand is 570 t/km^2/year (Phillips et al, 2005).

Table 78 – Annual sediment yields from harvesting studies in New Zealand

Location & sampling period	Geology	Topography	Harvesting method	Catchment area		Pre-harvest yield (t/km²/yr)	Post-harvest yield (t/km²/yr)				Reference
				Total	Harvested		Range	Track building	Logging	Post-logging	
Whangapoua (2000-2003)	Weathered volcanics	Very steep (up to °40)	Mostly cable yarders, some ground-based	36ha	~35ha (0.5yr)	-	59-116	-	116	81.5	Phillips et al. 2005
Big Pokororo (1997-2008)	Weathered granite	Steep (mean slope 15°)	Roaded and harvested	2360ha	296ha (5yrs)	11	8-111	-	21-111	8-13	Basher et al. 2011
Little Pokororo (1997-2008)	Weathered granite	Steep (mean slope 14°)	-	860ha	136ha (5yrs)	18	15-151	-	44-151	15-21	Basher et al. 2011
Herring (1997-2008)	Weathered granite	Very steep (mean slope 18°)	Windfall damage	610ha	297ha (2yrs)	30	116-181	-	181	116	Basher et al. 2011
Greenhill (1996-2001)	Weathered granite	-	Roaded and harvested	309ha	-	32.9	7.5-60	7.5	81.5	60	Hewitt 2000, 2001b
Pakuratahi (1995-2005)	Tertiary mudstone	Very steep (60% over 20°)	Skyline hauler (85%) skidder (15%), 3.5km new road	345ha	~345ha (2yrs)	18	99-270	270	134	99	Fahey et al. 2003; Eyles & Fahey, 2006
Kaiteriteri (1995-2001)	Weathered granite	-	Roaded and harvested	76ha	-	40-180	56-378	365	378	56	Basher & Hicks 2002;
Apahi (1995-2001)	Weathered granite	-	Roaded and harvested	71ha	-	-	27-570	570	205	-	Hewitt 2001a, 2002
Blue mountains (unknown)	Schist	-	-	-	-	9-10	16	-	-	-	Duncan 2012
Redwood (1994-1998)	Sandstone or coarse siltstone	Very steep (mean slope 20°)	Roaded and harvested	6ha	~6ha (1yr)	183	280	-	280	-	Hicks et al. 2009
Glenbervie (1981-1987)	Deeply weather greywacke	-	-	-	-	-	46	-	-	-	Hicks & Harmsworth 1989
Big Bush (1976-1992)	Moutere Gravel	Very steep (mean slope 27°)	Clearfelling/skidder	9ha	-	-	200-530	-	-	-	Basher & Hicks 2002; O'Louglin et al. 1978
			Selection logging	20ha	-	-	20-85	-	-	-	

Location & sampling period	Geology	Topography	Harvesting method	Catchment area		Pre-harvest yield (t/km²/yr)	Post-harvest yield (t/km²/yr)				Reference
				Total	Harvested		Range	Track building	Logging	Post-logging	
Maimai (1974-1977)	Old Man Gravels	Extremely steep (mean slope 36°)	Clearfelled & skyline, no riparian zone	4.14ha	4.14ha (1yr)	56	80	-	80	-	Basher & Hicks 2002; O'Louglin et al. 1980
			Clearfelled & skidder, 20m riparian	8.26ha	~6.2ha (1yr)	56	450	-	450	-	

F.2.3 RECOVERY

Following the harvesting of plantation forests, generally forests are replanted with saplings and after some time the sediment yields reduce to the pre-harvest levels. The 2003 study into sediment yields from plantation forestry in Hawkes Bay (Fahey et al, 2003) found that yields from the harvested catchment declined markedly after over sowing and replanting and return to pre-harvest sediment yields two years after planting.

The study at the Coromandel Peninsula (Phillips et al, 2006) found that the sediment yields were higher in the 12-month period following harvesting compared to the later period of monitoring, indicating a quick reduction (<1 year) in sediment supply from slopes as bare areas are revegetated.

The study into the Motueka Forest Hydrological monitoring (Basher et al, 2008) discusses three sites: Big Pokororo, Little Pokororo and Herring. These sites have long-term monitoring beginning in 1997 to 2001. The results indicate that the Big Pokororo and Little Pokororo sites fully recovered to pre-harvesting levels within 5 years after harvesting, however this may be less as there is a 5-year gap (2001-2006) in the data (Basher et al, 2011).

