REPORT

Hawke's Bay Regional Investment Company Limited

Ruataniwha Water Storage Scheme Sedimentation Assessment

Tonkin & Taylor

ENVIRONMENTAL AND ENGINEERING CONSULTANTS

REPORT

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Ruataniwha Water Storage Scheme Sedimentation Assessment

Report prepared for:

Hawke's Bay Regional Investment Company Limited

Report prepared by:

Tonkin & Taylor Ltd

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Executive summary

This report summarises the main results of the sedimentation assessment conducted for Hawke's Bay Regional Investment Company (HBRIC) by Tonkin & Taylor Ltd (T&T) for the Ruataniwha Water Storage Scheme (the "Scheme") in Central Hawke's Bay.

Assessments undertaken

The four main aspects of the assessment scope are:

1) Develop a sediment allowance for the Reservoir
2) Assess the effects of the Dam on downstream sediments and the coast
3) Review the sediment management options
4) Develop the sediment mitigation plan.

The methodology utilises the good sources of measured data that exist for the Tukituki/ Waipawa River system. The measured data consists primarily of river cross sections that are used to develop a sediment budget, and the measured accumulation at Folger's Lake. Suspended sediment yields are estimated using the WRENZ model calibrated to the Waipukurau gauge (Tukituki River) and the trapping efficiency in the reservoir based on the Brune method.

The changes to the sediment budget due to the Dam are quantified for each reach and the effects qualitatively assessed. A number of reports/papers provide useful information on sedimentation for the Tukituki/Waipawa River system, which are used where relevant.

Assessments of changes to gravel transport capacity and assessments of degradation depths and armouring effects are made.

Results of the assessments undertaken

The estimate of sedimentation in the Reservoir is 15-26 million m^3 over 100 years based on the range of estimates. These sedimentation estimates result in reservoir half full times ranging from 175 to 287 years and ultimate fill times ranging from 355 to 603 years.

There remains considerable uncertainty in the bed load estimates, which is inherent with this type of estimate. We consider that the lower estimate to be non-conservative due to unaccounted sediment losses in the sediment budget, and the upper estimate to be conservative due to the stormier period that was the basis of the Folger's Lake derived estimate for bed material.

The suspended sediment estimates are from the WRENZ model based on the unscaled estimate and the Waipukurau measured suspended sediment upscaled for the upper Makaroro catchment characteristics, which give similar estimates.

Sediment generation is greatly influenced by extreme events such as extreme floods and/or earthquakes and these have the ability to increase the rate of reservoir sedimentation. Similarly, prolonged periods of quiescent conditions will reduce sedimentation rates.

A sediment delta will form within the reservoir. The physical impacts of sedimentation are loss of storage, restrictions to access (in areas where sediment has deposited) and the potential for impacts on the Dam outlets. These impacts can be mitigated by design. The delta and hydraulic backwater effects from the reservoir will eventually cause an increase in flood levels upstream of the reservoir. There are no existing bridges or river management infrastructure upstream of the reservoir that will be affected.

When the reservoir is drawn down there is the potential for dust generation. The Dam site is remote with few surrounding dwellings. Therefore, the potential for affecting the general public appears to be low.

The interruption of sediment from the Dam will have greatest effect on the 12 km reach of the Makaroro River between the dam and the confluence with the Waipawa River. The likely effects are degradation and coarsening of the bed sediment.

These effects will be mitigated to some extent by the reduction in sediment transport due to the armouring and the reduction in flood flows. However, the reduction in flood flows will reduce the ability of the flows to erode vegetation. The encroachment of vegetation will likely reduce the channel width and form. The river will trend towards fewer channels.

There is no river management infrastructure on this reach. Therefore, changes to the channel form and levels will have no effect on river management infrastructure. Burnt Bridge (Makaroro River) and to a lesser extent the Wakarara Road Bridge (Waipawa River) have the potential to be affected by lowering of bed level. These should be monitored as part of the draft sediment management plan.

The interruption of sediment from the Dam will have a lesser effect on the rivers downstream of the confluence of the Makaroro and Waipawa, as there will still be a surplus of gravel for these reaches from other rivers. The interruption of sediment supply from the Makaroro River will result in less aggradation (currently occurs) and can be accommodated by less extraction (if required). A reduction in sediment transport capacity is predicted at the upstream water intake, which may result in local aggradation.

An additional effect is the reduction in gravel transport capacity to the coast of 1,700 m^3/year. Mitigation by coastal nourishment is proposed so that existing coastal erosion that is occurring in the vicinity of the mouth of the Tukituki River is not worsened.

There will be a net long term reduction in the gravel resource for extraction and construction industry purposes from the Waipawa and Tukituki. Although gravel will become available at the Reservoir, this is further away from markets (i.e. the Dam and reservoir location is more remote than the current extraction locations).

The ecological effects that result from the change in river morphology are described in ecology assessments.

Suggested approach for mitigation of the effects of the Scheme

Sediment management options have been assessed and the preferred suggested options are included in the draft sediment management plan in this report. A summary is provided below.

Location/ issue	Monitoring	Management
Reservoir	Cross-section/bathymetry survey to monitor sedimentation and delta development. Frequency 3 years. Flow gauging of releases from the Dam.	*Design* Include sedimentation allowances in the volume requirement of the Dam. Design of outlet structures for sedimentation. The location of recreation areas and access points to the reservoir to consider sedimentation. Land management measures including sediment management practices for forestry areas and fire protection programmes for the Ruahine Forest Park and the commercial forestry. *Medium to long-term* (not included in the Application Design) Extraction of gravel for construction industry e.g. roading aggregate Hydraulic flushing of fine sediments via low outlets (would need to be provided for at the detailed design stage). Sediment focussing by in-reservoir works to manage sediment storage within the reservoir. These can consist of training banks and similar structures to enhance flushing of sediment from live storage to dead storage, and for access up-river. *Closure* (not included in the Application Design) Dam removal is an option to consider at the end of the operating life if required. Restrictions to access (in areas where sediment has deposited) and the potential for impacts on the Dam outlets.
Reservoir dust	Dust generation should be monitored with inhabitants provided a contact number of the Dam operator if they wish to make complaints. The operator should keep a register of complaints consistent with or similar to Appendix 2 of Good Practice Guide for Assessing and Managing the Environmental Effects of Dust Emissions (MfE 2001). Copies of the register should be forwarded to HBRC for their consideration of whether further preventative action is appropriate.	Should a dust issue arise then consideration to planting shelter belts.

Makaroro River downstream of the Dam	Cross-section survey at 3 year frequency to match existing HBRC monitoring programme. Maximum spacing to match existing HBRC monitoring programme of 500 m and to include Burnt Bridge. Measure particle size distribution of bed surface particle-size distribution at three year frequency at representative and accessible locations to monitor armour development.	Respond to degradation of channel at Burnt Bridge (if required). Options include grade control (rock weir) or underpinning of piers.
Waipawa River between Makaroro confluence and SH50	Cross-section survey at 3 year frequency which is a continuation of existing HBRC river monitoring. Additional cross sections to be included for Waipawa upstream of the Waipawa/Makaroro confluence including Wakarara Road Bridge and Pendle Hill Bridge (1 km upstream) with maximum spacing of 500 m. Additional cross section for the Upstream Water Intake.	Respond to degradation of channel at Wakarara Road Bridge (if required). Options include grade control (rock weir) or underpinning of piers. The long term reduction in extraction (if required) based on monitoring in accordance with current HBRC flood and sediment management practices. Extraction of excess gravel at the irrigation intake and elsewhere in accordance with HBRC river management practices. Optional spraying and raking of gravel beds to increase the supply of gravel (if required). Significant accumulation of gravel has occurred in this reach.
Waipawa/ Tukituki Rivers downstream of SH50	Cross-section survey at existing cross section locations at 3 year frequency, which is a continuation of existing HBRC river monitoring.	Normal river management practises undertaken by HBRC. The long term reduction in extraction (if required) based on monitoring in accordance with current HBRC flood and sediment management practices, refer to Section 3.5 for details.
Coast	Cross-section surveys at existing cross section locations, which is a continuation of existing location and frequency of HBRC coastline monitoring.	Beach nourishment of 3,400 m^3/year comprising of 1700 m^3/year of river sediment placed within the Coastal Marine Area directly along the barrier beach between Richmond Road and School Road extension and an additional 1,700 m^3/year to the south along the spit. Review the beach nourishment requirements based on updated assessments of reduction in capacity (and renourishment needs) due to the Scheme using the consented reservoir operating regime. Review to be based on monitoring and modelling at year 3 and at subsequently at nine year intervals. Changes in beach nourishment to be approved by HBRC manager.
Tukituki River basin	Cross-section monitoring (as above), selected PSD sampling, sediment and flow gauging.	Morphological model be developed for the Tukituki River basin including Waipawa and Makaroro Rivers.

Glossary Abbreviations and Definitions[1]

AEP: Annual Exceedance Probability

CEMP: Construction Environmental Management Plan

CFRD: Concrete Faced Rockfill Dam

CHBDC: Central Hawke's Bay District Council

CHBDP: Central Hawke's Bay District Plan

CTMP: Construction Traffic Management Plan

Dam: The Proposed Makaroro Dam (on the Makaroro River) or RWSS Dam also referred to as "the Dam", "storage dam" or "the Makaroro Dam"

Includes all facets of the Dam and associated structures

D&C: Design and Construct

DWI: Downstream Water Intake

The point and structure at the lower end of the Waipawa River where water released from the dam is taken to supply Zone M

EPA: Environmental Protection Authority

EOI: Expressions of Interest

Headrace: Also referred to as "headrace canal" as part of the PDS

Headrace canal watercourse system stemming from the UWI

HBRIC: Hawke's Bay Regional Investment Company

HBRC: Hawke's Bay Regional Council

HDC: Hastings District Council

HDP: Hastings District Plan

MALF: Mean Annual Low Flow

IEMP: Irrigation Environmental Management Plan

Overseer: A computer model that calculates and estimates the nutrient flows in a productive farming system and identifies risk for environmental impacts through nutrient loss, including run off and leaching, and greenhouse gas emissions

PC6: "Plan Change 6" or the Tukituki River Catchment Plan Change

A draft plan change which to objective, policies and rules of the RRMP

[1] Where required a brief description is provided. For more detailed definitions and descriptions refer to the technical reports relating to the RWSS.

PD:	Project Description
	Provides a description of the proposed Ruataniwha Water Storage Scheme, see the PD for a full description
PDS:	Primary Distribution System
	Comprises of the primary headrace canals and pipelines that are connected to the intake structures that provide water to the SDS, see the PD for a full description
PLUA:	Production Land Use Areas
	Areas of irrigable land suitable for primary production within the schemes five command zones
Reservoir:	The body of water stored behind the dam on the Makaroro River
RMA:	Resource Management Act
ROR:	Reservoir Operating Regime
	Describes the procedure, methodology and system for operating the dam relative to reservoir and river water levels for the storage dam to service the overall scheme
RRMP:	The Hawke's Bay Regional Resource Management Plan (generally referred to as the "regional plan")
RPS:	The Hawke's Bay Regional Policy Statement (forming part of the RRMP)
RPS Change 5:	Regional Policy Statement Change 5 "Land use and freshwater management".
RWSS:	Ruataniwha Water Storage Scheme (also referred to as "the Scheme" or "RWS Scheme")
SDS:	Secondary Distribution System
	Comprises of a network of pipelines that are connected to the PDS that deliver water to properties i.e. "the farm gate", see the PD for a full description
SEMP:	Supplementary Environmental Management Plan
SPASMO:	Soil Plant Atmosphere System Model.
	A computer model that provides allocation of irrigation water for chosen crops and land area. It models the transport of water, microbes and solutes through soils integrating variables such as climate, soil, water uptake by plants in relation to farm and orchard practices, and any other factors affecting environmental process and plant production
TRIM:	Tukituki River Model
	A computer model incorporating models, environmental data and GIS used to manage nutrient inputs, land use and water quality
UWI:	Upstream Water Intake
	The point and structure at the upper end of the Waipawa River where water released from the dam is taken to supply Zones A, B, C and D

WDN:	Water Distribution Network Comprises of the PDS and SDS, see the PD for a full description
Zone:	An area labelled A, B, C, D or M that the scheme is providing water to. Also referred to as “command zones”. The word zone is also used in relation to zones in planning maps in the CHBDP and HDP and can be used in different contexts.

1 Introduction

This report summarises the results of the sedimentation assessment conducted for Hawke's Bay Regional Investment Company Limited (HBRIC Ltd) by Tonkin & Taylor Ltd (T&T) for the Ruataniwha Water Storage Scheme (RWSS or "the “Scheme”) in Central Hawke's Bay. The Scheme essentially involves surface water harvesting, storage and distribution for servicing irrigable land principally located on the Ruataniwha Plains.

The four main aspects of the scope are:

1) Develop a sediment allowance for the Reservoir
2) Assess the effects of sedimentation within the reservoir and the interruption of sediment on downstream rivers and the coast
3) Review sediment management options
4) Develop sediment mitigation plan.

The report structure is as follows with Sections 1-3 setting the scene, Section 4 detailing the methodology, Section 5 summarising the sediment budget and Sections 6 to 10 addressing the four main scope aspects listed above.

Section 1	Introduction
Section 2	Proposed Scheme
Section 3	Setting
Section 4	Methodology
Section 5	Sediment budget
Section 6	Sediment allowance for Reservoir
Section 7	Effects from sediment
Section 8	Sediment management
Section 9	Draft sediment management plan.

The sedimentation assessment provides input to the terrestrial and aquatic ecology assessments. The sediment assessment should be read in conjunction with the ecological studies for a full understanding of the effects of the Dam on the river systems.

Appendix J includes comments from the peer reviewer and responses from the report authors. Updates to the report have been made to address the comments made by the peer reviewer and pre-lodgement and completeness comments from the Environmental Protection Authority’s (EPA) engineering advisors Pattle Delamore Partners (PDP).

2 Proposed Scheme

2.1 Scheme

The Ruataniwha Water Storage Scheme consists of surface water harvesting, storage and distribution for servicing of irrigable land in the Ruataniwha Plains. The Scheme is described in the Project Description (PD) (T&T, May 2013). The PD describes the Application Design proposed for resource consent. The main elements of the Scheme are shown in Figure 2.1 and are listed below:

- Dam on the Makaroro River with maximum storage of approximately 91 million m3, inclusive of a hydropower operating buffer
- Waipawa River upstream water intake (UWI)
- Waipawa River downstream water intake (DWI)
- Distribution system from intakes to five discrete zones forming the productive land use area.

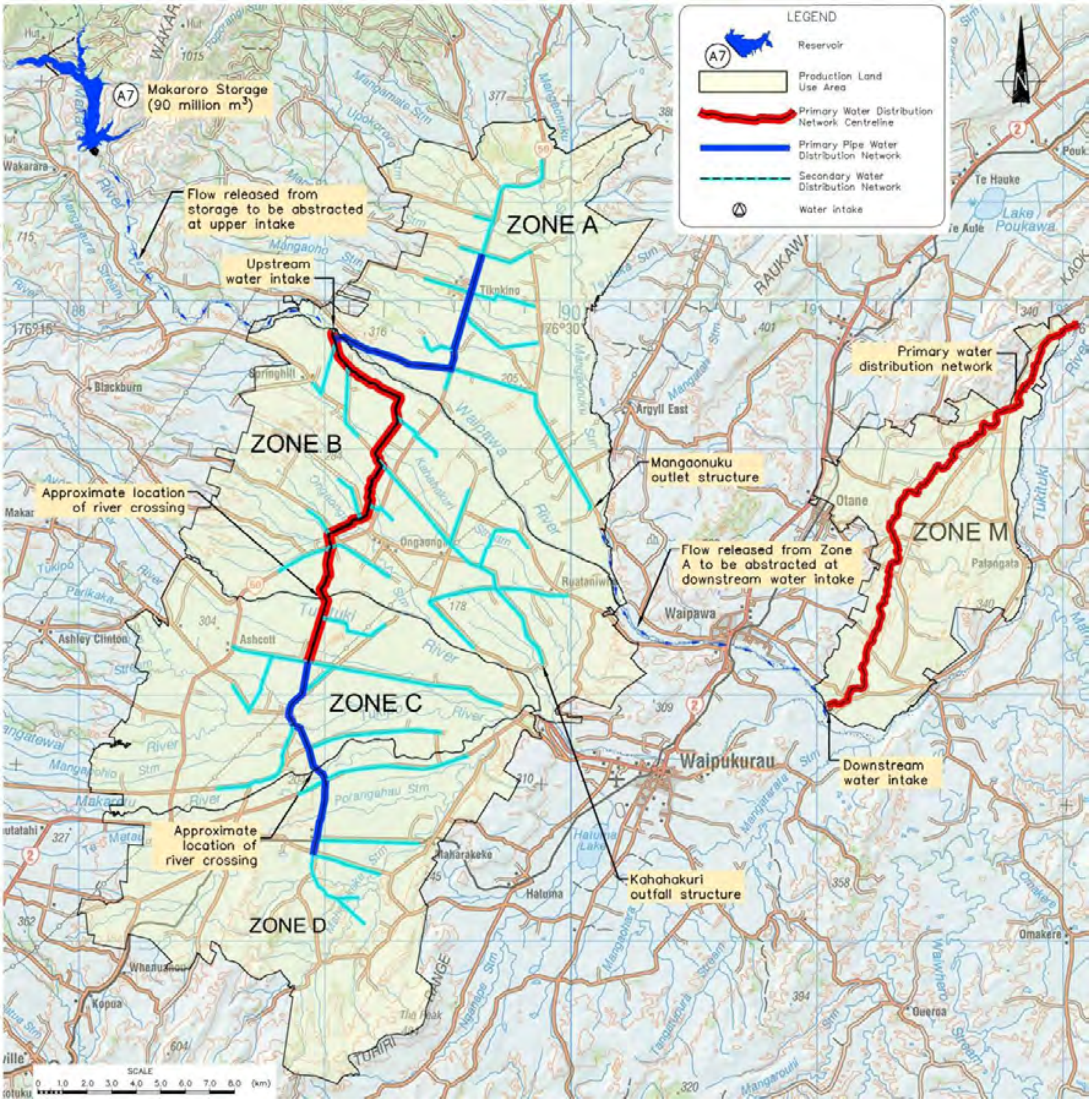

Figure 2.1: Scheme overview showing dam location, reservoir extent, production land use areas, and the proposed water distribution network (T&T, May 2013)

2.2 Dam and reservoir

2.2.1 Dam

The proposed Dam is approximately 83 m high to foundation level at the river's deepest point. A Concrete Faced Rockfill Dam (CFRD) is proposed for the site. The Dam is described in more detail in the PD (T&T, May 2013) and the general arrangement drawing (Dwg. No. 27690-DA-100) is included in Appendix A.

2.2.2 Outlet structures

The Application Design outlet works comprise a full height intake tower for selective withdrawal of water from multiple ports and a low level intake with an operating range of approximately RL 405 m to RL 417 m. The outlets through the Dam consist of a 2100 mm diameter penstock and a 600 mm diameter bypass pipe. Each pipe outlet is controlled by a fixed cone dispersion valve with butterfly guard valves located upstream, and the main penstock has an offtake to the hydro power station.

The Application Design includes two spillways, a primary spillway that operates for all floods and an auxiliary spillway that operates only during very large floods. The preferred locations are the right abutment of the Dam for the primary spillway and the far left abutment for the auxiliary spillway. The primary spillway is concrete lined with a hydraulic jump type energy dissipator, whereas the auxiliary spillway is initially excavated into rock, then discharges onto the existing natural slopes and into a side gully of the gorge. Erosion in the side gully from activation of the auxiliary spillway (events exceeding the 200 year ARI inclusive of an adjustment for climate change) is expected (T&T, May 2013). The final spillway arrangements and outlet works are areas that are identified for future optimisation.

The Application Design outlet structures do not provide for hydraulic flushing of sediment.

2.2.3 Reservoir

The reservoir has a maximum storage volume of approximately 91 million m^3, with a surface area of approximately 370 ha at the Full Supply Level (FSL) of RL 469.5 m. The length of the reservoir is approximately 6.2 km. The reservoir extent is shown in Figure 2.2. The reservoir extent is shown in more detail in the reservoir arrangement drawings (Dwg. No.27690-DA-104 and 105) in Appendix A.

The reservoir floods the Makaroro River valley to a location upstream of the historic Mill site. The reservoir also floods the downstream ends of tributary streams; most significantly Dutch Creek and Donovan Gully.

The elevation versus storage curve is shown in Figure 2.3. The storage elevation curve is derived from LiDAR data. The operating regime and drawdown levels are described in Section 2.3.

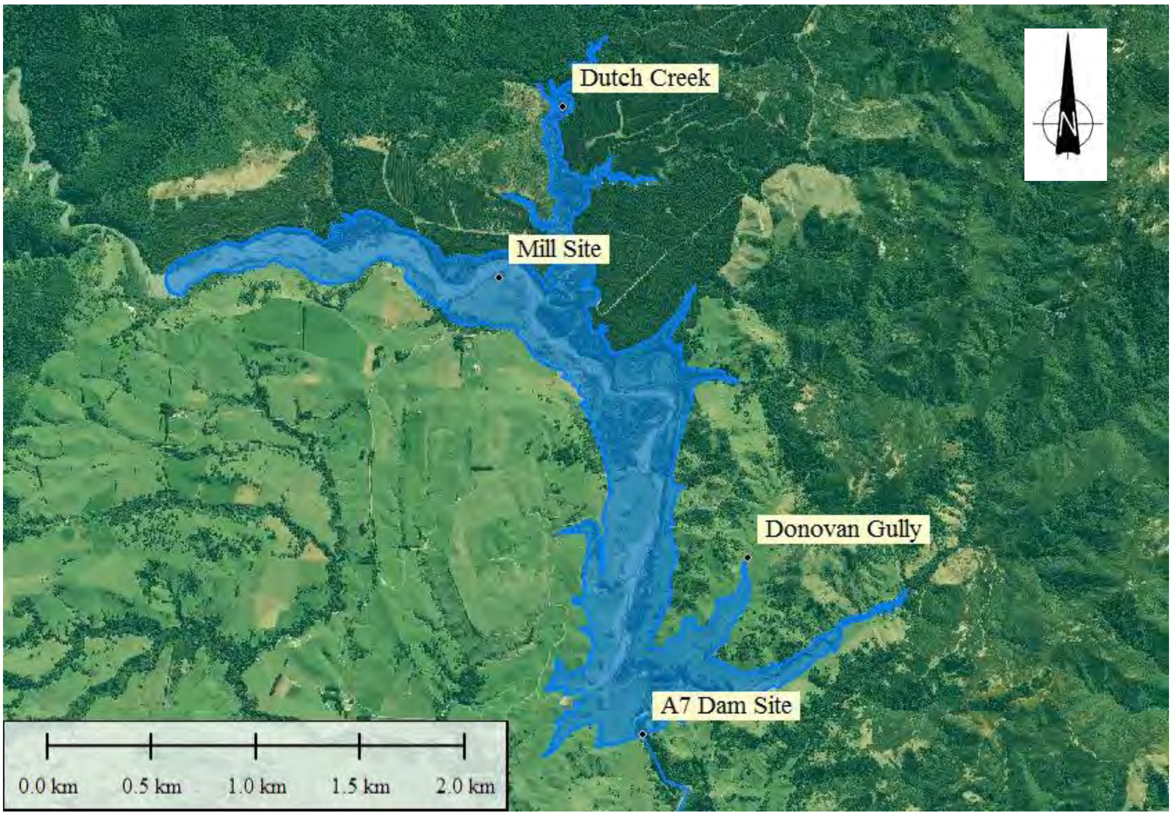

Figure 2.2: Reservoir extent

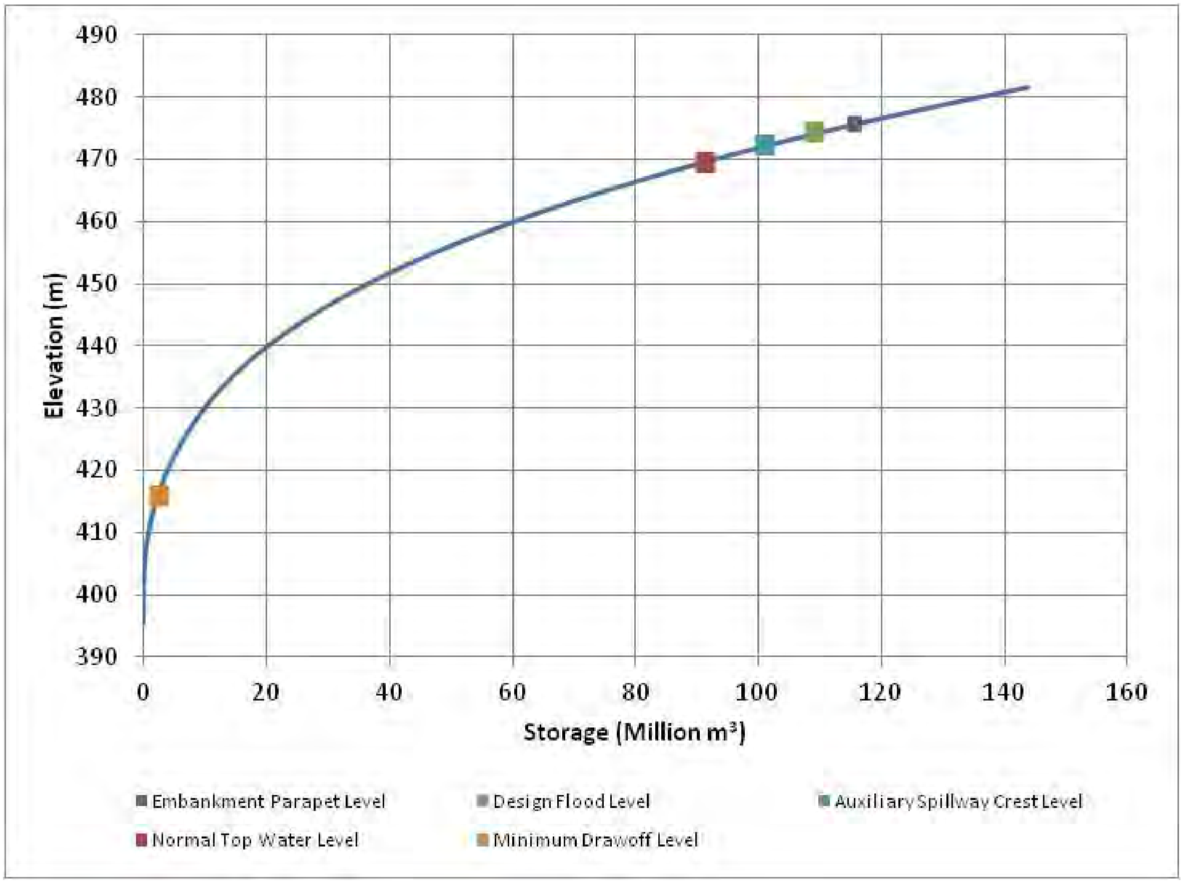

Figure 2.3: Storage elevation curve showing key operating levels

2.3 Operating regime

2.3.1 General

The purpose of the Dam is to harvest, store and release flows back to the river to meet irrigation demand and an environmental flow regime, and to generate hydro-electric power. The operating regime is detailed in the PD (T&T, May 2013).

