NZ TRANSPORT AGENCY
WAKA KOTAHI

Roads of national significance

Ara Tūhono – Pūhoi to Wellsford

This document records technical and factual information used to support the NZTA's Assessment of Environmental Effects for the Pūhoi to Warkworth Project. It has been supplied to the Environmental Protection Authority by the NZTA in response to a section 149(2) Resource Management Act 1991 request. This document did not form part of the NZTA's application for the Project, which was lodged on 30 August 2013.

FURTHER NORTH

Pūhoi to Warkworth

Water Assessment Factual Report 3

Estimates of Construction Sediment Loads using the GLEAMS Model

August 2013

Pūhoi to Warkworth

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Further North Alliance
Level 2, Carlaw Park
12-16 Nichols Lane
Parnell, Auckland
New Zealand

Tel: 0800 P2W NZTA (0800 729 6982)
E-mail: puhoi-wellsford@nzta.govt.nz
Web: www.nzta.govt.nz/projects/puhoi-wellsford

Puhoi - Warkworth Road of National Significance: Estimates of Construction Sediment Loads

Prepared for the Further North Alliance

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Authors/Contributors:
Sharleen Harper
Jonathan Moores
Sandy Elliott

For any information regarding this report please contact:

Jonathan Moores
Group Manager
Urban Aquatic Environments
+64-9-375 2043
Jonathan.Moores@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
41 Market Place
Auckland Central 1010
Private Bag 99940
Newmarket
Auckland 1149

Phone +64-9-375-2050
Fax +64-9-375-2051

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Reviewed by

……

Sandy Elliott
Group Manager, Catchment Processes

Approved for release by

……

Ken Becker
Regional Manager, Auckland

Executive Summary

NIWA has been contracted by the Further North Alliance ('the Alliance') to provide an assessment of sediment loads associated with construction of the Puhoi – Warkworth Road of National Significance. The alignment for the road is approximately 20 km long, and runs through areas of predominantly forested and pastoral land in the Puhoi River and Mahurangi River catchments. Earthworks associated with construction of the road will be undertaken in stages over a proposed 5-year period.

Assessment of sediment loads for the proposed earthworks has involved two main tasks, comprising estimates of:

1. Catchment background sediment loads; and
2. Construction phase sediment loads

The catchment background loads have been derived from previous studies of sediment generation in the Mahurangi Harbour catchment using the Basin New Zealand (BNZ) model, and are presented for:

- Each stream outlet discharging to the Mahurangi Harbour;
- Two stream assessment sites in the Mahurangi River; and
- The outlets of the Puhoi River and Te Muri Beach Stream catchments and one stream assessment site in the Puhoi River.

The values for the Puhoi River and Te Muri Beach are derived by comparison of catchment characteristics with the Mahurangi River, given that these catchments were not modelled in previous studies. In each case, the sediment loads reported include:

- Mean annual sediment loads and associated runoff volumes; and
- Event-based daily sediment loads and associated runoff volumes corresponding to average recurrence intervals (ARIs) of 2, 10 and 50 years. These values are estimated from the quantiles of statistical distributions fitted to the long-term series of daily loads and runoff volumes produced by the BNZ model.

The construction phase sediment loads have been estimated for two focus areas of the alignment ('Hills' and 'Flats'), as specified by the Alliance, for both the 5-year construction period and an alternative 10-year scenario. In each case, the loads are estimated using the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model, which is a physically-based model developed for continuous simulation of surface runoff and sediment losses on a field-scale. The model operates based on combinations of land-cover, soil type and slope in conjunction with a long-term climate record and other hydrological parameters. We have applied GLEAMS to calculate mean annual loads as well as 2, 10 and 50 year ARI daily loads for:

- The existing land-cover;
- Each year of the 5- and 10-year construction periods, reflecting changes in land-cover based on the staging of earthworks; and

- Fixed land-cover, reflecting the maximum area of exposed earthworks in the 5- and 10-year construction periods.

In each case, the results are presented both with and without treatment by erosion and sediment control measures. The type of erosion and sediment control measures applied, as well as the corresponding load reduction factors for different event sizes have been specified by the Alliance.

For each focus area, the additional loads represent the difference between the construction loads and the existing load. For the Mahurangi River, the construction loads represent the background load plus the additional loads from each focus area. Based on these results, for the Mahurangi River:

- The mean annual sediment load based on the changing land-cover over the 5-year construction period is increased by 39 % (untreated) and 13 % (treated) over the catchment background.
- The mean annual sediment load based on the changing land-cover over the 10-year construction period is increased by 22 % (untreated) and 6 % (treated) over the catchment background.
- The 2, 10 and 50 year ARI daily loads based on the fixed land-cover reflecting the maximum area of exposed earthworks for the 5-year construction period are increased, respectively, by 113 %, 82 % and 57 % (untreated), and 13 %, 15 % and 19 % (treated) over the catchment background.
- The 2, 10 and 50 year ARI daily loads based on the fixed land-cover reflecting the maximum area of exposed earthworks for the 10-year construction period are increased, respectively, by 52 %, 38 % and 26 % (untreated), and 4 %, 6 % and 9 % (treated) over the catchment background.

It is noted that the loads based on changing land-cover reflect not only the amount of exposed earthworks in any one month, but also the size of rainfall events which are expected to occur whilst the slopes are open. In contrast, the loads based on fixed land-cover represent a worst-case scenario by assuming that the maximum area of exposed earthworks remains open for all months of the year.

The sediment loads presented in this report will be used by the Alliance in subsequent assessments of ecological effects in freshwater and coastal water bodies. To support these further assessments, we have also prepared estimates of:

3. Representative particle size distributions (PSDs) for the sediment loads, both pre- and post-treatment;
4. Suspended solids (SS) concentrations over a 24-hour period at
    a. Each stream outlet discharging to the Mahurangi Harbour (for the background sediment loads); and
    b. The outlet of the Mahurangi River for the construction loads;
5. Loads and concentrations of the particulate forms of the nutrients nitrogen and phosphorus.

The representative particle size distributions are based on borehole logs provided by the Alliance as well as previous NIWA studies and data provided by Auckland Council. Based on the variation in PSD suggested by these data sources, adopting a relatively fine PSD is considered a conservative assumption for the ecological assessments. As such, we have assumed that all sediment generated during construction is delivered to the harbour, with no losses due to stream channel deposition.

1 Introduction

1.1 Background

The Further Northern Alliance ('the Alliance') is developing an Assessment of Environmental Effects (AEE) in relation to the proposed Puhoi to Warkworth (P-WK) Road of National Significance. The proposed road will be an extension of the existing Northern Gateway Toll Road from Johnstone's Hill Tunnels south of Puhoi to Warkworth, including a Warkworth Bypass (Figure 1-1). The alignment is approximately 20 km long and runs through areas of predominantly forested and pastoral land in the Puhoi River and Mahurangi River catchments. The topography of the area ranges from the low lying floodplain of the Mahurangi River to the relatively steep headwaters of the two catchments. Large volumes of earthworks will be required along this route, with numerous areas of cut and fill. These earthworks work will be undertaken in stages with the Alliance proposing the development of the road over a 5 year period.

The Alliance contracted NIWA to provide estimates of the sediment load generated during the construction phase of the project, and to compare these estimates with background sediment loads in the Puhoi and Mahurangi River catchments. This assessment involved calculating sediment loads associated with the projected extent and staging of earthworks in two specified focus areas along the road alignment, designated 'Hills' (Zone 7B) and 'Flats' (Zone 9). Sediment loads associated with the proposed 5-year construction programme in each focus area have also been compared with an alternative 10-year scenario, which reduces the amount of exposed earthworks area at any one time.

The sediment load estimates will be used by the Alliance in assessments of ecological effects in receiving freshwater and coastal water bodies. In order to support these ecological assessments, estimates of the suspended solid concentrations in streams and at catchment outlets within the project area have also been developed from the sediment load estimates. In addition, estimates of sediment-related nutrient loads and concentrations have been made to support the stream assessment work.

Further details on the scope of the sediment load assessment described by this report are given below in Section 1.2.

1.2 Scope

Our assessment of the sediment loads generated during the construction phase of the project is divided into four specific tasks, involving estimates of:

1. Catchment background sediment loads;
2. Construction phase sediment loads;
3. Concentrations of suspended solids; and
4. Nutrient loads and concentrations.

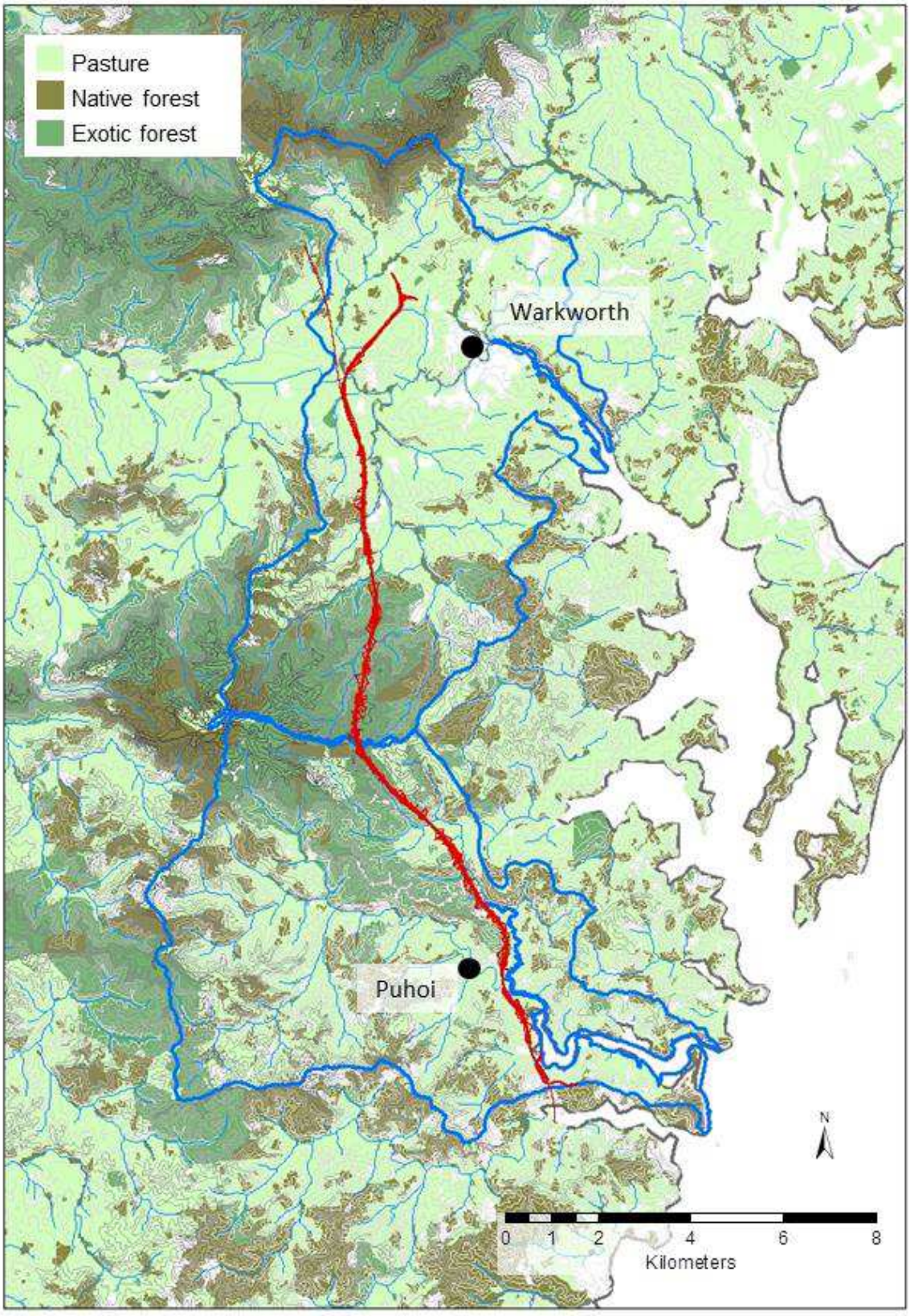


Figure 1-1: Project location map. The red line shows the approximate alignment (as of April 2013) of the proposed Puhoi to Warkworth RoNS. The catchment boundaries of the Mahurangi (to the north of the figure) and Puhoi (to the south of the figure) Rivers are shown in blue.

For each task, results are presented in terms of the following loads (or concentrations):

- Mean annual loads; and
- Event-based daily[1] loads associated with average recurrence intervals (ARIs) of 2, 10 and 50 years.

Estimates of these loads are supported by recommendations on:

- Representative particle size distributions; and
- Estimates of the proportion of the sediment load retained in streams and delivered to the coast.

Task 1 - Catchment Background Sediment Loads

NIWA has been involved in previous modelling studies of sediment generation in the Mahurangi Harbour catchment (see Section 2.2). Task 1 involved drawing on the results of these previous studies to estimate background catchment sediment loads in the project area. These load estimates are provided for:

- Each stream outlet discharging to the Mahurangi Harbour, based on analysis of previous modelling results;
- Two stream assessment sites in the Mahurangi River catchment, also based on analysis of previously modelling results;
- The outlets of the Puhoi River and Te Muri Beach stream catchment and one stream assessment site in the Puhoi River catchment, based on comparison of catchment characteristics with the Mahurangi River given that these catchments were not modelled in the previous studies.

Task 2 – Construction Sediment Loads

Task 2 involved implementing and running the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) hill-slope processes model for the two specified focus areas ('Hills' and 'Flats'), and analysing the model outputs to estimate annual and event-based loads for the following construction scenarios:

- Hills focus area, construction staged over 5 years;
- Hills focus area, construction staged over 10 years;
- Flats focus area, construction staged over 5 years; and
- Flats focus area, construction staged over 10 years.

For each of these scenarios, the loads before and after treatment by specified erosion and sediment control measures are provided. Different approaches were specified by the Alliance for the estimation of annual vs. event-based loads as follows:

[1] Loads per calendar day, not for any continuous 24-hour period.

- The estimation of mean annual loads and the load in each year of the project were based on the change in land cover associated with the staging of earthworks specified for each of the 5- and 10-year construction scenarios; whilst
- The estimation of the 2, 10 and 50 year ARI daily loads was based on the maximum area of open earthworks specified for each of the 5 and 10 year construction scenarios.

It should be noted that the sediment load estimates provided in this report relate solely to construction within the specified focus areas. The estimation of sediment loads derived from construction activities outside of these focus areas and from the project in total lay outside the scope of this assessment.

Task 3 – Concentrations of Suspended Solids

Task 3 involved estimating hourly mean suspended solids concentrations from the 2, 10 and 50 year daily sediment load estimates. These estimates are provided for:

- The background sediment loads discharged from each stream outlet to the Mahurangi Harbour, Puhoi River estuary and Te Muri Beach;
- The background sediment loads at the three stream assessment sites in the Mahurangi River and Puhoi River catchments;
- The project sediment loads (construction + background) at the outlet of the Mahurangi River; and
- The project sediment loads (construction + background) at the two stream assessment sites in the Mahurangi River catchment.

Task 4 – Nutrient Loads and Concentrations

The previous modelling studies of sediment generation in the Mahurangi Harbour catchment have also involved modelling of nitrogen and phosphorus loads delivered to the harbour. Task 4 involved drawing on the results of these previous studies to estimate loads, and concentrations, of sediment-related nitrogen (sediment-N) and sediment-related phosphorus (sediment-P). These estimates of daily loads and hourly concentrations associated with the 2, 10 and 50 year ARI sediment loads are provided for:

- The background sediment loads at the two stream assessment sites in the Mahurangi River catchment; and
- The project sediment loads (construction + background) at the two stream assessment sites in the Mahurangi River catchment.

1.3 Report Contents

This report outlines the methodologies involved and summarizes the results for each of the four tasks described above.

Chapter 2 provides an overview of previous NIWA studies of relevance for this assessment, including the modelling of long-term sediment loads to the Mahurangi Harbour and a field study to evaluate the performance of chemically-treated sediment retention ponds. It then

describes the way in which the results of these studies have been used in the present assessment to generate estimates of catchment background sediment loads and as the basis of recommendations on particle size distributions and sediment delivery to receiving water bodies.

Chapter 3 provides estimates of catchment background and project sediment loads. It firstly describes the methods employed in the analysis of the results of a previous study to estimate catchment background loads. Secondly, it describes the use of the GLEAMS hill-slope processes model to estimate sediment loads associated with the project. Results are summarised for the two specified focus areas ('Hills' and 'Flats') of the road alignment under both the 5- and 10-year construction scenarios.

Chapters 4 and 5 describe the methods by which the suspended sediment concentrations and nutrient loads and concentrations, respectively, have been estimated from the catchment background and construction sediment load estimates. The report concludes with a summary and description of the principal limitations, and a series of appendices provide detailed load and concentration estimates.

2 Previous Studies

2.1 Introduction

This chapter provides an overview of previous NIWA studies in and around the Mahurangi Harbour catchment which are of relevance for this assessment. These include:

- A modelling study of long-term sediment loads delivered to the Mahurangi Harbour, conducted for the then Auckland Regional Council (ARC) in the late 1990s; and
- A field study undertaken to evaluate the performance of chemically-treated sediment retention ponds, also commissioned by ARC and carried out in 2007.

Sections 2.2 and 2.3 provide a brief summary of each of these studies, respectively, whilst Section 2.4 describes the way in which the results have been used in the current assessment to generate estimates of catchment background loads, as well as to form the basis of recommendations on particle size distributions and sediment delivery to receiving water bodies.

2.2 Modelling of Long-Term Sediment Loads to the Mahurangi Harbour

In 1997, ARC commissioned NIWA to undertake a modelling study of long-term sediment loads delivered to the Mahurangi Harbour (Stroud & Cooper, 1997); with the aim of increasing their knowledge base and providing management strategies around issues such as catchment land-use activities and their effect on water quality. The study uses the Basin New Zealand (BNZ) model, which divides the catchment into grid-cells, each of which is assumed to have uniform land-use, soil type and slope. For each unique combination of these inputs, a long-term climate record is then applied to determine daily estimates of runoff volume and associated sediment loads (as well as nutrient loads including nitrogen and phosphorus) per unit area. In this instance, the long-term climate record consists of a 20 year time-series (1976 – 1995) of daily rainfall as well as temperature and solar radiation data. The daily sediment and nutrient loads from each cell are spatially distributed by the BNZ model and routed to sub-catchment outlets via the drainage network. The routing process adds point source loads, and also simulates sediment removal via riparian and stream channel deposition.

The model predictions were tested against flow and suspended sediment concentrations measured at the outlets to three test catchments over the period 1 July 1994 to 30 June 1995. In each case, the model predictions showed good agreement with the measured data.

2.3 ALPURT Sediment Pond Study

In 2007 ARC commissioned a field study to evaluate the effectiveness of Polyaluminium Chloride (PAC) treatment to improve the removal of sediment from earthworks run-off in a sediment retention pond (Moores & Pattinson, 2008). A field programme comprising hydrological monitoring and the collection of water samples was implemented at the ALPURT B2 motorway construction site near Orewa, north of Auckland.

A rainfall gauge, weirs, water level recorders and automatic water samplers were installed at a pair of ponds that each received approximately half of the run-off from an earthworks area of 4.4 hectares in the Nukumea Stream catchment, approximately 4km south of the southern boundary of the Puhoi River catchment. The inflow to one pond was treated with PAC by a rainfall activated dosing system whilst the inflow to the other pond was not treated.

Water samples were obtained from seven storm events over the period March to December 2007. Samples collected at the shared pond inlet and at the outlet of each of the two ponds were analysed for their concentrations of total suspended solids (TSS) and particle size distribution (PSD). Given the proximity of the ALPURT study site to the P-WK project, the results of those analyses have been considered as part of the assessment of representative PSDs for the treated and untreated sediment loads modelled in the present study (see Section 2.4.2).