A land use study of Pakuratahi (Eyles & Fahey, 2006) found that the first year of post-harvesting the sediment yield was higher than pre-harvesting, however by the second year sediment yields reduced dramatically similar to pre-harvest levels, indicating that recovery can occur in 2-years post-harvest. This study (Eyles & Fahey, 2006) also found that the first year post-harvest, flows downstream were higher than pre-harvest, however this reduced significantly by the second year.

A study into the effects of plantation forestry on hydrology and flooding (Fahey, 1994) indicates that the effect of harvesting on water yields can result in increased water yield for three to five years after clearfelling, and yields should return to pre-harvesting levels within 6-8 years.

The literature review has found that on-site plantation forest sediment yields return to pre-harvested levels at timeframes of 2-5 years following replanting, however the hydrological effects downstream may continue to occur for a longer time period.

F.3 NATIONAL ENVIRONMENTAL STANDARD FOR PLANTATION FORESTRY

The National Environmental Standard (NES) for plantation forestry came into force on 1st May 2018.

These standards state that forestry activities are generally permitted activities provided that regulations are complied with. The NES is split into different sections, including earthworks and deforestation, however the NES regulations are strict on environmental standards especially relating to run-off.

Forestry earthworks and harvesting are permitted activities under the NES provided that the activity complies with regulations, methodologies and earthwork/deforestation limits that vary in relation to erosion risk and land slope. Earthworks and harvesting must also comply with regulations relating to water quality and sediment, including:

- Management to avoid significant effects to water quality;
- Development of a forestry earthworks management plan, identifying environmental risks, for large earthworks;
- Development of a harvest plan, identifying environmental risks, for all erosion susceptibility classification zones;
- Avoidance of rivers and wetlands (5-10 m setback), the coastal marine area (30 m setback) and ephemeral flow paths where possible.
- Soil must be stabilised as soon as practicable; and
- Run-off from roads, tracks and landings must be managed.

Following the above, any forestry activities occurring prior to or concurrent to the construction phase of the Project would have to comply with environmental standards relating to erosion and sediment control.

F.4 MATARIKI FOREST

RMF are the owners of a large plantation pine forest located on the steep slopes of the Dome ridges. RMF call this forest Mahurangi Forest and divide it into Mahurangi East Forest and Mahurangi West Forest. We refer, collectively, to the forest as Matariki Forest, and note that the forest is located within the Hōteo River catchment.

The East Forest is the area of the forest to the north of the SH1, the West Forest is to the south of the SH1. RMF have provided a plan showing the total areas of plantation forestry. There is 4,830ha of plantation forestry within the Dome Ranges.

The Matariki Forest is a second generation forest and was previously harvested between 2000-2004 (Kamarinas et al, 2016).

F.4.1 HARVESTING SEQUENCING

A study into land disturbance in the Hōteo Forest (Kamarinas et al, 2016) analysed forest disturbance in the Hōteo River catchment associated with harvesting. The study found that at the beginning of the study (2000) there was approximately 5,580 ha of exotic forestry within the catchment. The study found that 65% of the forestry in the Hōteo catchment was harvested between 2000-2004; that corresponds to approximately 3,600 ha harvested in these four years.

RMF have provided an indicative harvesting plan for the Hōteo catchment (RMF, 2018, pers. comm., 9 May). This results in the 4,830ha being harvested across 16-years, with up to 630ha of forest harvested each year. The likely harvesting sequencing for the East Forest and the West Forest are shown on Figure 46 and Figure 47. This is an indicative harvesting plan and is likely to alter prior to harvesting.

It is assumed that all plantation forest within the proposed designation boundary will be harvested prior to the commencement of construction. Some harvesting of forest outside of the proposed designation boundary may occur concurrently with the Project.

An assessment has been undertaken on the potential sediment yield from forest harvesting, based on the sequence provided by RMF.