2.3.2 Operating levels

On average, the lowest reservoir level reached each year would be around 24.5 m below FSL, but would range between about 18 m in a wet year (25th percentile value) and about 29 m in a dry year (75th percentile value) – this would typically occur around March/April. The reservoir would typically be full between mid-July and mid-September (T&T, May 2013).

The water level versus duration curve for all time is shown in Figure 2.4. The water level for 50% exceedance is about RL 464.0 m, which is 5.5 m below FSL. More details on the reservoir water level operating regime are provided in T&T (May 2013).

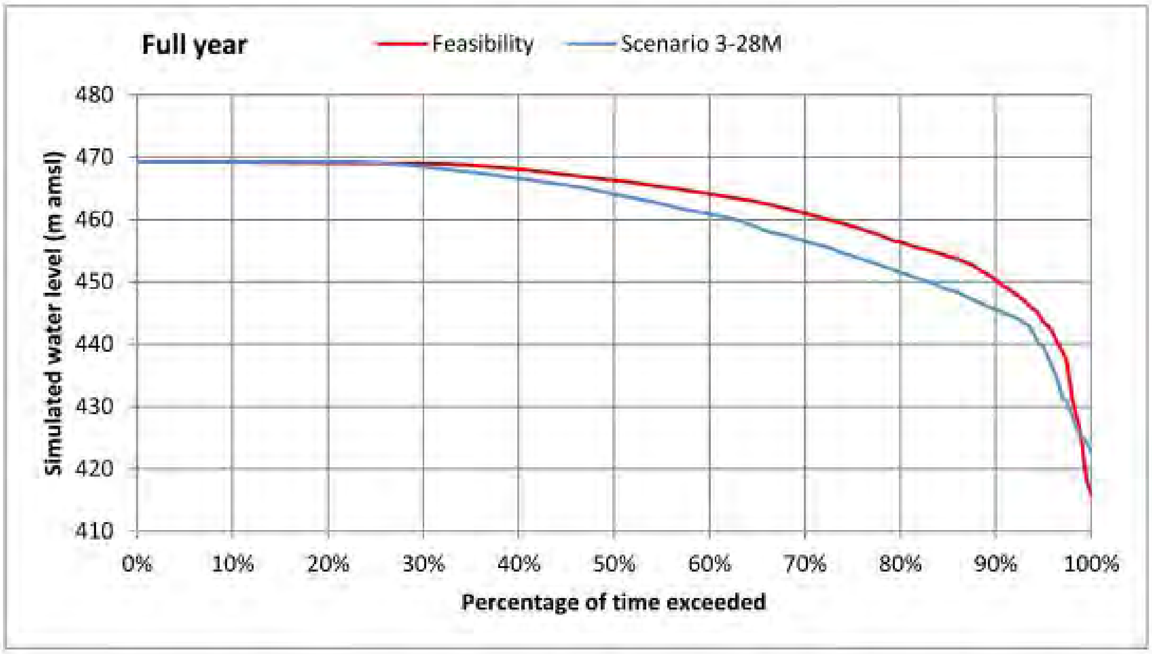

Figure 2.4: Water level duration curve (includes hydro) showing the difference between T&T 2012 Feasibility Study and the Project Description (Scenario 3-28M) (T&T, May 2013); the latter represents the Application Design.

2.3.3 Operating flows

In terms of the Dam outflow regime, monthly mean flows would be broadly more uniform throughout the year, with a lesser bias towards winter. As expected, average flows would be substantially higher during the main irrigation season (October to April), particularly over January and February (more than 100% higher), while average flows would be significantly lower in April, May and June as the reservoir retains flow to refill (T&T, May 2013). The outflow versus duration curve for the Dam is shown in Figure 2.5. The flow duration curve from the Feasibility Study (T&T, August 2012) is slightly different to that in the Application Design (which is shown in Figure 2.5), principally because the former includes the effect of hydropower operation. The application of the outflow versus duration curve in this assessment, as described in Section 4.7.2, is based on the Feasibility Study version of the outflow duration curve.

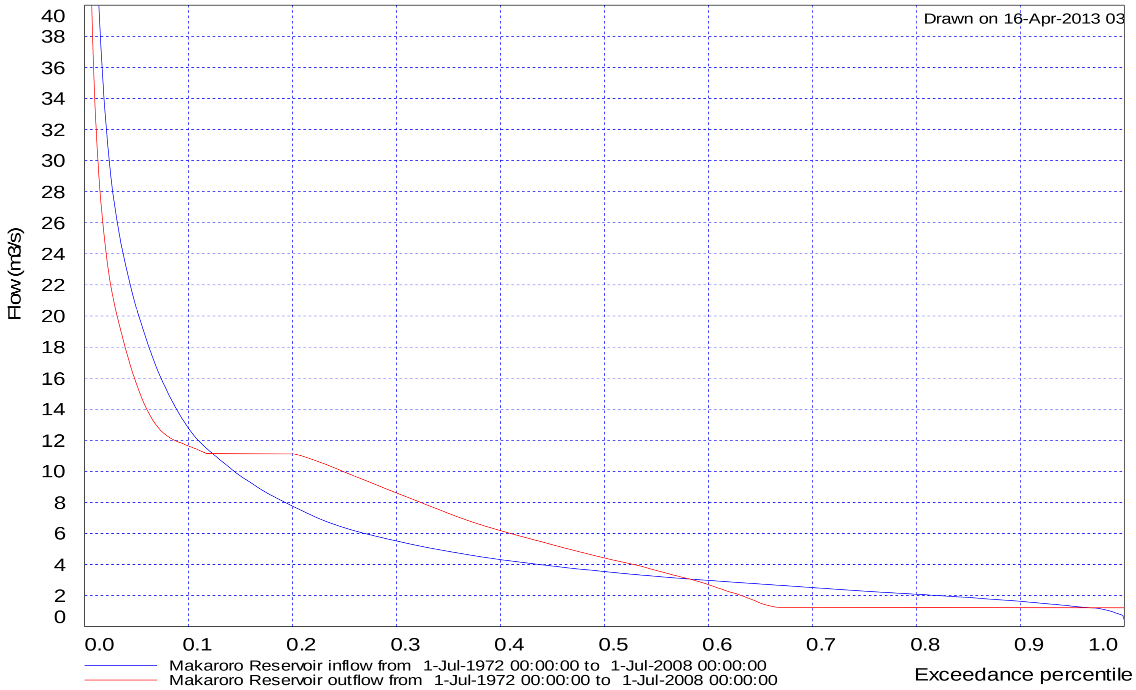

Figure 2.5: Flow duration curves pre-development (blue curve) and post-development (red curve) at the Dam (excluding hydropower operation); flows in litres per second on vertical axis, and fraction of time flow is exceeded on horizontal axis.

2.3.4 Flood flows

The flood flows downstream of the Dam for the pre-development situation and post construction of the Dam are summarised in Table 2.1. The flow attenuation modelling assumes the reservoir level is at the FSL at the storm onset and flow over the spillways only (no flow via the low level outlet works). If the water level is lower than the FSL then greater attenuation will occur and the post-development flood peak will be further reduced.

The reduction in the mean annual flood event (return period of 2.33 years) will be 47% if the flood occurs when the reservoir level is at FSL (RL 469.5 m). However, for water levels less than RL 467.25 m this annual flood event will be stored in the reservoir without any flow over the spillways. The reservoir water level is below this level for approximately 62% of the time. This is based on the mean annual flood event having a 48 hour flow volume of 8.2 million m^3 (T&T, August 2012c).

Table 2.1: Pre and post-development flood peak flow estimates for the Dam

Return period	Peak inflow (m^3/s)	Peak outflow (m^3/s)
2.33 year	95	51
20 year	216	145
100 year	282	198

2.4 Irrigation intakes

2.4.1 Upstream water intake

The Application Design upstream water intake (UWI) is located on the Waipawa River on the right hand (southern) bank, near Caldwell Road, upstream of SH50 (refer Figure 2.1). The general arrangement drawing for the intake is included in Appendix A. The upstream water intake has a design flow of 11.1 m^3/s. The location of the intake was chosen based on expected river morphology, site topography and the presence of a favourable rock outcrop at the outside bend of the current river braid.

Key design considerations for the UWI were the management of coarse and fine sediment inflows into the intake and protection from flood flows in the river. A rock infiltration bund excludes coarse sediment from the intake. A realigned and modified river channel forms the intake river braid at the interface with the rock infiltration bund. Refer to the PD (T&T, May 2013) for more details.

The PD notes that active management of coarse sediment will be required at the proposed intake location. The intake river braid will be maintained during the life of the project to manage velocities adjacent to the intake to minimise deposition and requirements for excavation of sediment at critical locations.

2.4.2 Downstream water intake

The Application Design downstream water intake (DWI) is a relatively small structure and is located on the left hand (northern) bank of the Waipawa River, approximately 1 km upstream of the confluence with the Tukituki River (Figure 2.1). The general arrangement drawing for the intake is included in Appendix A. The DWI has a design flow of 1.82 m^3/s. Refer to the PD (T&T, May 2013) for more details.

The PD recognises that due to the braided nature of the Waipawa River, in-river works will be necessary from time to time throughout the operational life of the project to maintain the river channel (flow and level) at the intake location, and manage the deposition of coarse sediment in the vicinity of the intake and intake diversion channel. In particular, the single river braid along this reach of the relatively straight Waipawa River reach has the potential to move within the river bed. In these situations in-river work will be required to divert a relatively modest flow a short distance back to the intake location. HBRC has indicated that to a large extent this sort of river training work and coarse sediment removal work may be undertaken at minimal cost by local contractors that require aggregate.

3 Setting

3.1 Catchment

The Tukituki and Waipawa catchments and features are shown in Figure 3.1. Key features include the Ruahine Ranges, Tukituki and Waipawa Rivers and their tributaries (including the Makaroro River) and Hawke's Bay. The towns in proximity to the rivers are Waipawa and Waipukurau and in the lower catchment, Havelock North and Haumoana on the coast.

The Tukituki and Waipawa Rivers are managed by HBRC as part of the Upper Tukituki Flood Control Scheme (refer Section 3.5). Stopbanks and gravel extraction in conjunction with other measures are used downstream of SH50 to manage the flood risk (refer to Figure 3.1).

The key catchment areas are:

- Makaroro at the Dam = 111 km^2
- Makaroro just upstream of Waipawa confluence = 121 km^2
- Waipawa just upstream of Tukituki confluence = 681 km^2
- Tukituki just upstream of Waipawa confluence = 1,472 km^2
- Tutituki at coast = 2,496 km^2.

The catchment of the Makaroro upstream of the Dam consists primarily of native bush within the Ruahine Forest Park and exotic forest, with the remainder in the lower catchment comprising of farm land, refer to Figure 3.2. The highest point in the catchment is Te Atua Mahuru peak that has an elevation of RL 1534 m.

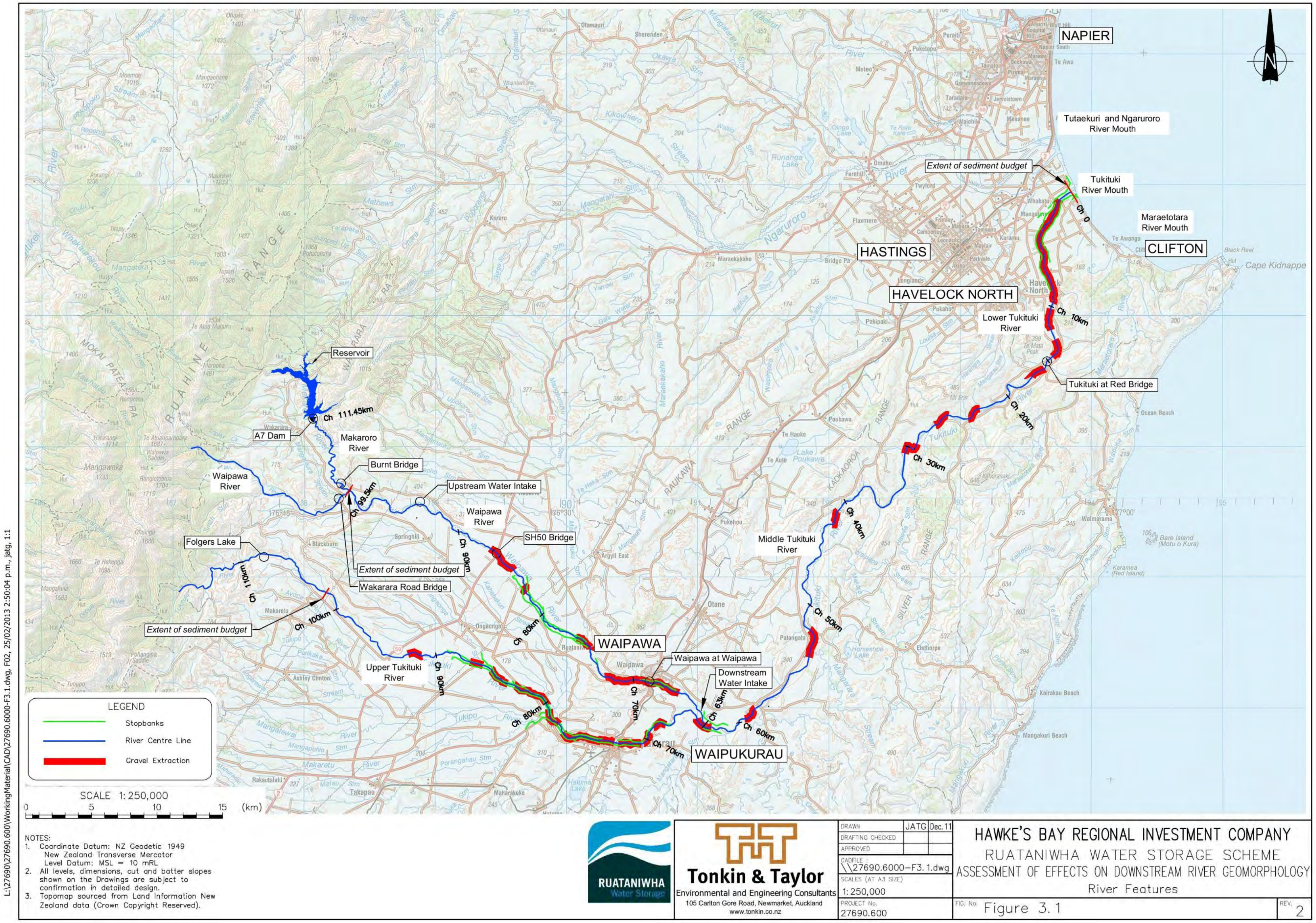

Figure 3.1: The Tukituki and Waipawa catchments and features

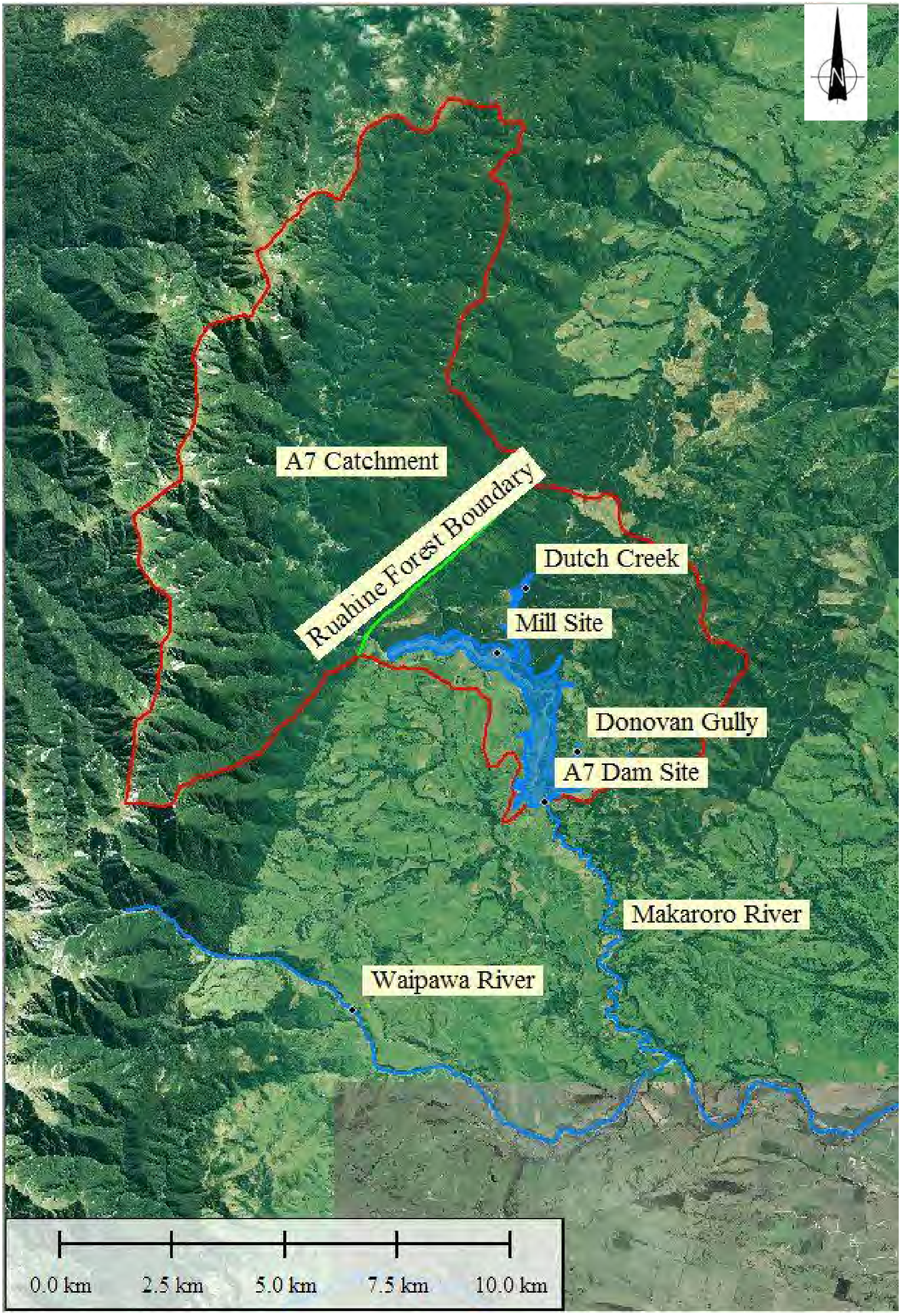

Figure 3.2: The Dam, catchment and reservoir extent

3.2 Hydrology

The hydrology for the catchment is summarised in the Feasibility Report (T&T, August 2012c). Table 3.1 summarises the gauge information and mean annual rainfall.

Table 3.1 Summary of rainfall data analysed (T&T, August 2012c)

Site Name	Site No.	Elevation	Period of data	Mean annual rainfall for record period
Kaumatua at Parks Peak	967310	RL 579 m	1974 – 1991	2,817 mm p.a.
Waipawa at Waipawa Fork	968210	RL 700 m	1974 – 1991	2,807 mm p.a.
Waipawa at Glenwood	968225	RL 610 m	1985 – 2011	2,205 mm p.a.

3.3 Geology

The Ruahine Range is composed chiefly of Upper Jurassic alternating sandstones and argillites, which are complexly folded and faulted (Kingma (1962) and Te Punga (1978) cited in Grant (1982)). Above an altitude of 1000 m, there are large areas of eroded rock that constitute the main sources for coarse sediment in the river channels (Grant, 1982). The geological history of the area is detailed in T&T (March 2012b).

The river channel at the site is deeply entrenched in a narrow gorge cut down to approximately 40 m below alluvial terraces. The rate of down-cutting appears to have been rapid as few of the smaller streams joining the Makaroro River have concordant junctions, and most have waterfalls at, or near to, the geologically recently deepened valley edge (T&T, March 2012b).

3.4 River morphology

3.4.1 Tukituki/Waipawa River system

The river system consists of steep headwater streams in the Ruahine Ranges that feed numerous rivers (including the Makaroro) that collect in the Waipawa and Tukituki, refer Figure 3.1. The Dam site on the Makaroro is 115 km from the coast.

The rivers within the Tukituki/Waipawa system are typically braided, although often controlled within a managed channel (refer Section 3.5). They are characterised by a surplus of gravel bed material. Photographs of the rivers are included in Appendix B.

Figure 3.3 shows a long section of the river with key locations. The lower and middle Tukituki have a consistent grade over 60 km of approximately 0.2%. Both the Tukituki and Waipawa Rivers have a reduction in gradient in the middle section, which occurs upstream of SH2. Upstream of SH50 the upper Tukituki and Waipawa/Makaroro Rivers have constant steeper gradients of 0.82% and 0.72%, respectively.

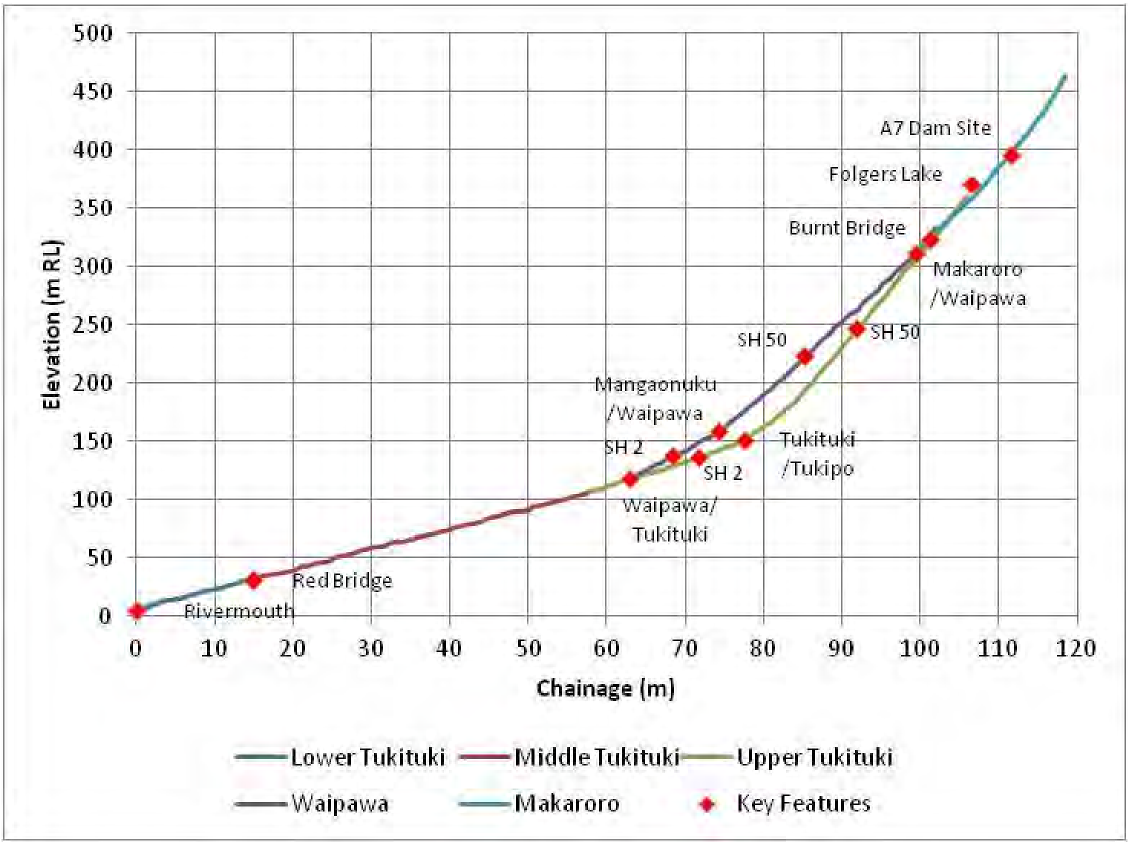

Figure 3.3: Long section of Tukituki and Tukituki/Waipawa/Makaroro with road bridges and confluences of main tributaries

3.4.2 Makaroro River

The Makaroro is characterised by gravel bed substrate. It is laterally confined within a valley. Where width permits, the river has multi channels. Elsewhere in narrower parts of the valley, the river has channel and bar sequences, refer to Figures 3.5 and 3.6.

Table 3.2 summarises the size distribution of bed material in Makaroro River at the Mill site located at the upstream end of the proposed reservoir. The median D50 is 16.0 mm. At other locations such as the gorge at the Dam site, larger rocks are present, having been sorted by higher velocities that preferentially transport the smaller stones. Anecdotally, the bed material varies in size over time due to episodic transport processes and sediment supplies in the catchment (pers. comms. Steve Wilson). Williams (1985) documented a D50 of the armour layer of 65 mm at the Burnt Bridge gauge. HBRC (December 2012) reported the D50 of surface sediments at the Dam site and Burnt Bridge of 21 mm and 28 mm, respectively.

Table 3.2: Summary of particle size distribution for Makaroro River at Mill site

Sample	D10 (mm)	D50 (mm)	D90 (mm)
N11. 760 / 1 (RG1)	1.60	16.0	88.0
N11. 760 / 2 (RG2)	0.55	13.0	53.0
N11. 760 / 3 (RG3)	1.70	23.0	105.0
Median	1.60	16.0	88.0
Mean	1.28	17.33	82.0

T&T (March 2012b) contains additional information on particle size distribution and the geology of recent gravels as well as for older gravels in terrace deposits. Figure 3.4 summarises the particle size distribution for recent gravels (in the active river channel) for RG test pits at the Mill site and test pits at the Dam site (refer to T&T March 2012b for location map).