2.4 Application in this Assessment

2.4.1 Catchment Background Loads

Runoff and sediment load estimates in the BNZ modelling study of the Mahurangi Harbour catchment were determined for each of the numbered sub-catchments shown in Figure 2-1. The Puhoi River and Te Muri Beach catchments are also shown in this figure to indicate the extent of the P-WK project area for which previous load estimates are unavailable.

The output from the BNZ model includes a 20 year time-series of daily runoff and sediment load estimates for each of the sub-catchments as shown. The loads are estimated at the sub-catchment outlets, and include losses due to hill-slope delivery and stream channel deposition (see Section 2.2). For each sub-catchment, the daily sediment loads were analysed to determine mean annual loads as well as event-based loads delivered to the harbour. The methodology used in analysing these loads is discussed in Chapter 3, along with the methodology for estimating the corresponding loads for the Puhoi River and Te Muri Beach catchments, for which the same level of information is unavailable.

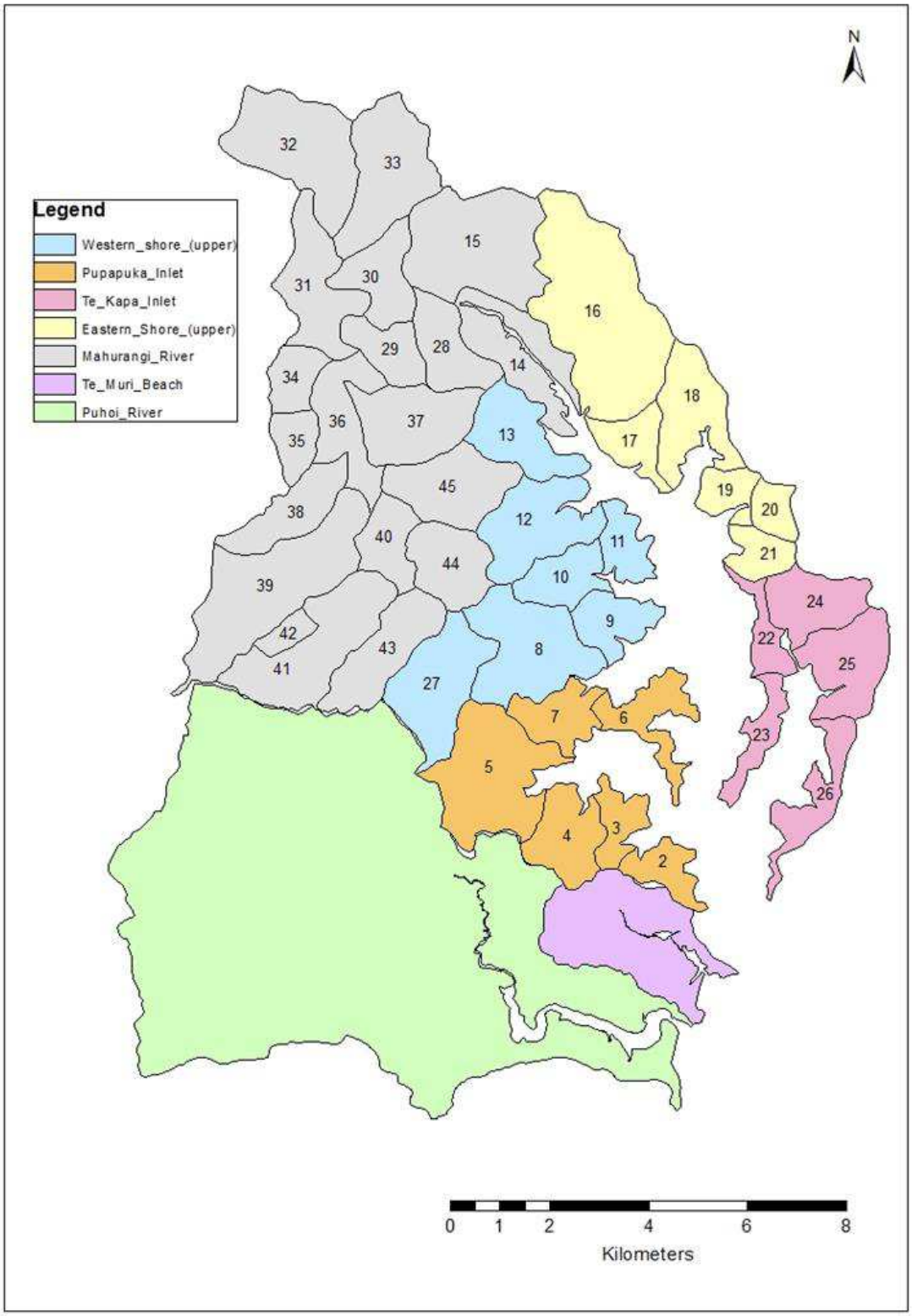


Figure 2-1: Sub-catchments of the Mahurangi Harbour (as defined in the BNZ study) and the catchments of Puhoi Estuary and Te Muri Beach.

2.4.2 Particle Size Distributions

Data Sources

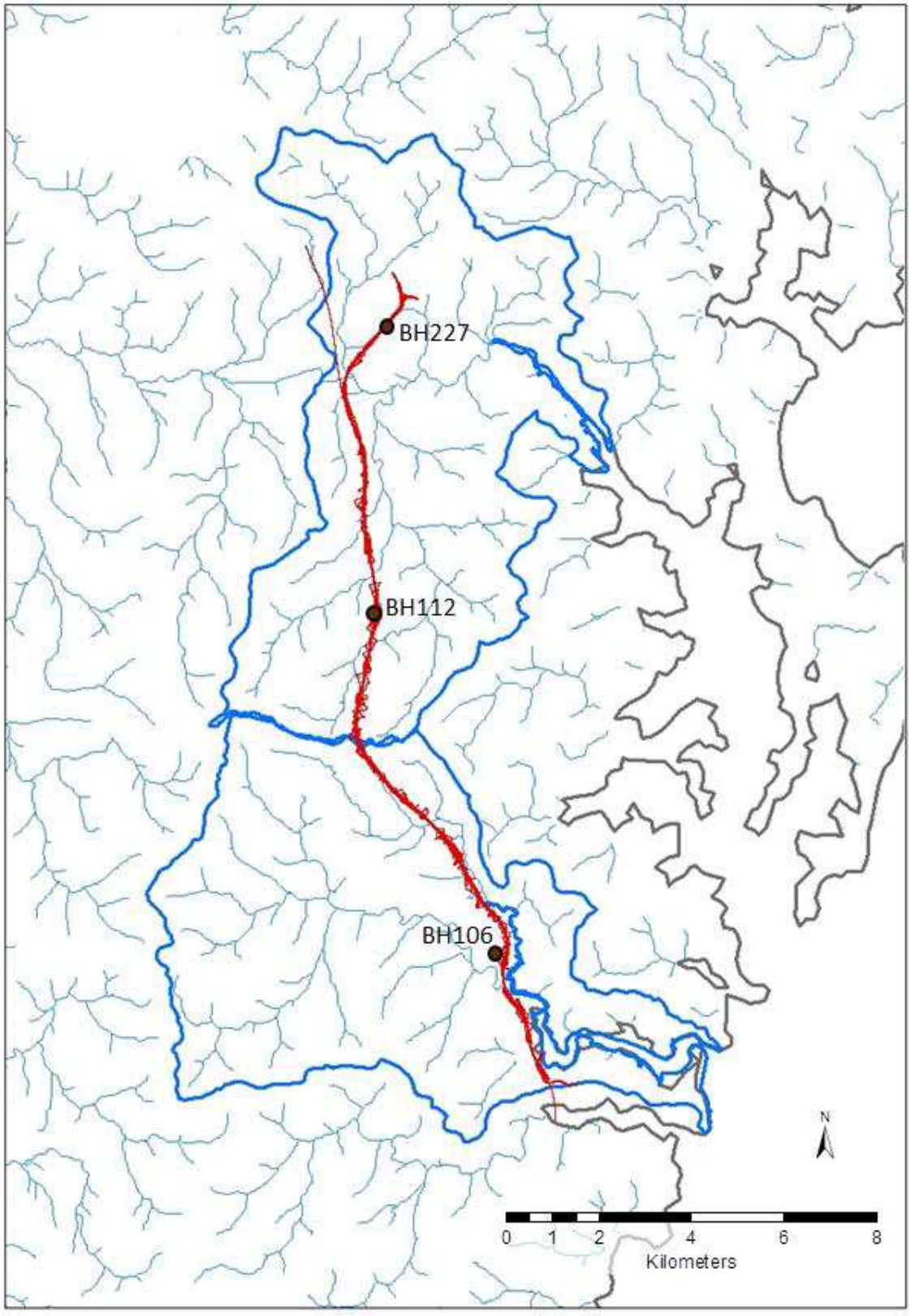
The following data were considered as part of the assessment of representative PSDs for the background and construction sediment loads:

- Results provided by the Alliance from particle size analysis of samples from three boreholes in the vicinity of the alignment (BH106, BH112 and BH 227; see Figure 2-2 for a map of borehole locations). The PSD of these samples was determined by wet sieving and hydrometer analysis for particle sizes < 63µm (NZS 4402:1986 Test 2.8.4, Opus International Consultants). The results for the upper most sample analysed in each of three boreholes was considered as part of the assessment described here.
- Data on the PSD of sediments in influent and effluent water samples collected as part of the ALPURT sediment pond study described in Section 2.3. These samples were collected by automatic water samplers and PSDs were determined by laser diffraction (Galai WCIS-100, NIWA Hamilton), without the addition of a dispersant. The results of samples collected during a 2-year ARI storm event as well as the mean PSD from all events sampled were considered as part of the assessment described here.
- Results provided by Auckland Council from the analysis of one to two samples collected from four rivers in the northern part of the Auckland region during flood conditions. Samples were collected using a D48 depth-integrated sampler and PSDs were determined by laser diffraction (Malvern Mastersizer 2000, University of Waikato) without the addition of a dispersant other than water.

The PSDs from these three data sources vary widely (see Figure 2-3). Reasons for this variation may include:

- Differences in sampling conditions. For instance, Auckland Council recommended caution in the use of results from the river water sample analyses for deriving representative PSDs because of the limited number of samples and the observation that flood size and the timing of sample collection relative to flood peak had a marked influence on PSD[2].
- Differences in sampling methods. Particles greater than 250 µm can be under-represented in water samples collected by automatic samplers (Clark et al., 2009). In contrast, the depth-integrated method used to collect the river water samples can include collection of coarse bed sediments that have been reworked. As noted above the river water samples were collected during flood conditions.
- Differences in analytical methods. Different methods can measure the PSD of either the primary (aggregated) or disaggregated particles. While dispersants were not recorded as being used in the ALPURT or Auckland Council samples, it is not known whether they were used in the hydrometer testing of the finer sediment fractions of the Alliance borehole samples.

[2] *pers. comm.*, N. Holwerda, 2013.


BH227
BH112
BH106
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0 1 2 4 6 8
Kilometers

Figure 2-2: Approximate location of FNA borehole sites. The red line shows the approximate alignment (as of April 2013) of the proposed Puhoi to Warkworth RNS. The catchment boundaries of the Mahurangi (to the north of the figure) and Puhoi (to the south of the figure) Rivers are shown in blue.

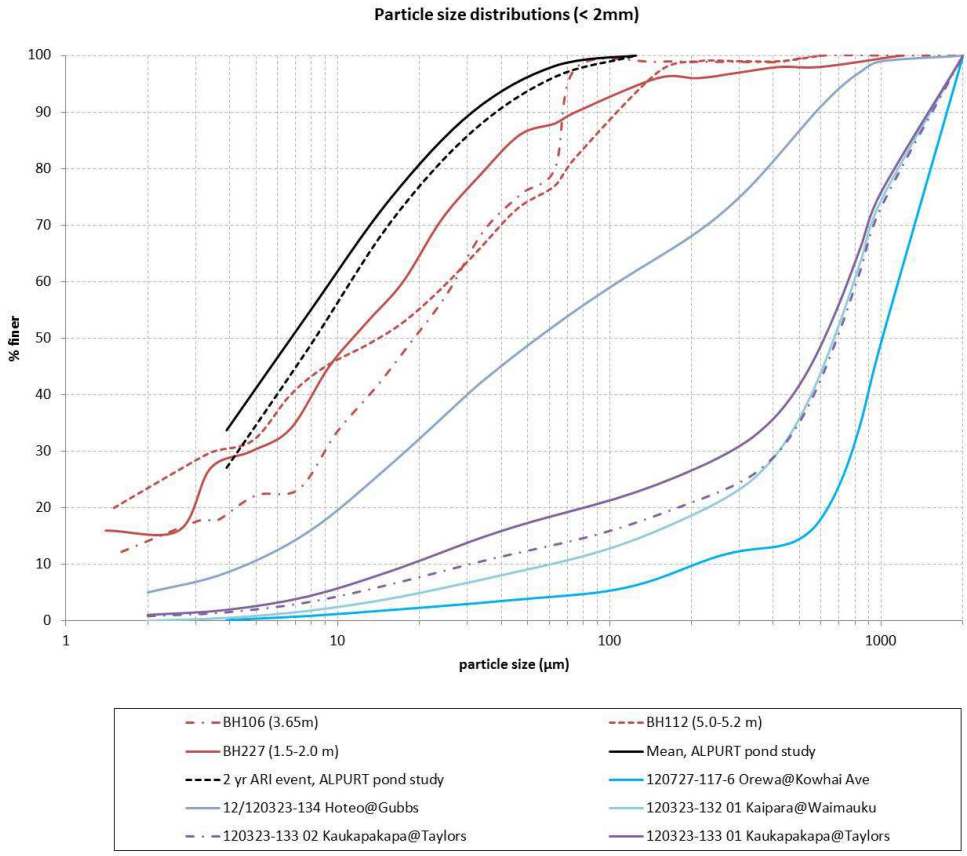


Figure 2-3: Particle size distributions of Alliance borehole soil samples, ALPURT pond study untreated influent runoff samples and Auckland Council river water samples.

The wide variation in the PSDs of the various samples creates a high level of uncertainty in arriving at a representative PSD. In view of that, this assessment assumed that adopting a relatively fine PSD would represent a conservative approach for the assessments of effects on harbour and stream ecology. On that basis, representative PSDs were largely derived from the FNA borehole sample data and informed by the ALPURT pond study results. The results of the Auckland Council river water sampling were excluded from the assessment of a representative PSD.

Representative PSDs

Table 2-1 gives the recommended representative PSDs of sediments in untreated runoff from the catchment, and construction site and in construction runoff, following treatment by chemical and non-chemical erosion and sediment control practices. PSDs are specified as the proportion of the sediment load in the Wentworth clay, silt and sand size ranges.

Table 2-1: Recommended representative particle size distributions (proportion of total sediment load in each size class).

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

The rationale recommending these PSDs is as follows:

1. Catchment background and untreated construction runoff
    - This is the mean PSD of the upper-most soil samples taken from the three boreholes in the FNA study area for which detailed PSD data is available (see Figure 2-4).
    - The proportion of clay-sized particles in this PSD is also similar to that measured in influent runoff to the ALPURT sediment pond during a 2 year ARI rainfall event. There was, however, a smaller proportion of sand in that ALPURT sample (and a larger proportion of silt) than in the FNA borehole data. This may reflect the under-representation of particles >250 µm in the ALPURT influent runoff sample, which was collected by auto-sampler.
2. Treated construction runoff
    - These fractions were derived from the mean PSDs of samples of influent, non-chemically treated effluent and chemically-treated effluent collected as part of the ALPURT pond study.
    - In those mean PSDs, there was 29% and 34% more clay in non-chemically treated effluent and chemically-treated effluent, respectively, than in influent (see Figure 2-5). These same increases in the proportion of clay-sized particles were applied here to the untreated construction runoff PSD.
    - There were no sand-sized particles in the effluent samples from the ALPURT study. While this could again reflect the sampling method, it is considered reasonable that sand-sized particles would be largely removed by the erosion and sediment control measures. It is also considered a conservative approach to assume that all sediment discharged from the construction areas are clay and silt sized particles.

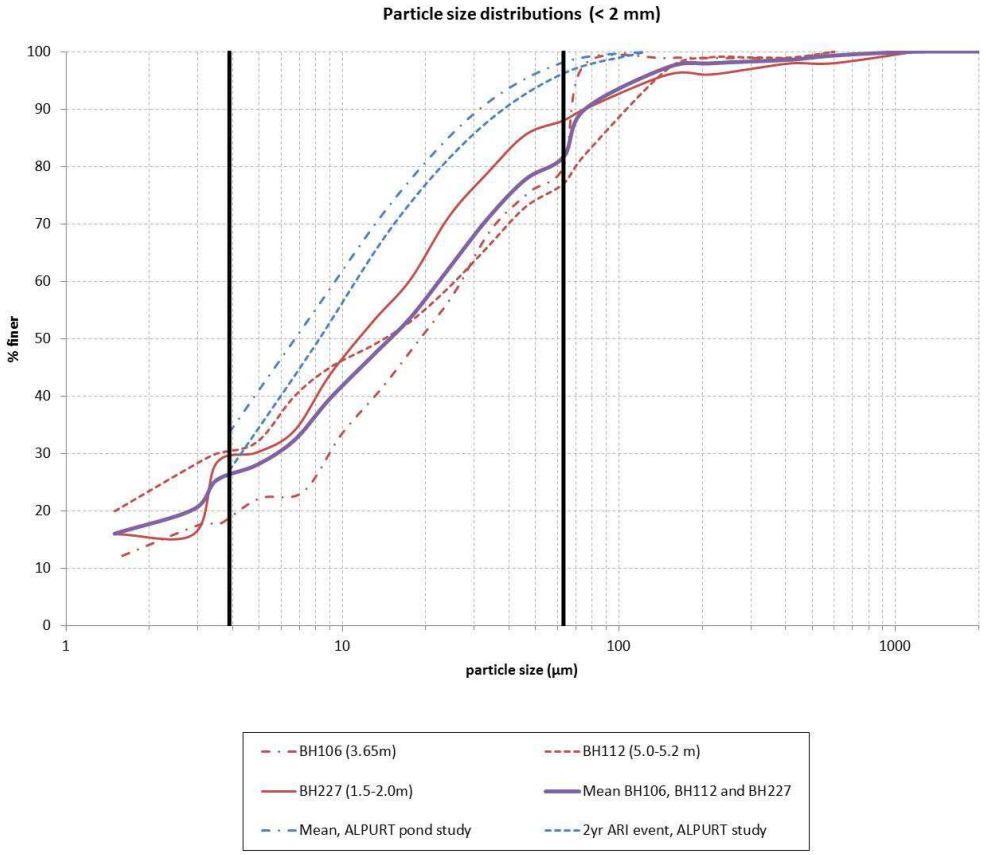


Figure 2-4: Particle size distributions of FNA borehole soil samples and ALPURT pond study untreated influent runoff samples.