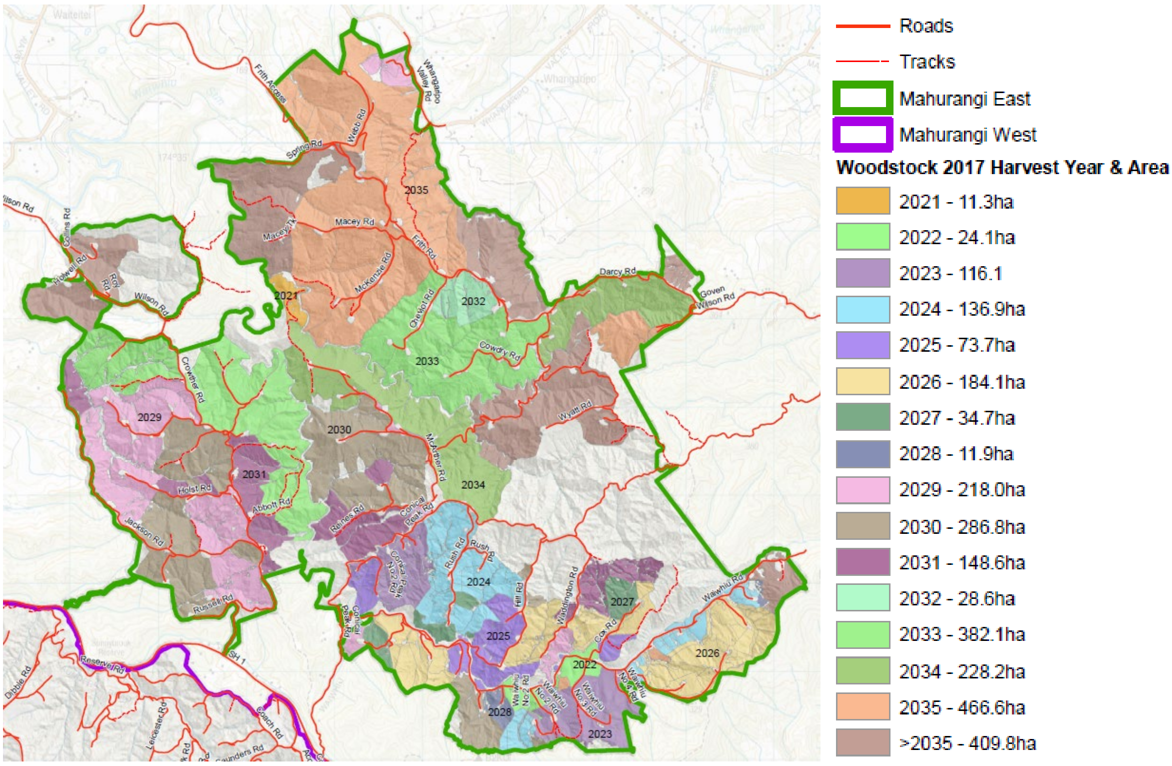

Figure 46 – Indicative Matariki East Forest harvesting plan (provided by RMF, April 2018)