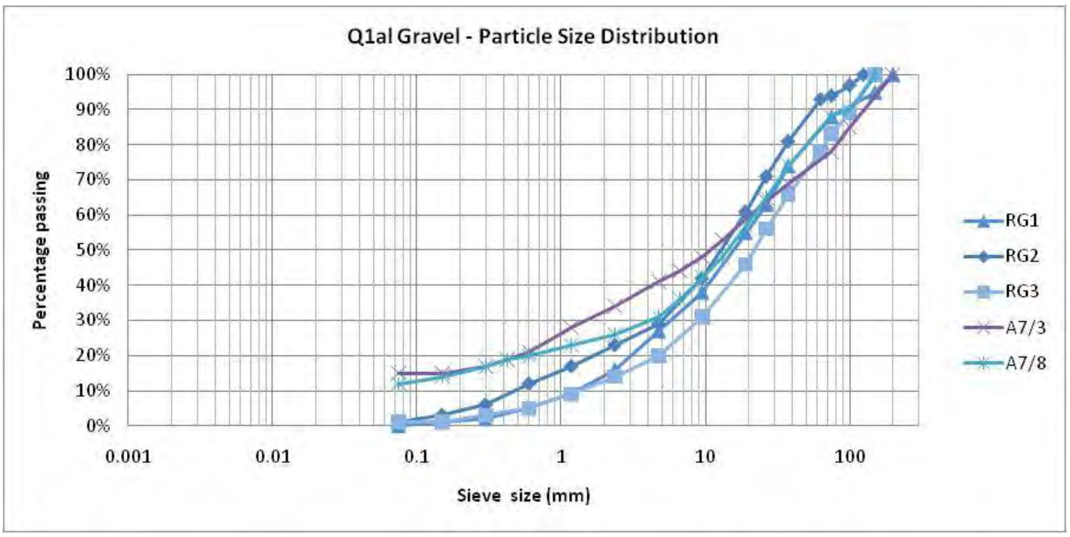

Figure 3.4: Particle size distribution curves for recent gravels (T&T, March 2012b)

The Makaroro River gravels are dominantly made up of unweathered (with some slightly weathered), strong to very strong greywacke sandstone clasts eroded from the Ruahine Range to the west of the site. The greywacke rock mass in the Ruahine Range is from the Kaweka Terrain, part of the Torlesse Composite Terrain, and is of a higher metamorphic grade than the Waioeka petrofacies and does not contain the zeolite mineral, laumontite. The Makaroro River gravels contain varying minor amounts of sand and silt, which is likely to be dependent on the sampling location within the river channel.

The Makaroro River is very dynamic with frequent changes in bed forms and bed levels due to episodic flood events and variability in sediment supply. Cross-section data for the Makaroro River at the Mill site (upper end of reservoir) and at Burnt Bridge show differing trends for the same period. The Mill site exhibited aggradation at a rate of 1,600 m^3/year over the period from 1994 to 2011, which is consistent with anecdotal reports (pers. comms. Steve Wilson). Whereas at Burnt Bridge, the river bed has been degrading at a rate of 5,400 m^3/year over the period from 1992 to 2011.

Figure 3.5: Makaroro River upstream of the Dam site (looking upstream)

Figure 3.6: Makaroro River downstream of the Dam site (looking downstream)

3.5 River management

3.5.1 River management

The flooding and sediment aspects of the Tukituki/Waipawa Rivers are managed by HBRC as part of the Upper Tukituki Flood Control Scheme. The Council use a range of measures to manage flooding and sediment that include:

- Stopbanks for flood protection
- Active channel to carry the main flow
- Channel banks stabilised with willow trees to contain the active channel
- Flood berms for flood conveyance and to buffer/protect the stopbanks
- Gravel extraction to maintain the flood carrying capacity of the river
- Raking of gravel beaches to encourage sediment transport in floods.

Stopbanks and gravel extraction are used downstream of SH50 to manage the flood risk (refer to Figure 3.1).

Generally the rivers upstream of SH50 (Caldwell Road to be specific) have less active river management. In these areas, exotic weeds such as lupin, encroach onto gravel bars. This has the effect of reducing the transport from the bars and also to trap sediment in the vegetation. If trees become established then the active channel becomes narrower.

3.5.2 Gravel extraction process

The process undertaken by HBRC for flood and gravel management is broadly as follows:

- Cross section surveys every three years (typically 500 m spacing)
- Mean bed levels in the active channel are compared to the "extraction grade line", which is the bed level required for flood conveyance of the design flood (100 year ARI)
- Volume of gravel to be extracted is the mean bed level less the extraction grade line spread over three years
- Site verification of surplus gravel
- Gravel extraction contractors request gravel volumes and types (quality)
- HBRC allocates the locations along the rivers and volumes to gravel extraction contractors on an annual basis
- Consents for gravel extraction are requested and processed
- Gravel extraction is monitored.

3.5.3 Gravel extraction historically

Figure 3.7 below is a plot of gravel extraction over time from 1994 to 2009 for each of the river sources within the Hawke's Bay Region. The single largest source of gravel is the Ngaruroro River which fluctuates from just under 200,000 m^3/year to a maximum extracted volume of 360,000 m^3/year in 2004.

For the Tukituki/Waipawa river system, the lower Tukituki reach has historically been the largest contributor to the regional gravel supply reaching a peak of 127,000 m^3/year in 1997. However, in recent years the extraction from this reach has reduced to below 30,000 m^3/year. In contrast, extraction from the Waipawa increased significantly in the early 2000s and from 2003 to 2009 it has been maintained at over 100,000 m^3/year.

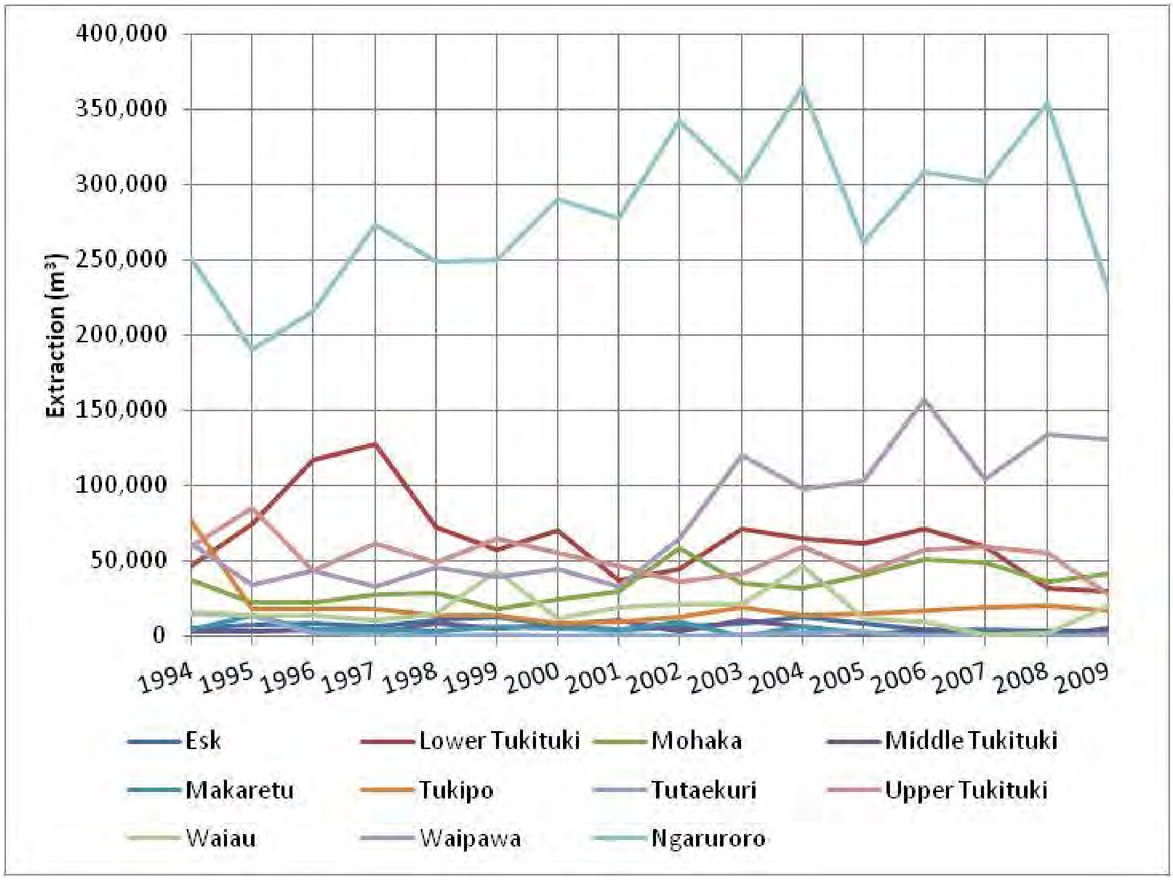

Figure 3.7: Regional gravel extraction from 1994 - 2009

Table 3.3 below summarises the average annual extraction from 2005 – 2009 in the Hawke's Bay Region. Over this period an average of 592,000 m^3/year of gravel was extracted from all the river reaches, 244,000 m^3/year (41%) of which was sourced from the Tukituki and its tributaries.

The sources downstream of the Makaroro/Waipawa confluence, i.e. those that would be potentially affected by the Dam, are the Waipawa, the middle Tukituki and the lower Tukituki, excluding the upper Tukituki. On average these sources contributed 178,000 m^3/year (30%) to the regional gravel supply. The contribution from the Waipawa (with its major tributaries being the Waipawa and Makaroro) was approximately 126,000 m^3/year (21%).

Table 3.3: Regional average annual extraction 2005 – 2009

River Reach	Extraction (m^3/yr)	Percent of Total
Ngaruroro	291,030	49.15%
Waipawa	125,596	21.21%
Lower Tukituki	50,445	8.52%
Upper Tukituki	48,193	8.14%
Mohaka	43,119	7.28%
Tukipo	17,250	2.91%
Waiau	8,705	1.47%
Esk	4,400	0.74%
Middle Tukituki	2,004	0.34%
Tutaekuri	753	0.13%
Makaretu	621	0.10%
Total	592,116	100%

The extraction in the Tukituki and Waipawa Rivers is shown for Figure 3.7 and includes measures for 2012. There has been a decrease in extraction over the last five years due to reduced demand attributed to the global financial crisis. The average annual sediment extractions over the last ten years are summarised in Table 3.4. The average annual extraction has been 97,000 m^3/year for the Waipawa and 187,000 m^3/year for the entire Tukituki River system over the last ten years.

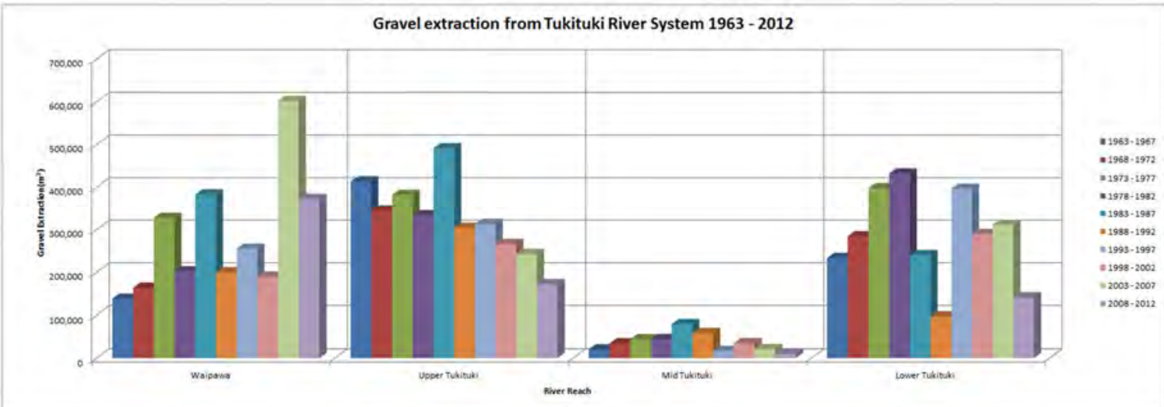

Figure 3.7: Gravel extraction for Tukituki River system 1963 – 2012 in 5 year periods

Table 3.4: Tukituki River system average annual extraction 2005 – 2009

River Reach	Extraction (m^3/year)		
	2002 - 2007	2008 - 2012	Decade Average
Waipawa	120,376	74,485	97,430
Upper Tukituki	48,523	34,301	41,412
Middle Tukituki	4,175	1,889	3,032
Lower Tukituki	62,142	28,170	45,156
Total	235,216	138,845	187,030

3.6 Coastal sediment

The coastline of Hawke's Bay from Clifton to Port of Napier (refer Figure 3.1) consists of gravel beaches. The beaches within this littoral cell are composed of mixed sand and gravel, containing pebbles and cobbles derived from the erosion of greywacke rocks found in the mountain range to the west of Hawke's Bay.

The coastline in the vicinity of the Tukituki River mouth is generally retreating with measured trends of erosion of around 0.4 m/year to 0.6 m/year from the mid 1970's to the present (T&T, February 2012a). Immediately to the north of the Tukituki River mouth the long term trend of erosion is higher, with erosion rates of around 1.6 m/year from beach profile data recorded from 1989 to the present.

Three rivers discharge to this sector of the coastline; the Maraetotara, Tukituki and the combined outlet of the Ngaruroro and Tutaekuri (refer Figure 3.1). The Ngaruroro/Tutaekuri do not supply gravel to the coast. The supply from the Maraetotara is unknown, but expected to be small. The Tukituki River does supply gravel to the sea. Edmondson (1981) estimated the average gravel supply to the sea to be 28,000 m^3/year based on sediment budgets using comparisons of cross-sections between 1978 and 2000.

Actual supply to the coast is more sporadic, with significant movement during floods and very little supply during low river flows (refer Table 3.5). This data also shows that while more frequent floods increase the supply of gravel to the coast, there appears to be a lag between the floods and the time for the sediments to reach the coast.

Table 3.5: Average supply of gravels to the coast from the Tukituki (from Edmondson, 2001)

Period	Average supply during period (m^3/year)	No of floods (return period <5years)	No of floods (return period 5 - 20 years)
1978 to 1981	57,830*[1]	5	0
1981 to 1987	7,964	4	1
1987 to 1990	0	3	2*[2]
1990 to 1993	158,996	2	1
1993 to 1996	0	1	0
1996 to 2000	1,132	2	0

*[1] Cyclone Alison in 1975 had an estimated return period of 7.5 years (Grant, 1982). T&T have recently estimated the return period to be approximately 30 years (based on rainfall analysis (Appendix F). However, flood frequency estimates for the Makaroro River indicate a return period in excess of 70 years; it remains the largest flood event observed in the Makaroro and Upper Waipawa Rivers since formal observations began.

*[2] Cyclone Bola in March 1988 was the largest flood event recorded at the Burnt Bridge gauge and had an estimated return period of 70 years (T&T, 2011). Cyclone Bola may be reason for the increase in sediment supply in the subsequent period.

The T&T UNIBEST model was used to develop an understanding of the shoreline evolution in the southern Hawke's Bay (T&T, 2005). The UNIBEST model simulates longshore sediment transport and shoreline position. This model required an average annual sediment supply from the Tukituki River of 13,000 m^3/year to replicate the observed long term longshore sediment transport and shoreline position and shape. However, erosion rates to the north of the river mouth have accelerated since this study and more recent modelling to evaluate the potential effects of a groyne field constructed at Haumoana (T&T, February 2012a) suggest recent gravel supply to the coast from the Tukituki is 3,000 m^3/year. The Tukituki sediment supply rates used in this model are only the component of the Tukituki sediments that are deposited within the active transport zone of the beach and additional Tukituki sediments are likely to be deposited further offshore.

T&T (February 2012a) describes the Hawke's Bay gravels as having relatively low resistance to abrasion. T&T (February 2012a) cites the abrasion rate from Kantor (2009) as 1.8% of mass loss per annum and uses a similar abrasion rate of 0.5 m^3/m/year using an active profile of 6 m and an active profile width of 5 m for a shoreline evolution model.

4 Methodology

In this Section the methodology for the sedimentation allowance is detailed. Firstly, the general philosophy is explained, followed by the specifics of the information review and methods for suspended sediment and bed material sediment. The additional methodologies for the downstream effects such as gravel transport changes and degradation/armouring are also described.

4.1 General

The methodologies that have been used in the sedimentation assessment are summarised in Table 4.1.

Table 4.1: Summary of methods

Assessment	Methods/Analysis
Sediment allowance (Section 6) and effects of sediment in the reservoir (Section 7.2).	Suspended sediment estimates - WRENZ (Sections 4.3.1, 6.1) with Brune method (Sections 4.3.2, 6.3) Bedload estimates - Folger's Lake data (Section 4.4, 6.2.2) - Sediment budget (Sections 4.5, 6.2.3) - Bedload formula (Sections 4.7, 6.2.4 and Appendix G)
Effect on downstream/coast (Section 7.3) – due to interruption of Sediment Supply (Section 7.3.2)	Sediment budget (Sections 4.5 and 5)
Effect on downstream/coast (Section 7.3) – due to change in gravel transport capacity (Section 7.3.3)	Sediment transport capacity analysis (Section 4.6, Appendix G)
Effect on downstream/coast (Section 7.3) – degradation and armouring (Section 7.3.4)	USBR degradation method (Section 4.8)
Management of sediment (Section 9)	Morphological model (Section 4.9)

The methodology utilises the good sources of measured data that exist for the Tukituki/Waipawa River system. The measured data consists primarily of river cross-sections that are used to develop a sediment budget and the measured accumulation at Folger's Lake. This is then supplemented by estimates of suspended sediment from the WRENZ model that are calibrated to downstream suspended sediment measurements/gauges, with the trapping efficiency in the reservoir calculated by the Brune method.

A number of reports/papers in the literature provide useful information on sedimentation for the Tukituki/Waipawa River system and a review of these is summarised.

Site work has consisted of field observations and testing of bed material sediments for particle size distributions.

Bed load transport calculations are also used but have more uncertainty than the approach of using measured data. Bed load transport calculations do have the advantage of being able to simulate the changes and are therefore better able to quantify effects.

4.2 Information review

An extensive review of both published and unpublished data was undertaken for this Scheme. Although only limited information was available specifically for the Makaroro reach, a number of relevant investigations have been made into the wider Tukituki/Waipawa River system and these have helped to guide our estimates for the Makaroro. The following sources provided sediment estimates for suspended sediment, bed load sediment and total sediment:

Suspended sediment

- Makaroro and all rivers
- NIWA Water Resources Explorer NZ (WRENZ) incorporating the suspended sediment yield model (Hicks et al, 2011) for any location
- Waipawa
  - Annual suspended sediment yield for Waipawa at Waipawa by Hicks et al (2011)
  - Suspended sediment rating curve for Waipawa at Waipawa by Williams (1985)
- Tukituki
  - Annual suspended sediment yield for Tukituki at Red Bridge by Hicks et al (2011)
  - Suspended sediment rating curve for Tukituki at Red Bridge by Williams (1985)
  - Annual suspended sediment estimate for Tukituki basin by Mosely (1992)
  - Annual suspended sediment yield for Tukituki at Red Bridge by Adams (1979)

Bed material sediment

- Makaroro
  - Changes in gravel storage from HBRC survey/spreadsheets
- Waipawa
  - Bed material rating curve for Waipawa at Waipawa by Williams (1985)
  - Annual bed material estimate for Waipawa at Waipawa by Williams (1985)
  - Bed material in upper Waipawa during Cyclone Alison (1975) by Grant (1982)
- Tukituki
  - Bed transport rating curve for Tukituki River at Red Bridge by Williams (1985)
  - Annual bed material estimate for Tukituki River at Red Bridge by Williams (1985)
  - Annual bed material estimate for Tukituki River at Red Bridge by Adams (1979)
  - Annual bed material estimate for Tukituki River by HBRC (2001)

Total sediment

  - Folger's Lake (bed material and trapped suspended sediment)
  - Williams (1985) estimate
  - HBRC (report by DJ Hamilton) cited in Grant (1982) estimate
  - Adams (1979) estimate
  - HBRC spreadsheets (2011)
- Makaroro
  - 100 year return period sediment transport for Makaroro by Williams (1985).

The sediment estimates drawn from these sources are tabulated in Appendix C and compared on the basis of catchment characteristics, river flow regime, source data quality and methodology of estimation. This information enabled understanding of the sedimentation characteristics of the river system and the applicability of transferring specific sediment estimates from one location to another.

4.3 Suspended sediment

4.3.1 WRENZ

Following the literature review it was concluded that the most reliable estimate of suspended sediment yields was that obtained by the NIWA suspended sediment model in the internet based Water Resources Explorer NZ (WRENZ) tool (http://wrenz.niwa.co.nz). WRENZ is an empirical GIS model that can predict suspended sediment yield from any river in New Zealand. The imbedded suspended sediment model is described in Hicks et al (2011).

The WRENZ model estimates sediment yield based on the integration of the product of a "supply" factor and a "driving" factor. The supply factor is dependent on an erosion terrain classification that incorporates lithology, slope and erosion processes. The driving factor is dependent on local mean annual precipitation.

The WRENZ model is locally calibrated to suspended sediment gauge data for the Tukituki River at Red Bridge. Dr Hicks has provided additional results from WRENZ to refine the suspended sediment estimate based on the Tukituki River at the Waipukurau gauge and the characteristics of the Makaroro catchment upstream of the Dam.

Regional flow and suspended sediment concentration records were collected from the TIDEDA database. However, it was judged that there were limited data points from nearby gauges to use this information to estimate suspended sediment yields for the Dam. The data that does exist has been used comprehensively in the development of the WRENZ model.

Suspended sediment estimates are most commonly given in kt/year, but for the purpose of this study, these are converted in to m^3/year. This is more compatible with bed material volumes from the sediment budget and the requirement for volume estimates of sediment allowances at the Dam. The Williams (1985) suspended sediment grading curve indicates predominantly silt fractions.

Greiger (1963, cited in Morris et al, 2007) suggests specific weights for silt dominated reservoir deposits of 0.88-1.20 t/m^3 for submerged and 1.20-1.36 $t/m^3$for aerated. This is lighter than the estimates for gravel dominated reservoir deposits of 1.36-2.00 t/m^3 for submerged and 1.52-2.08 t/m^3 for aerated. In this assessment an average specific weight for the silt dominated suspended sediment of 1.2 t/m^3 is assumed.

4.3.2 Brune method

The trap efficiency for suspended sediments within the reservoir was estimated using the empirical Brune (1953) methodology. The Brune method applies a trap efficiency to the sediment transport of the river to calculate an annual sedimentation in the reservoir. The trap efficiency is based on the reservoir retention time calculated from the reservoir volume and the annual inflow. Figure 4.1 provides a graph showing this relationship. The Brune method is recommended for large storage reservoirs over alternative empirical methods such as that of Churchill (1948) (Morris, Annandale and Hotchkiss, 2008).

The Brune (1953) trap efficiencies were developed by comparing the total trapped sediment to total sediment inflow. These empirical relationships were based on suspended load dominated rivers. However, the Makaroro is a mountain river with a large proportion of bed load. Therefore, the Brune curves have been applied to determine the trap efficiency of the suspended sediment only, as they do a reasonable job at predicting the trap efficiency of suspended sediment. The entire bed load is assumed to be trapped. The following sections describe the methods for estimating the bed load.

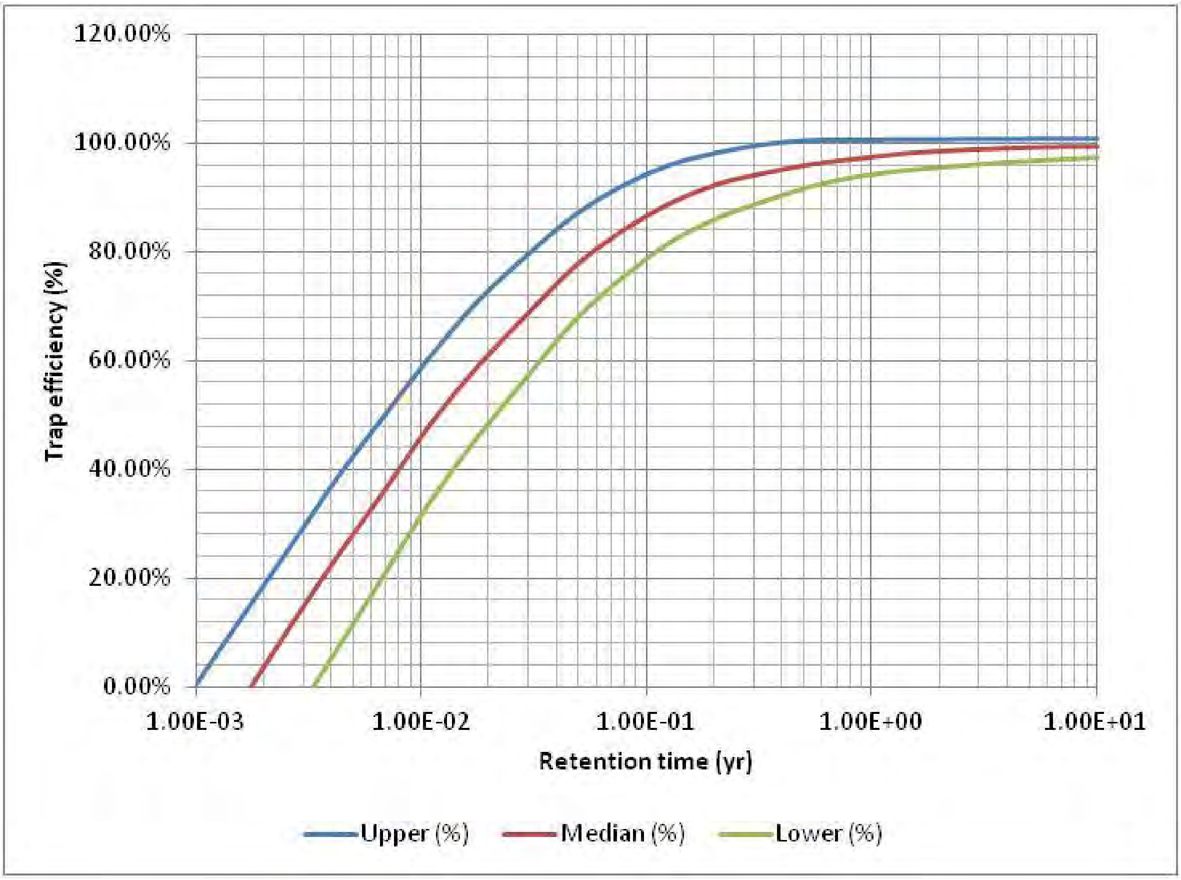

Figure 4.1: Brune curve showing the empirical relationship between retention time and trap efficiency

The reservoir volume of approximately 91.1 million m^3 associated with the NTWL of RL 469.5 m was used as the basis for the Brune method. For the purposes of calculating the trapping efficiency this is a conservative assumption as the reservoir volume will be less than 81.2 million m^3 (below RL 466.6 m) 50% of the time (refer to Section 2). This will result in a higher and conservative estimate of the trapped suspended sediment.