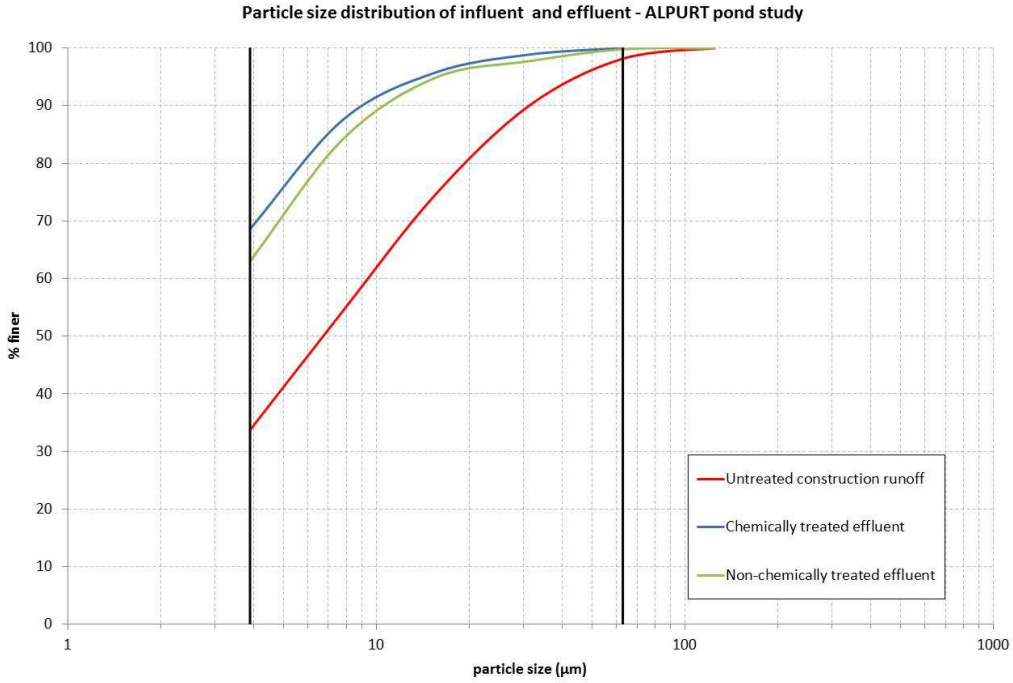


Figure 2-5: Mean particle size distributions of ALPURT pond study untreated influent, non-chemically treated effluent and chemically-treated effluent samples.

2.4.3 Fraction of Sediment Delivered to the Coast

The Fraction of Sediment Delivered to the Coast (FSDC) is defined as the proportion of sediment that enters a freshwater environment that is delivered to the coastal environment[3].

Table 2-2 gives the FSDC for each sub-catchment of the Mahurangi Harbour (as mapped in Figure 2-1); modelled by the routing of sediment loads in the BNZ study which includes stream channel deposition, as described in Section 2.3.

Table 2-2: Fraction of Sediment Deliver to the Coast (FSDC); the estimated proportion of sediment entering streams in each sub-catchment which is delivered to the Mahurangi Harbour (as estimated in the 1997 BNZ modelling study).

Outlet	Sub-catchment	Area (ha)	FSDC (-)
Mahurangi River	-	5825	0.48
Pukapuka Inlet	2	125	0.74
	3	125	0.74
	4	225	0.71
	5	525	0.75
	6	200	0.75
	7	200	0.66
Western shore (upper)	8	800	0.65
	9	200	0.77
	10	175	0.77
	11	125	0.75
	12	350	0.80
	13	275	0.75
Eastern shore (upper)	16	825	0.70
	17	175	0.66
	18	200	0.66
	19	100	0.75
	20	100	0.74
	21	125	0.71
Te Kapa Inlet	22	125	0.68
	23	125	0.68
	24	250	0.65
	25	275	0.77
	26	225	0.76

The estimates of FSDC given in Table 2-2 have not been validated by a programme of sampling or field measurement. As a consequence, they remain uncertain and it is not possible to quantify the level of that uncertainty. While recognising this limitation, the relativity between FSDC values in different parts of the catchment appears sensible: FSDCs are

[3] The FSDC is more commonly referred to as the Sediment Deliver Ratio (SDR), as was the case in the previous studies of the Mahurangi River catchment. However, the term FSDC is used here to avoid confusion with an alternative use of the term SDR in the P-WK project. In this project, SDR is defined as "the proportion of the soil eroded from within a catchment area that reaches sediment treatment controls" (*pers. comm.*, G. Ridley, 2013).

lowest from the Mahurangi River catchment within which the distance over which sediment transport occurs is greatest.

In the absence of any measurements to validate these FSDCs, an alternative approach is to assume that all sediment is delivered to the receiving environment (i.e. an FSDC of 1). This is consistent with a 'steady state' conceptual model of these catchments in which the rivers and streams are not aggrading over the long term (upstream of tidal reaches). In reality, deposition and sediment delivery are likely to vary with storm event size and cycles of bank accretion and erosion, with a long-term balance. Note that, again however, there have been no formal studies to investigate these processes in these catchments.

After treatment, sediment derived from earthworks will have a fine particle size distribution, and this has been observed in effluent from sediment retention ponds monitored as part of the ALPURT project (see above). Most of the readily-settleable material will be removed by the earthworks controls, so that the discharge will contain finer fractions (fine silts and clays) which are less likely to be deposited in the stream network. The FSDC of these fractions is likely to be large, approaching 1.

More complex models of sediment delivery could be applied to the catchment, but these are likely to have large uncertainties due to the range of complex and poorly-characterised processes involved in the transport of sediment with a range of particle sizes in small heterogeneous streams under flood conditions. Such modelling would not be practicable within the timeframe of this project, nor do we consider that it would be cost-effective.

It is also difficult to measure FSDCs directly. Usually, FSDC from stream systems is inferred from sediment budgets covering long timescales (for example, observation of long-term changes in storages or sediment load at different points in a large river system). Coarse empirical relationships are available for determining FSDCs but these were derived from large river systems, and are not directly applicable to small steep systems such as the Mahurangi or Puhoi.

Given the difficulties associated with attempting to further quantify FSDCs in these catchments, a reasonable approach is to adopt the modelled FSDCs and the assumption of a steady state catchment as the two extremes of the likely range for the FSDC for these catchments. The FSCDs that apply to each part of the assessment are then:

In relation to catchment background loads:

- For the harbour modelling, the FSDCs as modelled in the BNZ study apply, because these fractions are implicit in the modelled loads entering the Mahurangi Harbour which were calibrated against measurements.
- For the stream assessment, the sediment load remaining in the stream is the background load discharged to the harbour multiplied by (1-FSDC)/FSDC. For the catchments outside of the previous Mahurangi Harbour study area the following FSDCs apply, based on the similarity of catchment characteristics with those for which FSDCs have been previously modelled:
  - Puhoi River; 0.5 (based on Mahurangi River catchment)
  - Te Muri Beach; 0.75 (based on similar-sized Pukapuka Inlet catchments)

In relation to the construction earthworks loads:

- For the harbour modelling, it is reasonable to adopt a conservative assumption consistent with a steady-state conceptual model of these catchments (and the finer PSD of earthworks generated sediments), i.e. all sediment is delivered to the harbour (FSDC of 1); and
- For the stream assessments, adopting the same FSDC as suggested for the harbour modelling implies no deposition of earthworks generated sediment in the stream. Alternatively, a more conservative approach could be adopted for the stream assessment by using the FSDCs that apply to the background sediment loads[4].

[4] However, note that if this approach was adopted the sum of the sediment loads used for the harbour modelling and estimated to be deposited in the streams would exceed the modelled loads discharged from the construction site.

3 Sediment Loads

3.1 Introduction

This chapter provides estimates of catchment background and project sediment loads. Section 3.2 describes the methods employed in the analysis of the results of the previous BNZ modelling study to estimate catchment background loads, including for the Puhoi River and Te Muri Beach catchments which were not modelled in the BNZ study. Section 3.3 describes the use of the GLEAMS hill-slope processes model to estimate sediment loads associated with the project. Results are summarised for the two specified focus areas ('Hills' and 'Flats') of the road alignment under both the 5- and 10-year construction scenarios.

3.2 Catchment Background Loads

3.2.1 Methods

Background sediment loads delivered to the Mahurangi and Puhoi harbours under the current land-use were drawn from previous NIWA studies of the Mahurangi Harbour catchment using the Basin New Zealand (BNZ) model (see Section 2.2). The output from the BNZ model is a 20-year time-series (1976 – 1995) of daily sediment loads and associated runoff from the numbered sub-catchments as shown in Figure 2-1, assuming no change in land cover over this period[5]. The sediment loads are estimated at the sub-catchment outlets and include losses due to hill-slope delivery and stream channel deposition.

The background sediment loads reported for each sub-catchment outlet include mean annual loads as well as event-based loads associated with selected average return intervals (ARIs). Mean annual loads for sub-catchments discharging to the Mahurangi Harbour were calculated by aggregating the daily loads from the BNZ time-series and averaging over the 20-year period. For the Puhoi River and Te Muri Beach catchments, where previous load estimates were unavailable, we used the Catchment Landuse for Environmental Sustainability model (CLUES; Semadeni-Davies et al., 2011, 2012) to generate the mean annual load ratio against the Mahurangi River. CLUES is a GIS-based framework which integrates a suite of related models to estimate mean annual sediment load, amongst other contaminants. The procedure by which mean annual loads are calculated may be found in Elliott et al. (2008).

The event-based loads represent daily sediment loads discharged from each sub-catchment outlet with ARIs of 2, 10 and 50 years. These were calculated by performing a frequency analysis on the annual maximum series for the whole Mahurangi Harbour, formed by selecting the highest daily load from the BNZ time-series each year. The return period of each value in the annual maximum series is given by $T = 1/p$, where p is the exceedance probability according to the Gringorten plotting position formula (Chow et al., 1988). The best fit was obtained from a Generalized Extreme Value (GEV) distribution (Figure 3-1) with

[5] The BNZ model study did not attempt to distinguish between different phases of forestry operations. Water sampling downstream of Redwoods Forest (used in the validation of the model) indicated no significant difference between the sediment yield of the pre-harvesting and forest harvesting phases (Hicks and McKerchar, 2000). However, it is important to note that this finding contrasts with those reported elsewhere. For example, a study in Northland's Glenbervie Forest found marked increases in sediment yields, mainly during the phase of preparatory earthworks preceding harvesting operations (Hicks and Harmsworth, 1989). In general, the extent of any increase in sediment yield during the preparatory and harvesting phases is likely to be influenced by the weather (i.e. whether or not large storms occur over the vulnerable period), the proportion of the catchment harvested, and how well erosion and sediment control measures are managed during the operations.

location, scale and shape parameters $\mu = 7724.9$, $\sigma = 4169.2$ and $k = 0.58$, respectively. The distribution was fitted using the *gevfit* function in MATLAB™, and the 95 % confidence intervals were estimated using a likelihood-based method (The MathWorks, Inc., n.d.). To generate the 2, 10 and 50 year ARI loads for each sub-catchment, the 2, 10 and 50 year ARI loads estimated from the quantiles of the distribution were scaled by the ratio of the mean annual load for each sub-catchment to that of the whole Mahurangi Harbour. For the Puhoi River and Te Muri Beach sub-catchments, the Mahurangi River estimates was scaled by the CLUES mean annual load ratio described above.

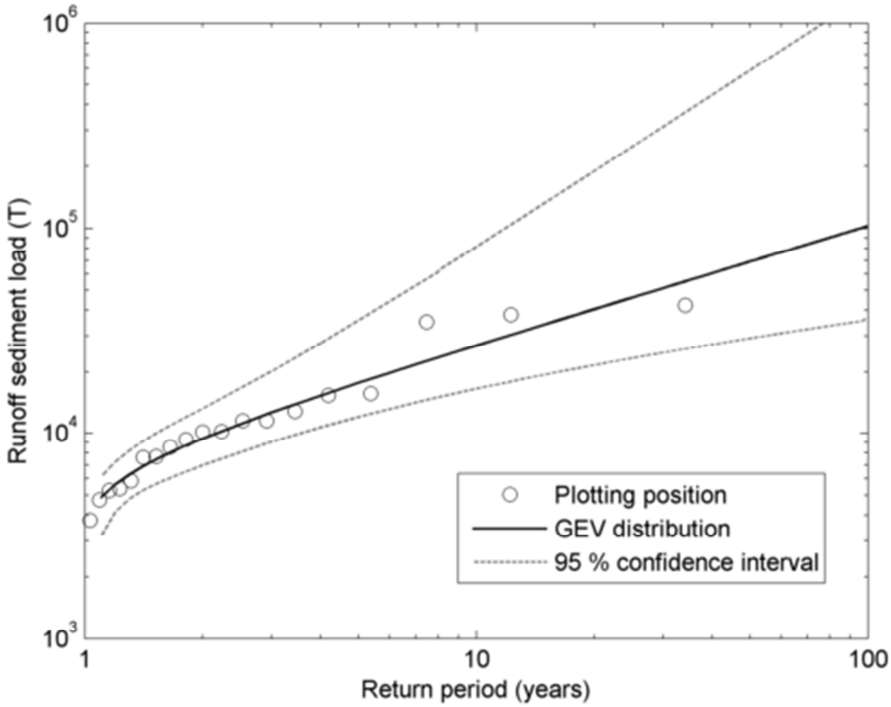


Figure 3-1: Generalized Extreme Value (GEV) distribution fitted to the annual maximum series of daily sediment loads delivered to the Mahurangi Harbour.

3.2.2 Load Estimates

The tables below summarize:

- Mean annual sediment loads and associated runoff volume for each sub-catchment as well as the Puhoi and Te Muri Beach catchments; Table 3-1.
- Mean annual sediment load and associated runoff volume at selected stream assessment sites in the Mahurangi and Puhoi Rivers (see Figure 3-2 for locations); Table 3-2.
- Event-based daily sediment loads for each sub-catchment as well as the Puhoi and Te Muri Beach catchments with ARIs of 2, 10 and 50 years; Table 3-3.
- Event-based daily sediment loads at selected stream assessment sites in the Mahurangi and Puhoi Rivers; Table 3-4.

The runoff volumes are used to provide estimates of suspended solid (SS) concentrations at each sub-catchment outlet over a 24-hour period (Chapter 4). The runoff volumes

associated with the 2, 10 and 50 year events for each sub-catchment as well as the stream assessment sites are included in Appendix A.

Table 3-1: Estimated mean annual sediment load and runoff delivered to the Mahurangi Harbour and Puhoi River Estuary by sub-catchment.

Outlet	Sub-catchment	Area (ha)	Load (T)	Runoff (10^3 m^3)
Te Muri Beach	-	501	958	1795
Puhoi River	-	5252	18311	18868
Mahurangi River	-	5825	12193	24459
Pukapuka Inlet	2	125	698	475
	3	125	1079	671
	4	225	2009	1153
	5	525	2895	2893
	6	200	982	1013
	7	200	1023	1111
Western shore (upper)	8	800	2916	3534
	9	200	1298	964
	10	175	1318	973
	11	125	1042	699
	12	350	2658	1798
	13	275	1590	1535
Eastern shore (upper)	16	825	3167	4277
	17	175	645	786
	18	200	535	867
	19	100	374	635
	20	100	363	625
	21	125	456	659
Te Kapa Inlet	22	125	424	503
	23	125	545	471
	24	250	2147	1397
	25	275	3773	1595
	26	225	1801	898
Puhoi River Estuary		5252	18311	18868
Mahurangi Harbour		11675	45931	53988

Table 3-2: Estimated mean annual sediment load and runoff at selected stream assessment sites in the Mahurangi and Puhoi rivers.

Location	Site ID	Load (T)	Runoff (10^3 m^3)
Mahurangi River	AC-FHQ	1101	1258
	MW	6316	11647
Puhoi River	P10	1923	2736

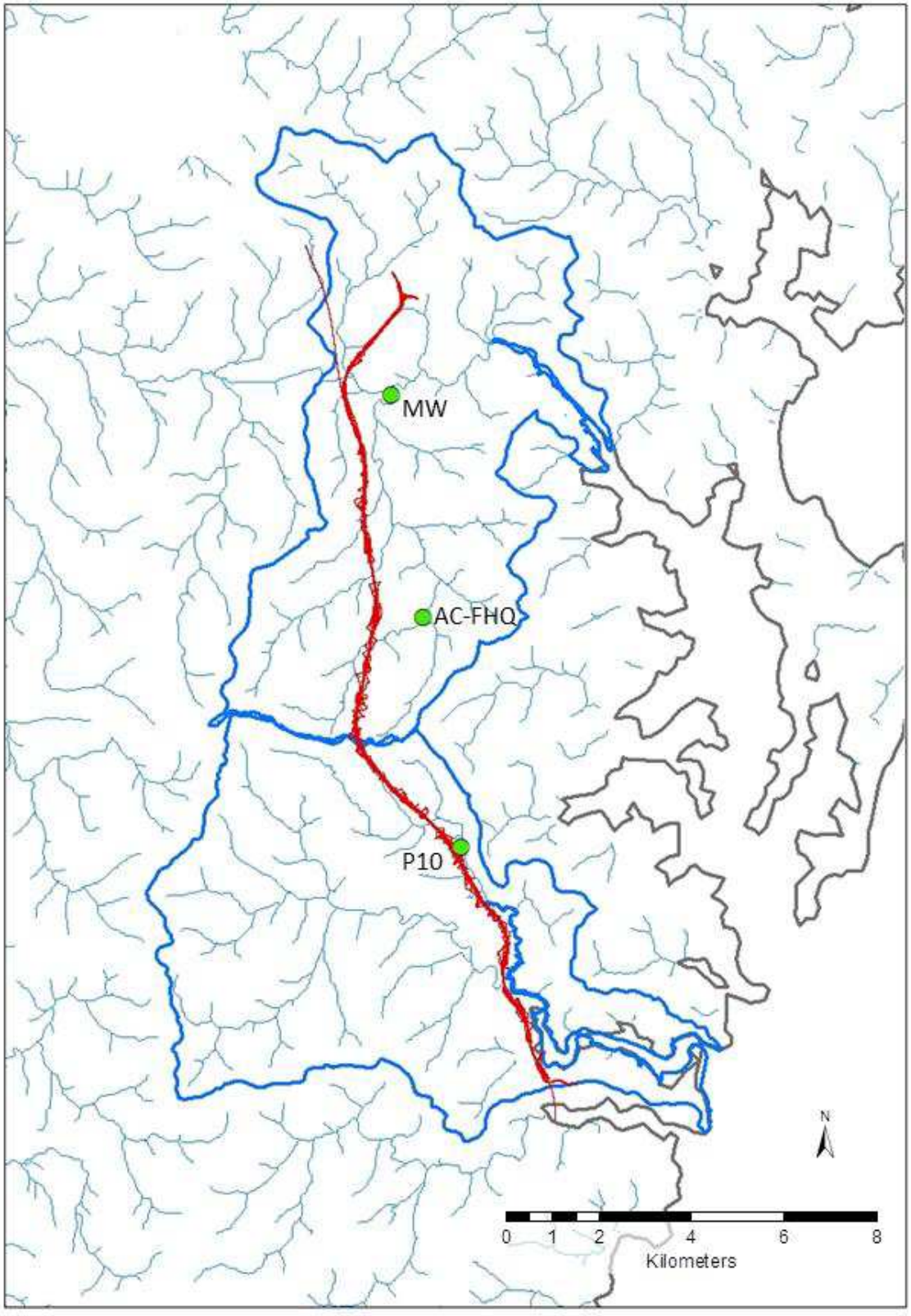


Figure 3-2: Location of stream assessment sites. The red line shows the approximate alignment (as of April 2013) of the proposed Puhoi to Warkworth RNS. The catchment boundaries of the Mahurangi (to the north of the figure) and Puhoi (to the south of the figure) Rivers are shown in blue.

Table 3-3: Estimated daily sediment loads (with associated 95 % lower and upper confidence intervals) delivered to the Mahurangi Harbour and Puhoi River Estuary by sub-catchment, for ARIs of 2, 10 and 50 years.