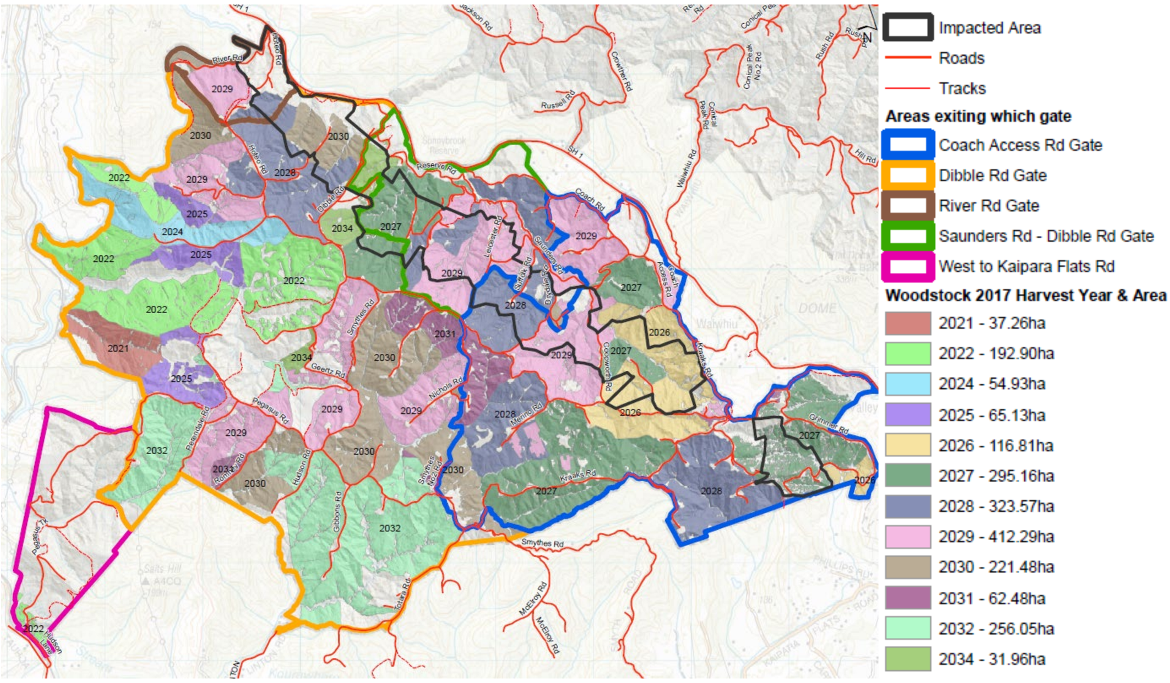

Figure 47 – Indicative Matariki West Forest harvesting plan (provided by RMF, April 2018)

F.4.2 TOPOGRAPHY AND GEOLOGY

Kamarinas et al. (2016) study into land disturbance in the Hōteo catchment found that exotic forests are almost exclusively situated on areas of high elevation with steep slopes, and thus are more connected to the river network. A review of the DEM topography indicates that the slopes within the Matariki Forest are steep (mean slope of 27°).

The geology in this area is the Pakiri formation, classified as a sedimentary formation comprising interbedded, graded sandstone and siltstone or mudstone. The soils in this area have been classified as clays or clay loams.

Based on similar topography (steep) and geology (mudstone), the studies identified in Table 78 that correspond most to the Hōteo catchment are the Pakuratahi study (Fahey et al, 2003; Eyles & Fahey, 2006) in Hawke's Bay and the Redwood study (Hicks et al, 2009) in the Mahurangi catchment.

F.4.3 HARVESTING METHODS

The exact harvesting technique to be applied to the Matariki Forest is not known, however conversations with the Matariki Forest owners indicate that some form of skyline logging is likely to be applied. This is similar to the Pakuratahi Forest study. Given that the forest is a second generation forest, there are existing roads available and no major tracking building needs to take place (RMF, 2018, pers. comm., 9 May). The Pakuratahi Forest study (Fahey et al, 2003; Eyles & Fahey, 2006) includes different post-harvesting sediment yields for different stages of harvesting. Given that there will be no new track building, the logging sediment yield from the Pakuratahi Forest study will be applied as the best representation of the logging yield of Matariki Forest.

Matariki Forest will be harvested in accordance to the NES, which will implement sediment controls and measures. This may result in greater reduction in sediment yields than applied in the Pakuratahi Forest study (1995-2005), however given the lack of recent studies into harvesting with similar controls in place, we have used the available literature values to assess the effect of sediment.

F.4.4 SEDIMENT YIELD ESTIMATIONS

The pre-harvesting yield has been calculated for the Hōteo River, based upon the reporting point Project-Hōteo 9b-BL, located in the upper reaches of the Waiteraire Stream. The entire catchment (236 ha) upstream of this reporting point is plantation forest.

As detailed in the previous section, the study that corresponds most to the Matariki Forest harvesting is the Pakuratahi study, the harvesting values applied in this assessment are shown in Table 79.