The average inflow for the Dam is 6.35 m^3/s which equates to an average annual inflow of 200,253,600 $m^3/year$. The methodology for estimating the average inflow is described in the Feasibility Report (T&T, August 2012c).

The trapped suspended sediment within the reservoir was calculated as the product of the WRENZ annual suspended sediment estimate and the Brune trap efficiency. A simple spreadsheet model was used for the calculations, which were undertaken using an annual time-step. At each time-step, the sum of the trapped suspended sediment and annual bed material supply for the previous time-step were subtracted from the accumulated reservoir storage and a new retention time was calculated. This model was run for a 100 year period.

4.4 Bed material sediment – Folger's Lake

4.4.1 Folger's Lake

A bed material estimate for the reservoir was derived from the analogous situation of Folger's Lake in the nearby upper Tukituki River basin.

4.4.2 Folger's Lake background

Folger's Lake on the upper Tukituki River was formed by a significant landslide that took place on 1 July 1968. In excess of 750,000 m^3 of material was mobilised and this completely blocked the river channel to a depth of 15 m forming what became known as Folger's Lake. The lake became filled with 1.2 million m^3 of sediment over a period of 11 years. The lake trapped all bed material coming down the river. The grading curves suggest that about 15% of the accumulated material is sand that would have passed down the river as suspended material (Williams, 1985). The embankment failed in circa 1980 and the sediments steadily eroded after this time.

From 1969 until 2009 bed levels within the lake were surveyed and from 1975 until 1983 bed levels within the upstream gorge were also surveyed. Williams (1985) used the survey information available at the time to estimate the accumulation of material within the lake.

The published estimates for sedimentation in Folger's Lake exhibit a significant degree of variation and these are discussed in detail in Section 6.

4.4.3 Folger's Lake as an analogue for the reservoir

Folger's Lake is considered to be a good analogue for the reservoir for a number of reasons:

- Catchment areas are similar with the catchment for the Dam of 111 km^2 compared with Folger's Lake of 77 km^2 (refer Figure 4.2)
- Proximity of the catchments - at their closest point there is a distance of just over 8 km between the two (refer Figure 4.2)
- Geology, topography and vegetation are similar with the reservoir/lake at similar elevations (refer to Section 3 and Figure 4.2) and both catchments extend from the foothills into the upland areas of the Ruahine Range
- Rainfall is similar with both catchments having mean annual rainfall between 2,800 – 3,200 mm/year at the highest elevations (NZMS 193, Sheet 3)
- Hydrological analysis has been undertaken to compare the 13 year period during which Folger's Lake filled to a longer 52 year rainfall record (refer to Appendix F). This demonstrates that the Folger's Lake filling period experienced a higher than average number of rainfall events with depths in excess of the 2 year ARI depth for all durations. Whereas, for events greater than the 10 year ARI rainfall, there was a higher than average number of rainfall events for the 48 and 72 hour durations, but less for the 24 hour and 96 hour duration. Overall the Folger's Lake filling period was stormier than normal based of this analysis. Therefore, considering only this hydrological aspect, the bed material estimate based on Folger's Lake should be conservative
- Cyclone Alison (March 1975) played a role in the sedimentation of Folger's Lake. It is evident as a step in the accumulative sedimentation plots by Williams (1985). However, it does not feature strongly in the hydrological analysis (refer to Appendix F), which were based on synthetic rainfall records, as there were no rainfall gauges operating in the upper Tukituki River. The closest rain gauge in operation during Cyclone Alison was Waipawa Fork in the upper Waipawa catchment immediately to the north of the Folger's Lake catchment, which indicated much higher rainfall totals than those from the synthetic rainfall. The return period for Cyclone Alison has been estimated to be 30 years at both Parks Peak (upper Makaroro) and Waipawa Fork (upper Waipawa). Flood frequency estimates for the Makaroro River indicate a return period in excess of 70 years; it remains the largest flood event observed in the Makaroro and Upper Waipawa Rivers since formal observations began. Grant (1982) details some of the highest sediment yields observed in New Zealand for the headwater areas of the Waipawa catchments after Cyclone Alison in 1975 (refer Section 6.2.1)

Therefore, the hydrological analysis may not properly account for Cyclone Alison, so the hydrological conditions of the Folger's Lake filling period may be more extreme than indicated by the hydrological analysis and thus the bed estimate based on Folger's Lake may be more conservative than indicated above.

The upper catchments of the Tukituki, Makaroro and Waipawa are shown in Figure 4.2.

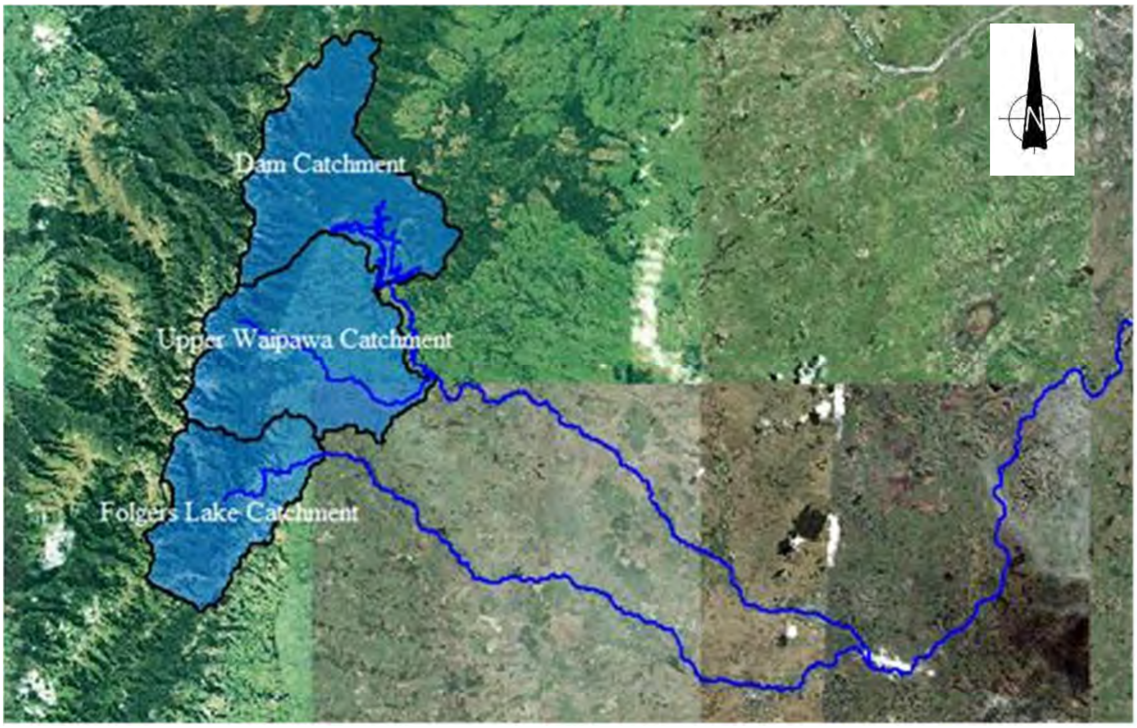

Figure 4.2: Upper Tukituki, Makaroro and Waipawa catchments above Folger's Lake, the Dam (A7) site and Waipawa/Makaroro confluence respectively

The main difference between Folger's Lake and the proposed reservoir is the volume. Folger's Lake filled with sediment reaching a volume of ~1,200,000 m^3, which is much less than the 91 million m^3 proposed for the Reservoir. The difference in lake volume affects the retention time and the trap efficiency of suspended sediment. This issue was resolved by Williams (1985) who estimated that approximately 15% of the accumulated sediment in Folger's Lake was derived from suspended sediment based on comparison of sediment gradations upstream, in the accumulated sediments and downstream of Folger's Lake. This correction is applied to sedimentation estimates from Folger's Lake to estimate the bed load at this location in the Tukituki River.

The other difference is temporal with the observed sedimentation occurring for Folger's Lake from 1968 to 1981. The great storminess of this period is noted above. This difference is recognised and partially overcome by the alternative estimate for bed material from the sediment budget for the more recent period of 1980 to 2009 (refer Section 4.5) and the alternative estimates from sediment transport capacity calculations.

4.4.4 Translation of Folger's Lake sediment estimates

Sediment yield is highly variable over space and time. The driving forces for sediment yield are a complex combination of rainfall, geology, terrain and land use.

Grant (1982) described the main sources for coarse sediment in the upper Waipawa catchment as the large areas of eroded rock above an altitude of 1000 m. Grant (1982) applied a methodology of scaling the sediment yield by the ratio of erodible surface ratio to catchment area to estimate the coarse sediment yield in an adjacent catchment.

For this study satellite imagery from 2007 was used to measure areas of eroded rock that are thought to be contributing erodible material to the river system.

Typically these eroded rock areas were landslips that started high on the ridge lines and descended to the stream in the valley floor. GIS software was used to map the landslips within the catchments. A snap shot of a typical valley in the upper Makaroro and the measured erodible surface area is shown in Figure 4.3.

Figure 4.3: Typical valley in the upper Makaroro and the measured erodible surface area

The erodible areas, catchments and ratios are summarised in Table 4.2. The erodible areas were the basis of translating the Folger's Lake sedimentation estimates to the Dam and for apportioning the bed material between the Makaroro and the Waipawa in the sediment budget.

Table 4.2: Summary of erodible material mapping

Catchment Name	Catchment Area (km^2)	Erodible Area (km^2)	Ratio of Erodible to Catchment Areas
Upper Tukituki (to Folger's Lake)	77	1.51	0.020
Makaroro (to the Dam)	111	2.61	0.024
Makaroro (to Waipawa confluence)	122	2.61	0.021
Waipawa (to Makaroro confluence)	127	2.13	0.017

4.5 Bed material sediment - budget

4.5.1 Description

A sediment budget for gravel in the Tukituki/Waipawa River system has been developed to determine the sediment supply in these rivers. The sediment budget has been undertaken for the period of 1980 to 2009. The sediment budget makes use of the cross-section surveys and gravel extraction records maintained by HBRC.

Sediment supply into reach = change in gravel storage (aggradation = positive)

+ extraction (positive)

+ supply to downstream reach.

4.5.2 Data sources

Cross-sectional surveys of the main reaches of the Tukituki/Waipawa River system are available from 1943/44 to 2010. The cross-sections are typically surveyed every three years although this varies. Cross-sections since 1980 have been used because Williams (1985) undertook a sediment budget and it was considered that his work could be referred to for pre-1985 sediment transport estimates. Also, extending the sediment budgets to earlier periods is more difficult as the changes to river management infrastructure are harder to understand and data quality issues are more difficult to resolve.

The gravel extraction data is from HBRC records. HBRC manage the gravel extraction process (refer Section 3.5). The extraction volumes are based on pre-approved volumes (refer Section 3.5), and there is monitoring of gravel extraction activities. The peer review notes the chance that extraction volumes are under-reported, which would reduce the sediment flux in the sediment budget.

For the purpose of the sediment budget the gravel supply to the coast has been assumed to be 10,000 m^3/year. This was based on a mid-value of estimates used from the T&T UNIBEST model (refer to Section 3.6). The sediment supply of gravel to the coast, as for the variation in sediment transport in the river, varies significantly with time with fluctuations from zero (no transport) to as much as 150,000 m^3/year (refer Section 3.6).

4.5.3 Assumptions

A number of assumptions have been made for the sediment budget and are outlined in this Section.

The supply to the coast was assumed to be 10,000 m^3/year based on the T&T UNIBEST model. HBRC (December 2012) have subsequently undertaken a sediment budget for the lower Tukituki that estimates the long term sediment supply to the coast to be 32,119 m^3/year (refer Appendix G). This estimate is for all sediment, whereas the T&T UNIBEST model uses an estimate of sediment supply to the coast for only the coarser sediment that is retained in the beach system.

The sediment budget for the river should be based on all bed material. Therefore the estimates by the sediment budget may be underestimated by 22,000 m^3/year in the lower Tukituki River. Based on the gravel transport splits detailed below, the sediment budgets for the Waipawa and the Makaroro may be underestimated by 12,000 and 7,000 m^3/year, respectively.

The change in gravel storage is based on the active channel only. The active channel has been defined by HBRC based on the 1982 cross-sections. It is necessary to use the active channel rather than say the end of cross-section or the top of the stopbank as these alternative locations change (even stopbanks due to new construction works). For the purpose of gravel management

HBRC use the active channel only. The position and continued relevance of the defined edge of active channel was checked for each cross-section and adjustments made if necessary.

Accounting for changes in gravel storage for only the active channel ignores the deposition that occurs from time to time on the flood berms (between the active channel and the stopbanks). To assess the quantum of sediment that may be missing from the sediment budget, an alternative sediment budget was established for the reach of the Waipawa River upstream of the SH50 bridge for the full width of the floodplain. This location was used because there are no flood management structures and it is a particular area of interest for this assessment.

The alternative sediment budget had 40% more volume (82,250 m^3/year vs. 59,300 m^3/year), which can be attributed to gravel and deposited suspended sediment, and possibly also land changes and vegetation. These “losses” of sediment to areas outside of the active channel should be accounted for in sediment estimates.

The sediment budget attributes sediment supply to only the Tukituki, Waipawa and Makaroro Rivers. The extents of the sediment budget model are shown in Figure 3.1. Other tributaries within the extent of sediment budget are not explicitly accounted for, which will result in an overestimate of sediment at the upstream end of the model. This is likely to be an issue for the upper Tukituki that has many tributaries within the model extent which have headwaters in the Ruahine Ranges. However, the upper Tukituki estimate is not used as part of the Project assessment. This is considered to be less of an issue for the Waipawa, where only the Waipawa and Makaroro and their tributaries outside of the model extent have tributaries in the Ruahine Ranges. The major tributary to the Waipawa River within the model extent is the Mangaonuku Stream, with tributaries from the lower Wakarara Range. This is a gravel bed river and the sediment supply is not accounted for in the model. The summary of the sediment budget presents temporally averaged data. It is necessary to temporally average the data as cross-section surveys are undertaken for different reaches of the rivers at different times. In Section 5 the important temporal variability is examined.

The gravel transport at the Tukituki/Waipawa confluence was split based on the ratio of the 100 year return period flood transport rates as estimated by Williams (1985). This method resulted in 56% of the transport being attributed to the Waipawa and 44% to the upper Tukituki. This is summarised in Table 4.3 below.

Table 4.3: Summary of gravel transport split between the Waipawa and upper Tukituki

River Reach	Williams (1985) 100 year return period sediment transport estimate (m^3/s)	Percent of Gravel Transport Contribution
Waipawa	2.25	56%
Upper Tukituki	1.75	44%

The gravel transport at the Makaroro/Waipawa confluence was split based on the ratio of the erodible area in each catchment as per the method described in Section 4.4.4 above. This method resulted in 55% of the transport being attributed to the Makaroro and 45% to the Waipawa.

4.5.4 Abrasion

The peer review suggests that abrasion should be added to the sediment budget. However, abrasion was not included in the sediment budget for the reasons described below. As a result, the losses due to sediment abrasion are not accounted for and the sediment budget will under-predict sediment volumes in the upper reaches.

References to abrasion coefficients for Greywacke have not proven to be readily available. We have only been able to locate one value for Greywacke of approximately 1.5×10^{-4} km^{-1} which was derived from mill testing performed by Krumbein as presented by Kodama (1994). Using this coefficient a half distance for abrasion of 4,620 km can be calculated. This suggests that the effect of abrasion would be negligible for the Waipawa/Tukituki system (approximately 100 km). However, Kodoma (1994) is of the opinion that this study did not adequately replicate the higher rates of abrasion that would occur during significant flood flows. As such the abrasion rate may be an under-estimate.

A reduction in the D50 grain size down the river was demonstrated by Williams (1985). However, Parker (2008) notes that the application of abrasion coefficients to rivers is more complicated than merely plotting grain size as a function of distance. This is because the methodology does not account for grain-size variation due to selective transport or the potential for in-situ abrasion to occur when a moving particle strikes a non-moving particle.

There may be a further complicating factor relating to the quality of the Greywacke in the Waipawa/Tukituki system. T&T (March 2012b) and Black (2011) found that gravels upstream of the Dam are mostly upstream of the Wakarara block and therefore are sourced mainly from the Ruahine Ranges and are harder and suitable for concrete aggregates. Rock from the Wakarara Range contains laumontite (a zeolite mineral), which swells and shrinks during cycles of wetting and drying, and is more prone to breaking down, therefore are unsuitable for concrete aggregates. Therefore, the durability and abrasion rates of greywacke are variable depending on the source of greywacke within the catchment.

Abrasion estimates for the coast are described in T&T (February 2012a) and summarised in Section 3.6. The abrasion rates for the coast will be different to those for the Waipawa/Tukituki river system due to the different geology of gravels and the different abrasion processes (i.e. likely to be higher for the coast due to abrasion from wave action).

4.6 Bed material - particle size distribution

Bed material sampling was undertaken of bed material in the Makaroro River at the Mill site located at the upstream end of the proposed reservoir. Five bulk samples of river gravels were taken. An excavator was used to obtain a large sample (>5 m^3) of the whole of bed material down to a depth of approximately 1.5 m, which was mixed and sub-sampled. Opus International laboratory in Napier undertook the testing for particle size distribution (PSD). The PSD curves are described in Section 3.4.2 and are included in Appendix D.

4.7 Change in gravel transport capacity

4.7.1 Gravel transport capacity method

Analysis was undertaken to quantify the change in sediment transport capacity due to changes in the flow regime caused by the RWSS. The changes in flow regime are caused by the flood attenuation in the reservoir. Changes in the flow regime are also caused by the water intakes, but only the UWI was considered in this analysis, which is reasonable as the DWI has a small water take of just 1.82 m^3/s.

The analysis was undertaken by HBRC and is reported in HBRC (December 2012) Ruataniwha Water Storage Project: Gravel Transport Changes with Changed Flow Regime, refer to Appendix G. The validity, assumption and limitations of the work is further detailed in HBRC (February 2013), refer to Appendix G.

The method assessed the sediment transport capacity at eight cross-sections between the Dam and the sea. The analysis used surveyed cross-sections, measured particle size distributions and hydraulic parameters from HBRC's MIKE11 model. The sediment transport is calculated for the pre- and post-dam flow duration curves. The sediment transport calculations use the Wilcock and Crowe (2003) method. The methodology is detailed in HBRC (December 2012) in Appendix G.

The sediment transport calculations also provide sediment transport estimates for the Makaroro at the Dam site, which supplement the alternative estimates from Folger's Lake and the sediment budget.

Gravel transport capacity is a theoretical estimate of sediment transport and is not measured nor is it calibrated. The gravel transport capacity can be less than actual sediment transport if the supply of sediment is not available e.g. supply interrupted by dam (so less applicable to Makaroro River), or bedrock conditions or vegetation growth mean that gravel is not available for transport. The gravel transport capacity was found to be very sensitive to the particle size distribution and the local river slope, so some caution is required with the assessment using this data.

The gravel transport capacity estimates used a single particle size distribution at each cross-section, because of limitations in access to the main braids (flowing channel), rather than the preferred approach of a distributed particle size distribution, refer HBRC (February 2013) in Appendix G and NIWA (March 2013a) in Appendix JI. The sediment in the main braids is normally coarser due to armouring processes. Therefore the method as applied will estimate more sediment transport at lower flows because of a finer particle size distribution than actual in the main channel.

Nevertheless, the gravel transport capacity has been used for an indicative comparative analysis of the effects of changes to the flow regime.

4.7.2 Flow data

The flow duration curves used for the gravel transport capacity estimates were based on hourly flow data supplied to HBRC by T&T in November 2012. This data was based on the operating regime proposed in the feasibility study (T&T, August 2012c). This data is referred to as "T&T hourly" and summarised in Appendix I.

The Application Design described in the PD (T&T, May 2013) includes changes to the environmental flows released from the Dam as well as provision of secondary irrigation when there is sufficient storage at the Dam. These changes are not reflected in HBRC (December 2012), and manifested as follows (refer T&T, March 2013a, 2013b):

- Generally lower reservoir levels (by around 2 m) in the PD operating regime
- Smaller proportion of time that the reservoir is full or close to full (about 25% in the PD operating regime versus about 33% in the Feasibility Stage operating regime)
- Less spill flow overall and potentially smaller peak outflows from the Dam in the PD operating regime
- Changes in flow distribution between 1.2 m^3/s and 10 m^3/s from different provisions for environmental flows and inclusion of hydropower (in T&T hourly and T&T daily only).

The differences in the flow duration curve for the Application Design described in the PD "Scenario 3-28M" compared to the feasibility study "T&T hourly" or T&T daily" are detailed in T&T (March 2013b) in Appendix I. These differences in the flow duration curves and the likely consequences on the gravel transport capacity are as follows:

- Differences in flows exceeded approximately 26% of the time from the three scenarios are relatively minor. Gravel transport capacity is not likely to differ greatly for this part of the flow range.
- Scenario 3-28M flows exceeded between 26% and 46% of the time are lower than in T&T hourly and T&T daily. The flow range is 5-10 m^3/s for this part of the flow duration curve. Gravel transport capacity for this part of the flow duration curve is likely to be lower for the Application Design than that used by HBRC (December 2012) and interpreted in this report.
- Scenario 3-28M flows exceeded between 46% and 64% of the time are higher than in T&T hourly and T&T daily. The flow range is ~ 1.2-5 m^3/s for this part of the flow duration curve. Gravel transport capacity for this part of the flow duration curve is likely to be greater for the Application Design than that used by HBRC (December 2012) and interpreted in this report. However, the increase in sediment transported by this part of the flow duration curve (~2-5 m^3/s) will be less than the increase expected for the 5-10 m^3/s part of the flow duration curve as the velocities and corresponding transport capacity are greater there.
- Minimum flows (1.228 m^3/s) occur in all scenarios 36% of the time.

Therefore, the differences in gravel transport capacity between the Application Design and that used for used by HBRC (December 2012) and interpreted in this report are likely to be small and should not materially affect this assessment. This opinion is shared by the peer review refer NIWA (April 2013) in Appendix J.

4.8 Degradation and armouring

Analysis was undertaken to quantify the degradation of the river bed below the Dam and the coarsening of the surface sediments in the river. The analysis used the Armour Method from USBR (1987). The armour method assumes that the degradation is limited by the coarser sediments that are not transported. The coarser sediments form an armour layer as the finer sediments are preferably transported downstream. Vertical degradation will progress at a progressively slower rate until the armour is deep enough and sufficiently resistant to transport to inhibit further degradation.

The Armour Method uses the dominant discharge, which was assumed to be the bankfull flow of the active channel. The hydraulic parameters for the bankfull flow were taken from HBRC (December 2012) and flow-elevation curves were supplied by HBRC from their MIKE11 model. The discharge -elevation curves were pre-dam, so the effect of the changes to flow regime was not considered, which makes this variable conservative in the calculations. The pre-dam PSD at each cross-section was from HBRC (December 2012). The sediment particle size required for armouring ("armour size") was estimated using the Meyer-Peter-Muller and Shields methods (USBR, 1987).

The Armour Method was applied to estimate degradation downstream of Burnt Bridge (XS Number 5). The analysis is only valid for the Makaroro River downstream of the Dam because the analysis assumes clear water flow (no sediment supply).

The Armour Method also provides an estimate of the coarsening of surface sediment (the armour layer) that is expected to occur downstream of the Dam. The armour size is the minimum diameter of the sediment that forms the armour layer. Therefore, the armour sediment will comprise of the sediment sizes that exceed the sediment sizes from the pre-dam PSD.

4.9 Morphological model

Morphological sediment transport modelling does not form part of the assessment, but is described here because it is included in the sediment management plan (Section 9).

The complex balance between changes to sediment supply and transport capacity can only be fully described by detailed morphological transport modelling. In particular the dynamic effects of immediate changes to sediment transport capacity all the way to the coast (albeit with diminishing influence as flow enters from tributaries), versus the longer term interruption of sediment from the Dam (that will require many years to propagate all the way to the coast) can be simulated by a morphological model. Even with a morphological transport model there remains uncertainty in predictions, especially for sediment as the timing of major drivers such as floods and earthquakes are not known.

HBRC are developing these models for their rivers starting with the Ngaruroro. The modelling programme was not sufficiently advanced for the development of this model for the Tukituki basin. However, it is proposed that a morphological model be developed for the Tukituki River basin to further assist in the management of these rivers and this is included in the sediment management plan (Section 9).

5 Sediment budget

In this Section the results for the sediment budget are detailed. The methodology for the sediment budget is detailed in Section 4.5. The findings of the sediment budget are subsequently applied to the sediment allowance for the Dam in Section 6.2.

5.1 Average sediment transport

The sediment budget is summarised in Figure 5.1 – 5.4. The sediment budget is for the period 1980 to 2009 and the sediment volumes are temporally averaged.

Figure 5.1 shows a long section of the river with key locations. Changes of gradient are particularly relevant. A reduction in slope is normally associated with a reduction in sediment transport and areas of sediment deposition (aggradation). On the Waipawa River the slope reduces at the Mangaonuku confluence. On the Tukituki River the slope reduces at the Tukipo confluence. As such we would expect sediment aggradation around these locations. Both of these locations are upstream of SH2.

Figure 5.2 shows the average change in sediment storage between each cross section. The distance between cross-sections is approximately 500 m. These are based on the cross-sections across the active channel and do not include the gravel that might have been extracted in that reach over the period. In gravel management areas (refer to Figure 3.1) where gravel is being extracted to maintain the “extraction grade line” (the design bed level to maintain capacity for flood defence) then little change in storage is expected. Figure 5.3 shows the gravel extraction.

The following observations can be made considering the combined change in channel storage and extraction (Figures 5.2, 5.3 and Figure 5.4):

- Lower Tukituki (0 – 10 km) there is a lowering of the bed (gravel storage is negative) that is concurrent with gravel extraction
- Lower/middle Tukituki (10 – 58 km) there are fluctuations in gravel storage, but little intervention via gravel extraction
- Upper Tukituki (58 – 63 km) and Waipawa (63 – 71 km) little change in sediment storage, which is concurrent with gravel extraction over these areas. There is a net surplus of gravel in this area (Figure 5.4) that is managed by extraction
- Waipawa (71 – 82 km) [XS16-36] shows a small increase in sediment storage with extraction only occurring at chainage ~75 km. There is a net surplus of gravel in this area that is partially managed by gravel extraction.