Outlet	Sub-catchment	2-year ARI (T)			10-year ARI (T)			50-year ARI (T)		
		Load	Lower	Upper	Load	Lower	Upper	Load	Lower	Upper
Te Muri Beach	-	197	146	276	562	344	1704	1439	611	12250
Puhoi River	-	3758	2783	5274	10740	6582	32556	27489	11668	234062
Mahurangi River	-	2502	1853	3512	7152	4383	21678	18304	7769	155855
Pukapuka Inlet	2	143	106	201	409	251	1241	1048	445	8920
	3	221	164	311	633	388	1918	1619	687	13788
	4	412	305	579	1178	722	3572	3016	1280	25679
	5	594	440	834	1698	1040	5146	4345	1844	36999
	6	202	149	283	576	353	1746	1474	626	12553
	7	210	155	295	600	368	1818	1535	652	13073
Western shore (upper)	8	598	443	840	1710	1048	5185	4378	1858	37275
	9	266	197	374	761	467	2308	1949	827	16592
	10	270	200	380	773	474	2343	1978	840	16845
	11	214	158	300	611	375	1853	1564	664	13320
	12	546	404	766	1559	955	4726	3990	1694	33975
	13	326	242	458	932	571	2826	2387	1013	20321
Eastern shore (upper)	16	650	481	912	1858	1138	5631	4754	2018	40482
	17	132	98	186	378	232	1147	968	411	8245
	18	110	81	154	314	192	951	803	341	6838
	19	77	57	108	219	134	664	561	238	4777
	20	74	55	104	213	130	645	544	231	4635
	21	94	69	131	267	164	811	685	291	5829

Table 3-3 cont.: Estimated daily sediment loads (with associated 95 % lower and upper confidence intervals) delivered to the Mahurangi Harbour and Puhoi River Estuary by sub-catchment, for ARIs of 2, 10 and 50 years.

Outlet	Sub-catchment	2-year ARI (T)			10-year ARI (T)			50-year ARI (T)		
		Load	Lower	Upper	Load	Lower	Upper	Load	Lower	Upper
Te Kapa Inlet	22	87	64	122	249	152	754	636	270	5419
	23	112	83	157	320	196	969	818	347	6968
	24	441	326	618	1259	772	3816	3222	1368	27438
	25	774	573	1087	2213	1356	6708	5664	2404	48225
	26	370	274	519	1056	647	3202	2703	1147	23018
Puhoi River Estuary		3758	2783	5274	10740	6582	32556	27489	11668	234062
Mahurangi Harbour		9425	6977	13231	26938	16508	81658	68945	29265	587069

Table 3-4: Estimated daily sediment loads (with associated 95 % lower and upper confidence intervals) at selected stream assessment sites in the Mahurangi and Puhoi Rivers for ARIs of 2, 10 and 50 years.

Location	Site ID	2-year ARI (T)			10-year ARI (T)			50-year ARI (T)		
		Load	Lower	Upper	Load	Lower	Upper	Load	Lower	Upper
Mahurangi River	AC-FHQ	226	167	317	646	396	1957	1652	701	14069
	MW	1296	960	1819	3704	2270	11229	9481	4024	80732
Puhoi River	P10	395	292	554	1128	691	3418	2886	1225	24577

3.3 Construction Loads

3.3.1 Model Description

The construction-phase sediment loads were estimated using the Groundwater Loading Effects of Agricultural Management Systems model (GLEAMS; Knisel, 1993), which is a physically-based model developed for continuous simulation of surface runoff and sediment losses on a field-scale. GLEAMS works by applying a long-term climate record (rainfall, temperature, wind run and solar radiation) to individual cells which represent unique combinations of land-cover, soil type and slope. For each cell, the climate, land-cover, soil type and slope information is combined with a set of hydrological parameters which describe an arbitrary hill-slope (e.g. slope length, surface roughness), in order to continuously simulate surface runoff and sediment generation. The output from GLEAMS is a long-term series of daily sediment loads per unit area of each cell type (i.e. daily sediment yields). Sediment loads for an entire catchment can then be estimated by aggregating the GLEAMS yields according to the area in each cell type.

3.3.2 Inputs and Assumptions

The construction phase sediment loads were estimated for two different focus areas, 'Hills' (Zone 7B; 57.6 ha) and 'Flats' (Zone 9; 34.6 ha), under two different scenarios, representing 5 and 10 year construction periods as specified by the Alliance. As a first step, the different land-covers, soil types and slopes occurring in each focus area had to be identified in order to define the number and type of cells involved. Details of this process are as follows:

- **Land-cover**
  Existing land-cover was taken from the LCDB3 shapefile and included farmland, forestry and native forest, whilst construction land-cover could be either exposed soil, exposed rock, mulched or stabilized. Yields for the mulched and stabilized land-covers were modelled by applying reduction factors of 85 % and 93 % to the yields for exposed soil, respectively, as directed by the Alliance.

- **Soil type**
  Soil types within GLEAMS are described by a number of parameters including particle size distribution, saturated conductivity and soil erodibility. We used existing GLEAMS soil types that most closely matched the particle size distributions for soil and rock from borehole logs provided by the Alliance. The borehole logs indicate a relatively high silt content throughout the project area, and a higher sand content in rock than in soil.

- **Slope**
  A breakdown of the existing topography of each focus area into 3° slope classes (ranging from 0° – 3° up to 30°+) was provided by the Alliance from LIDAR data. The topography was assumed to remain unchanged during and following the construction period, as specified by the Alliance.

The breakdown of both focus areas resulted in 55 different cell types representing the unique combinations of existing and exposed land-cover, soil type and slope. The GLEAMS model was then applied to each cell using a 50-year climate record (1963 – 2012) consisting of daily rainfall, as well as monthly temperature, wind run and solar radiation data drawn from

stations in the Mahurangi Harbour catchment. Where no stations were available, data from the nearby Leigh climate station was used which has a long and near-uninterrupted record. All other hydrological parameters within GLEAMS were held at previous values used in modelling sediment loads discharged to the Central Waitemata Harbour (Parshotam & Wadhwa, 2007), and can be supplied upon request.

Erosion and sediment control options proposed for the construction period were provided by the Alliance along with anticipated load reduction factors. These options included super-silt fences and chemically-treated sediment retention ponds and decanting earth bunds. The load reduction factors corresponding to different event sizes for each option are summarized below in Table 3-5.

Table 3-5: Load reduction factors for erosion and sediment control options for different ARI events.

Option	Load 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

The ultimate result from running GLEAMS is a 50-year time-series of daily sediment loads per unit area of each cell type. A further 22 cell types were identified from the unique combinations of mulched and stabilized land-covers, however the yields for these cell types were estimated directly from those for exposed soil using the reduction factors previously stated. The final step in estimating the construction-phase sediment loads for each focus area involves aggregating the GLEAMS daily yields according to the area in each cell type, which is specified by the land-cover breakdown in the construction staging. Note that in the absence of more detailed spatial information, the area in each land-cover is assumed to be distributed evenly across all slope classes.

3.3.3 Methods

For each focus area and each construction scenario we have estimated mean annual sediment loads, as well as ARI daily loads both with and without treatment by erosion and sediment control measures based on:

1. Changing land-cover reflecting the proposed staging of earthworks over the 5 and 10 year construction periods, and
2. Fixed land-cover reflecting the maximum area of open earthworks in any one month over the 5 and 10 year construction periods.

Calculation of these loads involved aggregating the GLEAMS daily yield series according to the area in each cell type specified by:

a. The existing land-cover;

b. The land-cover as planned for each month based on the staging sequences provided for the 5 and 10 year construction periods, and

c. The land-cover as planned for January 2019 for the 5 year construction period and March 2020 for the 10 year construction period, representing the maximum area of exposed earthworks in any one month.

The result is a 50-year time-series of daily sediment loads for the existing land-cover, for each year of the proposed 5 and 10 year construction periods, and for the maximum area of exposed earthworks in any one month. The daily loads estimated for each year of both construction periods reflect not only the amount of area exposed, but also the size of rainfall events which may be expected to occur during the months when the slopes are open (generally the summer months). In contrast, the daily loads estimated for the maximum area of exposed earthworks reflect a worst-case scenario by assuming those slopes remain open during all months of the year. As a result, the exposed slopes are subject to higher rainfall events which are generally expected to occur during the winter months.

In each case, mean annual sediment loads were calculated by aggregating the daily loads and averaging over the 50-year period. The 2, 10 and 50 year ARI daily sediment loads were calculated following the same methodology as for the background loads, by:

- Extracting the maximum daily load from each of the 50 years to form an annual maximum series, then
- Fitting a Generalized Extreme Value (GEV) distribution to the annual maximum series and using the quantiles of the distribution to estimate the 2, 10 and 50 year loads.

To calculate the mean annual and ARI daily sediment loads after treatment by erosion and sediment control measures, the 50-year time-series of daily loads for each month of the fixed and changing land-cover sequences were reduced by the appropriate load reduction factors from Table 3-5, for the months when erosion and sediment control measures are in place. Months when treatment measures are in place, and the type of treatment applied, is specified in the construction staging sequences. The cut off points for the selection of which of the LRFs given in Table 3-5 apply were assumed to be the 6 and 30 year ARI daily loads, respectively.

3.3.4 Load Estimates

The tables below summarize the mean annual and ARI daily sediment loads both with and without treatment by erosion and sediment control measures. The results are presented for each focus area as well as the wider Mahurangi River[6] catchment as follows:

1. Mean annual sediment loads reflecting the changing land-cover during each year of the 5 and 10 year construction periods; Tables 3-6 – 3-11.
2. ARI daily sediment loads reflecting the changing land-cover during each year of the 5 and 10 year construction periods; Tables 3-12 – 3-15.
3. ARI daily sediment loads for the fixed land-cover corresponding to the maximum area of exposed earthworks in the 5 and 10 year construction periods; Tables 3-16 – 3-21.

[6] Excluding additional loads from construction outside of the two focus areas, if any. The scope of this study was explicitly limited to loads generated in these focus areas.

For each focus area, the additional loads represent the difference between the existing load and the construction loads. For the Mahurangi River catchment, the construction loads represent the background load (from Section 3.2) plus the additional loads from the focus areas. Given the difficulty is estimating FSDC, it is assumed that the full construction load is delivered to the catchment outlet, which represents a conservative assumption as discussed in Section 2.4.3.

In addition to the catchment loads, we have estimated the ARI daily sediment loads at selected stream assessment sites in the Mahurangi River for the fixed land-cover, corresponding to the maximum area of exposed earthworks in the 5 and 10 year construction periods. The construction loads for these sites (Tables 3-22 – 3-23) represent the background loads (from Section 3.2) plus the additional loads from the extent of each focus area upstream.

To aid interpretation of the estimates presented here, we note that:

- Variations in additional loads between years reflect difference in the extent of construction activities (e.g. the largest areas of exposed earth occur in 2019 in the 5-year construction scenario and in 2020 in the 10-year construction scenario); and
- The total load in the 10-year scenario is greater than the total load in the year 5-year scenario because these estimates take account of the sediment load generated from all land covers over the 10-year period, not just from areas of bare earth.

Finally, we have also provided an indication of the increased likelihood of the pre-construction 2, 10 and 50 year ARI daily sediment loads occurring under the fixed land-cover (reflecting the maximum area of exposed earthworks in the 5 and 10 year construction periods) by calculating:

- The change in ARI for the 2, 10 and 50 year background loads under the construction land-cover; and
- The change in ARI for the 2, 10 and 50 year construction loads under the existing land-cover.

The results of this assessment, for the Mahurangi and Puhoi river catchments and the three stream assessment sites, may be found in Appendix B.

Table 3-6: Mean annual sediment load (T) for the 'Hills' focus area corresponding to changing land-cover during the 5 year construction period, both with and without treatment by erosion and sediment control measures.

Year	Existing	Untreated		Treated	
		Construction	Additional	Construction	Additional
2016	478	1066	588	563	85
2017	478	3101	2623	853	375
2018	478	6555	6077	1413	935
2019	478	8770	8292	1953	1475
2020	478	2594	2116	1598	1120
5 year total	2390	22086	19696	6380	3990
Mean annual	478	4417	3939	1276	798

Table 3-7: Mean annual sediment load (T) for the 'Flats' focus area corresponding to changing land-cover during the 5 year construction period, both with and without treatment by erosion and sediment control measures.

Year	Existing	Untreated		Treated	
		Construction	Additional	Construction	Additional
2016	435	833	398	472	37
2017	435	1659	1224	532	97
2018	435	1487	1052	533	98
2019	435	1650	1215	560	125
2020	435	483	48	483	48
5 year total	2175	6113	3937	2581	406
Mean annual	435	1223	787	516	81

Table 3-8: Mean annual sediment load (T) discharged from the Mahurangi River catchment outlet; corresponding to changing land-cover during the 5 year construction period, both with and without treatment by erosion and sediment control measures.

Year	Existing	Untreated		Treated	
		Construction	Increase	Construction	Increase
2016	12193	13179	8%	12315	1%
2017	12193	16040	32%	12666	4%
2018	12193	19322	58%	13226	8%
2019	12193	21700	78%	13793	13%
2020	12193	14357	18%	13361	10%
5 year total	60965	84598	39%	65361	7%
Mean annual	12193	16920	39%	13072	7%

Table 3-9: Mean annual sediment load (T) for the 'Hills' focus area corresponding to changing land-cover during the 10 year construction period, both pre- and post-treatment by erosion and sediment control measures.

Year	Existing	Untreated		Treated	
		Construction	Additional	Construction	Additional
2016	478	814	336	525	47
2017	478	1934	1456	642	164
2018	478	2087	1609	720	242
2019	478	2766	2288	773	295
2020	478	6256	5778	1320	842
2021	478	3524	3046	1329	851
2022	478	2486	2008	1384	906
2023	478	2335	1857	1412	934
2024	478	2289	1811	1570	1092
2025	478	2151	1673	1777	1299
10 year total	4780	26642	21862	11451	6671
Mean annual	478	2664	2186	1145	667

Table 3-10: Mean annual sediment load (T) for the 'Flats' focus area corresponding to changing land-cover during the 10 year construction period, both pre- and post-treatment by erosion and sediment control measures.

Year	Existing	Untreated		Treated	
		Construction	Additional	Construction	Additional
2016	435	647	212	442	7
2017	435	1172	737	431	-4
2018	435	1114	679	431	-4
2019	435	969	534	450	15
2020	435	1078	643	456	21
2021	435	1408	973	479	44
2022	435	1113	677	456	21
2023	435	483	48	483	48
2024	435	483	48	483	48
2025	435	483	48	483	48
10 year total	4350	8951	4601	4595	245
Mean annual	435	895	460	459	24

Table 3-11: Mean annual sediment load (T) discharged from the Mahurangi River catchment outlet; corresponding to changing land-cover during the 10 year construction period, both with and without treatment by erosion and sediment control measures.

Year	Existing	Untreated		Treated	
		Construction	Additional	Construction	Additional
2016	12193	12741	4%	12247	0%
2017	12193	14386	18%	12352	1%
2018	12193	14481	19%	12431	2%
2019	12193	15016	23%	12503	3%
2020	12193	18614	53%	13056	7%
2021	12193	16212	33%	13087	7%
2022	12193	14878	22%	13120	8%
2023	12193	14098	16%	13175	8%
2024	12193	14052	15%	13334	9%
2025	12193	13914	14%	13540	11%
10 year total	121930	148393	22%	128846	6%
Mean annual	12193	14839	22%	12885	6%

Table 3-12: Daily sediment loads (T) for the 'Hills' focus area corresponding to ARIs of 2, 10 and 50 years, reflecting the changing land-cover during the 5 year construction period both with and without treatment by erosion and sediment control measures.

Year	Untreated			Treated		
	2 year ARI	10 year ARI	50 year ARI	2 year ARI	10 year ARI	50 year ARI
2016	263	898	2461	152	421	980
2017	825	1948	3367	196	578	1473
2018	1389	2970	5158	284	900	1909
2019	1811	4294	8257	357	1157	3482
2020	528	1458	3385	299	697	1449

Table 3-13: Daily sediment loads (T) for the 'Flats' focus area corresponding to ARIs of 2, 10 and 50 years, reflecting the changing land-cover during the 5 year construction period both with and without treatment by erosion and sediment control measures.

Year	Untreated			Treated		
	2 year ARI	10 year ARI	50 year ARI	2 year ARI	10 year ARI	50 year ARI
2016	189	623	1667	116	289	598
2017	425	1023	1818	108	372	1177
2018	380	844	1358	103	297	769
2019	409	1243	2782	100	367	1260
2020	93	201	374	93	201	374

Table 3-14: Daily sediment loads (T) for the 'Hills' focus area corresponding to ARIs of 2, 10 and 50 years, reflecting the changing land-cover during the 10 year construction period both with and without treatment by erosion and sediment control measures.

Year	Untreated			Treated		
	2 year ARI	10 year ARI	50 year ARI	2 year ARI	10 year ARI	50 year ARI
2016	206	619	1524	142	400	937
2017	488	1195	2227	155	431	1013
2018	523	1231	2189	166	437	972
2019	705	1531	2439	175	490	1183
2020	1239	2713	5073	260	802	2233
2021	830	2134	4211	256	786	2262
2022	539	1252	2337	263	613	1270
2023	497	1129	2064	269	598	1162
2024	481	1044	1817	305	652	1195
2025	435	1048	2100	339	785	1579

Table 3-15: Daily sediment loads (T) for the 'Flats' focus area corresponding to ARIs of 2, 10 and 50 years, reflecting the changing land-cover during the 10 year construction period both with and without treatment by erosion and sediment control measures.

Year	Untreated			Treated		
	2 year ARI	10 year ARI	50 year ARI	2 year ARI	10 year ARI	50 year ARI
2016	148	418	977	108	269	561
2017	289	712	1341	87	285	894
2018	271	653	1204	91	271	717
2019	227	549	1039	89	254	670
2020	265	575	925	94	255	605
2021	339	799	1413	85	292	986
2022	258	735	1596	84	255	709
2023	93	201	374	93	201	374
2024	93	201	374	93	201	374
2025	93	201	374	93	201	374

Table 3-16: Daily sediment load (T) for the 'Hills' focus area corresponding to ARIs of 2, 10 and 50 years, under the fixed land-cover (January 2019) reflecting the maximum area of exposed earthworks for the 5 year construction scenario. Results are presented both with and without treatment by erosion and sediment control measures.

ARI	Existing	Untreated		Treated	
		Construction	Additional	Construction	Additional
2 years	135	2377	2243	430	296
10 years	402	5084	4682	1298	895
50 years	999	9307	8308	3590	2590

Table 3-17: Daily sediment load (T) for the 'Flats' focus area corresponding to ARIs of 2, 10 and 50 years, under the fixed land-cover (January 2019) reflecting the maximum area of exposed earthworks for the 5 year construction scenario. Results are presented both with and without treatment by erosion and sediment control measures.

ARI	Existing	Untreated		Treated	
		Construction	Additional	Construction	Additional
2 years	106	685	579	135	28
10 years	270	1486	1216	472	202
50 years	579	2742	2163	1528	949

Table 3-18: Daily sediment load (T) discharged from the Mahurangi River catchment corresponding to ARIs of 2, 10 and 50 years, under the fixed land-cover (January 2019) reflecting the maximum area of exposed earthworks for the 5 year construction scenario. Results are presented both with and without treatment by erosion and sediment control measures.

ARI	Existing	Untreated		Treated	
		Construction	Increase	Construction	Increase
2 years	2502	5323	113%	2826	13%
10 years	7152	13050	82%	8249	15%
50 years	18304	28775	57%	21844	19%

Table 3-19: Daily sediment load (T) for the 'Hills' focus area corresponding to ARIs of 2, 10 and 50 years, under the fixed land-cover (March 2020) reflecting the maximum area of exposed earthworks for the 10 year construction scenario. Results are presented both with and without treatment by erosion and sediment control measures.

ARI	Existing	Untreated		Treated	
		Construction	Additional	Construction	Additional
2 years	135	1282	1148	240	106
10 years	402	2776	2374	788	386
50 years	999	5152	4153	2381	1382

Table 3-20: Daily sediment load (T) for the 'Flats' focus area corresponding to ARIs of 2, 10 and 50 years, under the fixed land-cover (March 2020) reflecting the maximum area of exposed earthworks for the 10 year construction scenario. Results are presented both with and without treatment by erosion and sediment control measures.