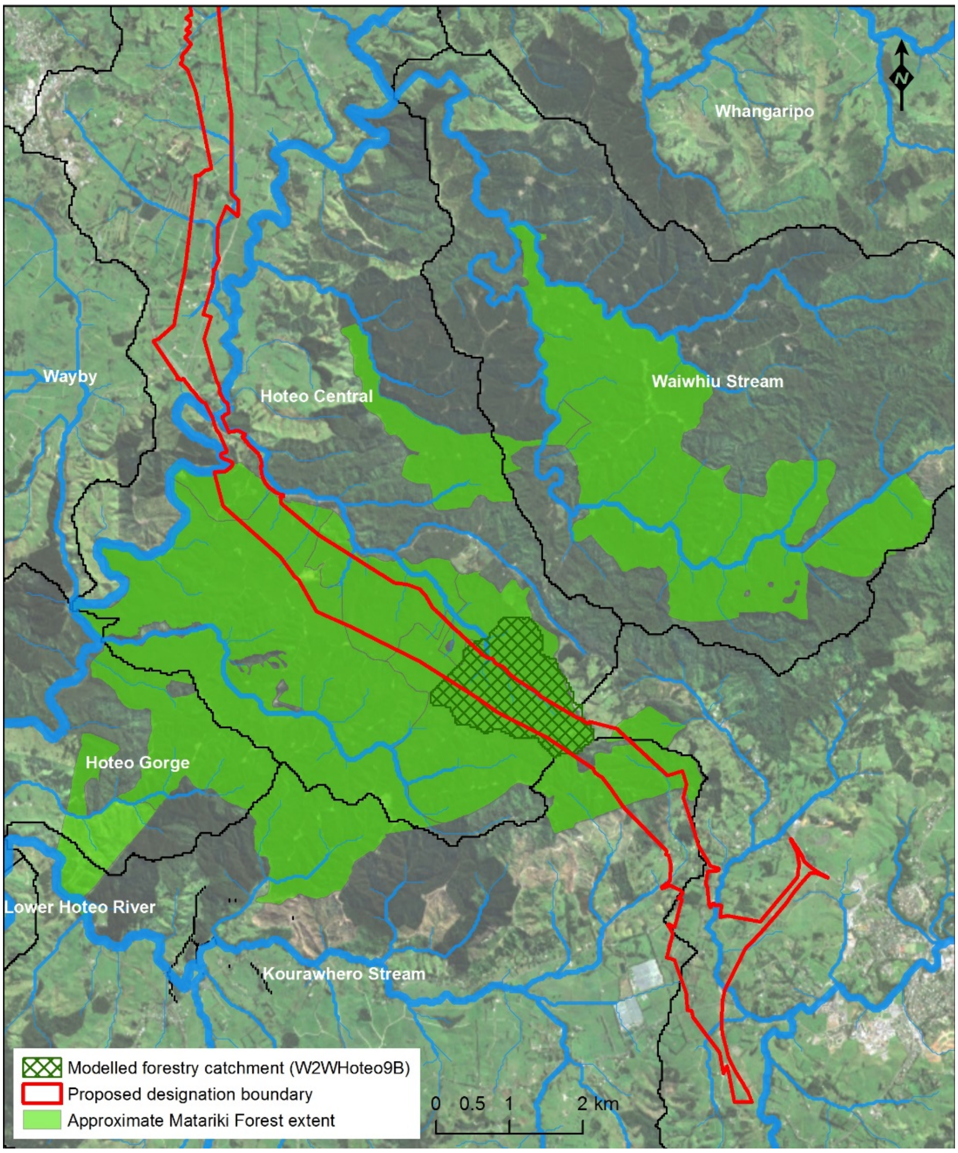

Figure 48 – Pre-harvesting reporting point Project-Hōteo 9b-BL location

Table 79 – Estimated sediment yields for harvesting of Matariki forest

Harvesting stage		Sediment yield ($t/km^2/yr$)	Notes
Pre-harvesting		50	Source hydrological input
Post-harvesting	*Track building*	*270*	*Pakuratahi study – not used*
	Logging	134	Pakuratahi study
	1-year post harvesting	99	Pakuratahi study
	2-year post harvesting	99	Pakuratahi study (no 2nd year data)
	3-year post harvesting	50	Based on literature review

F.4.5 SEDIMENT LOAD ESTIMATES

The forest to be harvested is 4,831 ha (48.3 km^2) over 16 years. The likely changes to land cover during the 16-year harvesting, as provided by RMF, are contained in Table 80, while Table 81 includes a high level estimate of the potential increases in sediment yield that could occur based upon the literature review data.