  Note: This area of the river has excess gravel i.e. the bed levels are above the extraction grade line for the reach between XS16-39. However, access to these areas is difficult, so extraction is targeted upstream [XS36-47] (pers. coms Graham Edmondson, HBRC)
- Waipawa (82 – 85 km) shows decrease in gravel storage and large quantity of gravel extraction at chainage ~85 km

  Note: High extraction in this area [XS 36-47] to below the extraction grade line to manage sediment accumulation in the downstream section (pers. coms Graham Edmondson, HBRC)
- Waipawa (85 – 91 km) shows decrease in gravel storage associated with over-extraction downstream. No gravel extraction in this area (as the river is broadly contained by river terraces upstream of SH50 so no requirement for flood protection). Net surplus of gravel
- Waipawa (91-100 km) shows greatest increases in gravel storage associated with increased bed levels. No gravel extraction in this area. Net surplus of gravel.

There are some temporal changes that are lost in the averaging, which are clearer in the extraction trends (refer Figure 3.7). For the lower Tukituki there has been a reduction in extraction since 1996 - 1998 where it exceeded 100,000 m^3/year to be now approximately 30,000 m^3 in 2008 - 2009. Conversely there has been an increase in extraction from the Waipawa since 2003 to in excess of 100,000 m^3/year.

Figure 5.5 shows the sediment transport (defined as sediment supply into reach, refer to Section 4.5.1). A reduction of transport with distance downstream (negative slope) represents areas where there is sediment surplus, which manifests itself as aggradation and increases in bed levels unless these are controlled by extraction. This is the general trend for the entire Tukituki/ Waipawa River system.

An increase in transport with distance downstream (positive slope) represents areas where there is degradation. This is evident at two locations, the first for Waipawa chainage 85 - 90 km, which is immediately upstream of an area where over-extraction is deliberately occurring. This may result from local increase in slope to adjust to this downstream disturbance.

The other reach where there is a slight negative slope is from Tukituki chainage 10 - 58 km. Correspondingly, in this reach the sediment transport is negative, which is not possible as the minimum sediment transport is zero. The negative slope and the negative transport indicate that there is some sediment missing from the sediment budget. It was identified in Section 4.5.3 that up to 40% may be missing from the budget due to sediment trapped in the flood berms.

Other reasons for missing sediment volume may be the loss of bed material to the suspended sediment fraction by abrasion and other breakdown process, reliability of extraction data and uncertainty in the gravel outflow to the coast. Given these issues with the sediment budget it is considered that estimates for bed material based on the sediment budget are non-conservative (actual sediment supply is likely to be higher).

Table 5.1 summarises the average annual sediment transport rates from the sediment budget.

Table 5.1: Summary of average annual sediment transport rates (1980 - 2009)

Location	Chainage (km)	Sediment transport (m^3/year)
Tukituki River – Coast	0.00	10,000
Tukituki River – Red Bridge	14.87	14,300
Tukituki River – d/s Waipawa confluence	62.45	3,700
Tukituki River – u/s survey reach	102.39	49,000
Waipawa River – Waipawa (SH2)	68.41	5,200
Waipawa River – SH50	85.21	58,700
Waipawa River – d/s Makaroro confluence	98.34	101,000
Waipawa River – u/s Makaroro confluence	101.90	48,700
Makaroro River – u/s Waipawa confluence	99.47	55,600

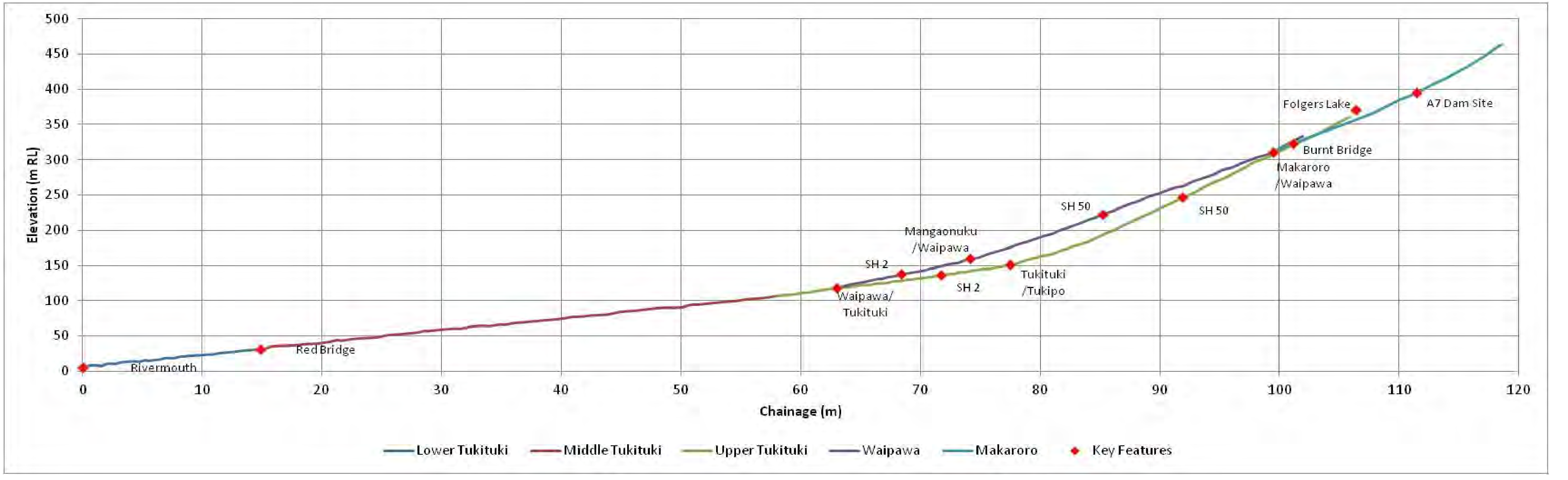

Figure 5.1: Minimum bed level at chainage location

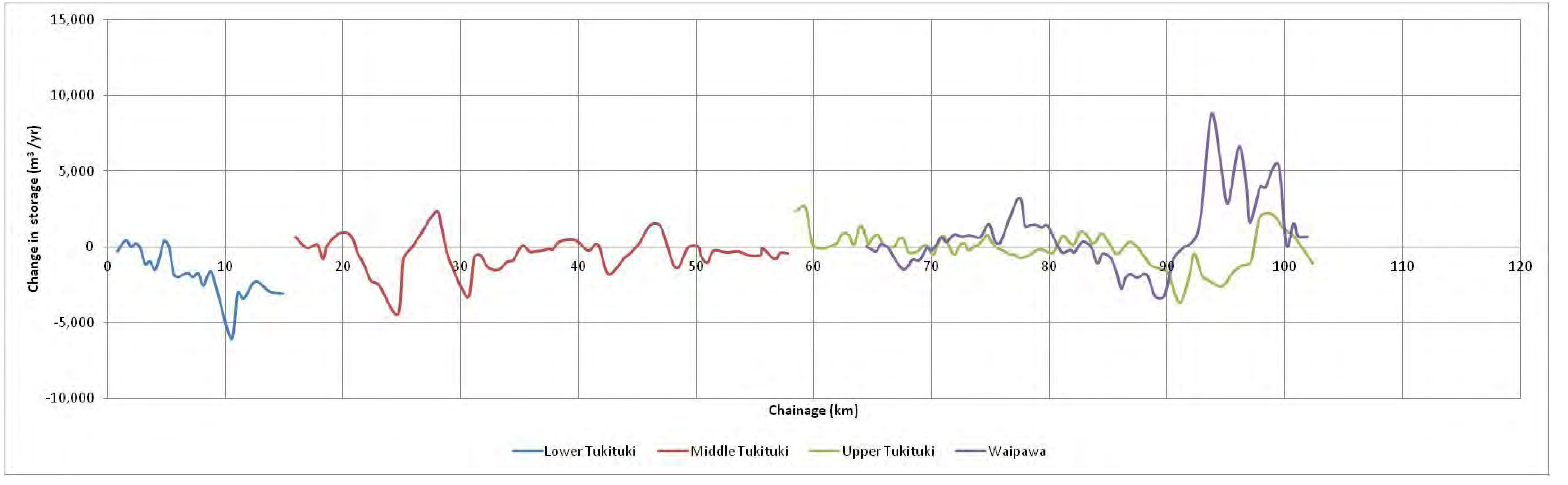

Figure 5.2: Change in storage at chainage location excluding extraction

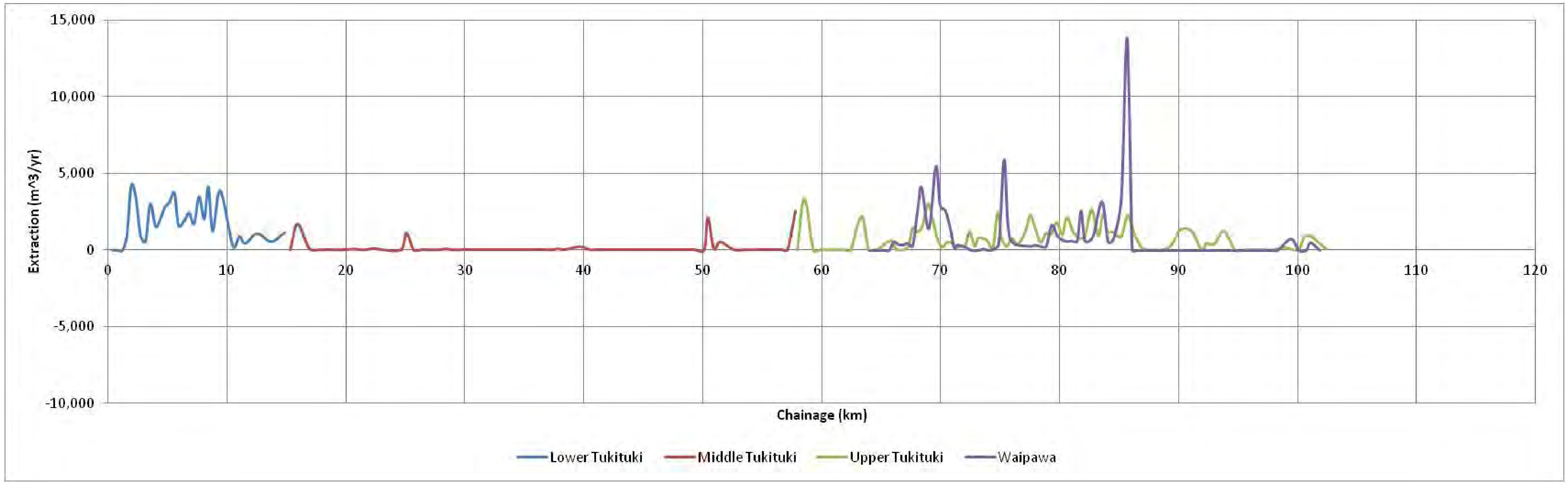

Figure 5.3: Extraction by chainage location

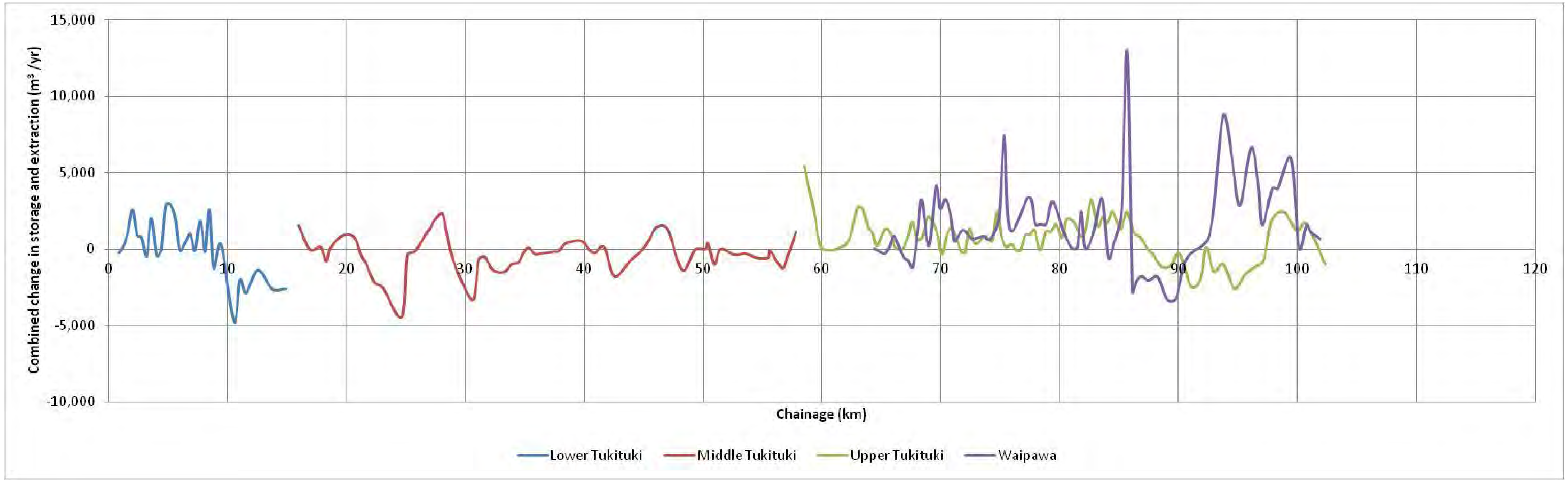

Figure 5.4: Combined change in storage and extraction at chainage location

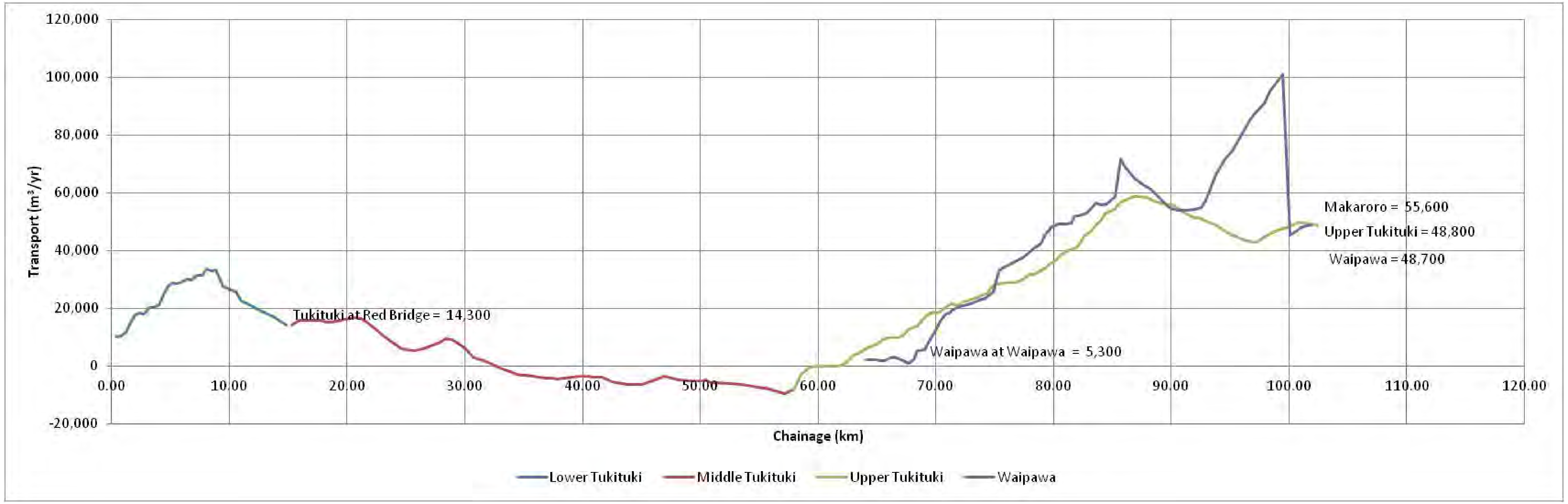

Figure 5.5: Gravel transport at chainage location

5.2 Temporal and spatial variability within sediment budget

Figure 5.6a shows that the general trend over the period from 1981 – 2009 is for degradation of the lower Tukituki reach. For the most part, this is relatively minor apart from peaks in the two periods from 1990 – 1993 and 2003 – 2006. The only period of significant aggradation is from 1988 – 1990, potentially associated with Cyclone Bola in 1988. Figure 5.6b shows that extraction rates from this reach of the river were low in the early 1980s and progressively built to a peak of 50,000 m^3/year from cross-sections 11-20 in the period from 1996 – 2000. Note the relationship between cross-sections numbers and chainages (km) is given in Appendix E.

Figure 5.7a shows that the middle Tukituki reach was predominantly degrading from 1980 – 1994. From 1994 – 2005 the bed level is relatively balanced with a slight tendency towards aggradation. Figure 5.7b shows that extraction across all periods is minimal from this reach.

Figure 5.8a shows that for the upper Tukituki reach, the volume change is in flux across all periods measured with no clear general trend emerging. The period from 1993 – 1998 exhibits relative stability however all the other periods show peaks of both aggradation and degradation across the full length of the river sub-reach for different periods. Figure 5.8b shows that extraction is tending to decrease across the period of investigation apart from two peaks in cross-sections 61 – 70 and 51 – 60 in the periods of 1998 – 2002 and 2002 – 2008 respectively.

Figure 5.9a shows that from 1982 – 1995 the Waipawa reach exhibited aggradation in its upper portion, which continued to a lesser extent between 1995 – 2001. Figure 5.9b shows that extraction rates increased significantly in the period from 2001 -2007, especially for cross-sections 41 – 50. This corresponds to the previously noted extraction at Waipawa chainage 85 km [XS 41]. This will be contributing to the degradation at that sub-reach and period, but located further upstream than the extraction area.

The general conclusion is that the sediment transport and management practises in the Tukituki/Waipawa River system are temporally and spatially variable. This can be seen in the sediment data, but is averaged out in the sediment budget. Management practises need to account for this temporal and spatial variable by being flexible and based on an ongoing monitoring programme, which is the current approach of HBRC (refer Section 3.5).