ARI	Existing	Untreated		Treated	
		Construction	Additional	Construction	Additional
2 years	106	264	157	94	-12
10 years	270	589	319	287	17
50 years	579	1123	543	768	189

Table 3-21: Daily sediment load (T) discharged from the Mahurangi River catchment corresponding to ARIs of 2, 10 and 50 years, under the fixed land-cover (March 2020) reflecting the maximum area of exposed earthworks for the 10 year construction scenario. Results are presented both with and without treatment by erosion and sediment control measures.

ARI	Existing	Untreated		Treated	
		Construction	Increase	Construction	Increase
2 years	2502	3807	52%	2596	4%
10 years	7152	9845	38%	7555	6%
50 years	18304	23000	26%	19875	9%

Table 3-22: Daily sediment load (T) at selected stream assessment sites in the Mahurangi River corresponding to ARIs of 2, 10 and 50 years, under the fixed land-cover (January 2019) reflecting the maximum area of exposed earthworks for the 5 year construction scenario. Results are presented both with and without treatment by erosion and sediment control measures.

Site ID	ARI	Background	Untreated		Treated	
			Construction	Increase	Construction	Increase
AC-FHQ	2 years	226	2306	921%	492	118%
	10 years	646	4990	672%	1478	129%
	50 years	1652	9365	467%	4146	151%
MW	2 years	1296	4117	218%	1620	25%
	10 years	3704	9602	159%	4801	30%
	50 years	9841	20311	106%	13381	36%

Table 3-23: Daily sediment load (T) at selected stream assessment sites in the Mahurangi River corresponding to ARIs of 2, 10 and 50 years, under the fixed land-cover (March 2020) reflecting the maximum area of exposed earthworks for the 10 year construction scenario. Results are presented both with and without treatment by erosion and sediment control measures.

Site ID	ARI	Background	Untreated		Treated	
			Construction	Increase	Construction	Increase
AC-FHQ	2 years	226	1274	464%	311	38%
	10 years	646	2816	336%	989	53%
	50 years	1652	5456	230%	2990	81%
MW	2 years	1296	2601	101%	1389	7%
	10 years	3704	6397	73%	4106	11%
	50 years	9841	14537	48%	11413	16%

4 Suspended Sediment Concentrations

4.1 Introduction

As part of its preparation of the AEE for the Puhoi-Warkworth RNS project, the Alliance is conducting assessments of ecological effects in receiving freshwater and coastal water bodies. In order to support these assessments, estimates of suspended solid (SS) concentrations in streams and at catchment outlets within the project area have been developed from the sediment load estimates described in Chapters 3 and 4. This chapter describes the methods by which these SS concentrations have been estimated and directs the reader to the location of the results.

4.2 Methods

Hourly mean SS concentrations over a 24-hour period were estimated from the following 2, 10 and 50 year ARI daily sediment load estimates:

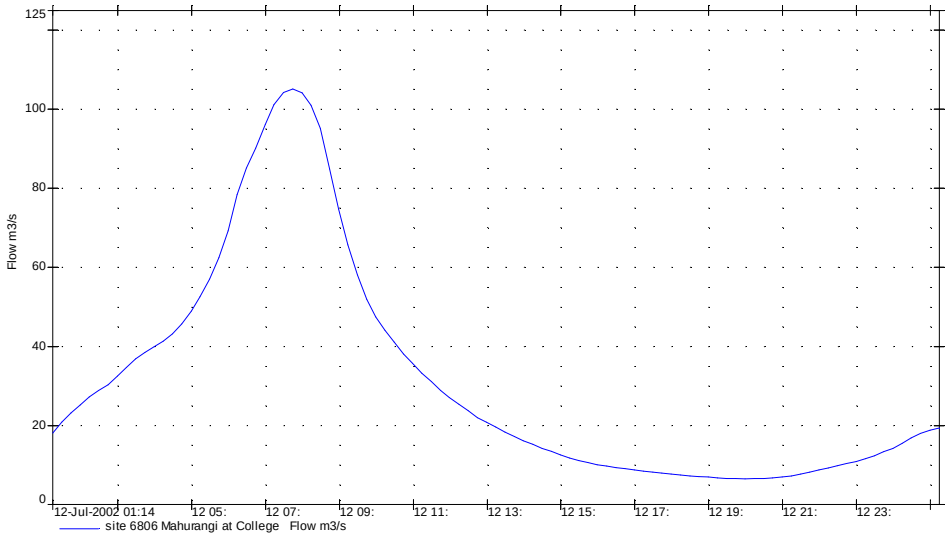
- Catchment background loads delivered to each stream outlet in the project area;
- Catchment background loads at each of three stream assessment sites (two on the Mahurangi River and one on the Puhoi River);
- Construction loads delivered to the Mahurangi River outlet associated with the maximum area of open earthworks in both the 5- and 10-year construction scenarios; and
- Construction loads delivered to the two Mahurangi River stream assessment sites associated with the maximum area of open earthworks in both the 5- and 10-year construction scenarios.

The latter two sets of SS concentrations were estimated from the construction loads added to the corresponding catchment background loads for each ARI event. SS concentrations were estimated for both treated and untreated construction loads.

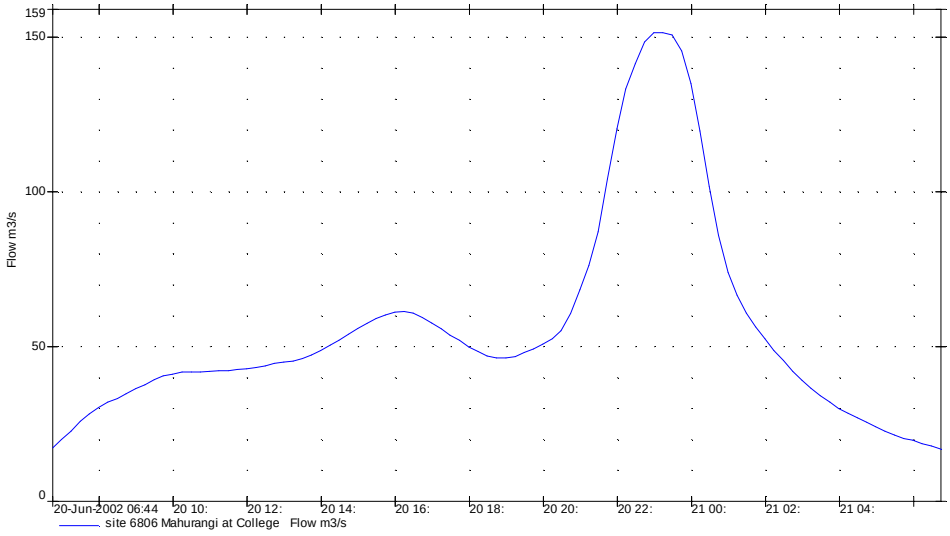
The steps involved in estimating the SS concentrations are described below:

1. A frequency analysis of the full river flow record of the Mahurangi River @ College (Auckland Council site number 6806) was conducted to identify events of 24-hour duration with return periods of approximately 2, 10 and 50 years.
2. One event corresponding with each of the three ARIs was selected for use in the estimation of SS concentrations. In the case of the 2 and 10 year ARIs, there were multiple events to choose from and the event with the highest peak flow was selected. Hydrographs of the selected events are shown in Figure 4-1. For each of the three events, the fraction of the total daily flow in each hour was calculated.

(a)



(b)



(c)

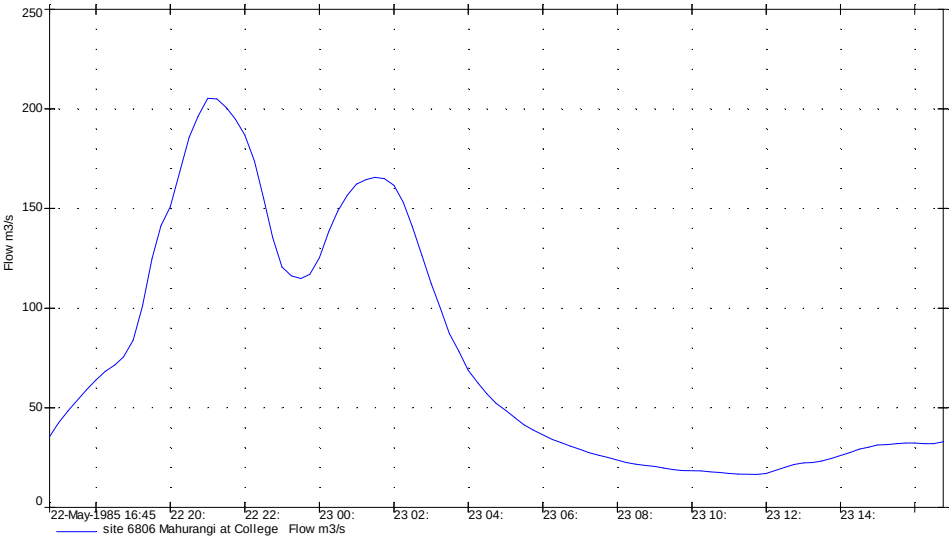


Figure 4-1: Hydrographs of Mahurangi River flows used in the estimation of suspended solids concentrations from (a) 2, (b) 10 and (c) 50 year ARI daily sediment loads.

3. Hourly mean SS concentrations were estimated over a 24-hour period from each daily sediment load by:

    a. Estimating an hourly mean 'GLEAMS flow' by distributing the total daily storm runoff estimated by GLEAMS in proportion to the fraction of the daily flow calculated in Step 2 above;

    b. Estimating a 'raw' SS concentration from the GLEAMS flow using the following relationship (Hicks et al., 2009):

    $$SS = \alpha Q^{\beta},$$

    where SS is the suspended sediment concentration (mg/L), Q is the flow (L/s) and α and β are constants whose values vary with Q as follows:

Q	α	β
$Q \leq 1000$	12.1	0.025
$1000 < Q \leq 3190$	0.0163	0.98
$3190 < Q \leq 16730$	0.0057	1.11
$16730 < Q \leq 62630$	0.33	0.69
$Q > 62630$	0.149	0.76

    c. Calculating the 'raw' hourly sediment load associated with the raw SS concentration and the proportion of the raw daily sediment load in each hour;

    d. Estimating the GLEAMS hourly sediment load by distributing the GLEAMS daily sediment load in proportion to the raw hourly sediment loads in each hour estimated in Step 3c; and

    e. Estimating the GLEAMS SS concentration from the GLEAMS hourly flow estimated in Step 3a and the GLEAMS hourly sediment loads estimated in Step 3d.

The estimation of SS concentrations by this method did not consider any potential differences associated with dry-weather flow conditions under the background and construction scenarios. In other words, the SS concentrations preceding (and following) the 24 hourly estimates generated here were assumed to be the same for each corresponding pair of background and construction storm events. In addition, the estimates of SS concentrations associated with the discharge of treated construction runoff did not consider the potential influence of flow attenuation in sediment retention ponds.

4.3 Concentration Estimates

Appendix B contains tables of:

- Estimated catchment background hourly runoff SS concentrations by sub-catchment for 24-hr load events with an average recurrence interval of 2, 10 and 50 years (Tables C-1 – C-3);

- Estimated catchment background hourly runoff SS concentrations at stream assessment sites for 24-hr load events with an average recurrence interval of 2 year, catchment background (Tables C-4 – C-6);
- Estimated hourly runoff SS concentrations at the Mahurangi River outlet for 24-hr load events with an average recurrence interval of 2, 10 and 50 years for the maximum open area of earthworks compared to catchment background (Table C-7);
- Estimated hourly runoff SS concentrations at stream assessment sites AC-FHQ and MW for 24-hr load events with an average recurrence interval of 2, 10 and 50 years for the maximum open area of earthworks compared to catchment background (Tables C-8 – C-9); and
- Estimated hourly sediment loads contributed by the Hills and Flats focus areas for 24-hr load events with an average recurrence interval of 2, 10 and 50 years for the maximum open area of earthworks (Tables C-10 – C-11). These loads, which were estimated at Step 3d described above, are provided in addition to the hourly SS concentration estimates as they are required as an input to the harbour modelling.

5 Nutrients

5.1 Introduction

As noted in Chapter 4, the preparation of the project's AEE involves assessing ecological effects in receiving freshwater environments. In order to support this assessment, estimates of sediment-related nutrient loads and concentrations have been made drawing on the results of the previous Mahurangi Harbour modelling studies described in Section 2.2. This chapter describes the methods by which nutrient concentrations and loads have been estimated and directs the reader to the location of the results.

5.2 Methods

The BNZ modelling study of sediment generation in the Mahurangi Harbour catchment also involved modelling loads of nitrogen and phosphorus (Stroud & Cooper, 1997). Loads of both soluble and particulate forms of the nutrients were estimated, with model validation based on measured concentrations in samples collected at three sites in the catchment: Redwood Forest, Wylies Road and Mahurangi College.

This assessment of nutrient loads and concentrations for the Puhoi-Warkworth RoNS has been limited to particulate forms of the nutrients modelled in the BNZ study, that is, sediment-N and sediment-P. It was assumed that background loads of sediment-N and sediment-P would be strongly related to background loads of sediment, and that the same relationships will apply to sediment generated by construction activities. Adopting this assumption allowed construction loads of sediment-N and sediment-P to be estimated from the sediment loads reported in the previous chapters. In contrast, the same assumption could not be adopted for soluble forms of the nutrients and, accordingly, the estimation of construction loads of soluble forms of N and P lay outside the scope of this assessment[7]. In addition, the estimates provided here do not include mineralisation of N and P associated with soil disturbance.

Ratios of both sediment-N and sediment-P to sediment were estimated from modelled sub-catchment annual loads extracted from the BNZ results files. These ratios were then compared with those estimated from concentrations of suspended solids and nutrients measured in samples collected as part of model validation (see Table 5-1). In order to estimate the ratios from the sampling results, Sediment-N was calculated as Total Kjeldahl Nitrogen (TKN) minus Ammoniacal Nitrogen (NH_4-N). This calculation gives Total Organic Nitrogen (TON), and is likely to be an overestimate of Sediment-N because it includes the dissolved fraction of TON. Sediment-P was calculated from the sampling results as Total Phosphorus (TP) minus Dissolved Reactive Phosphorus (DRP). The result of this calculation is also likely to be an overestimate of Sediment-P because it includes unreactive phosphorus in the dissolved phase as well as the particulate phases of both reactive and unreactive phosphorus.

The ratios estimated for sediment-N and sediment-P from the model and sampling results were generally consistent, noting that higher estimates were derived from the sampling results, probably for the reasons given above. The ratios derived from the results of the BNZ

[7] While the estimation of soluble forms of N and P lay outside the scope of this study, it is noted that a large proportion of the catchment background loads of TN and TP can be expected to be in the dissolved phase. It is recommended that this be accounted for when considering the increased loads of N and P associated with the construction.

modelling (0.066 for sediment-N:sediment and 0.00081 for sediment-P:sediment) were used to estimate nutrient loads and concentrations from the estimates of sediment loads and SS concentrations described in the previous chapters.

Table 5-1: Estimated ratios of loads and concentrations of sediment-N and sediment-P to sediment.

Source	Sediment-N:Sediment ratio[1]	Sediment-P:Sediment ratio[1]
Modelled annual loads, BNZ study[2]	0.0066	0.00081
Sample concentrations, Mahurangi River sampling sites[3]	0.0077	0.0012
Loads estimated from Mahurangi sample concentrations[4]	0.0049 - 0.0075	0.0008 – 0.0014

Notes:

[1]Units are dimensionless, i.e.: for loads, g N or P / g sediment; and for concentrations g m^{-3} N or P / g m^{-3} sediment.

[2] mean ratio of annual loads for each sub-catchment, 1976-1995.

[3] median of ratios calculated for individual samples from all three sampling sites.

[4] range of ratios calculated from mean annual loads (1 July 1994 to 30 June 1995) estimated at each of the three sampling sites.

5.3 Nutrient Load and Concentration Estimates

Tables 5-2 – 5-5 below summarize the estimated daily loads of sediment-N and sediment-P associated with the 2, 10 and 50 year ARI daily sediment loads. The results are presented in relation to the background sediment loads as well the project sediment loads (background + construction) at the two stream assessment sites in the Mahurangi River. The corresponding hourly concentration estimates of sediment-N and sediment-P are given in Appendix D (Tables D-1 – D-4).

Table 5-2: Daily sediment-N load (T) at the AC-FHQ and MW stream assessment sites in the Mahurangi River corresponding to ARIs of 2, 10 and 50 years, under the fixed land-cover (January 2019) scenario reflecting the maximum area of exposed earthworks for the 5 year construction scenario. Results are presented both with and without treatment by erosion and sediment control measures**.**

Site ID	ARI	Background	Untreated		Treated	
			Construction	Increase	Construction	Increase
AC-FHQ	2 years	1.49	15.2	921%	3.24	118%
	10 years	4.26	32.9	672%	9.75	129%
	50 years	10.9	61.8	467%	27.4	151%
MW	2 years	8.55	27.2	218%	10.7	25%
	10 years	24.5	63.4	159%	31.7	30%
	50 years	65.0	134.1	106%	88.3	36%

Table 5-3: Daily sediment-N load (T) at the AC-FHQ and MW stream assessment sites in the Mahurangi River corresponding to ARIs of 2, 10 and 50 years, under the fixed land-cover (March 2020) scenario reflecting the maximum area of exposed earthworks for the 10 year construction scenario. Results are presented both with and without treatment by erosion and sediment control measures**.**

Site ID	ARI	Background	Untreated		Treated	
			Construction	Increase	Construction	Increase
AC-FHQ	2 years	1.49	8.41	464%	2.05	38%
	10 years	4.26	18.6	336%	6.53	53%
	50 years	10.9	36.0	230%	19.7	81%
MW	2 years	8.55	17.2	101%	9.17	7%
	10 years	24.5	42.2	73%	27.1	11%
	50 years	65.0	95.9	48%	75.3	16%

Table 5-4: Daily sediment-P load (T) at the AC-FHQ and MW stream assessment sites in the Mahurangi River corresponding to ARIs of 2, 10 and 50 years, under the fixed land-cover (January 2019) scenario reflecting the maximum area of exposed earthworks for the 5 year construction scenario. Results are presented both with and without treatment by erosion and sediment control measures**.**

Site ID	ARI	Background	Untreated		Treated	
			Construction	Increase	Construction	Increase
AC-FHQ	2 years	0.18	1.87	921%	0.40	118%
	10 years	0.52	4.04	672%	1.20	129%
	50 years	1.34	7.59	467%	3.36	151%
MW	2 years	1.05	3.33	218%	1.31	25%
	10 years	3.00	7.78	159%	3.89	30%
	50 years	7.97	16.45	106%	10.8	36%

Table 5-5: Daily sediment-P load (T) at the AC-FHQ and MW stream assessment sites in the Mahurangi River corresponding to ARIs of 2, 10 and 50 years, under the fixed land-cover (March 2020) scenario reflecting the maximum area of exposed earthworks for the 10 year construction scenario. Results are presented both with and without treatment by erosion and sediment control measures**.**

Site ID	ARI	Background	Untreated		Treated	
			Construction	Increase	Construction	Increase
AC-FHQ	2 years	0.18	1.03	464%	0.25	38%
	10 years	0.52	2.28	336%	0.80	53%
	50 years	1.34	4.42	230%	2.42	81%
MW	2 years	1.05	2.11	101%	1.13	7%
	10 years	3.00	5.18	73%	3.33	11%
	50 years	7.97	11.8	48%	9.24	16%

6 Summary

This report has described the methodology and results from NIWA's assessment of sediment loads associated with construction of the Puhoi – Warkworth Road of National Significance, undertaken on behalf of the Further North Alliance. The assessment was divided into four key tasks, which involved estimating:

1. Catchment background sediment loads;
2. Construction phase sediment loads;
3. Suspended sediment (SS) concentrations; and
4. Nutrient loads and concentrations

The background sediment loads were estimated using the results of previous NIWA studies of the Mahurangi Harbour catchment using the BNZ model. The sediment loads reported include mean annual loads and 2, 10 and 50 year ARI daily loads for each stream outlet discharging to the Mahurangi Harbour, as well as the Puhoi River and Te Muri Beach stream catchments and selected stream assessment sites in the Mahurangi and Puhoi Rivers.