Table 80 – Potential harvesting pattern across the 15-year harvesting (logging) and recovery (Source: RMF)

Year	Total area (ha)	Forest (ha)	Logging area (ha)			Recovery area (ha)		
			East	West	Total	1-year post	2-year post	3 years+ post
1 (2021)	4,831	4,782	11	37	49	0	0	0
2 (2022)		4,565	24	193	217	49	0	0
3 (2023)		4,449	116	0	116	217	49	0
4 (2024)		4,257	137	55	192	116	217	49
5 (2025)		4,119	73	65	138	192	116	266
6 (2026)		3,818	184	117	301	138	192	382
7 (2027)		3,488	35	295	330	301	138	573
8 (2028)		3,153	12	324	335	330	301	711
9 (2029)		2,523	218	412	630	335	330	1,012
10 (2030)		2,014	287	221	508	630	335	1,342
11 (2031)		1,803	149	62	211	508	630	1,678
12 (2032)		1,519	29	256	285	211	508	2,308
13 (2033)		1,137	382	0	382	285	211	2,816
14 (2034)		876	228	32	260	382	285	3,027
15 (2035)		410	467	0	467	260	382	3,312
16 (2036)		0	410	0	410	467	260	3,694
17 (2037)		0	0	0	0	410	467	3,954
18 (2038)		0	0	0	0	0	410	4,421

Table 81 – High level assessment of potential change in annual sediment yields for harvesting of Matariki forest through a 15-year logging and recovery period (based on sediment yield identified in literature review) assuming no new tracks

Year	Existing sediment yield (T)	Estimated annual sediment yield during harvesting (T)						
		Forest load	Logging load	1-year post	2-year post	3 years+ post	Total	Change
1 (2021)	2,415	*2,391*	*65*	*0*	*0*	*0*	2,456	41
2 (2022)	2,415	*2,282*	*291*	*48*	*0*	*0*	2,621	206
3 (2023)	2,415	*2,224*	*156*	*215*	*48*	*0*	2,643	228
4 (2024)	2,415	*2,129*	*257*	*115*	*215*	*24*	2,740	324
5 (2025)	2,415	*2,060*	*185*	*190*	*115*	*133*	2,682	267
6 (2026)	2,415	*1,909*	*403*	*136*	*190*	*191*	2,830	414
7 (2027)	2,415	*1,744*	*442*	*298*	*136*	*287*	2,907	492
8 (2028)	2,415	*1,576*	*450*	*327*	*298*	*356*	3,006	591
9 (2029)	2,415	*1,261*	*845*	*332*	*327*	*506*	3,271	855
10 (2030)	2,415	*1,007*	*681*	*624*	*332*	*671*	3,315	900
11 (2031)	2,415	*902*	*283*	*503*	*624*	*839*	3,150	735
12 (2032)	2,415	*759*	*381*	*209*	*503*	*1,154*	3,007	592
13 (2033)	2,415	*568*	*512*	*282*	*209*	*1,408*	2,979	564
14 (2034)	2,415	*438*	*349*	*378*	*282*	*1,514*	2,961	545
15 (2035)	2,415	*205*	*625*	*258*	*378*	*1,656*	3,122	707
16 (2036)	2,415	*0*	*549*	*462*	*258*	*1,847*	3,116	700
17 (2037)	2,415	*0*	*0*	*406*	*462*	*1,977*	2,845	429
18 (2038)	2,415	*0*	*0*	*0*	*406*	*2,210*	2,616	201
Total	43,475	-	-	-	-	-	52,266	8,792
Mean annual	2,415	-	-	-	-	-	3,267	549

This high level assessment indicates that harvesting of the Matariki Forest could result in an additional 8,792 tonnes of sediment entering the Hōteo River, and a mean annual increase of 549 tonnes, however up to 900 tonnes, based on the indicative Matariki Forest harvesting plans. The modelling undertaken as part of this report indicates that the mean annual sediment load at the mouth of the Hōteo River is 25,600 tonnes, indicating that the harvesting could increase the sediment load within the Hōteo River by an average 2.1% each year across 18-years.

This is significantly larger than the modelled increase in sediment load to the Hōteo River mouth from the 7-year indicative construction programme of the Project. The construction of the Project is estimated to result in a total increase of 1,335 tonnes of sediment to the Hōteo River, or a mean annual sediment load increase of 191 tonnes/year (1.0% increase). Even considering the large assumptions made in the estimate of the forest harvesting yield, the sediment load associated with forest harvesting will have a larger effect on the Hōteo River than the Project.

F.5 REDWOOD FOREST

Redwood Forest is a large plantation pine forest located towards the south of the Mahurangi River catchment to the west of Pohuehue. An approximate extent of the forest within the Mahurangi catchment is shown on Figure 30 in Section 5.3 of the report. There is approximately 16.25 km^2 of the Redwood plantation forest within the Mahurangi Catchment.