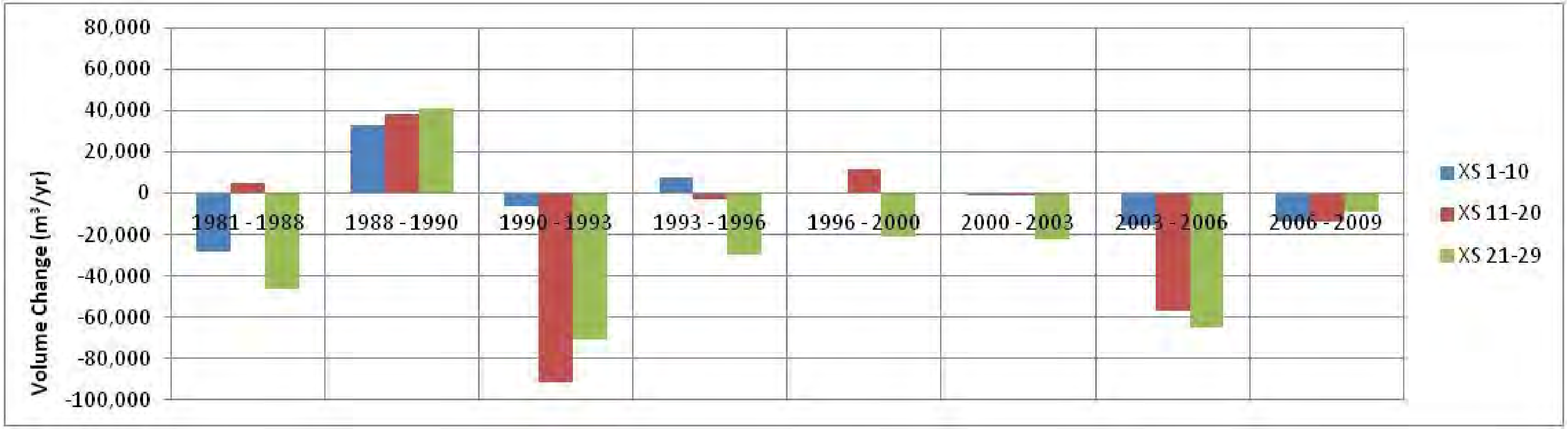

Figure 5.6a: Lower Tukituki - Volume change per annum

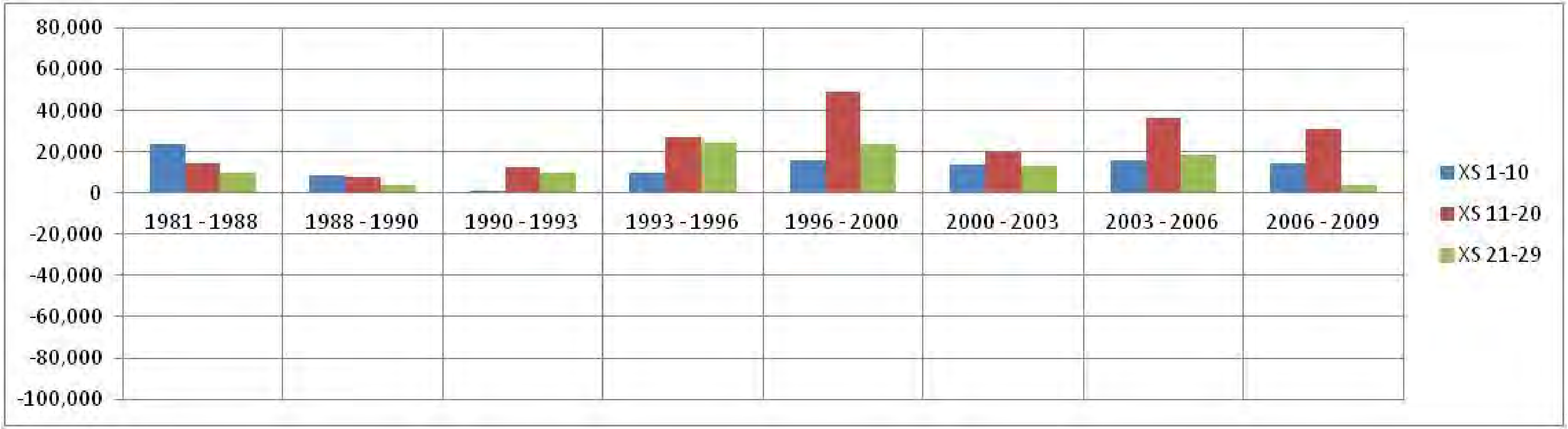

Figure 5.6b: Lower Tukituki - Extraction per annum

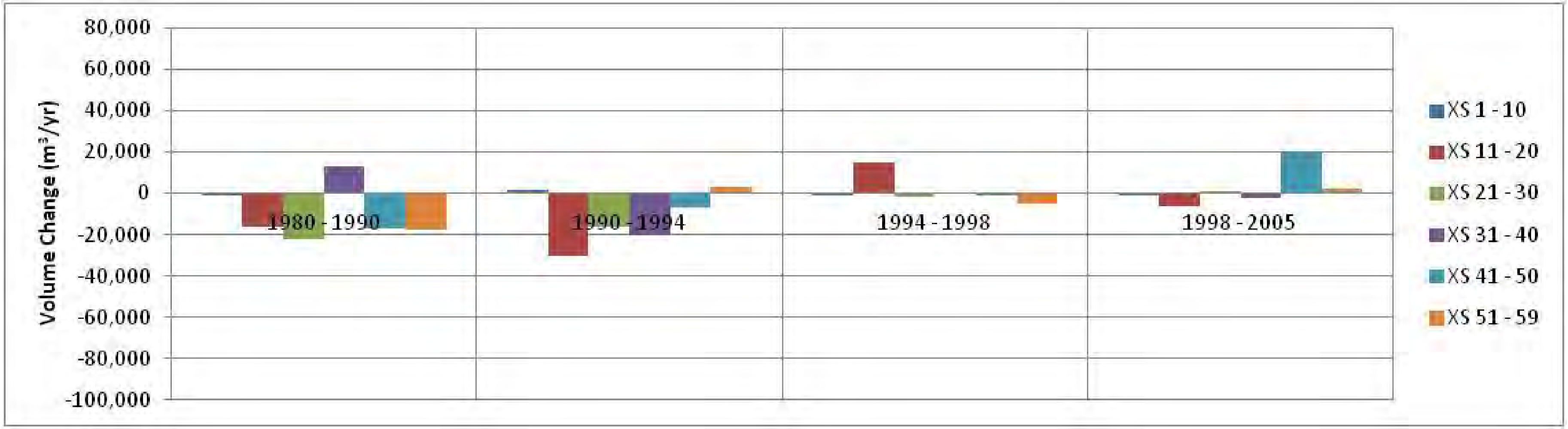

Figure 5.7a: Middle Tukituki - Volume change per annum

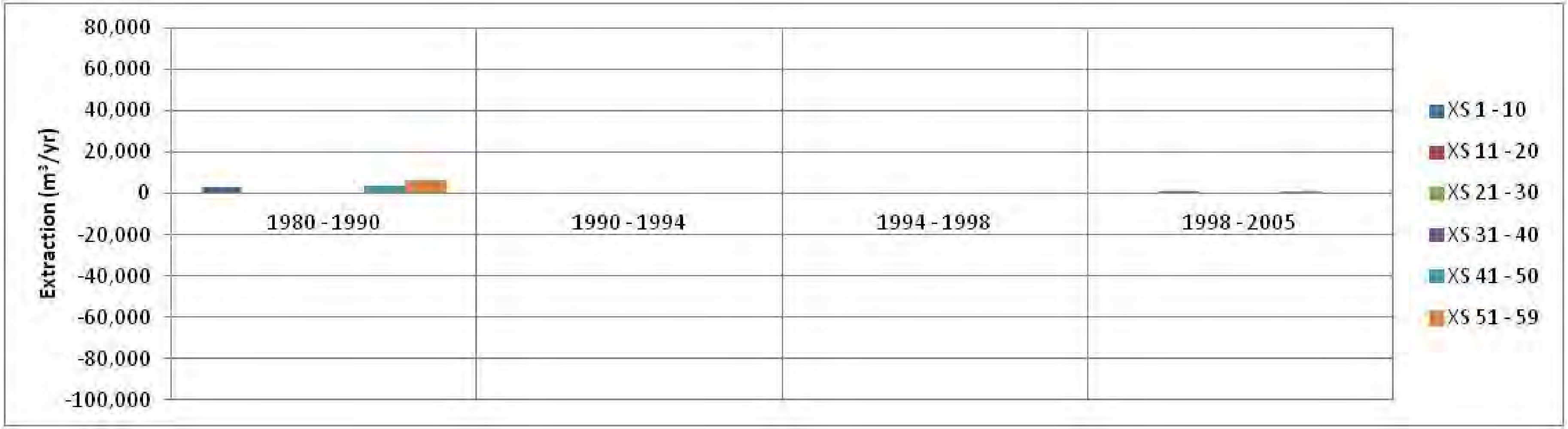

Figure 5.7b: Middle Tukituki - Extraction per annum

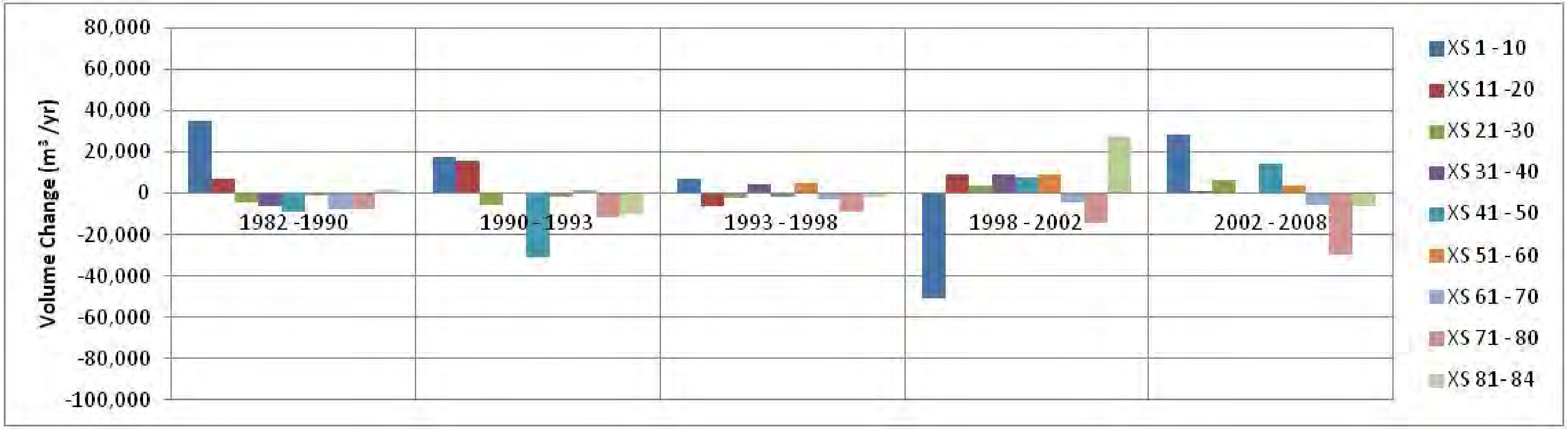

Figure 5.8a: Upper Tukituki - Volume change per annum

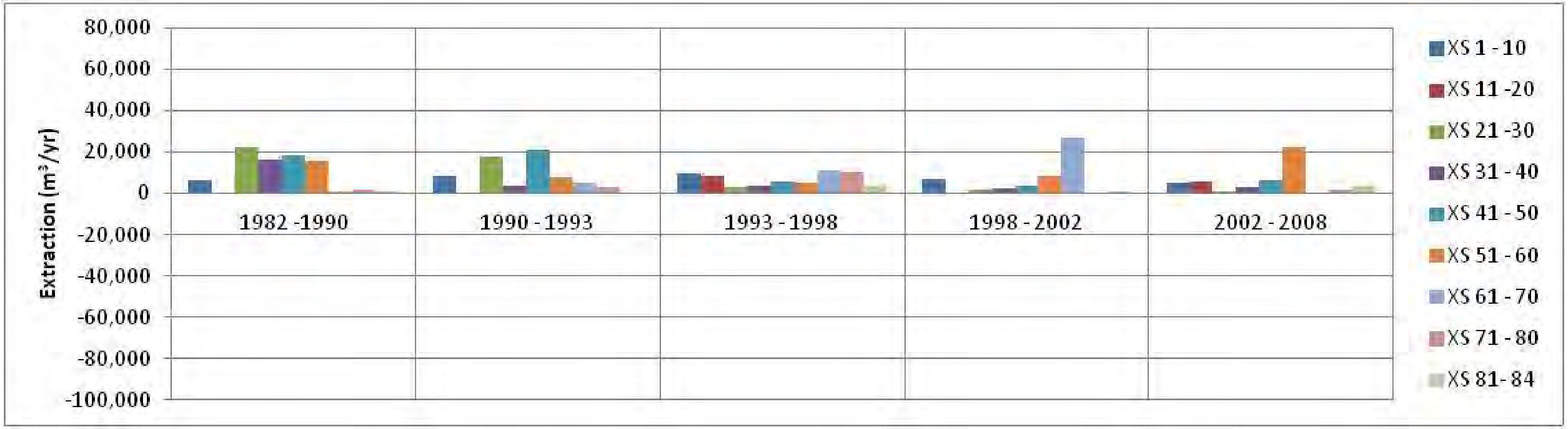

Figure 5.8b: Upper Tukituki - Extraction per annum

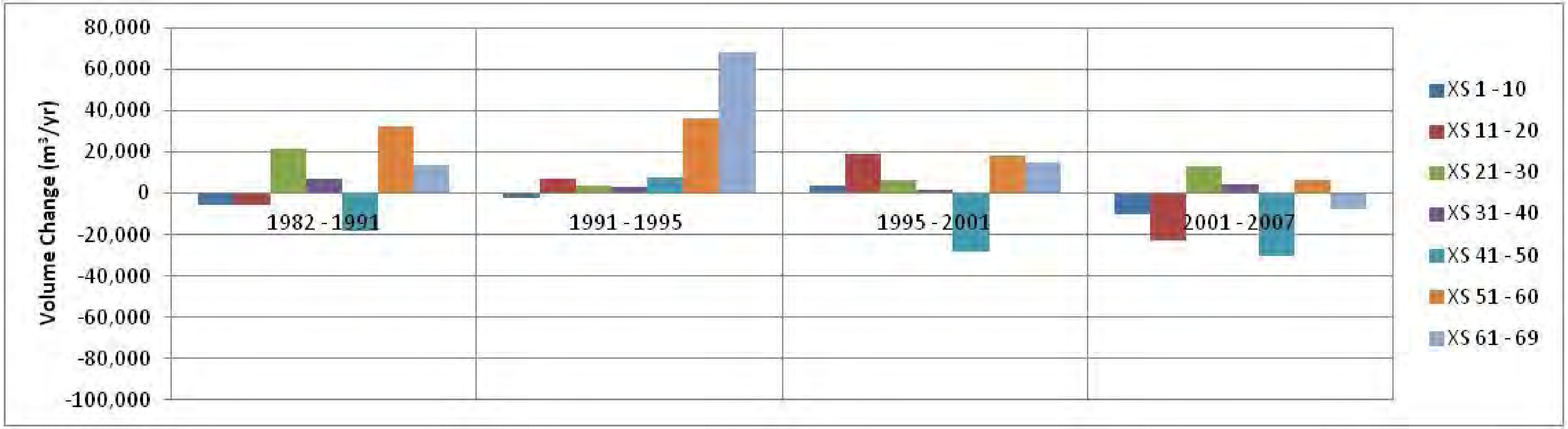

Figure 5:9a: Waipawa - Volume change per annum

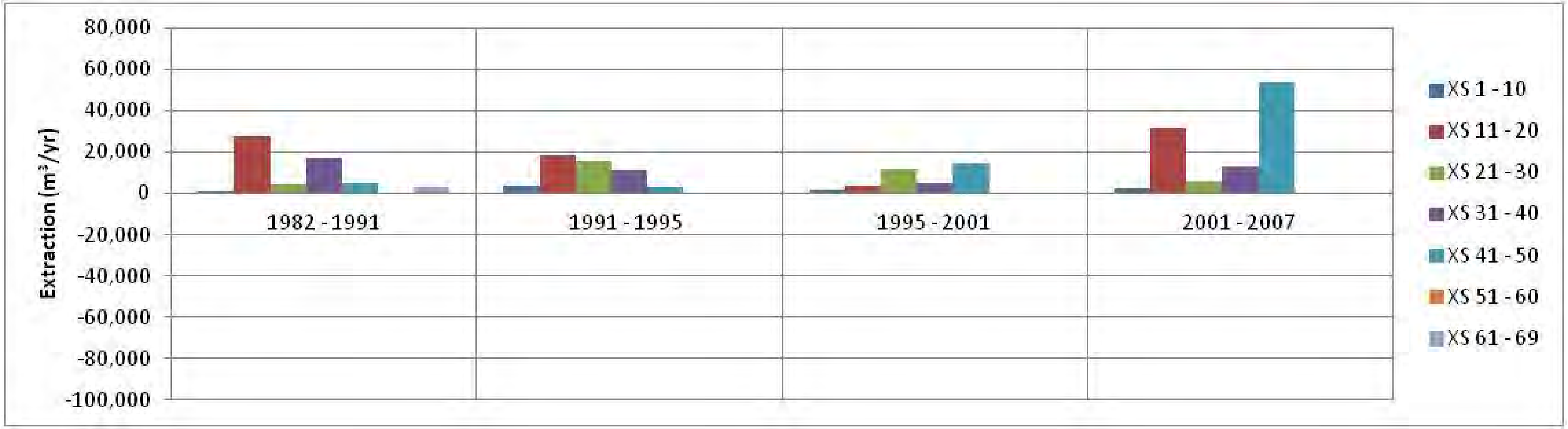

Figure 5.9b: Waipawa - Extraction per annum

6 Sediment allowance for Dam

In this Section the sediment allowance for the Dam is detailed. Refer to Section 6.4 for a summary of the sediment allowance.

6.1 Suspended sediment estimate

There are no suspended sediment studies specific to the Makaroro catchment. However, there are a number of estimates for suspended sediment for the Tukituki/Waipawa River system including Adams (1979), Williams (1985), Mosley (1992) and Hicks et al (2011), refer to Table 1, Appendix C for details. The analysis by Hicks et al (2011) for the development of the WRENZ model includes the suspended sediment records for the Tukituki River at Waipukurau and Red Bridge. The recommended approach for estimating the suspended sediment at the Dam is to use the WRENZ estimate as it is supported by catchment data and is well documented by Hicks et al (2011).

The estimates of suspended sediment from the WRENZ model for Red Bridge are similar to those developed by Mosley (1992), refer to Table 1, Appendix C. The estimate by Adams (1979) is higher at approximately 2.2 times the other two estimates at the Red Bridge gauge.

The estimate of suspended sediment from the WRENZ model at the Dam is 46 Kt/year, which is based on a calibration factor of 2.03 using data from the Red Bridge gauge in the lower catchment. The raw (uncalibrated) WRENZ estimate for suspended sediment at the Dam is 2.03 higher or 93 Kt/year. An alternative calibration that is likely to be more representative of the upper Makaroro/Waipawa catchment is for the Waipukurau gauge on the upper Tukituki, which gives an estimate of suspended sediment at the Dam of 61 Kt/year. However, it is expected that the estimate of suspended sediment at the Dam will be higher due to the greater average steepness of the Makaroro above the Dam site compared to the catchment above the Waipukurau gauge. Therefore, the measured Waipukurau yield has been scaled by the factor (WRENZ specific yield at Dam)/(WRENZ specific yield at Waipukurau) = 1.61, which gives the suspended sediment at the Dam of 98 Kt/year. These results are summarised in Table 6.1 below.

Table 6.1: Suspended sediment estimates using the WRENZ model

	Kt/year	$t/km^2/year$	$m^3/km^2/year$	$m^3/year$
WRENZ estimate (scaled to Red Bridge)	46	415	346	38,300
Raw WRENZ estimate (unscaled *2.03)	93	843	702	77,800
WRENZ (scaled to Waipukurau)	61	550	458	50,700
WRENZ (Waipukurau gauge estimate scaled for steepness *1.61)	98	886	738	82,000

The higher estimates of suspended sediment at the Dam of 93 and 98 kt/year, corresponding to 77,800 and 82,000 m^3/year, are consider to best represent the suspended sediment yields in the upper catchment. These estimates are used with the Brune (1953) method to estimate the amount of suspended sediment that is trapped within the reservoir (refer Section 6.3).

6.2 Bed load sediment estimate

6.2.1 Literature

There are no bed load sediment studies specific to the Makaroro catchment. The HBRC has surveyed cross-sections for two areas of the Makaroro River, one upstream of the proposed Dam and the second near the confluence of the Makaroro and Waipawa Rivers, from 1992 to 2011. The upstream location shows cumulative volume loss of -5,380 m^3/year (-57 m^3/km^2/year), refer Appendix C. The downstream location shows cumulative volume gain of 1,580 m^3/year (13 m^3/km^2/year). These two surveys are limited in their extent and as such represent localised changes in gravel storage rather than bed load transport rates.

The nearest bed load estimates are for the Waipawa at Waipawa at 160,000 m^3/year (231 m^3/km^2/year) (Williams, 2011) and further downstream for the lower Tukituki of 45,000 - 59,500 m^3/year, (HBRC, 2001, Adams, 1979), refer Appendix C. However, the Makaroro as a headwater river of the Waipawa and Tukituki system, is likely to have a higher specific bed load yield due to its proximity to sources of coarse sediment, so a direct translation by catchment area would likely be an under estimate of the bed load yield.

Grant (1982) details some of the highest sediment yields observed in New Zealand for the headwater areas of the Waipawa catchments after Cyclone Alison in 1975. He estimated sediment yields of up to 4,500 m^3/year for small catchments of 1.2 km^2. These catchments had eroded surface area to drainage area ratios as high as 1:4.5 (refer Appendix C). This sediment yield is for a small headwater catchment with a high erodible surface ratio and therefore cannot be applied to the Dam.

Williams (1985) estimated sediment transport for flood events along reaches in the Tukituki basin including the Makaroro and Waipawa. The mean sediment transport for the 2 year and 100 year return period events along the Makaroro were estimated to be nil and 0.25 m^3/s, respectively. These values seem low compared to values given for Waipawa and for the upper Tukituki downstream of Folger's Lake. The nil value for the 2 year return period in the Makaroro is not considered realistic. Sediment transport is expected for the 2 year event in the Makaroro River based on observations of the changeable morphology and active river bed.

6.2.2 Estimate by translation of Folger's Lake sedimentation.

The methodology for translating the sedimentation observed within Folger's Lake to the reservoir is detailed in Section 4.4.

The published estimates for sedimentation in Folger's Lake exhibit a significant degree of variation of between 103,900 – 215,300 m^3/ year (1,350 - 2800 m^3/km^2/year) (refer Appendix C). The Folger's Lake data we have the most confidence in, is that obtained by Williams (1985) of 122,700 m^3/year. This is because Williams study encompasses the longest period and includes the most detailed background information.

The Williams (1985) estimate has recently been validated by a revised HBRC (2011) estimate of 103,900 m^3/year. This estimate is lower than Williams (1985) due to missing volume in the HBRC estimate from upstream and downstream of the survey areas. The Williams (1985) estimate is supported by the de Leon (1980) study, which although estimates a higher specific yield, it does this for a shorter duration and therefore is more biased by the effects of Cyclone Alison (1975). The highest estimate by Hamilton (circa 1980, cited in Grant 1982) is 215,300 m^3/year. This report has been requested from HBRC but has not yet been found and therefore cannot be validated. The Hamilton estimate cannot be supported due to the weight of the evidence towards the Williams (1985) estimates and because Hamilton (1980) was an earlier study and was superseded by Williams (1985).

The Williams (1985) estimate of 122,700 m^3/year is scaled by 0.85 to exclude the suspended sediment (refer Section 4.4.3) and scaled by the erodible area in each catchment for the Makaroro and Tukituki catchments of 1.73 (2.61 km^2/1.51 km^2 from Table 4.1). Therefore, the estimated bed load for the reservoir based on Folger's Lake is 180,300 m^3/year.

6.2.3 Estimate from sediment budget

The estimated bed material sediment from the Makaroro River based on the sediment budget is 55,600 m^3/year. If this is increased by 40%, which is the estimated losses of sediment to outside the active channel (refer Section 4.5.3), then this increases to 77,850 m^3/year. This assumes that the bed material transport at the Dam is the same as the Makaroro confluence with the Waipawa (extent of the sediment budget).

As mentioned in Sections 4.5 and 5.1 there are reasons for an under-estimate from the sediment budget, so this estimate is considered to be non-conservative for the purpose of a sedimentation estimate for the Makaroro reservoir and thus provides a lower estimate.

6.2.4 Estimate from bed transport formula

HBRC (December 2012) used the sediment transport formula of Wilcock and Crowe (2003) to estimate sediment transport for the Makaroro at the Dam. The pre-dam sediment transport estimate was 134,000 m^3/year (refer Appendix G for details).

HBRC (December 2012) noted that the sediment transport capacity estimates for the Makaroro at the Dam of 134,000 m^3/year and at Burnt Bridge of 115,000 m^3/year were higher than downstream sites and attributed this to the gorge like nature of the sites and resulting high shear stresses. They suggested that the actual transport rate may be limited by supply of sediment at the sites rather than the transport capacity. The Makaroro does not appear to have a limited supply of sediment as the observed bed comprises of gravel and there is considerable storage of sediment in the active channel. The bed material and bed levels vary over time due to floods causing episodic transport processes and sediment supplies in the catchment. Conversely, for the downstream Waipawa River the supply does exceed transport capacity and it is aggrading, so the higher transport in the Makaroro (supplying the Waipawa) is supported by the downstream aggradation.

6.2.5 Summary of bed load estimates

The bed load estimates are summarised in Table 6.2. The bed load estimate based on Folger's Lake is the highest, but may be conservative due to a stormier than normal period of weather during sediment filling including Cyclone Alison (refer Section 4.4.3). The sediment budget estimate is the lowest, but is expected to under-predict bed load (refer Section 4.5 and 5.1). The bed transport formula is a theoretical estimate and is uncalibrated, but provides a supporting value that is approximately midway between the other two estimates. The approach taken in this assessment is to estimate the sediment retention for the reservoir using the upper and lower estimates of 77,800 m^3/year to 180,300 m^3/year.

Table 6.2: Summary of bed load estimates

Methods	Bed load (m^3/year)
Folger's Lake	180,300
Bed transport formula	134,000
Sediment budget	77,850

6.2.6 Suspended vs bed load sediment

The relationship between suspended sediment and bed load is variable between catchments and within a catchment. Hicks et al (2011) provides estimates of bed load to the coast as a percentage of suspended sediments ranging from <1% – 13%. Hicks et al (2011) notes that in an 'ideal' river system, the ratio of bed load to suspended sediment load diminishes as you travel downstream. Therefore, we would expect higher percentages than these values in the Makaroro. Indeed Williams (1985) established that suspended sediment and bed loads were approximately equal (i.e. bed load is 100% of suspended load) for the Tukituki at Red Bridge and Waipawa at Waipawa (refer to Figure 6.1 below). We would expect a similar ratio or increase in percentage in bed load higher in the catchment.

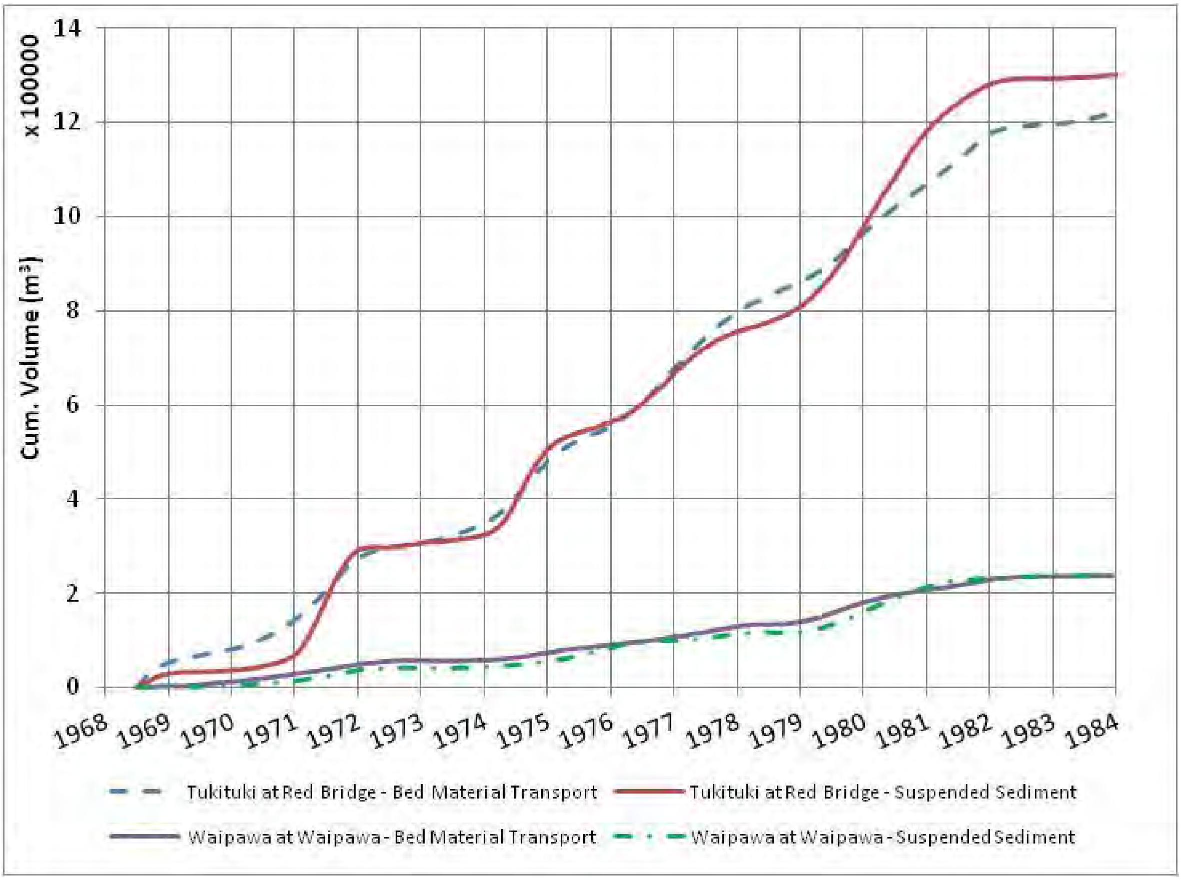

Figure 6.1: Estimated cumulative sediment transport (recreated from Williams, 1985)

The ratio of bed load to suspended sediment load for the estimates for the reservoir are calculated in Table 6.3. The bed load is equal or higher than the suspended sediment load, which is consistent with the Williams (1985) findings and the expectation that the proportion of bed load should be higher in the upper catchment. The bed load estimate from Folger's Lake is considered to be conservative (refer Section 4.4.3), which may explain the percentages of 220-230%. Conversely, the bed load estimate from the sediment budget is considered to be an under-prediction. Alternatively, the suspended sediment estimate may be low. However, it cannot be otherwise verified without extensive field investigations. For the purpose of estimating the reservoir sedimentation there is sufficient range in the estimates to account for these uncertainties.

Table 6.3: Percentage of bed load to suspended sediment for sediment estimates

	Bed load (Sediment budget) = 77,850 m^3/year	Bed load (Folger's Lake) = 180,300 m^3/year
WRENZ suspended sediment estimate (unscaled) = 77,800 m^3/year	100%	230%
Waipukurau gauge suspended sediment estimate (scaled for steepness) = 82,000 m^3/year	95%	220%

6.3 Sediment retention in the reservoir

The preliminary estimate of sedimentation in the reservoir is based on the bed load estimates for the Makaroro River at the Dam and the trapping of suspended sediment using the Brune method (refer Section 4.3.2). This Section details the trapping efficiency calculations using the Brune method.

The annual suspended sediment transport used in the Brune method is based on the unscaled WRENZ suspended sediment estimate of 77,800 m^3/year and the scaled Waipukurau gauge suspended sediment estimate of 82,000 m^3/year.

The Brune method has three curves for trapping efficiency, which provides ranges for the trapping efficiency (refer Section 4.3.2). The effect of the trapping efficiency is demonstrated in Table 6.4 for the higher bed load estimate. The results are not very sensitive to the assumed curve for trapping efficiency. Due to the relatively large volume of the reservoir the trapping efficiency remains over 90% for all curves, all suspended sediment loads and future years (<100 years).

Using the Brune method the worst case scenario is obtained by applying the upper curve for trapping efficiency in conjunction with the higher suspended sediment estimate (82,000 m^3/ year) resulting in a storage loss of 26 million m^3 and a remaining live storage of 65.4 million m^3 after 100 years. The complete results are shown to three significant figures in Table 6.4 below to demonstrate that the differences with respect to assumed Brune curves for trapping efficiencies are not large.

Table 6.4: Sedimentation using Brune method after 100 years (for bed load = 180,300 m^3/year)

Brune Trap efficiency	Unscaled WRENZ suspended sediment of 77,800 m^3/year		Scaled Waipukurau gauge suspended sediment estimate of 82,000 m^3/year	
	Sediment (m^3)	Remaining storage (m^3)	Sediment (m^3)	Remaining storage (m^3)
Upper	25,600,000	65,800,000	26,000,000	65,400,000
Median	25,200,000	66,200,000	25,600,000	65,800,000
Lower	24,800,000	66,600,000	25,200,000	66,200,000

6.4 Estimate of sedimentation in the reservoir

For the estimate of sedimentation in the Reservoir is 15-26 million m^3 over 100 years based on the range of estimates, refer Table 6.5.

There remains considerable uncertainty in the bed load estimates, which is inherent with this type of estimate. We consider that the lower estimate to be non-conservative due to unaccounted sediment losses in the sediment budget, and the upper estimate to be conservative due to the stormier period that was the basis of the Folger's Lake derived estimate for bed material.

The suspended sediment estimates are from the WRENZ model based on the unscaled estimate and the Waipukurau measured suspended sediment upscaled for the upper Makaroro catchment characteristics, which give similar estimates.

Sediment generation is greatly influenced by extreme events such as extreme floods and/or earthquakes and these have the ability to increase the rate of reservoir sedimentation. Similarly, prolonged periods of quiescent conditions will reduce sedimentation rates. The upper and lower estimates for sedimentation in the Reservoir provide a range in the estimates to demonstrate for these uncertainties.

Table 6.5: Sedimentation and remaining storage after 100 years

Description	Annual suspended sediment (m^3/year)	Annual bed load sediment (m^3/year)	Sediment (m^3)	Live Storage (m^3)
Unscaled WRENZ suspended sediment and Folger's Lake bed load estimates	77,800	180,300	25,600,000	65,800,000
Scaled Waipukurau gauge suspended sediment and Folger's Lake bed load estimates	82,000	180,300	26,000,000	65,400,000
Unscaled WRENZ suspended sediment and sediment budget bed load estimates	77,800	77,850	15,400,000	76,000,000
Scaled Waipukurau gauge suspended sediment and sediment budget bed load estimates	82,000	77,850	15,800,000	75,600,000

These sedimentation estimates result in reservoir half lives ranging from 175 to 287 years and ultimate fill times ranging from 355 to 603 years. The duration results for each scenario are presented in Table 6.6.