The construction phase sediment loads were estimated using the GLEAMS model for the two focus areas of the alignment ('Hills' and 'Flats') specified by the Alliance, under 5- and 10-year construction scenarios. In each case we presented results based on:

- Changing land-cover during each year of the 5- and 10-year construction scenarios according to the staging of earthworks; and
- Fixed land-cover reflecting the maximum area of exposed earthworks in the 5- and 10-year construction scenarios.

The results for the changing land-cover reflect not only the area of exposed earthworks in each year, but also the size of rainfall events which may be expected to occur whilst the slopes are open. In contrast, the fixed land-cover represents a worst-case scenario by assuming that the maximum area of exposed earthworks remains open for all months of the year.

The SS concentrations, as well as nutrient loads and concentrations, were calculated to support further assessments of the ecological effects of the construction on freshwater and coastal water bodies. The SS concentrations, reported on an hourly basis, were calculated by distributing the estimated sediment loads and associated runoff volumes according to measured hydrographs from the catchment, corresponding to different event sizes. The nutrient loads and concentrations, including sediment-N and sediment-P, were drawn from the results of the previous BNZ modelling study compared with data collected as part of model validation for that study.

7 Limitations

The assessment described in this report is subject to the following limitations:

- GLEAMS estimates sediment loads that result only from rainfall-runoff generated erosion. That being the case, the sediment load estimates provided in this report do not include loads of sediment generated by mass movements such as slope failure into a waterway or erosion of stream channels.
- GLEAMS estimates sediment loads and runoff at a daily time step. The hourly approximations of the distribution of runoff and concentrations of suspended solids provided in this report are therefore subject to an unquantified level of uncertainty.
- While information on the background catchment sediment loads for the Mahurangi Harbour catchment were available, this was not the case for the remainder of the project area. Estimates derived for the Puhoi River and Te Muri Beach catchments have relied on expert interpretation of data and are considered more uncertain than those for the Mahurangi River catchment.
- Estimates of the proportion of sediment loads delivered to the catchment outlets have not been validated and are also be subject to an unquantified level of uncertainty.
- Recommendations on PSD are based on the available information described in Section 2.4. While this information can be used to interpret the outputs of the GLEAMS model provided here, it should be noted that PSD has not been modelled as part of this assessment.

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Appendix A Catchment Background Runoff Volumes

Table A-1: Estimated daily storm runoff (with associated 95 % lower and upper confidence intervals) delivered to the Mahurangi Harbour and Puhoi River Estuary by sub-catchment, for ARIs of 2, 10 and 50 years.

Outlet	Sub-catchment	2-year ARI (10^3 m^3)			10-year ARI (10^3 m^3)			50-year ARI (10^3 m^3)		
		Runoff	Lower	Upper	Runoff	Lower	Upper	Runoff	Lower	Upper
Te Muri Beach	-	220	181	246	437	318	694	799	484	2788
Puhoi River	-	2313	1899	2583	4589	3347	7291	8397	5087	29306
Mahurangi River	-	2999	2462	3349	5949	4339	9451	10886	6595	37990
Pukapuka Inlet	2	58	48	65	115	84	183	211	128	737
	3	82	68	92	163	119	259	299	181	1042
	4	141	116	158	280	205	445	513	311	1791
	5	355	291	396	704	513	1118	1287	780	4493
	6	124	102	139	246	180	391	451	273	1573
	7	136	112	152	270	197	429	495	300	1726
Western shore (upper)	8	433	356	484	859	627	1365	1573	953	5488
	9	118	97	132	234	171	372	429	260	1497
	10	119	98	133	237	173	376	433	262	1511
	11	86	70	96	170	124	270	311	188	1085
	12	220	181	246	437	319	695	800	485	2793
	13	188	155	210	373	272	593	683	414	2384
Eastern shore (upper)	16	524	431	586	1040	759	1653	1904	1153	6644
	17	96	79	108	191	139	304	350	212	1221
	18	106	87	119	211	154	335	386	234	1347
	19	78	64	87	154	113	245	282	171	986
	20	77	63	86	152	111	241	278	168	970
	21	81	66	90	160	117	255	293	178	1023

Table A-1 cont.: Estimated daily runoff volume (with associated 95 % lower and upper confidence intervals) delivered to the Mahurangi Harbour and Puhoi River Estuary by sub-catchment, for ARIs of 2, 10 and 50 years.

Outlet	Sub-catchment	2-year ARI (10^3 m^3)			10-year ARI (10^3 m^3)			50-year ARI (10^3 m^3)		
		Runoff	Lower	Upper	Runoff	Lower	Upper	Runoff	Lower	Upper
Te Kapa Inlet	22	62	51	69	122	89	194	224	136	781
	23	58	47	64	114	84	182	209	127	731
	24	171	141	191	340	248	540	622	377	2170
	25	196	161	218	388	283	616	710	430	2478
	26	110	90	123	218	159	347	400	242	1395
Puhoi River Estuary		2313	1899	2583	4589	3347	7291	8397	5087	29306
Mahurangi Harbour		6619	5434	7392	13131	9578	20861	24029	14557	83855

Table A-2: Estimated daily runoff volume (with associated 95 % lower and upper confidence intervals) for selected stream assessment sites in the Mahurangi and Puhoi Rivers, for ARIs of 2, 10 and 50 years.

Location	Site ID	2-year ARI (10^3 m^3)			10-year ARI (10^3 m^3)			50-year ARI (10^3 m^3)		
		Runoff	Lower	Upper	Runoff	Lower	Upper	Runoff	Lower	Upper
Mahurangi River	AC-FHQ	154	127	172	306	223	486	560	339	1954
	MW	1428	1172	1595	2833	2066	4501	5184	3141	18091
Puhoi River	P10	335	275	375	665	485	1057	1218	738	4249

Appendix B Changes in Recurrence Interval under Construction vs. Existing Land-Cover

Table B-1: Estimated change in ARI (years) for 2, 10 and 50 year background daily sediment loads at selected stream assessment sites occurring under the fixed construction land-cover, reflecting the maximum area of exposed earthworks in both the 5 and 10 year construction scenarios. Results are presented both with and without treatment by erosion and sediment control measures**.**

Location	Site	Background ARI	Load (T)	Construction ARI, 5 year scenario		Construction ARI, 10 year scenario	
				Untreated	Treated	Untreated	Treated
Mahurangi River	AC-FHQ	2	226	1.00	1.37	1.00	1.60
		10	646	1.00	4.81	1.23	5.43
		50	1652	1.73	18.73	6.16	25.08
Mahurangi River	MW	2	1296	1.06	1.66	1.52	1.67
		10	3704	3.47	6.32	5.95	6.40
		50	9481	23.29	28.60	24.59	29.91

Table B-2: Estimated change in ARI (years) for 2, 10 and 50 year construction daily sediment loads (for the fixed land-cover, reflecting the maximum area of exposed earthworks in the 5 year construction scenario) occurring under the existing land-cover. Results are presented for the Mahurangi and Puhoi river catchments both with and without treatment by erosion and sediment control measures**.**

Catchment	Construction ARI	Untreated		Treated	
		Load (T)	Background ARI	Load (T)	Background ARI
Mahurangi River	2	5323	6	2826	2
	10	13050	28	8249	13
	50	28775	110	21844	68
Puhoi River	2	6001	4	4054	2
	10	15422	18	11635	11
	50	35797	79	30079	58

Table B-3: Estimated change in ARI (years) for 2, 10 and 50 year construction daily sediment loads (for the fixed land-cover, reflecting the maximum area of exposed earthworks in the 10 year construction scenario) occurring under the existing land-cover. Results are presented for the Mahurangi and Puhoi river catchments both with and without treatment by erosion and sediment control measures.

Catchment	Construction ARI	Untreated		Treated	
		Load (T)	Background ARI	Load (T)	Background ARI
Mahurangi River	2	3807	4	2596	2
	10	9845	17	7555	11
	50	23000	74	19875	58
Puhoi River	2	4906	3	3864	2
	10	13114	14	11126	11
	50	31642	64	28871	54

Table B-4: Estimated change in ARI (years) for 2, 10 and 50 year construction daily sediment loads (for the fixed land-cover, reflecting the maximum area of exposed earthworks in the 5 year construction scenario) occurring under the existing land-cover. Results are presented for the three stream assessment sites in the Mahurangi and Puhoi rivers, both with and without treatment by erosion and sediment control measures.

Location	Site	Construction ARI	Untreated		Treated	
			Load (T)	Background ARI	Load (T)	Background ARI
Mahurangi River	AC-FHQ	2	2306	89	492	6
		10	4990	341	1478	41
		50	9365	1017	4146	247
Mahurangi River	MW	2	4117	12	1620	3
		10	9602	51	4801	16
		50	20311	188	13381	91
Puhoi River	P10	2	2638	43	691	4
		10	5810	168	2023	27
		50	11194	526	5476	152

Table B-5: Estimated change in ARI (years) for 2, 10 and 50 year construction daily sediment loads (for the fixed land-cover, reflecting the maximum area of exposed earthworks in the 10 year construction scenario) occurring under the existing land-cover. Results are presented for the three stream assessment sites in the Mahurangi and Puhoi rivers, both with and without treatment by erosion and sediment control measures**.**

Location	Site	Construction ARI	Untreated		Treated	
			Load (T)	Background ARI	Load (T)	Background ARI
Mahurangi River	AC-FHQ	2	1274	32	311	3
		10	2816	126	989	21
		50	5456	398	2990	140
Mahurangi River	MW	2	2601	6	1389	2
		10	6397	25	4106	12
		50	14537	105	11413	69
Puhoi River	P10	2	1543	17	501	3
		10	3502	70	1514	16
		50	7039	235	4268	98

Appendix C Hourly Suspended Sediment Concentration and Sediment Load Estimates

Table C-1: Estimated hourly runoff SS concentration (mg/L) by sub-catchment for 24-hr load events with an average recurrence interval of 2 years, catchment background.

Outlet	Time																							
	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Te Muri Beach	329	430	542	654	894	1355	1683	1491	905	607	461	353	276	215	188	187	187	186	186	186	186	188	190	253
Puhoi River	897	1084	1276	1443	1753	2242	2602	2394	1767	1379	1137	944	792	599	457	378	327	286	260	259	308	399	519	717
Mahurangi River	456	551	648	733	873	1160	1346	1239	880	701	578	480	403	339	259	214	186	162	147	147	175	226	294	379
Pukapuka Inlet	1747	1759	1770	1778	2182	3149	3814	3426	2206	1775	1762	1750	1739	1728	1718	1711	1705	1700	1696	1696	1703	1713	1723	1735
	1487	1497	1646	1961	2586	3731	4519	4060	2614	1838	1500	1490	1481	1471	1462	1456	1451	1447	1444	1444	1449	1458	1467	1477
	1106	1446	1822	2171	2862	4299	5341	4730	2893	2034	1548	1188	977	971	965	961	958	955	953	953	957	962	968	975
	586	782	1016	1238	1694	2566	3188	2823	1714	1151	844	629	491	384	302	256	225	210	210	210	213	268	338	450
	617	807	1017	1211	1597	2359	2930	2595	1614	1135	864	663	617	613	610	607	605	603	602	602	604	608	611	616
	584	764	963	1147	1513	2261	2809	2488	1529	1075	818	628	535	532	528	526	524	523	522	522	524	527	530	534
Western shore (upper)	476	646	839	1023	1399	2119	2633	2332	1416	950	697	517	395	309	243	206	181	161	148	147	172	216	272	362
	903	1121	1413	1683	2219	3255	4044	3582	2242	1577	1200	921	899	893	888	884	881	878	877	876	880	885	890	897
	900	1128	1421	1693	2232	3279	4073	3608	2256	1586	1207	926	896	891	885	882	879	876	874	874	878	883	888	894
	1336	1346	1538	1832	2415	3484	4222	3791	2441	1716	1348	1339	1330	1322	1314	1308	1304	1300	1297	1297	1302	1310	1318	1327
	911	1191	1501	1811	2476	3751	4661	4128	2507	1682	1275	979	763	597	520	518	516	515	514	513	515	518	526	699
	646	845	1065	1269	1722	2608	3241	2870	1743	1189	905	695	542	432	429	427	426	425	424	424	426	428	431	496
Eastern shore (upper)	443	601	780	951	1301	1971	2220	2059	1317	884	649	481	363	280	220	187	164	146	134	134	156	196	247	329
	665	679	856	1020	1345	1940	2387	2114	1359	956	727	666	662	658	654	651	649	647	646	646	648	652	656	661
	457	513	646	770	1015	1468	1824	1616	1026	721	549	458	455	452	449	447	446	444	443	443	445	448	450	454
	569	573	598	712	938	1354	1640	1473	949	667	574	570	567	563	560	557	555	554	553	553	555	558	561	565
	568	572	587	700	923	1331	1612	1448	932	656	573	569	565	562	558	556	554	553	551	551	554	557	560	564
	650	654	707	842	1110	1602	1940	1743	1122	789	655	651	647	643	639	636	634	632	631	631	633	637	641	645
Te Kapa Inlet	966	972	978	982	1275	1839	2227	2001	1288	981	974	967	961	955	950	946	942	940	938	938	941	947	952	959
	1383	1393	1401	1407	1714	2473	2996	2691	1732	1405	1395	1386	1377	1368	1360	1354	1350	1346	1343	1343	1348	1356	1364	1374
	965	1263	1591	1895	2540	3848	4781	4234	2571	1776	1351	1037	809	706	701	698	696	694	693	692	695	699	703	741
	1472	1925	2426	2890	3941	5969	7416	6568	3989	2708	2061	1582	1234	964	942	938	935	932	930	930	934	939	945	1130
	1437	1668	2102	2504	3301	4799	5963	5281	3336	2346	1785	1440	1431	1422	1413	1407	1403	1398	1395	1395	1401	1409	1417	1428

Table C-2: Estimated hourly runoff SS concentration (mg/L) by sub-catchment for 24-hr load events with an average recurrence interval of 10 years, catchment background.

Outlet	Time																							
	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Te Muri Beach	296	404	523	617	663	674	701	746	852	971	995	875	763	779	941	1578	2539	2685	1783	1018	726	534	423	340
Puhoi River	919	1142	1372	1527	1598	1613	1653	1719	1866	2024	2055	1898	1742	1765	1986	2740	3795	3943	2979	2084	1690	1391	1181	1012
Mahurangi River	469	583	700	779	815	823	843	877	933	1021	1038	951	889	900	999	1423	1972	2048	1548	1054	862	710	602	516
Pukapuka Inlet	1946	1962	1975	1982	1961	1987	2058	2175	2444	2745	2803	2505	2218	2258	2670	4213	6442	6812	4694	2860	2123	1976	1964	1953
	1525	1537	1723	2007	2139	2169	2246	2373	2667	2995	3059	2733	2420	2464	2913	4597	7353	7775	5164	3121	2317	1758	1539	1531
	1017	1386	1797	2094	2232	2263	2343	2476	2782	3148	3224	2851	2525	2571	3051	5114	8231	8703	5781	3298	2417	1834	1453	1167
	550	763	1025	1218	1310	1330	1384	1473	1681	1917	1964	1728	1506	1537	1858	3115	4493	4651	3521	2009	1434	1049	805	631
	605	780	1012	1179	1256	1274	1319	1394	1566	1759	1796	1605	1421	1447	1711	2830	4556	4817	3199	1833	1361	1032	818	657
	539	734	952	1110	1183	1199	1242	1312	1474	1660	1700	1511	1338	1362	1609	2697	4341	4590	3049	1739	1281	972	770	618
Western shore (upper)	462	655	880	1046	1124	1142	1188	1265	1443	1646	1686	1484	1293	1320	1595	2674	3546	3671	2846	1725	1231	900	691	539
	884	1087	1410	1643	1751	1775	1838	1943	2183	2452	2504	2237	1981	2017	2385	3920	6310	6672	4431	2555	1897	1439	1140	916
	881	1093	1418	1652	1761	1785	1848	1953	2195	2465	2517	2249	1992	2028	2398	3946	6351	6716	4461	2569	1907	1447	1146	921
	1360	1370	1596	1859	1982	2009	2080	2199	2470	2774	2833	2532	2242	2283	2699	4254	6848	7240	4809	2891	2146	1629	1372	1364
	820	1117	1449	1709	1837	1865	1941	2066	2358	2689	2754	2424	2112	2156	2606	4368	7032	7435	4938	2817	2011	1479	1171	941
	586	798	1035	1206	1286	1306	1358	1446	1650	1882	1927	1697	1478	1509	1824	3057	4921	5204	3456	1972	1407	1057	837	672
Eastern shore (upper)	435	617	828	984	1058	1075	1118	1190	1358	1549	1586	1396	1217	1242	1501	2291	3079	3188	2472	1623	1158	847	650	508
	664	672	872	1016	1083	1098	1137	1201	1350	1516	1548	1383	1225	1247	1475	2361	3800	4018	2669	1580	1173	890	705	666
	451	502	651	758	808	819	848	897	1008	1131	1156	1032	914	931	1101	1785	2872	3037	2017	1179	875	664	526	453
	591	595	632	737	785	796	824	871	979	1099	1123	1003	888	905	1070	1688	2680	2834	1882	1146	851	645	596	593
	591	596	624	727	775	785	813	859	966	1084	1108	990	876	892	1055	1664	2638	2789	1853	1130	839	637	597	593
	669	674	742	865	922	935	968	1023	1149	1291	1318	1178	1043	1062	1256	1981	3161	3343	2220	1345	999	758	675	671
Te Kapa Inlet	1058	1066	1073	1077	1126	1141	1182	1249	1404	1576	1610	1438	1274	1297	1533	2419	3728	3942	2696	1643	1220	1074	1067	1062
	1544	1556	1566	1572	1575	1564	1620	1712	1924	2160	2206	1971	1745	1777	2101	3316	5065	5356	3695	2251	1671	1567	1558	1549
	879	1197	1553	1809	1929	1955	2025	2143	2445	2789	2856	2514	2190	2236	2703	4530	7292	7710	5121	2922	2085	1585	1255	1008
	1332	1814	2353	2741	2937	2982	3103	3303	3769	4299	4403	3875	3376	3447	4167	6984	11241	11886	7895	4504	3215	2402	1902	1528
	1415	1627	2111	2459	2622	2657	2752	2908	3268	3670	3748	3349	2965	3020	3570	5814	9358	9895	6572	3824	2839	2154	1706	1420

Table C-3: Estimated hourly runoff SS concentration (mg/L) by sub-catchment for 24-hr load events with an average recurrence interval of 50 years, catchment background.