F.5.1 BNZ MODEL RUN FOR FOREST HARVESTING

In 1998, NIWA undertook a study for Auckland Council estimating the increased sediment load that may be discharged to the Mahurangi Harbour when the forest is harvested, (Oldman, Stroud & Cummings, 1998). For this modelling study, the area of the Redwood Forest that drains to the Mahurangi Harbour (via the Mahurangi River) was modelled as being harvested.

The BNZ model was run for the Mahurangi Harbour catchment with Redwood Forest grid cell parameters set for a harvested condition, and assuming no sediment control measures (e.g., no riparian setbacks, no ponds).

The model predicted median, 5^{th} and 95^{th} percentiles sediment loads, which are given in Table 82 for the outlet of the catchment which contains the Redwood Forest (see Table 82). The table compares the predicted sediment load of the pre-harvesting catchment (trees still standing) to the predicted load leaving the catchment when the trees are harvested.

Table 82 – NIWA predicted sediment loads from the catchment containing the Redwood Forest and the Mahurangi River catchment (Oldman, Stroud & Cummings, 1998)

Location	Area (km^2)	Pre-harvest (standing forest) sediment load (tonnes/year)			Harvested Forest sediment load (tonnes/year)			Increase (tonnes/year)		
		5%ile	Median	95%ile	5%ile	Median	95%ile	5%ile	Median	95%ile
Redwood forest catchment	16.25	1,060	2,780	12,100	9,900	22,900	69,900	8,840	20,120	57,800
Mahurangi River at mouth[1]	58.25	-	10,700	-	10,200	24,400	82,700	-	13,700	-

Notes:

1 – The BNZ report do not explicitly state the pre-harvest 5%ile and 95%ile loads

After considering in-stream retention, the model predicts that with the Redwood Forest under a harvested condition the sediment load delivered to the estuary by the Mahurangi River has a 50% risk of increasing from 10,700 tonnes per year to 24,400 tonnes per year. The model also predicts a 5% risk of increasing to 82,700 tonnes/annum (although the study does not specify the relevant pre-harvest modelled load).

The more recent BNZ/GLEAMS model discussed in Section 3 indicates that the existing mean annual load delivered from the Mahurangi River to the Mahurangi Harbour is 12,190 tonnes, which is broadly similar to the Oldman, Stroud & Cummings (1998), which predict an increase of up to 13,700 tonnes due to harvesting.

The BNZ/GLEAMs model for the Project predicts an additional 405 tonnes of sediment across the indicative construction programme. That is significantly smaller than the load associated with forest harvesting by the Oldman, Stroud & Cummings (1998) report.

It should be noted that the Oldman, Stroud & Cummings scenario modelling was undertaken in 1998 and does not account for any ESC measures. As such it is expected that the Oldman, Stroud & Cummings (1998) scenario modelling is likely to overestimate the sediment load associated with harvesting.

F.5.2 AUCKLAND REGIONAL ANALYSIS OF SEDIMENT YIELDS AT REDWOOD FOREST

As detailed in the literature review contained in Appendix F.2, an analysis of sediment yields within the Auckland Region was carried out in 2009 (Hicks et al. 2009) with one of the sites in Redwood Forest. This site was monitored 1994-1998 during pre-harvesting conditions (2.7 years) and post-harvesting conditions (1 year). The resulting sediment yields for the pre-harvest is 183 tonnes/km/year, and 280 tonnes/km/year for logging (Table 78).

The modelled estimate from the BNZ modelling of forest harvesting (Oldman, Stroud & Cummings, 1997) ranges from 605 t/km^2 to 4300 t/km^2. These modelled estimates are significantly higher than those measured in the Redwood Forest (Hicks et al, 2009). The measured background was 180 t/km^2, similar to the BNZ model, but the measured harvested yield was 280 t/km^2, much lower than the modelled estimate. Therefore the Oldman, Stroud & Cummings (1997) modelled forestry outputs have been discounted and are not used further in this assessment.

The sediment yields from the Auckland Regional analysis (Hicks et al, 2009) study have been applied to the Matariki Forest (Appendix F.3) to carry out a high-level estimate of the sediment yield that could be expected from harvesting of the 48.3 km^2 forest. A similar assessment has been applied to the Redwood Forest in the following section utilising the pre-harvesting and post-harvesting sediment yields from the 2009 regional study (Hicks et al, 2009).