Table 6.6: Reservoir half lives and ultimate fill times

Description	Annual suspended sediment (m^3/year)	Annual bed material sediment (m^3/year)	Half life (years)	Ultimate fill time (years)
Unscaled WRENZ suspended sediment and Folger's Lake bed load estimates	77,800	180,300	178	359
Scaled Waipukurau gauge suspended sediment and Folger's Lake bed load estimates	82,000	180,300	175	355
Unscaled WRENZ suspended sediment and sediment budget bed load estimates	77,800	77,850	287	603
Scaled Waipukurau gauge suspended sediment and sediment budget bed load estimates	82,000	77,850	285	588

7 Effects from sedimentation

In this Section, the effects from sedimentation in the Reservoir and the changes to the downstream river are investigated. A general description of the sedimentation patterns and impacts is provided. The potential physical effects of the sedimentation caused by the Dam are then assessed.

The sedimentation assessment provides input to the aquatic ecology studies (Cawthron, 2013).

Mitigation measures are identified in this Section, but are summarised in Section 9 - Sediment Management Plan.

7.1 General

7.1.1 Deposition patterns

The generalised deposition patterns for sedimentation in reservoirs are summarised in Figure 7.1. As the river enters the slack water of the reservoir, the flow decelerates and the transported sediment drops out. The result is the formation of a delta at the head of the reservoir. The coarser sediment (typically sand and gravel) deposits fluvially to form an aggrading topset (annotated as “delta” in Figure 7.1). The downstream end of the deposits is less stable and forms a prograding foreset slope. The foreset advances down the reservoir as the delta accumulates sediment.

The finer sediment (typically silt and clay) deposits in deeper water to form bottomset sediments. These sediments are distributed across the lake by surface plumes and density currents depending on the relative density of the river water (inclusive of suspended sediment) to the reservoir water.

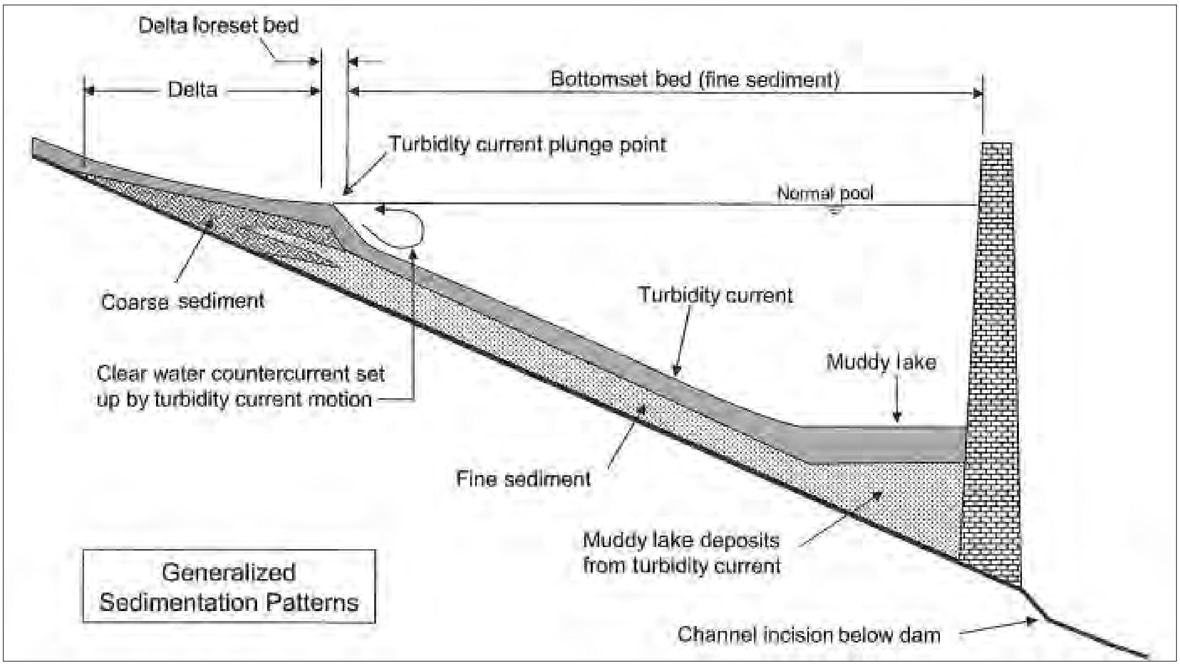

Figure 7.1 Generalised sedimentation patterns in a reservoir (Morris et al, 2007)

7.1.2 General impacts

Sedimentation due to the Reservoir has the potential to impact not only on the Reservoir, but also the river far downstream and the coast, as well as short distances upstream of the Reservoir.

The typical sedimentation impacts with their applicability to the Dam are summarised in Table 7.1. These are grouped into impacts upstream of the Reservoir associated with the hydraulic effects of the sediment delta, within the Reservoir associated with the delta and bottomset (fine) sediments and downstream of the Dam associated with interruption of sediment supply and changes to flow regimes.

Table 7.1: Sedimentation impacts and applicability to the Dam (adopted from Morris et al, 2007)

Impact location	Impact type	Impact description	Applicability to the Dam
Upstream of Reservoir	Delta deposition	Bed aggradation causing higher normal and flood water levels.	Likely, with effects on land and terrestrial vegetation. Considered further in the assessment of effects below.
		Higher groundwater levels.	Likely, with effects on land and terrestrial vegetation to be considered with the Reservoir in the assessment of effects.
Within Reservoir	Storage loss	Reduced storage capacity in lake.	Yes, but design includes for the expected sedimentation volume.
	Reservoir operations	Sediment impacts on intakes and gate operation and hydro-mechanical equipment.	Possible, but can be designed for at detailed design stage. Note no sluicing gates proposed.
	Turbidity	Effects on primary production and unpleasant for recreation.	Possible, to be considered in the assessment of effects.
	Navigation /access	Sedimentation impairs navigation in reservoir and fishery. Access harder during drawdown.	Yes, but opportunities also created. Consider in the assessment of effects.
	Air pollution	During drawdown fine sediment exposed to air can dry out and be eroded by wind.	Possible, to be considered in the assessment of effects below.
Downstream of Reservoir	Reduced bed load	Degradation and accelerated bank erosion. Can affect tributaries as well.	Likely, considered further in the assessment of effects below.
		Bed becomes coarse with effects on habitats and fish spawning.	Likely, considered further in the assessment of effects below.
		Structures such as bridges, river management infrastructure (edge protection to banks and flood banks).	Possible, considered further in the assessment of effects below.
		Reduced supply to coast and coastal erosion.	Possible, considered further in the assessment of effects below.
		Reduced supply of aggregate materials.	Likely, to be considered in the assessment of effects.
	Reduced fine sediment	Increased water clarity will alter ecological conditions and benefit recreational use.	To be considered in the assessment of effects.
	Flow changes	Reduction in flood flows reduces sediment transport capacity and moderates effects from interruption of sediment supply.	Likely, considered further in the assessment of effects below.
		Reduction in flood flows allows vegetation to encroach into channel modifying channel form.	Likely, considered further in the assessment of effects below.

7.2 Effect of sediment in the Reservoir

7.2.1 Effect within Reservoir

A sediment delta will form within the Reservoir in general accordance with the typical sedimentation patterns shown in Figure 7.1. The delta will progress down the Reservoir from the head of the Reservoir to the Dam over time.

The Reservoir has a large operating range of water levels. The delta will form with the topset/foreset position submerged under the lowest normal water level. On average, the lowest Reservoir level reached each year would be around 22 m below full supply level (refer Section 2.3.2). Sediment that is deposited on the topset of the delta at times when the Reservoir water levels are high will be remobilised during floods when the Reservoir water levels are low.

The only major tributary to the Reservoir is Dutch Creek (refer Figure 7.2). A secondary delta will form here, but its extent is expected to be minor as the bed material supply from this catchment is minor (as evident from aerial photographs). Furthermore, it is located closer to the head of the Reservoir than to the Dam, so will eventually get incorporated into the sediment delta from the Makaroro River.

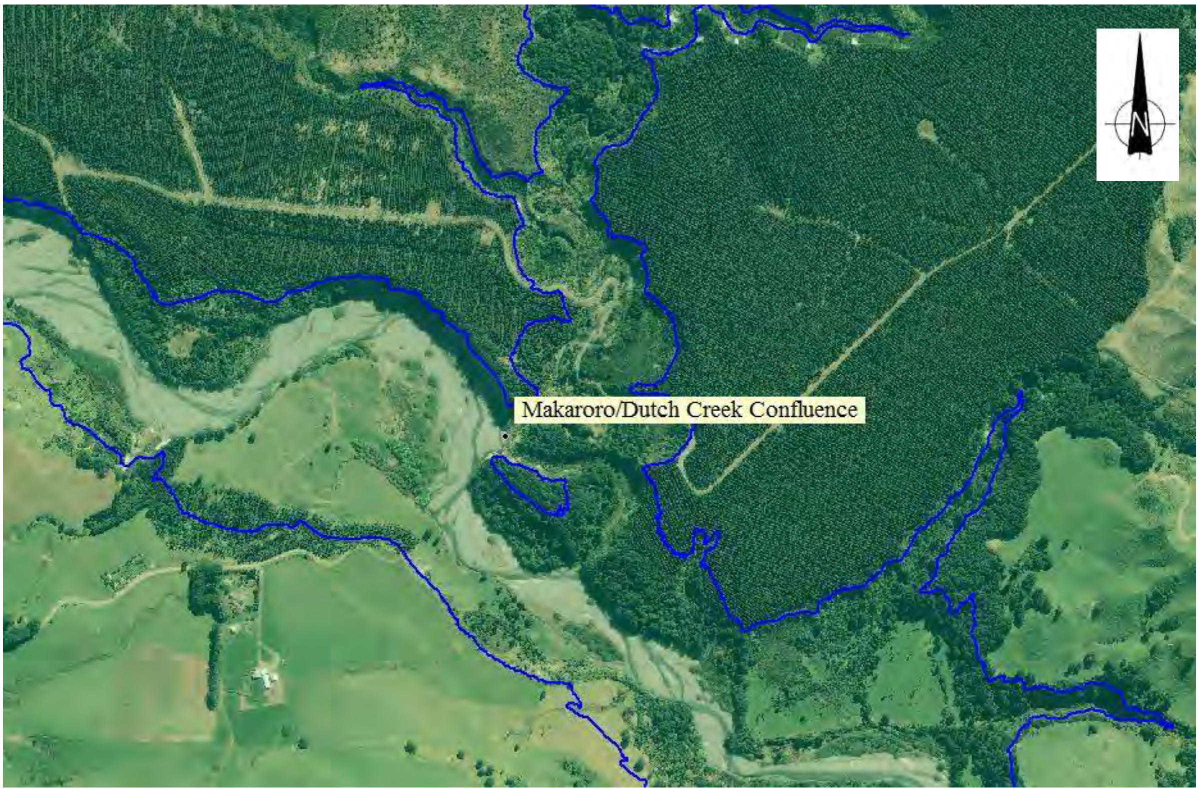

Figure 7.2: Makaroro/Dutch Creek confluence

The effects within the Reservoir are described in Table 7.1. The physical impacts of sedimentation are loss of storage, restrictions to access (in areas where sediment has deposited) and the potential for effects on the Dam outlets. These impacts are planned for as part of the Reservoir operation. Dust is considered in the next Section.

7.2.2 Effect of dust

The potential for dust generation has been considered in general terms for the Makaroro Dam. Factors that contribute to the quantity and likelihood of dust generation and potential for nuisance are:

- Area of exposed ground
- Nature of the exposed area
- Frequency and duration of exposure
- Particle size of exposed ground
- Mechanism of dust generation (e.g. wind, trafficking).

The Reservoir has a bottom inlet level range of between approximately RL 405 m and RL 417 m (Hawke's Bay Datum). NIWA (March 2013a) Scenario M1 adopts RL 405 m as the intake level in respect of water quality. The Full Supply Level of the reservoir is RL 469.5 m. Therefore, the Reservoir has a full operational range of approximately 65 m. At full drawdown nearly the whole Reservoir area will be exposed.

The most frequently exposed areas of the Reservoir bed will be the sediment delta and sides. The sediment delta will comprise of predominantly coarse, gravel sediment, which will be less prone to suspension by wind. Therefore, the potential for dust generation at the head of the Reservoir is less than for other areas.

The sides will form gravel beaches/slopes of approximately 1V to 2H and 1V to 5H (T&T, May 2013) and some fine sediment will be washed from these areas by changing water levels and wave action. The areas most prone to dust generation are the river terraces where the deposited finer sediment on these areas will be susceptible to wind erosion.

The least frequently exposed areas of the Reservoir will be the bottomset bed. The bottomset bed will comprise of fine sediments that are deposited by settling processes. While this material will be prone to dust generation by wind, the sediment generation from these areas will be limited due to the low frequency of exposure and short exposure times.

The Reservoir will be very infrequently trafficked (if at all), so the potential for vehicles or machinery to generate dust is very low.

Dust generation is expected to primarily be a nuisance issue possibility but also potentially affecting visibility. The Dam site is remote with few surrounding dwellings. Wakarara Road, the closest public vehicle access, is largely separated from the Reservoir by a ridge, until it crosses the Reservoir at the historic Mill site shown on LINZ maps. Therefore, the potential for affecting the general public appears to be low. The only dwellings located within sight of the Reservoir are at the head of the Reservoir where the extents of inundated and exposed terraces are limited.

In urban and industrial situations a buffer zone between dust generating activities can be applied to reduce the effects on neighbouring properties. This buffer zone varies, but may be approximately 200 to 500 m. Examination of aerial photos indicates that buildings at the head of the reservoir along Wakarara and Glenny Roads are located between approximately 200 and 800 m from the reservoir. Therefore, this distance would normally be considered an acceptable buffer.

Should dust become an issue, possible methods of mitigation are:

- Treating the exposed surface with a chemical compound to create a crust. Given that the terraces will be regularly inundated, we do not consider this to be appropriate

- Watering the ground to suppress the dust. This would require either the use of water carts or construction of an irrigation system. An irrigation system would be expensive to construct (for a large Reservoir such as this) so we do not consider this to be viable. The use of water carts is likely to be impractical given the access needed to varying elevations of the terraces and river channel
- Vegetation of exposed areas. This is not considered possible because of the regular inundation
- Raise the minimum operating water level to cover the bottomset sediments. This approach is not favoured as there would be a significant impact on the ability to supply irrigation and environmental flows from the reservoir at a time when the demand for such is likely to be critical
- A 20 m zone of buffer planting around the periphery of the reservoir is proposed as part of mitigation works offsetting the impact of vegetation removal within the reservoir area. This planting will have the dual effect of managing effects of any dust generated
- Shelter belt planting in areas close to dwellings at the head of the Reservoir to limit visibility of the dust and also to limit wind generation.

Dust generation should be monitored with inhabitants provided a contact number of the Dam operator if they wish to make complaints. The operator should keep a register of complaints consistent or similar with Appendix 2 of Good Practice Guide for Assessing and Managing the Environmental Effects of Dust Emissions (MfE 2001). Copies of the register should be forwarded to HBRC for their consideration of whether further preventative action is appropriate.

Should a dust issue arise then consideration could be given to planting shelter banks l.

7.2.3 Effect upstream of the reservoir

The effects to upstream areas from the formation of the delta are described in Table 7.1. The bed aggradation and hydraulic backwater effects from the reservoir will cause an increase in flood levels upstream of the reservoir. This may affect one farm upstream of the reservoir and Department of Conservation land. The effect from the bed aggradation will be mitigated in this circumstance because the delta will form at a lower level due to the operating range (see previous comments) and there is potential for future extraction of gravel from the sediment delta.

There are no bridges or river management infrastructure upstream of the reservoir.

7.3 Effect on downstream rivers

7.3.1 General

The effects from the RWSS on sediment downstream of the Dam are due to:

- Interruption of sediment supply (blocking by the Dam)
- A reduction in transport capacity due to reduced flood peaks due to attenuation within the Reservoir.

The interruption in sediment supply has the potential to cause degradation (channel incision along the river reach downstream of the Dam) and associated effects such as coarsening (armouring) of surface sediments. The Reservoir will also moderate the flood peaks, which reduces the gravel transport capacity. In the Makaroro River downstream of the Dam, the reduction in gravel transport capacity will offset/slow the degradation and armouring. Further downstream where sediment supply is not limited, the reduction in gravel transport will reduce the sediment transported in the river and exported to the coast.

The reduction in flood flows, especially the channel forming flows (1 - 2 year return period), also causes a change in the width and form of the channel, which can be compounded by encroachment of vegetation, which would otherwise be stripped by floods.

The effects on downstream rivers are most obviously from the disruption to bed load transport. The reduction in suspended sediment concentration will cause increased clarity, which is assessed in the ecological reports.

7.3.2 Interruption of sediment supply

The changes in sediment budgets to the downstream reaches due to the interruption in sediment supply by the Dam are detailed in Table 7.2. Note that the "Net after Dam" column refers to the situation after all degradation has ceased. In reality the lower Makaroro reach will continue to supply material to the Waipawa until its armour is fully developed. The sediment budget estimates are considered to under-predict transport of bed material. The sediment budgets estimates are used to assess the interruption in sediment supply as the change in supply from the Makaroro can be compared to other values from the sediment budget.

The zero supply in the Makaroro downstream of the Dam is obvious. The sediment transport for the Waipawa downstream of the confluence reduces to 63,550 m^3/year, which is based on the supply from the Waipawa upstream of the confluence. This supply is well matched by the predicted sediment transport capacity for this reach post-dam at 62,628 – 70,835 m^3/year (refer Table 7.3 below).

Table 7.2: Changes in sediment budget (bed material) downstream of the Dam

Location	Sediment transport (m^3/year) *1		
	Sediment transport	Effect of the Dam	Net after Dam
Makaroro (between dam and Waipawa confluence)	77,850	77,850*2	0
Waipawa (between Waipawa confluence and SH50)	141,400	77,850	63,550

*1 From sediment budget based on 1980 to 2009 increased by 40%.

*2 Alternate estimates are 134,000 m^3/year from sediment transport capacity calculations and 180.300 m^3/year derived from Folger's Lake.

The rivers downstream of the Dam and the Makaroro/Waipawa confluence that may be potentially affected by the Dam, are the Waipawa, the middle Tukituki and the lower Tukituki, excluding the upper Tukituki. The decadal (2003 – 2012) average annual extraction was 97,000 m^3/year for the Waipawa and 187,000 m^3/year for the entire Tukituki River system (refer Section 3.5.3).

Therefore, the change of sediment budget caused by the interruption of sediment supply by the Dam (of 78,850 – 180,300 m^3/year) can be mitigated by the reduction in extraction as the extraction rates are similar in magnitude to interruption in Makaroro sediment supply. The reduction in extraction will be as required and based on monitoring in accordance with current HBRC flood and sediment management practices, refer to Section 9 and Section 3.5 for details.

7.3.3 Change in gravel transport capacity

There is a reduction in gravel transport capacity due to the change in the flow regime as shown in Table 7.3 and Figure 7.3. HBRC estimates a reduction in gravel transport capacity of 5-9% in the Makaroro and Waipawa above the UWI due to the flow attenuation of the reservoir.

Downstream of the UWI, HBRC estimates that the flow reduction in the river causes a maximum reduction in gravel transport capacity of 21.5%. While a change in gravel transport capacity is expected, the magnitude of this change between upstream of the intake (5.6%) and downstream of the intake (21.5%) may result in part from the analysis technique. The gravel transport capacity calculations may be overestimating the gravel transport in the low-mid flow range as a distributed particle size distribution is not used (refer Section 4.7.1). The gravel transport capacity calculated across the intake will be most susceptible to this bias, as the flow changes that occur from the operation of the intake occur in the flow range that is most sensitive to this bias (when the river flows are within the main braid).

The reduction in gravel transport decreases with distance downstream and noticeably decreases to 8.2% downstream of the confluence with the Tukituki River due to the additional flow. For the lower Tukituki River HBRC estimates a reduction in sediment transport capacity of 6.4-6.8%.

Table 7.3: Changes gravel transport capacity pre and post dam (HBRC, December 2012)

	Dam	Burnt Bridge	Above Intake (UWI)	Below Intake (UWI)	Waipawa @ RDS	Below Waipawa / Tukituki Confluence	Red Bridge	Black Bridge
Distance from river mouth (km)	115.6	105.2	99	93.4	73.8	66.1	14.4	0.5
Pre-dam Sediment Transport (m^3/year)	134,230	115,410	75,010	79,789	38,185	75,033	17,734	24,739
Post-dam Sediment Transport (m^3/year)	127,328	105,675	70,835	62,628	31,022	68,869	16,596	23,051
Difference (m^3/year)	6,902	9,735	4,175	17,161	7,163	6,164	1,138	1,688
Difference (%)	5.1%	8.4%	5.6%	21.5%	18.8%	8.2%	6.4%	6.8%

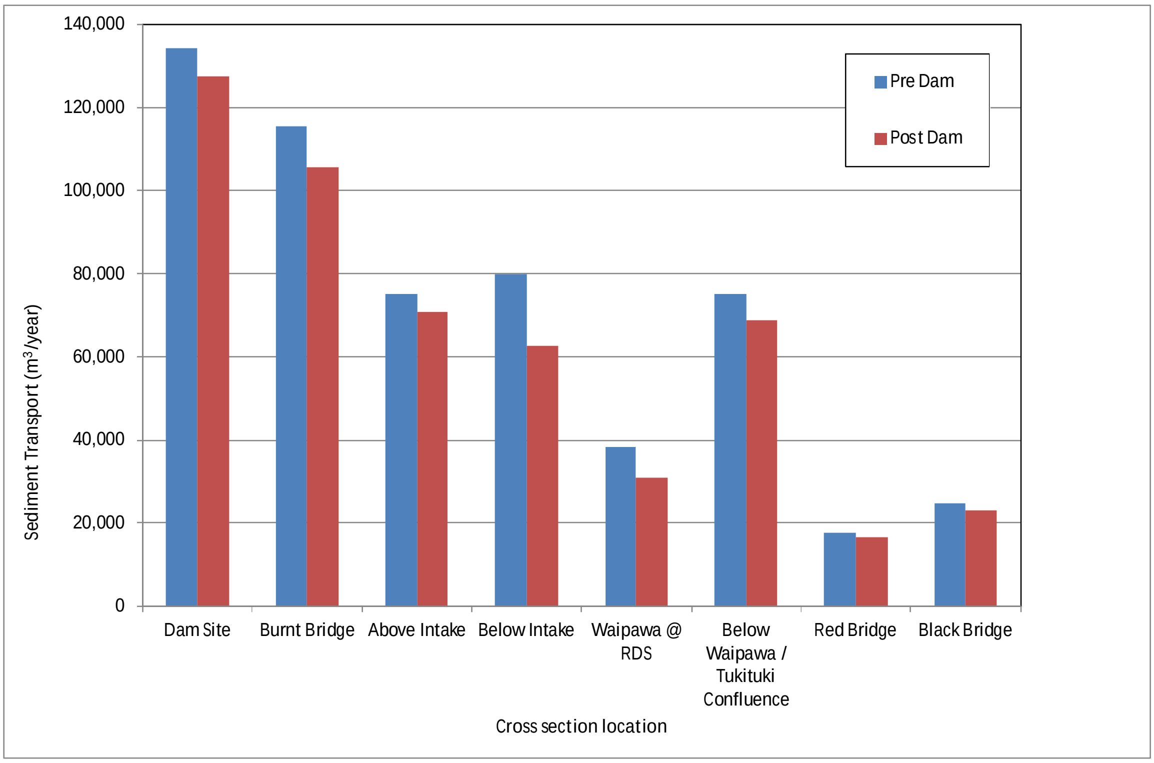

Figure 7.3: Pre and post dam sediment transport capacity (HBRC, December 2012)

The effect of the reduction in sediment transport capacity may be an aggradation of gravel along the Waipawa and Tukituki Rivers in the short to medium term. This reduction in sediment transport capacity will be felt relatively quickly all the way to the coast, whereas there will be considerable lag before the interruption in sediment supply influences lower reaches (or there may be minimal influence with the proposed mitigation of reduced extraction).

The transport of sediment by the river can be considered to be similar to a series of conveyors. There can be changes to the sediment (accumulation or degradation) when the conveyor speeds differ, or where the conveyor speed slows and an input of sediment cannot be moved as quickly as it was before, or at the end of the conveyor when the rate of discharge is different to before.

Effects from the reduction in gravel transport are possible where there is a change in rate. For example the reduction in sediment transport capacity downstream of the UWI may result in additional aggradation in this reach.

Effects are possible where the river has a reduced capacity to transport an uncharged sediment supply. For example the sediment supply from the Tukituki and other tributaries may accumulate and result in aggradation downstream of the Tukituki/Waipawa confluences.

These effects can be effectively mitigated by continued application of HBRC's adaptive river management system. The river management system extracts gravel to maintain capacity for flood conveyance in the rivers. The river management system relies on cross-section monitoring and staff expertise to identify areas that require extraction or other intervention. The river management system is responsive and adaptable, which is important as the rivers change rapidly both spatially and temporary e.g. due to floods and transport/deposition of sediment. The river management system may need to extend upstream to the UWI.

7.3.4 Potential for degradation and armouring

The interruption in sediment supply is expected to result in degradation and coarsening of surface sediments. The finer sediment will preferentially be transported and as larger sediment is available then an armour layer will form. Vertical degradation will progress at a progressively slower rate until the armour is deep enough and sufficiently resistant to transport to inhibit further degradation.

The armour size (minimum stable sediment size for the bankfull flow) for the cross-section downstream of Burnt Bridge is estimated to be 85 mm. This compares to the existing sediment that has a D50 = 28 mm and a D90 = 80 mm. The depth of degradation is estimated to be 1.6 m at the Burnt Bridge site, which would be indicative of the degradation for the reach downstream of the Dam, unless there are bed-rock substrates that limit the degradation (refer Section 4.8 for methods).

The post-dam surface sediment for the Burnt Bridge site is estimated to have a D50 = 99 mm, compared to the pre-dam surface sediment D50 = 28 mm. The armour layer will have a minimum diameter of 85 mm and this a coarser and narrow size range compared to the pre-dam sediment. Figure 7.4 shows the pre-dam and estimated post-dam particle size distributions.