Outlet	Time																							
	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Te Muri Beach	545	774	1078	1911	2598	2763	2319	1852	2240	2420	2161	1356	838	590	444	352	293	259	240	227	269	317	391	435
Puhoi River	1465	1793	2250	3330	4538	4856	4004	3259	3854	4196	3704	2633	1893	1538	1290	1116	981	897	852	819	923	1035	1190	1274
Mahurangi River	726	922	1157	1713	2335	2498	2060	1677	1983	2159	1906	1354	974	766	651	564	495	453	430	414	466	523	601	643
Pukapuka Inlet	1538	2095	2807	4770	7496	8276	6243	4622	5905	6686	5573	3438	2247	1648	1284	1234	1228	1224	1222	1220	1226	1231	1237	1261
	1623	2211	2970	5266	8276	9137	6892	5103	6519	7381	6153	3737	2372	1740	1355	1103	931	928	927	925	929	992	1209	1331
	1647	2322	3234	5735	9013	9950	7505	5557	7099	8038	6700	4069	2514	1770	1375	1119	932	822	763	721	855	1007	1227	1351
	1212	1720	2396	3569	4726	5026	4218	3499	4075	4402	3931	2883	1862	1311	988	782	636	551	507	476	576	694	868	968
	932	1291	1799	3189	5012	5534	4174	3091	3948	4470	3726	2263	1398	999	778	633	527	465	431	408	483	569	694	764
	874	1226	1707	3028	4758	5253	3962	2934	3748	4244	3537	2148	1327	937	729	594	494	436	405	383	453	534	651	717
Western shore (upper)	1078	1531	2045	2919	3867	4112	3451	2863	3334	3601	3216	2359	1657	1167	879	696	566	490	451	423	513	617	773	861
	1302	1793	2497	4428	6959	7683	5795	4291	5482	6207	5174	3142	1941	1396	1087	885	737	649	603	570	675	796	970	1068
	1308	1804	2512	4455	7002	7730	5831	4317	5515	6245	5205	3161	1953	1403	1092	889	740	653	606	573	679	800	975	1073
	1499	2042	2757	4890	7684	8483	6399	4738	6053	6853	5712	3469	2190	1607	1251	1018	848	825	823	822	826	916	1117	1229
	1510	2143	2986	5295	7192	7648	6419	5131	6201	6698	5981	3757	2321	1634	1231	975	812	716	665	629	745	877	1082	1206
	1010	1433	1997	3541	5139	5465	4634	3431	4383	4787	4137	2512	1552	1093	823	666	554	489	454	429	508	599	730	807
Eastern shore (upper)	1042	1478	1823	2602	3447	3665	3076	2552	2971	3210	2866	2102	1558	1127	849	672	546	474	435	409	495	596	746	832
	813	1108	1520	2695	4235	4675	3526	2611	3336	3777	3148	1912	1189	872	679	553	460	406	399	399	422	497	606	667
	604	823	1143	2027	3185	3517	2653	1964	2509	2841	2368	1438	888	648	504	410	342	301	280	270	313	369	450	495
	598	815	1092	1927	3028	3343	2522	1867	2385	2701	2251	1367	874	641	499	406	362	361	360	360	361	366	446	490
	591	805	1078	1899	2984	3294	2485	1840	2351	2661	2218	1347	863	633	493	401	363	362	361	360	362	361	440	484
	700	954	1278	2267	3563	3933	2967	2197	2806	3178	2649	1609	1023	751	585	476	409	408	407	406	408	428	522	574
Te Kapa Inlet	877	1195	1601	2742	4309	4757	3588	2657	3394	3843	3203	1961	1282	940	732	666	663	661	660	659	662	665	668	719
	1212	1651	2212	3755	5901	6515	4915	3639	4649	5263	4387	2709	1771	1299	1012	980	976	972	971	969	973	978	983	994
	1472	2089	2911	5161	7794	8288	6755	5002	6389	7234	6030	3662	2262	1593	1207	982	818	721	669	633	750	884	1077	1186
	2330	3307	4606	8168	11666	12406	10412	7915	10111	10865	9543	5796	3580	2521	1899	1528	1272	1122	1041	985	1167	1374	1676	1861
	1956	2668	3717	6592	10359	11436	8627	6387	8160	9239	7701	4677	2889	2097	1633	1329	1107	976	905	856	1015	1195	1457	1604

Table C-4: Estimated hourly runoff SS concentration (mg/L) at stream assessment sites for 24-hr load events with an average recurrence interval of 2 year, catchment background.

Site ID	Time																							
	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
AC-FHQ	553	724	912	1087	1437	2176	2704	2395	1454	1018	775	595	464	447	445	443	441	440	439	439	441	443	446	449
MW	446	604	721	815	990	1282	1467	1360	998	779	653	484	365	276	211	174	151	132	120	120	142	184	239	331
P10	414	549	713	869	1189	1801	2237	1981	1203	808	593	445	347	271	213	181	159	157	156	156	157	189	239	318

Table C-5: Estimated hourly runoff SS concentration (mg/L) at stream assessment sites for 24-hr load events with an average recurrence interval of 10 years, catchment background.

Site ID	Time																							
	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
AC-FHQ	506	690	895	1042	1111	1126	1166	1233	1389	1585	1623	1429	1257	1280	1536	2574	4144	4381	2910	1660	1203	913	723	581
MW	448	636	777	866	905	914	937	974	1057	1147	1165	1076	987	1000	1125	1551	2080	2160	1674	1181	958	789	671	524
P10	385	531	713	847	911	925	963	1025	1169	1334	1366	1202	1047	1069	1293	2167	3199	3312	2449	1397	997	730	560	442

Table C-6: Estimated hourly runoff SS concentration (mg/L) at stream assessment sites for 24-hr load events with an average recurrence interval of 50 year, catchment background.

Site ID	Time																							
	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
AC-FHQ	827	1173	1634	2898	4555	4864	3793	2809	3588	4062	3386	2057	1270	894	687	559	466	411	381	360	427	503	613	675
MW	843	1048	1287	1853	2525	2702	2227	1813	2144	2334	2061	1465	1101	885	742	642	564	510	468	440	533	596	685	733
P10	833	1182	1646	2510	3325	3535	2967	2462	2866	3096	2765	2072	1280	901	679	538	437	379	348	328	396	477	597	665

Table C-7: Estimated hourly runoff SS concentration (mg/L) at the Mahurangi River outlet for 24-hr load events with an average recurrence interval of 2, 10 and 50 years, maximum open area of earthworks compared to catchment background.

			Time																							
			0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
5 year construction (Jan 2019)	2 year ARI	Catchment background	456	551	648	733	873	1160	1346	1239	880	701	578	480	403	339	259	214	186	162	147	147	175	226	294	379
		Project, untreated	970	1172	1379	1560	1858	2468	2864	2635	1873	1490	1229	1021	857	722	550	456	395	345	313	313	372	481	626	806
		Project, treated	515	622	732	828	986	1311	1520	1399	994	791	653	542	455	383	292	242	210	183	166	166	197	255	332	428
	10 year ARI	Catchment background	469	583	700	779	815	823	843	877	933	1021	1038	951	889	900	999	1423	1972	2048	1548	1054	862	710	602	516
		Project, untreated	855	1063	1277	1422	1487	1501	1539	1600	1703	1863	1894	1735	1622	1643	1823	2597	3598	3738	2825	1923	1573	1295	1099	942
		Project, treated	541	672	807	899	940	949	973	1011	1076	1178	1197	1097	1025	1038	1153	1642	2274	2363	1785	1216	994	819	695	596
	50 year ARI	Catchment background	726	922	1157	1713	2335	2498	2060	1677	1983	2159	1906	1354	974	766	651	564	495	453	430	414	466	523	601	643
		Project, untreated	1141	1450	1819	2693	3670	3927	3238	2636	3117	3393	2996	2129	1531	1204	1024	886	779	713	676	650	733	822	945	1011
		Project, treated	866	1101	1381	2044	2786	2981	2458	2001	2366	2576	2274	1616	1162	914	777	673	591	541	513	494	556	624	718	768
10 year construction (Mar 2020)	2 year ARI	Catchment background	456	551	648	733	873	1160	1346	1239	880	701	578	480	403	339	259	214	186	162	147	147	175	226	294	379
		Project, untreated	694	838	986	1116	1328	1765	2048	1885	1339	1066	879	730	613	516	394	326	282	247	224	224	266	344	448	576
		Project, treated	473	571	673	761	906	1204	1396	1285	913	727	599	498	418	352	268	222	192	168	153	153	181	235	305	393
	10 year ARI	Catchment background	469	583	700	779	815	823	843	877	933	1021	1038	951	889	900	999	1423	1972	2048	1548	1054	862	710	602	516
		Project, untreated	645	802	963	1073	1122	1133	1161	1207	1284	1405	1429	1309	1224	1239	1376	1959	2714	2820	2131	1451	1187	977	829	711
		Project, treated	495	615	739	823	861	869	891	926	986	1078	1096	1005	939	951	1056	1503	2083	2164	1635	1113	911	750	636	545
	50 year ARI	Catchment background	726	922	1157	1713	2335	2498	2060	1677	1983	2159	1906	1354	974	766	651	564	495	453	430	414	466	523	601	643
		Project, untreated	912	1159	1454	2153	2933	3139	2588	2107	2491	2712	2394	1702	1224	962	819	708	623	570	541	520	586	657	756	808
		Project, treated	788	1001	1257	1860	2535	2712	2236	1820	2153	2344	2069	1471	1057	832	707	612	538	492	467	449	506	568	653	699

Table C-8: Estimated hourly runoff SS concentration (mg/L) at stream site AC-FHQ for 24-hr load events with an average recurrence interval of 2, 10 and 50 years, maximum open area of earthworks compared to catchment background.

			Time																							
			0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
5 year construction (Jan 2019)	2 year ARI	Catchment background	553	724	912	1087	1437	2176	2704	2395	1454	1018	775	595	464	447	445	443	441	440	439	439	441	443	446	449
		Project, untreated	5650	7390	9313	11093	14667	22217	27602	24446	14845	10395	7910	6071	4736	4567	4539	4520	4505	4492	4482	4482	4499	4525	4552	4585
		Project, treated	1205	1577	1987	2367	3129	4740	5889	5216	3167	2218	1688	1295	1011	974	968	964	961	958	956	956	960	966	971	978
	10 year ARI	Catchment background	506	690	895	1042	1111	1126	1166	1233	1389	1585	1623	1429	1257	1280	1536	2574	4144	4381	2910	1660	1203	913	723	581
		Project, untreated	3914	5331	6915	8056	8588	8705	9015	9527	10740	12249	12544	11042	9713	9892	11872	19899	32030	33868	22495	12834	9301	7058	5589	4490
		Project, treated	1159	1579	2048	2386	2544	2578	2670	2822	3181	3628	3716	3271	2877	2930	3516	5894	9487	10031	6663	3801	2755	2090	1655	1330
	50 year ARI	Catchment background	827	1173	1634	2898	4555	4864	3793	2809	3588	4062	3386	2057	1270	894	687	559	466	411	381	360	427	503	613	675
		Project, untreated	4685	6650	9264	16427	25816	27571	21498	15918	20335	23025	19192	11656	7200	5070	3894	3170	2640	2327	2160	2043	2421	2851	3476	3825
		Project, treated	2074	2944	4101	7273	11429	12206	9518	7047	9003	10193	8497	5160	3188	2244	1724	1403	1169	1030	956	904	1072	1262	1539	1694
10 year construction (Mar 2020)	2 year ARI	Catchment background	553	724	912	1087	1437	2176	2704	2395	1454	1018	775	595	464	447	445	443	441	440	439	439	441	443	446	449
		Project, untreated	3121	4083	5145	6129	8103	12274	15250	13506	8201	5743	4370	3354	2617	2523	2508	2497	2489	2481	2476	2476	2486	2500	2515	2533
		Project, treated	762	997	1256	1496	1978	2996	3723	3297	2002	1402	1067	819	639	616	612	610	608	606	604	604	607	610	614	618
	10 year ARI	Catchment background	506	690	895	1042	1111	1126	1166	1233	1389	1585	1623	1429	1257	1280	1536	2574	4144	4381	2910	1660	1203	913	723	581
		Project, untreated	2209	3008	3902	4546	4846	4913	5087	5376	6061	6912	7079	6231	5482	5582	6700	11230	18076	19112	12694	7242	5249	3983	3154	2534
		Project, treated	776	1057	1371	1597	1702	1725	1787	1888	2129	2428	2486	2189	1925	1961	2353	3944	6348	6712	4458	2544	1843	1399	1108	890
	50 year ARI	Catchment background	827	1173	1634	2898	4555	4864	3793	2809	3588	4062	3386	2057	1270	894	687	559	466	411	381	360	427	503	613	675
		Project, untreated	2730	3874	5397	9570	15040	16062	12525	9274	11847	13414	11181	6791	4195	2954	2269	1847	1538	1356	1258	1190	1410	1661	2025	2229
		Project, treated	1496	2123	2958	5245	8242	8803	6864	5082	6493	7351	6128	3722	2299	1619	1243	1012	843	743	690	652	773	910	1110	1221

Table C-9: Estimated hourly runoff SS concentration (mg/L) at stream site MW for 24-hr load events with an average recurrence interval of 2, 10 and 50 years, maximum open area of earthworks compared to catchment background.

			Time																							
			0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
5 year construction (Jan 2019)	2 year ARI	Catchment background	446	604	721	815	990	1282	1467	1360	998	779	653	484	365	276	211	174	151	132	120	120	142	184	239	331
		Project, untreated	1416	1920	2289	2589	3145	4071	4659	4320	3169	2473	2073	1536	1160	877	669	554	479	419	381	380	452	584	760	1050
		Project, treated	557	755	901	1019	1237	1602	1833	1700	1247	973	816	605	456	345	263	218	189	165	150	150	178	230	299	413
	10 year ARI	Catchment background	448	636	777	866	905	914	937	974	1057	1147	1165	1076	987	1000	1125	1551	2080	2160	1674	1181	958	789	671	524
		Project, untreated	1162	1649	2015	2244	2347	2369	2428	2525	2741	2974	3018	2788	2559	2592	2917	4021	5390	5600	4340	3062	2482	2044	1739	1357
		Project, treated	581	824	1007	1122	1173	1185	1214	1262	1370	1487	1509	1394	1280	1296	1458	2011	2695	2800	2170	1531	1241	1022	870	679
	50 year ARI	Catchment background	843	1048	1287	1853	2525	2702	2227	1813	2144	2334	2061	1465	1101	885	742	642	564	510	468	440	533	596	685	733
		Project, untreated	1805	2244	2758	3969	5408	5787	4771	3884	4593	5001	4415	3138	2358	1896	1590	1375	1209	1092	1003	942	1142	1276	1467	1570
		Project, treated	1189	1479	1817	2615	3563	3813	3143	2559	3026	3295	2908	2067	1554	1249	1047	906	796	719	661	621	752	841	967	1034
10 year construction (Mar 2020)	2 year ARI	Catchment background	446	604	721	815	990	1282	1467	1360	998	779	653	484	365	276	211	174	151	132	120	120	142	184	239	331
		Project, untreated	895	1213	1446	1635	1987	2572	2944	2730	2002	1562	1310	971	733	554	422	350	303	265	241	240	285	369	480	663
		Project, treated	478	648	772	873	1061	1374	1572	1458	1069	834	700	518	391	296	226	187	162	141	128	128	152	197	257	354
	10 year ARI	Catchment background	448	636	777	866	905	914	937	974	1057	1147	1165	1076	987	1000	1125	1551	2080	2160	1674	1181	958	789	671	524
		Project, untreated	774	1098	1342	1495	1564	1579	1618	1682	1826	1981	2011	1858	1705	1727	1943	2679	3591	3731	2891	2040	1654	1362	1159	904
		Project, treated	497	705	862	959	1004	1013	1038	1080	1172	1272	1291	1192	1094	1109	1247	1720	2305	2395	1856	1309	1062	874	744	580
	50 year ARI	Catchment background	843	1048	1287	1853	2525	2702	2227	1813	2144	2334	2061	1465	1101	885	742	642	564	510	468	440	533	596	685	733
		Project, untreated	1292	1606	1974	2840	3871	4142	3415	2780	3287	3579	3160	2246	1688	1357	1138	984	865	781	718	674	817	914	1050	1124
		Project, treated	1014	1261	1550	2230	3039	3252	2681	2183	2581	2810	2481	1763	1325	1065	893	773	679	613	564	529	641	717	825	882

Table C-10: Estimated hourly sediment loads (kg) discharged from Hills focus area for 24-hr load events with an average recurrence interval of 2, 10 and 50 years, maximum open area of earthworks.

Hills area			Time																							
			0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
5 year construction (Jan 2019)	2 year ARI	Untreated	35834	56939	84836	114714	181106	349856	493569	407125	184604	102553	64019	40566	26437	17317	10341	7221	5494	4259	3546	3532	4902	8004	13199	22725
		Treated	4727	7512	11192	15133	23892	46153	65112	53708	24353	13529	8445	5352	3488	2284	1364	953	725	562	468	466	647	1056	1741	2998
	10 year ARI	Untreated	25545	43518	68157	88698	99030	101375	107677	118438	141959	174847	181589	148341	122463	126366	166399	377410	802794	877023	458398	188274	113638	70596	47207	32368
		Treated	4886	8323	13035	16964	18940	19388	20594	22652	27150	33440	34730	28371	23421	24168	31824	72181	153537	167734	87670	36008	21734	13502	9028	6191
	50 year ARI	Untreated	77175	134464	227442	564076	1155090	1351298	864168	536622	791234	963459	721858	327395	152537	87453	57623	40405	29468	23711	20853	18940	25380	33655	47362	55882
		Treated	24064	41928	70921	175889	360178	421358	269463	167328	246721	300424	225088	102088	47564	27269	17968	12599	9189	7393	6502	5906	7914	10494	14768	17425
10 year construction (Mar 2020)	2 year ARI	Untreated	18339	29140	43418	58709	92687	179049	252599	208359	94477	52484	32763	20761	13530	8862	5292	3695	2812	2180	1815	1808	2509	4096	6755	11630
		Treated	1693	2689	4007	5418	8554	16525	23313	19230	8719	4844	3024	1916	1249	818	488	341	260	201	168	167	232	378	623	1073
	10 year ARI	Untreated	12951	22062	34553	44967	50205	51394	54589	60044	71969	88642	92060	75204	62085	64064	84359	191336	406993	444624	232394	95450	57611	35790	23932	16410
		Treated	2104	3584	5614	7305	8156	8349	8869	9755	11692	14401	14956	12218	10086	10408	13705	31084	66120	72234	37755	15507	9360	5814	3888	2666
	50 year ARI	Untreated	38579	67217	113697	281977	577421	675503	431991	268253	395532	481626	360851	163662	76252	43717	28805	20198	14731	11853	10424	9468	12687	16824	23676	27935
		Treated	12839	22369	37837	93838	192158	224798	143761	89271	131627	160278	120086	54465	25376	14548	9586	6722	4902	3944	3469	3151	4222	5599	7879	9296

Table C-11: Estimated hourly sediment loads (kg) discharged from Flats focus area for 24-hr load events with an average recurrence interval of 2, 10 and 50 years, maximum open area of earthworks.

Flats area			Time																							
			0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
5 year construction (Jan 2019)	2 year ARI	Untreated	9247	14693	21891	29601	46733	90277	127361	105055	47636	26463	16519	10468	6822	4468	2668	1863	1418	1099	915	911	1265	2065	3406	5864
		Treated	454	721	1075	1453	2294	4432	6252	5157	2339	1299	811	514	335	219	131	91	70	54	45	45	62	101	167	288
	10 year ARI	Untreated	6635	11303	17702	23038	25721	26330	27967	30762	36871	45413	47164	38529	31807	32821	43219	98025	208511	227790	119060	48901	29515	18336	12261	8407
		Treated	1101	1876	2937	3823	4268	4369	4641	5104	6118	7536	7826	6393	5278	5446	7171	16266	34599	37798	19756	8114	4898	3043	2035	1395
	50 year ARI	Untreated	20094	35010	59219	146867	300749	351835	225002	139719	206012	250854	187949	85243	39716	22770	15003	10520	7672	6174	5429	4931	6608	8763	12332	14550
		Treated	8817	15363	25986	64447	131972	154389	98734	61311	90401	110078	82474	37406	17428	9992	6584	4616	3367	2709	2382	2164	2900	3845	5411	6385
10 year construction (Mar 2020)	2 year ARI	Untreated	2513	3992	5948	8043	12699	24531	34607	28546	12944	7191	4489	2844	1854	1214	725	506	385	299	249	248	344	561	925	1593
		Treated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10 year ARI	Untreated	1743	2969	4650	6052	6757	6917	7347	8081	9686	11930	12390	10122	8356	8622	11354	25751	54776	59841	31277	12846	7754	4817	3221	2209
		Treated	93	158	247	322	359	368	390	430	515	634	659	538	444	458	603	1369	2911	3181	1662	683	412	256	171	117
	50 year ARI	Untreated	5048	8796	14878	36900	75562	88397	56531	35104	51760	63026	47221	21417	9978	5721	3769	2643	1928	1551	1364	1239	1660	2202	3098	3656
		Treated	1753	3054	5165	12811	26233	30689	19626	12187	17969	21881	16394	7435	3464	1986	1309	918	669	538	474	430	576	764	1076	1269

Appendix D Hourly Nutrient Concentration Estimates

Table D-1: Estimated hourly runoff sediment-N concentration (mg/L) at stream site AC-FHQ for 24-hr load events with an average recurrence interval of 2, 10 and 50 years, maximum open area of earthworks compared to catchment background.