F.5.3 HARVESTING SEQUENCING

We have no indication of the harvesting sequencing that will be applied to the Redwood forest, or of the likely harvesting dates. The forest is approximately 1,625 ha (16.25 km^2) or approximately one third of the size of Matariki Forest. Based on the size, we have assumed that it could be harvested in 6-years.

F.5.4 SEDIMENT YIELD ESTIMATIONS

The pre-harvesting yields are the assumed yield from the Auckland Regional Analysis (Hicks et al, 2009) which indicate a yield of 180 tonnes/km^2/year, which is higher than for the Matariki Forest catchment. An estimate of the potential sediment yields for harvesting of the Redwood Forest are contained in Table 83 using the Redwood Forest study (Hicks et al, 2009). The Redwood Forest study only remains for 1-year during logging, therefore an interpolated value has been applied for the post-logging years.

Table 83 – Estimated sediment yields for harvesting of Redwood Forest

Harvesting stage		Sediment yield ($t/km^2/yr$)	Source
Pre-harvesting		180	Redwood forest study (Hicks et al, 2009)
Post-harvesting	Logging	280	
	1-year post harvesting	230	Interpolated from Pakuratahi recovery estimate and Redwood study (Phillips et al, 2005)
	2-year post harvesting	230	
	3-year post harvesting	180	Based on literature review

F.5.4 SEDIMENT YIELD ESTIMATES

A summary of the potential changes to land cover during 6-year harvesting are contained in Table 84, while Table 85 includes a high level estimate of the potential increases in sediment yield that could occur with 6-year harvesting programme.

Table 84 – Potential harvesting pattern across a potential 6-year harvesting (logging) and recovery period for Redwood forest

Year	Total area (ha)	Forest (ha)	Logging area (ha)	Recovery area (ha)		
				1-year post harvesting	2-year post harvesting	3 years+ post harvesting
1	1,625	1,354	271	0	0	0
2		1,083	271	271	0	0
3		813	271	271	271	0
4		542	271	271	271	271
5		271	271	271	271	542
6		0	271	271	271	813
7		0	0	271	271	1,083
8		0	0	0	271	1,354

Table 85 – High level assessment of potential change in annual sediment yields for harvesting of Redwood forest through a 6-year logging and recovery period (based on sediment yield identified in literature review)

Year	Existing sediment load (T)	Estimated annual sediment yield during harvesting (T)						
		Forest load	Logging load	1-year post	2-year post	3 years+ post	Total	Change
1	2,925	*2,440*	*760*	*0*	*0*	*0*	3,200	270
2	2,925	*1,950*	*760*	*620*	*0*	*0*	3,330	410
3	2,925	*1,460*	*760*	*620*	*620*	*0*	3,470	540
4	2,925	*980*	*760*	*620*	*620*	*490*	3,470	540

Year	Existing sediment load (T)	Estimated annual sediment yield during harvesting (T)						
		Forest load	Logging load	1-year post	2-year post	3 years+ post	Total	Change
5	2,925	*490*	*760*	*620*	*620*	*980*	3,470	540
6	2,925	*0*	*760*	*620*	*620*	*1,460*	3,470	540
7	2,925	*0*	*0*	*620*	*620*	*1,950*	3,200	270
8	2,925	*0*	*0*	*0*	*620*	*2,440*	3,060	140
Total	23,400	-	-	-	-	-	26,650	3,250
Mean annual	2,925	-	-	-	-	-	3,330	410

This high-level assessment indicates that harvesting of the Redwood Forest could result in an additional 3,250 tonnes of sediment entering the Mahurangi River, or a mean annual increase of approximately 410 tonnes (6-year harvesting scenario). The earthworks modelling assessed as part of this Project indicates that the mean annual sediment load at the mouth of the Mahurangi River is 12,190 tonnes, indicating that the harvesting could increase the sediment load within the Mahurangi River by an average of 3.4% across the harvesting period.

The assessment for the Mahurangi River estimates that the Project construction results in an estimated 793 tonnes. This is significantly less than the sediment load associated with harvesting. The mean annual sediment load for the Project is estimated to be 113 tonnes/year, or a 0.9% increase over the existing, compared with 3.4% for forest harvesting.