AC-FHQ			Time																						
			0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
	2 year ARI	Background	3.65	4.78	6.02	7.17	9.48	14.36	17.85	15.81	9.60	6.72	5.12	3.93	3.06	2.95	2.94	2.92	2.91	2.90	2.90	2.90	2.91	2.92	2.94	2.96
		Project, untreated	37.29	48.77	61.47	73.21	96.80	146.63	182.17	161.34	97.98	68.61	52.21	40.07	31.26	30.14	29.96	29.83	29.73	29.65	29.58	29.58	29.69	29.87	30.04	30.26
		Project, treated	7.95	10.41	13.11	15.62	20.65	31.28	38.87	34.43	20.90	14.64	11.14	8.55	6.67	6.43	6.39	6.36	6.34	6.32	6.31	6.31	6.34	6.38	6.41	6.45
5 year (Jan 2019)	10 year ARI	Background	3.34	4.55	5.91	6.88	7.33	7.43	7.70	8.14	9.17	10.46	10.71	9.43	8.30	8.45	10.14	16.99	27.35	28.91	19.21	10.96	7.94	6.03	4.77	3.83
		Project, untreated	25.83	35.18	45.64	53.17	56.68	57.45	59.50	62.88	70.88	80.84	82.79	72.88	64.11	65.29	78.36	131.33	211.40	223.53	148.47	84.70	61.39	46.58	36.89	29.63
		Project, treated	7.65	10.42	13.52	15.75	16.79	17.01	17.62	18.63	20.99	23.94	24.53	21.59	18.99	19.34	23.21	38.90	62.61	66.20	43.98	25.09	18.18	13.79	10.92	8.78
	50 year ARI	Background	5.46	7.74	10.78	19.13	30.06	32.10	25.03	18.54	23.68	26.81	22.35	13.58	8.38	5.90	4.53	3.69	3.08	2.71	2.51	2.38	2.82	3.32	4.05	4.46
		Project, untreated	30.92	43.89	61.14	108.42	170.39	181.97	141.89	105.06	134.21	151.97	126.67	76.93	47.52	33.46	25.70	20.92	17.42	15.36	14.26	13.48	15.98	18.82	22.94	25.25
		Project, treated	13.69	19.43	27.07	48.00	75.43	80.56	62.82	46.51	59.42	67.27	56.08	34.06	21.04	14.81	11.38	9.26	7.72	6.80	6.31	5.97	7.08	8.33	10.16	11.18
	2 year ARI	Background	3.65	4.78	6.02	7.17	9.48	14.36	17.85	15.81	9.60	6.72	5.12	3.93	3.06	2.95	2.94	2.92	2.91	2.90	2.90	2.90	2.91	2.92	2.94	2.96
		Project, untreated	20.60	26.95	33.96	40.45	53.48	81.01	100.65	89.14	54.13	37.90	28.84	22.14	17.27	16.65	16.55	16.48	16.43	16.37	16.34	16.34	16.41	16.50	16.60	16.72
		Project, treated	5.03	6.58	8.29	9.87	13.05	19.77	24.57	21.76	13.21	9.25	7.04	5.41	4.22	4.07	4.04	4.03	4.01	4.00	3.99	3.99	4.01	4.03	4.05	4.08
10 year (Mar 2020)	10 year ARI	Background	3.34	4.55	5.91	6.88	7.33	7.43	7.70	8.14	9.17	10.46	10.71	9.43	8.30	8.45	10.14	16.99	27.35	28.91	19.21	10.96	7.94	6.03	4.77	3.83
		Project, untreated	14.58	19.85	25.75	30.00	31.98	32.43	33.57	35.48	40.00	45.62	46.72	41.12	36.18	36.84	44.22	74.12	119.30	126.14	83.78	47.80	34.64	26.29	20.82	16.72
		Project, treated	5.12	6.98	9.05	10.54	11.23	11.39	11.79	12.46	14.05	16.02	16.41	14.45	12.71	12.94	15.53	26.03	41.90	44.30	29.42	16.79	12.16	9.23	7.31	5.87
	50 year ARI	Background	5.46	7.74	10.78	19.13	30.06	32.10	25.03	18.54	23.68	26.81	22.35	13.58	8.38	5.90	4.53	3.69	3.08	2.71	2.51	2.38	2.82	3.32	4.05	4.46
		Project, untreated	18.02	25.57	35.62	63.16	99.26	106.01	82.67	61.21	78.19	88.53	73.79	44.82	27.69	19.50	14.98	12.19	10.15	8.95	8.30	7.85	9.31	10.96	13.37	14.71
		Project, treated	9.87	14.01	19.52	34.62	54.40	58.10	45.30	33.54	42.85	48.52	40.44	24.57	15.17	10.69	8.20	6.68	5.56	4.90	4.55	4.30	5.10	6.01	7.33	8.06

Table D-2: Estimated hourly runoff sediment-N concentration (mg/L) at stream site MW for 24-hr load events with an average recurrence interval of 2, 10 and 50 years, maximum open area of earthworks compared to catchment background.

MW			Time																						
			0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
	2 year ARI	Background	2.94	3.99	4.76	5.38	6.53	8.46	9.68	8.98	6.59	5.14	4.31	3.19	2.41	1.82	1.39	1.15	1.00	0.87	0.79	0.79	0.94	1.21	1.58	2.18
		Project, untreated	9.35	12.67	15.11	17.09	20.76	26.87	30.75	28.51	20.92	16.32	13.68	10.14	7.66	5.79	4.42	3.66	3.16	2.77	2.51	2.51	2.98	3.85	5.02	6.93
		Project, treated	3.68	4.98	5.95	6.73	8.16	10.57	12.10	11.22	8.23	6.42	5.39	3.99	3.01	2.28	1.74	1.44	1.25	1.09	0.99	0.99	1.17	1.52	1.97	2.73
5 year (Jan 2019)	10 year ARI	Background	2.96	4.20	5.13	5.72	5.97	6.03	6.18	6.43	6.98	7.57	7.69	7.10	6.51	6.60	7.43	10.24	13.73	14.26	11.05	7.79	6.32	5.21	4.43	3.46
		Project, untreated	7.67	10.88	13.30	14.81	15.49	15.64	16.02	16.67	18.09	19.63	19.92	18.40	16.89	17.11	19.25	26.54	35.57	36.96	28.64	20.21	16.38	13.49	11.48	8.96
		Project, treated	3.83	5.44	6.65	7.41	7.74	7.82	8.01	8.33	9.04	9.81	9.96	9.20	8.45	8.55	9.62	13.27	17.79	18.48	14.32	10.10	8.19	6.75	5.74	4.48
	50 year ARI	Background	5.56	6.92	8.49	12.23	16.67	17.83	14.70	11.97	14.15	15.40	13.60	9.67	7.27	5.84	4.90	4.24	3.72	3.37	3.09	2.90	3.52	3.93	4.52	4.84
		Project, untreated	11.91	14.81	18.20	26.20	35.69	38.19	31.49	25.63	30.31	33.01	29.14	20.71	15.56	12.51	10.49	9.08	7.98	7.21	6.62	6.22	7.54	8.42	9.68	10.36
		Project, treated	7.85	9.76	11.99	17.26	23.52	25.17	20.74	16.89	19.97	21.75	19.19	13.64	10.26	8.24	6.91	5.98	5.25	4.75	4.36	4.10	4.96	5.55	6.38	6.82
	2 year ARI	Background	2.94	3.99	4.76	5.38	6.53	8.46	9.68	8.98	6.59	5.14	4.31	3.19	2.41	1.82	1.39	1.15	1.00	0.87	0.79	0.79	0.94	1.21	1.58	2.18
		Project, untreated	5.91	8.01	9.54	10.79	13.11	16.98	19.43	18.02	13.21	10.31	8.65	6.41	4.84	3.66	2.79	2.31	2.00	1.75	1.59	1.58	1.88	2.44	3.17	4.38
		Project, treated	3.15	4.28	5.10	5.76	7.00	9.07	10.38	9.62	7.06	5.50	4.62	3.42	2.58	1.95	1.49	1.23	1.07	0.93	0.84	0.84	1.00	1.30	1.70	2.34
10 year (Mar 2020)	10 year ARI	Background	2.96	4.20	5.13	5.72	5.97	6.03	6.18	6.43	6.98	7.57	7.69	7.10	6.51	6.60	7.43	10.24	13.73	14.26	11.05	7.79	6.32	5.21	4.43	3.46
		Project, untreated	5.11	7.25	8.86	9.87	10.32	10.42	10.68	11.10	12.05	13.07	13.27	12.26	11.25	11.40	12.82	17.68	23.70	24.62	19.08	13.46	10.92	8.99	7.65	5.97
		Project, treated	3.28	4.65	5.69	6.33	6.63	6.69	6.85	7.13	7.74	8.40	8.52	7.87	7.22	7.32	8.23	11.35	15.21	15.81	12.25	8.64	7.01	5.77	4.91	3.83
	50 year ARI	Background	5.56	6.92	8.49	12.23	16.67	17.83	14.70	11.97	14.15	15.40	13.60	9.67	7.27	5.84	4.90	4.24	3.72	3.37	3.09	2.90	3.52	3.93	4.52	4.84
		Project, untreated	8.53	10.60	13.03	18.74	25.55	27.34	22.54	18.35	21.69	23.62	20.86	14.82	11.14	8.96	7.51	6.49	5.71	5.15	4.74	4.45	5.39	6.03	6.93	7.42
		Project, treated	6.69	8.32	10.23	14.72	20.06	21.46	17.69	14.41	17.03	18.55	16.37	11.64	8.75	7.03	5.89	5.10	4.48	4.05	3.72	3.49	4.23	4.73	5.45	5.82

Table D-3: Estimated hourly runoff sediment-P concentration (mg/L) at stream site AC-FHQ for 24-hr load events with an average recurrence interval of 2, 10 and 50 years, maximum open area of earthworks compared to catchment background.

AC-FHQ			Time																							
			0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
	2 year ARI	Background	0.45	0.59	0.74	0.88	1.16	1.76	2.19	1.94	1.18	0.82	0.63	0.48	0.38	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
		Project, untreated	4.58	5.99	7.54	8.99	11.88	18.00	22.36	19.80	12.02	8.42	6.41	4.92	3.84	3.70	3.68	3.66	3.65	3.64	3.63	3.63	3.64	3.67	3.69	3.71
		Project, treated	0.98	1.28	1.61	1.92	2.53	3.84	4.77	4.22	2.57	1.80	1.37	1.05	0.82	0.79	0.78	0.78	0.78	0.78	0.77	0.77	0.78	0.78	0.79	0.79
5 year	10 year ARI	Background	0.41	0.56	0.72	0.84	0.90	0.91	0.94	1.00	1.13	1.28	1.31	1.16	1.02	1.04	1.24	2.08	3.36	3.55	2.36	1.34	0.97	0.74	0.59	0.47
(Jan		Project, untreated	3.17	4.32	5.60	6.53	6.96	7.05	7.30	7.72	8.70	9.92	10.16	8.94	7.87	8.01	9.62	16.12	25.94	27.43	18.22	10.40	7.53	5.72	4.53	3.64
2019)		Project, treated	0.94	1.28	1.66	1.93	2.06	2.09	2.16	2.29	2.58	2.94	3.01	2.65	2.33	2.37	2.85	4.77	7.68	8.13	5.40	3.08	2.23	1.69	1.34	1.08
	50 year ARI	Background	0.67	0.95	1.32	2.35	3.69	3.94	3.07	2.28	2.91	3.29	2.74	1.67	1.03	0.72	0.56	0.45	0.38	0.33	0.31	0.29	0.35	0.41	0.50	0.55
		Project, untreated	3.79	5.39	7.50	13.31	20.91	22.33	17.41	12.89	16.47	18.65	15.55	9.44	5.83	4.11	3.15	2.57	2.14	1.88	1.75	1.65	1.96	2.31	2.82	3.10
		Project, treated	1.68	2.38	3.32	5.89	9.26	9.89	7.71	5.71	7.29	8.26	6.88	4.18	2.58	1.82	1.40	1.14	0.95	0.83	0.77	0.73	0.87	1.02	1.25	1.37
	2 year ARI	Background	0.45	0.59	0.74	0.88	1.16	1.76	2.19	1.94	1.18	0.82	0.63	0.48	0.38	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
		Project, untreated	2.53	3.31	4.17	4.96	6.56	9.94	12.35	10.94	6.64	4.65	3.54	2.72	2.12	2.04	2.03	2.02	2.02	2.01	2.01	2.01	2.01	2.03	2.04	2.05
		Project, treated	0.62	0.81	1.02	1.21	1.60	2.43	3.02	2.67	1.62	1.14	0.86	0.66	0.52	0.50	0.50	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.50	0.50
10 year	10 year ARI	Background	0.41	0.56	0.72	0.84	0.90	0.91	0.94	1.00	1.13	1.28	1.31	1.16	1.02	1.04	1.24	2.08	3.36	3.55	2.36	1.34	0.97	0.74	0.59	0.47
(Mar		Project, untreated	1.79	2.44	3.16	3.68	3.93	3.98	4.12	4.35	4.91	5.60	5.73	5.05	4.44	4.52	5.43	9.10	14.64	15.48	10.28	5.87	4.25	3.23	2.55	2.05
2020)		Project, treated	0.63	0.86	1.11	1.29	1.38	1.40	1.45	1.53	1.72	1.97	2.01	1.77	1.56	1.59	1.91	3.19	5.14	5.44	3.61	2.06	1.49	1.13	0.90	0.72
	50 year ARI	Background	0.67	0.95	1.32	2.35	3.69	3.94	3.07	2.28	2.91	3.29	2.74	1.67	1.03	0.72	0.56	0.45	0.38	0.33	0.31	0.29	0.35	0.41	0.50	0.55
		Project, untreated	2.21	3.14	4.37	7.75	12.18	13.01	10.15	7.51	9.60	10.87	9.06	5.50	3.40	2.39	1.84	1.50	1.25	1.10	1.02	0.96	1.14	1.35	1.64	1.81
		Project, treated	1.21	1.72	2.40	4.25	6.68	7.13	5.56	4.12	5.26	5.95	4.96	3.01	1.86	1.31	1.01	0.82	0.68	0.60	0.56	0.53	0.63	0.74	0.90	0.99

Table D-4: Estimated hourly runoff sediment-P concentration (mg/L) at stream site MW for 24-hr load events with an average recurrence interval of 2, 10 and 50 years, maximum open area of earthworks compared to catchment background.

MW			Time																						
			0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
	2 year ARI	Background	0.36	0.49	0.58	0.66	0.80	1.04	1.19	1.10	0.81	0.63	0.53	0.39	0.30	0.22	0.17	0.14	0.12	0.11	0.10	0.10	0.12	0.15	0.19	0.27
		Project, untreated	1.15	1.56	1.85	2.10	2.55	3.30	3.77	3.50	2.57	2.00	1.68	1.24	0.94	0.71	0.54	0.45	0.39	0.34	0.31	0.31	0.37	0.47	0.62	0.85
		Project, treated	0.45	0.61	0.73	0.83	1.00	1.30	1.48	1.38	1.01	0.79	0.66	0.49	0.37	0.28	0.21	0.18	0.15	0.13	0.12	0.12	0.14	0.19	0.24	0.33
5 year (Jan 2019)	10 year ARI	Background	0.36	0.52	0.63	0.70	0.73	0.74	0.76	0.79	0.86	0.93	0.94	0.87	0.80	0.81	0.91	1.26	1.68	1.75	1.36	0.96	0.78	0.64	0.54	0.42
		Project, untreated	0.94	1.34	1.63	1.82	1.90	1.92	1.97	2.05	2.22	2.41	2.44	2.26	2.07	2.10	2.36	3.26	4.37	4.54	3.52	2.48	2.01	1.66	1.41	1.10
		Project, treated	0.47	0.67	0.82	0.91	0.95	0.96	0.98	1.02	1.11	1.20	1.22	1.13	1.04	1.05	1.18	1.63	2.18	2.27	1.76	1.24	1.01	0.83	0.70	0.55
	50 year ARI	Background	0.68	0.85	1.04	1.50	2.05	2.19	1.80	1.47	1.74	1.89	1.67	1.19	0.89	0.72	0.60	0.52	0.46	0.41	0.38	0.36	0.43	0.48	0.55	0.59
		Project, untreated	1.46	1.82	2.23	3.21	4.38	4.69	3.86	3.15	3.72	4.05	3.58	2.54	1.91	1.54	1.29	1.11	0.98	0.88	0.81	0.76	0.93	1.03	1.19	1.27
		Project, treated	0.96	1.20	1.47	2.12	2.89	3.09	2.55	2.07	2.45	2.67	2.36	1.67	1.26	1.01	0.85	0.73	0.64	0.58	0.54	0.50	0.61	0.68	0.78	0.84
	2 year ARI	Background	0.36	0.49	0.58	0.66	0.80	1.04	1.19	1.10	0.81	0.63	0.53	0.39	0.30	0.22	0.17	0.14	0.12	0.11	0.10	0.10	0.12	0.15	0.19	0.27
		Project, untreated	0.72	0.98	1.17	1.32	1.61	2.08	2.38	2.21	1.62	1.27	1.06	0.79	0.59	0.45	0.34	0.28	0.25	0.21	0.20	0.19	0.23	0.30	0.39	0.54
		Project, treated	0.39	0.52	0.63	0.71	0.86	1.11	1.27	1.18	0.87	0.68	0.57	0.42	0.32	0.24	0.18	0.15	0.13	0.11	0.10	0.10	0.12	0.16	0.21	0.29
10 year (Mar 2020)	10 year ARI	Background	0.36	0.52	0.63	0.70	0.73	0.74	0.76	0.79	0.86	0.93	0.94	0.87	0.80	0.81	0.91	1.26	1.68	1.75	1.36	0.96	0.78	0.64	0.54	0.42
		Project, untreated	0.63	0.89	1.09	1.21	1.27	1.28	1.31	1.36	1.48	1.60	1.63	1.50	1.38	1.40	1.57	2.17	2.91	3.02	2.34	1.65	1.34	1.10	0.94	0.73
		Project, treated	0.40	0.57	0.70	0.78	0.81	0.82	0.84	0.87	0.95	1.03	1.05	0.97	0.89	0.90	1.01	1.39	1.87	1.94	1.50	1.06	0.86	0.71	0.60	0.47
	50 year ARI	Background	0.68	0.85	1.04	1.50	2.05	2.19	1.80	1.47	1.74	1.89	1.67	1.19	0.89	0.72	0.60	0.52	0.46	0.41	0.38	0.36	0.43	0.48	0.55	0.59
		Project, untreated	1.05	1.30	1.60	2.30	3.14	3.36	2.77	2.25	2.66	2.90	2.56	1.82	1.37	1.10	0.92	0.80	0.70	0.63	0.58	0.55	0.66	0.74	0.85	0.91
		Project, treated	0.82	1.02	1.26	1.81	2.46	2.63	2.17	1.77	2.09	2.28	2.01	1.43	1.07	0.86	0.72	0.63	0.55	0.50	0.46	0.43	0.52	0.58	0.67	0.71