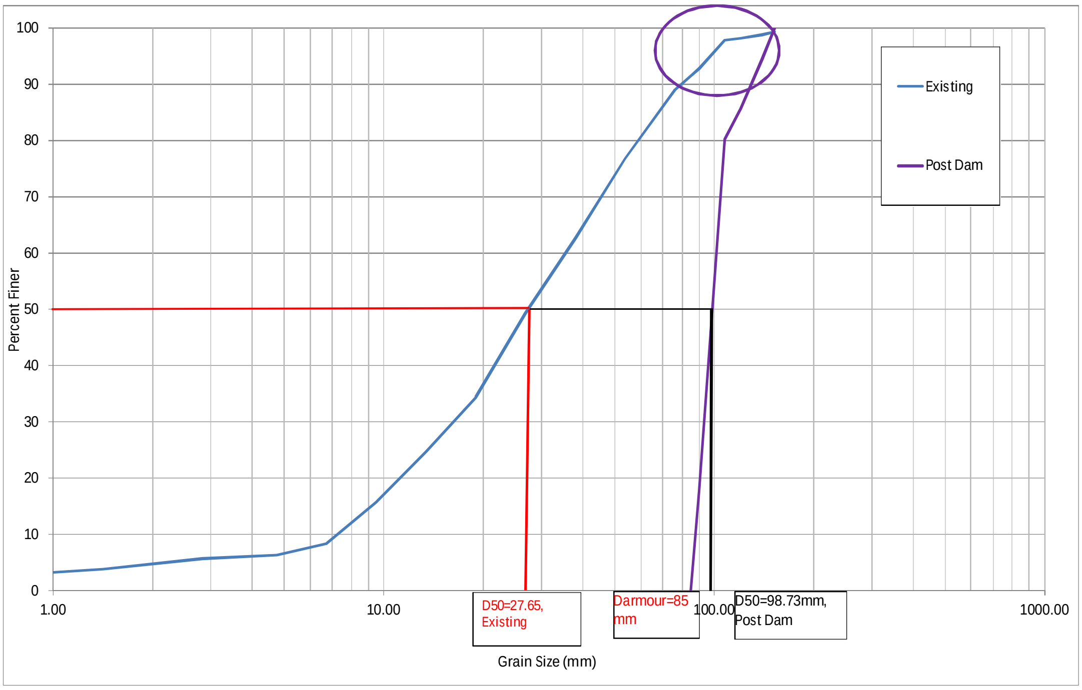

Figure 7.4: Particle size distribution downstream of Burnt Bridge (XS Number 5) for pre-dam and post-dam

7.3.5 Effects by location

7.3.5.1 Effects on Makaroro River between dam and confluence with the Waipawa

The interruption of sediment from the Dam will have greatest effect on the 12 km reach of the Makaroro River between the Dam and the confluence with the Waipawa River. In this reach the sediment supply will be essentially halted by the dam/reservoir.

The upper half of this reach of the Makaroro River is in a gorge. The remaining downstream section is in old terrace gravels. The channel is bed load dominated and depositional (supply>transport capacity) with the majority of the active and flood channel providing storage of gravel. The confinement by the gorge influences the channel and meander patterns. Note that over longer geological periods the gorge has been down cut by the river (refer Section 3.3).

A likely effect is degradation of the river channel. The degradation downstream of Burnt Bridge has been estimated to be 1.6 m (refer Section 7.3.4). There is potential for bank erosion but this is expected to be of gravel within the active channel.

A further effect will be the coarsening of the sediment on the river surface. The post-dam surface sediment as predicted to have D50 = 99 mm, compared to the pre-dam surface sediment D50 = 28 mm. The armour layer will have a minimum diameter of 85 mm and a narrow size range compared to the pre-dam sediment (refer Section 7.3.4).

These degradation and armouring effects will be mitigated to some extent (of slowed) by the reduction in sediment transport due to the reduction in flood flows. It can be seen from Section 2.3 and Table 2.1 that the reduction in annual flood event will be more than 47%. HBRC (2012) estimates this to cause a 5 -9% reduction in sediment transport capacity (refer to Section 7.3.3).

The reduction in flood flows will reduce the ability of the flows to erode vegetation. The encroachment of vegetation will reduce the channel width and form. The river will trend towards fewer channels. There is no river management infrastructure on this reach. Therefore, changes to the channel form and levels will have no effect on river management infrastructure.

Burnt Bridge, Makaroro Road (Makaroro River) has the potential to be affected by lowering of bed level (refer to Figures 7.5 - 7.7). Degradation has been estimated at 1.6 m for a cross section downstream of the bridge. The river at Burnt Bridge has been observed to be locally degrading (refer Section 3.4.2) and rock armouring to protect the eastern abutment is evident in Figure 7.5. To a lesser extent there may be risk of degradation affecting the Wakarara Road Bridge (Waipawa River). These bridges should be monitored as part of the management regime.

Figure 7.5: Burnt Bridge on Makaroro River with flow gauge

Figure 7.6: Burnt Bridge on Makaroro River (short distance upstream of the confluence with the Waipawa River)

Figure 7.7: Wakarara Road Bridge on Waipawa River (short distance upstream from the confluence with the Makaroro River)

7.3.5.2 Effects on Waipawa River downstream of the confluence with the Makaroro

The interruption of sediment from the Dam will have a lesser effect on the rivers downstream of the confluence of the Makaroro and Waipawa. This reach of the river is a continuation of the Waipawa. In this reach, the sediment supply will be reduced due to the interrupted supply from the Makaroro, but the Waipawa sediment supply will not be affected.

This reach of the Waipawa River to SH50 is less confined and wider than the Makaroro. The channel is bedload dominated with storage of gravel in the normal and flood channels. Without the confinement by the gorge a more braided pattern dominates, although the growth of exotic vegetation currently acts to stabilise the outer flood berms and gravel bars and narrow the active channel.

The river management infrastructure downstream of SH50 consists of managed active channel, stabilised channel banks, flood berms and stopbanks (refer to Figure 3.1). The river has a surplus of gravel and extraction is relied on to maintain the flood carrying capacity of the river.

This section of the Waipawa River has a gravel surplus and is aggrading (refer to Section 5.1). The pre-dam aggrading rate over the reach between Waipawa/Makaroro confluence and SH50 is 59,220 m^3/year (based on the change in sediment transport over the reach of (101,000 - 58,700)*1.4 with values from Table 5.1). The pre-dam aggradation rate of the downstream reach between SH50 and SH2 is 53,500 m^3/year (58,700-5,200)*1.4). The total pre-dam aggradation over both Waipawa reaches is 134,120 m^3/year. This surplus of gravel is currently managed by extraction of gravel. In the long term the interruption of gravel supply from the Makaroro of 78,850 – 180,300 m^3/year will reduce the aggradation. It will be necessary to reduce the gravel extraction in the Waipawa, which has had average annual extraction (for decade 2003 – 2012) of 97,000 m^3/year for the Waipawa.

The post dam supply of sediment to the Waipawa reduces from 141,400 m^3/year to 63,550 m^3/year, which is based on the supply from the Waipawa upstream of the confluence (refer Table 7.1). This supply is well matched by the predicted sediment transport capacity for this reach post-dam at 62,628 - 70,835 m^3/year (refer Table 7.3). This indicates better balance between supply and transport capacity than in the past when there has been an excess of supply and the river has stored the difference by aggrading. Further downstream for the Waipawa at RDS the sediment transport capacity drops to 31,022 m^3/year (refer Table 7.3), which further supports deposition of sediment upstream of this location.

Therefore, in the long term the likely effect of the Dam is the reduction in the rate of gravel aggradation and a reduced need for gravel extraction from the Waipawa.

A more immediate effect will be from the HBRC predicted 6 - 21.5% decrease in sediment transport capacity (refer to Section 7.3.3), which may increase aggradation at some locations in the short-term. Refer to previous comments about the accuracy of the sediment transport capacity assessments at this site in Sections 4.7.1 and 7.3.3. Areas at risk include the Waipawa/Makaroro confluence and the UWI (refer Section 7.5).

There is no river management infrastructure for the reach upstream of SH50 (Caldwell Road specifically). Therefore, changes to the channel form and levels will have no effects on river management infrastructure. The proposed UWI is considered in Section 7.5. There may be requirements for river management in this reach that is upstream of the current extent for extraction (Caldwell Road upstream of SH50) to extract local accumulations of gravel.

There is extensive river management infrastructure downstream of SH50. However, physical changes to the river are not anticipated as the active channel is already managed by flood defences, gravel extraction and raking. The reduction in bed load in the long term will, if anything, reduce the requirements for river management and works in the river as less gravel extraction may be required.

In summary, the reduction in sediment supply can be offset by a reduction in gravel extraction that is currently undertaken to manage an excess of sediment. The requirements for extraction are monitored and managed on an ongoing basis by HBRC and these practices, within the context of a current surplus of gravel, are sufficient to manage the effects from the expected changes to sediment supply and transport capacity.

There will be a net long term reduction in the gravel resource for extraction and construction industry purposes. Although gravel will become available at the Reservoir, but this is further away from markets.

7.3.5.3 Effects on Tukituki River

The average extraction for the entire Tukituki River system is 90,000 m^3/year for the decade 2003 to 2012. While the interruption in bed material due to the Dam will be managed in the Waipawa, there is excess gravel also in the Tukituki that is managed by this extraction. Therefore, there is opportunity to use extraction to mitigate the effects of the Dam on the Tukituki River.

A reduction in the sediment transport capacity is expected and is estimated to be 6-8% for the Tukituki (refer Section 7.3.3). This may cause short term effects such as aggradation in the river where the supply exceeds the transport capacity, such as at the Waipawa/Tukituki River confluence. Similarly, river management and extraction practices provide the tool to manage these issues.

The requirements for extraction are monitored and managed on an ongoing basis by HBRC and these practices, within the context of a surplus of gravel, are sufficient to manage the effects from the expected changes to sediment supply and transport capacity.

Physical changes to the river are not anticipated as the active channel is managed and gravel extraction and raking occurs. The reduction in bed load will if anything, reduce the requirements for river management and works in the river as less gravel extraction may be required. There may be a net long term reduction in the gravel resource for extraction and construction industry purposes.

7.4 Effect on the coast

An additional effect is the reduction in gravel transport capacity to the coast of 1,700 m^3/year (1,688 m^3/year in the Table 7.3). The coastline in the vicinity of the mouth of the Tukituki River is suffering from ongoing erosion (refer Section 3.6). The coastal sediment transport is predominantly to the north, although there may be times when sediment from the Tukituki River is deposited to the south of the river mouth.

To mitigate the effect of the reduction in gravel transport capacity it is proposed that 1700 m^3/year of river sediment will be placed directly along the barrier beach between the Richmond Road and School Road extension and an additional 1,700 m^3/year to the south along the spit within the Coastal Marine Area (i.e. a total of 3,400 m^3/year), see Figure 7.8. The provision of 3,400 m^3/year split north and south is considered to be a conservative approach to mitigate for the variability in the deposition and reduction of sediment transport due to the proposed dam.

The sediment extracted from upstream of Black Bridge would be transported by truck from Mill Road and then taken along both Haumoana Road on the southern bank of the Tukituki River and Lawn Road on the northern bank. This would result in approximately 280 return trips by truck and trailer vehicles (assuming 12 m^3 capacity). The beach nourishment will be carried out around October/November after the winter storms.

HBRC's commitment to this proposed mitigation is detailed in HBRC letter of 5 February 2013, refer Appendix H.

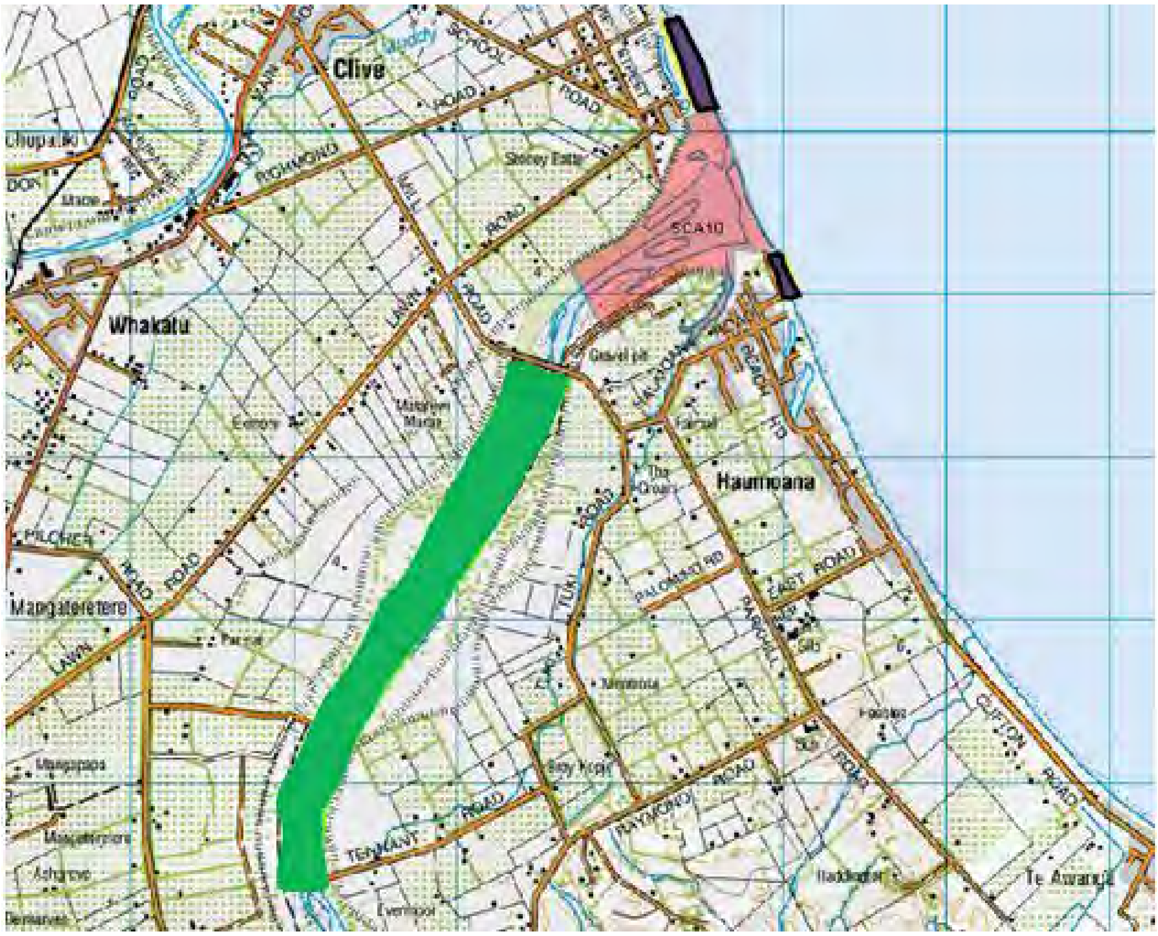

Figure 7.8: Location of gravel extraction and beach nourishment. The proposed extraction area is depicted by the green box upstream of Black Bridge. A significant conservation area as defined in the HBRC Regional Coastal Environment Plan is shown shaded red. The black bordered purple zones are where the material will be deposited.

The reduction in suspended sediment load due to the Dam will have a less than minor effect on the coastline because the beach comprises primarily of coarser material due to the high energy environment.

7.5 Changes at the irrigation intakes

The irrigation intakes have been designed to take water and remove suspended sediment in a settling basin, while leaving bed load in the river. The irrigation intakes are summarised in Section 2.4 and described more fully in the PD (T&T, May 2013).

The UWI has the greater potential to locally modify the sediment transport regime due to the larger extraction of flow. HBRC predicts a decrease in sediment transport capacity between upstream of the UWI of 5.6% and downstream of the UWI of 21.5%. This will cause aggradation downstream of the intake. Refer to previous comments about the accuracy of the sediment transport capacity assessments at this site in Sections 4.7.1 and 7.3.3.

To mitigate the impacts of sediment on the intake the design utilises a rock infiltration bund to exclude coarse sediment. A realigned and modified river channel forms the intake river braid at the interface with the rock infiltration bund.

The PD notes that active management of coarse sediment will be required at the proposed intake location. The intake river braid will be maintained during the life of the project to manage velocities adjacent to the intake to minimise deposition and requirements for excavation of sediment at critical locations.

The DWI is not likely to modify the sediment transport regime due to the low extraction of flow. The PD recognises that in-river works will be necessary from time to time throughout the operational life of the project to maintain the river channel (flow and level) at the intake location, and manage the deposition of coarse sediment in the vicinity of the intake and intake diversion channel.

8 Sediment management

8.1 Options

Sediment management strategies may be divided into five basic strategies (Morris, Annandale and Hotchkiss, 2008):

1. Sediment yield reduction
2. Sediment storage
3. Sediment routing
4. Sediment removal
5. Sediment focusing.

Each of these strategies and their different methods for implementation are described with pros, cons and their applicability to the Dam in Table 9.1 below. These are high level options.

Dam removal is discussed as a long term strategy in the following section.

Table 9.1: List of sediment management strategies including, pros, cons and applicability

Strategy	Method	Pros	Cons	Applicability
Sediment yield reduction – Land treatment measures	Land treatment measures are designed to decrease erodibility and thereby prevent the formation of sediment. They are the first line of defence and include: vegetative treatment in the form of preservation and improvement, the protection of existing vegetative cover through fire and grazing management practices and mechanical field practices such as contour farming, gradient terraces and grassed waterways.	Prevents the formation of sediment at its source therefore reduces the need for expensive civil works downstream. Not only beneficial for reducing sedimentation but also result in other positive benefits e.g. reducing soil and fertility loss and improving water quality.	They require community engagement and education and therefore can be very difficult to implement particularly when upstream land users may not see the direct benefits. There can be a long lag time between the implementation of the programme and the reduction of sediment yield within the reservoir.	The upper part of the catchment is located in the Ruahine Forest Park and is native bush. Therefore there are limited improvements that can be made to the vegetation cover. Landslides and other erodible areas are common, but are difficult to access and stabilise. Forestry practises that limit sediment runoff will reduce the sediment yield from those areas. For both native and forestry areas the protection of existing vegetative cover through fire protection programmes will be beneficial.
Sediment yield reduction – Structural measures	Structural measures focus on the waterways that transport sediment from the original sources. Stream channel improvement and stabilisation through armouring and straightening of stream beds helps to prevent scour. Whereas debris basins are generally	Debris basins in particular are an effective means of removing sediment at a point of concentration.	Ongoing maintenance and removal of accumulated sediment can be very costly dependent on the volumes involved. Additional capital costs are high. Straightening of streambeds	Possible applicable within the lower part of the catchment where land is used for commercial forestry such as Dutch Creek although high capital cost may be prohibitive and ongoing maintenance costs would be

Strategy	Method	Pros	Cons	Applicability
	designed to store sediment from 100 year flood events and require periodic removal of accumulated material.		can result in higher water velocities and corresponding increased peak flood events downstream, plus exacerbation of erosion issues in downstream reaches. Modifications to the rivers increases the disturbance of natural rivers by the Scheme.	incurred. Structures in river could have potential additional environmental effects. Not suitable in the upper part of the catchment which is in Ruahine Forest Park as the civil works required to install the structural measures will cause further impacts on the natural river system, apart from considerable access difficulties.
Sediment storage	Sedimentation rates are estimated for 100 years. Sufficient volume or "dead storage" is provided below the lowest outlet to allow for the sediment that accumulates in the Reservoir.	This is often the most cost effective method of managing sedimentation as it does not depend on ongoing maintenance and its associated expenses. Allows development of the full water yield potential as the flood flows are also captured. Provides flood attenuation which reduces downstream effects.	Assumes that sediments will deposit in the lower portion of the reservoir but sediment deposits are frequently not focussed in this zone and sedimentation problems may be caused by deposits forming in the delta prior to filling of the dead storage. Choosing an appropriate design life can be problematic as dams frequently remain operational outside of their intended design life. It is dependent on accurate estimation of sedimentation rates within the reservoir which	Very applicable to this case and incorporated into the design.

Strategy	Method	Pros	Cons	Applicability
			can be difficult to achieve.	
Sediment routing - Offstream Reservoir for sediment bypass	Involves bypassing sediment laden flood-waters by placing the storage pool offstream and only diverting relatively clear water from moderate flows into storage.	Reduces the rate of storage depletion by restricting sediment inputs. The Dam is not a barrier to migratory aquatic species or navigation. Instream water quality is not altered by the Reservoir. Riparian wetlands and river corridor habitats are not altered by the Reservoir. There is less impact on bed load transport processes. The need for a large capacity onstream spillway is eliminated. The intake can be closed to exclude contaminants from entering the Reservoir.	Not able to develop the full water yield potential as the flood flows are bypassed. Requires suitable topography for offstream reservoir arrangement. Does not provide flood attenuation benefits.	Not applicable due to inappropriate topography to create the offstream storage and construction costs.
Sediment routing - Sediment bypass of onstream Reservoir	Either involves locating the reservoir at the terminus of a meander and diverting flood flows across the meander floodplain or transporting gravels from the delta upstream of the Reservoir and depositing them below the Dam by trucking, pipelines or a tunnel.	Maintains bed load transport downstream of the reservoir. Reduces the rate of storage depletion by reducing bed load inputs.	Locating the Reservoir at the downstream terminus is dependent on the appropriate topography. Ongoing maintenance and operational costs are high. This method provides reduced flood attenuation.	Not applicable due to inappropriate topography for locating the dam downstream of a meander and the gravel transport options are prohibitively expensive.

Strategy	Method	Pros	Cons	Applicability
Sediment routing - Pass through by drawdown	Flood flows are heavily laden with suspended sediment. By drawing down the Reservoir levels and fully opening the gates to allow passage of flood flows the opportunity for sediments to deposit in the reservoir is minimised. Bed load sediment can potentially be transported through small reservoirs, whereas in larger reservoirs bed load can be transported into dead storage to preserve live storage volume.	High sediment flows are passed down the river system in the natural manner.	Not able to develop the full water yield potential as the flood flows are bypassed. This method provides reduced flood attenuation. Not practicable for larger reservoirs as drawdown to low levels takes too long to respond to floods. Also the refilling of the reservoir after drawdown for operational purposes is not always possible.	Requires tall spillway gates or deep sluicing gates which are not proposed for scheme. Not applicable due to the larger reservoir volume making rapid drawdown and refilling not practicable.
Sediment removal – Hydraulic dredging	Involves the removal of sediment that has deposited in the reservoir through the use of hydraulic dredges, a pump and a pipeline to convey the material to the point of discharge. Gravity (using siphon) dredging is also possible.	Allows focussed “tactical” sediment removal in problem areas. Enables the recovery of storage capacity. After dewatering the dredged material may be used in the construction industry as aggregate, sand etc. or returned to river downstream of the Dam.	Ongoing maintenance and operational costs are high. Requires extensive areas for the disposal of dredged material or consideration of sediment to return to river downstream of the Dam. In some instances tactical dredging may become a sink for accumulating material.	Possible applicability in the future to protect structures, but limited by cost initially. However, gravels are of high quality and value and may be extracted for the construction industry e.g. road aggregates.
Sediment removal - Hydraulic flushing	Involves the opening of low level outlets to empty out the reservoir and allow stream flow to scour any sediment deposits that may have accumulated. Natural river channels are re-established along	Minimal operating cost compared to hydraulic dredging. Enables the recovery of storage capacity and therefore extends the life of the Reservoir.	Technically difficult due to need to lower water levels in larger reservoir to achieve high shear stresses to mobilise sediment. The potential for sediment removal is limited to the area in	Applicable but not considered in PD due to high capital cost of low level outlets and technical difficulties. The worst case for the consent and reservoir design was to

Strategy	Method	Pros	Cons	Applicability
	the length of the Reservoir and scour is limited to this region. It is distinguished from pass through by drawdown because its principle objective is to scour and remove previously deposited sediment. For effective flushing the following factors need to be satisfied: appropriate hydraulic conditions to enable efficient flushing, sufficient quantity of water available for flushing and high mobility of reservoir sediments.		the immediate vicinity of the Dam. Upfront capital costs for installation of the scour valve are high. Potential for negative downstream environmental impacts due to high sediment concentration during flushing. This method does not address sedimentation that occurs on the flood plain or sediment delta as scour is limited to the original channel proximate to the Dam.	allow for maximum retention of sediment. Hydraulic flushing of fine sediments via low outlets could be considered at the detailed design stage.
Sediment focusing	Turbidity currents naturally focus sediment into the deeper parts of the Reservoir. The construction and maintenance of in-reservoir channels and other features can be used to hydraulically focus sediment to areas where adverse impacts are minimised.	Does not negatively impact downstream water quality. Sediment is stored within the reservoir removing the need for storage areas outside the reservoir. Live storage can be enhanced at the expense of dead storage (short-medium term gain).	Does not address net storage loss. Ongoing maintenance and operational costs are high.	Potential applicability once sediment delta becomes established.

8.2 Dam decommissioning

In recent years, as a response to concerns about sedimentation, safety and environment enhancement, there has been an increase in focus on decommissioning of older dams. This can be achieved by leaving the Dam with the reservoir filled with sediment, or removal of the Dam and managing the discharge of sediment. Once the Dam reaches the end of its useful life these may be potential strategies.

The effect of dam removal on sedimentation is similar to sediment removal via hydraulic flushing as natural river flow is re-established along the length of the Reservoir and scour occurs in this area. However, it differs in that the process is allowed to continue until a new stable geometry is produced. This would occur over a number of decades due to the large volume of sediment that would have accumulated in the Reservoir. The American Society of Civil Engineers (ASCE, 1997) has produced a guideline on the retirement of dams, which provides a source of more detailed information on dam decommissioning and removal.

Whilst the ultimate goal is to provide benefits, as mentioned above, there are potential negative environmental and socio-economic impacts from releasing high sediment concentrations into the river system. These include bed aggradation resulting in increased flood hazard, the closure of downstream water intakes for the duration of flushing forcing increased pressure on alternative water supplies, impairment of navigation and deleterious effects on fisheries and recreation, and the potential for massive mortality through the entire aquatic food chain. However, all these effects will decrease as sediment is washed through the system.

8.3 Summary

Applicable options for sediment management with immediate positive effects include:

- Land treatment measures including sediment management practices for forestry areas and fire protection programmes for the Ruahine Forest Park and the commercial forestry – it is recommended that this be considered by HBRC
- Sediment storage which has been incorporated in the design.

Options for sediment management in the medium to long term include (not included in the Application Design):

- Extraction of gravel for construction industry e.g. roading aggregate
- Hydraulic flushing of fine sediments via low outlets could be considered at the detailed design stage
- Sediment focussing by in-reservoir works to manage sediment storage within the reservoir.

Dam decommissioning should be considered at the end of the operating life. It is not possible to predict the final use for the Dam or the options available for sediment management as these will change as technologies develop and the economics of options change (subject to value of energy, construction materials, water and sediment).

Sediment management plans to monitor and mitigate the potential effects from the Dam are considered in Section 9.

9 Sediment management plan

The draft sediment management plan is divided into main locations of potential effect:

- Reservoir
- Makaroro River downstream of the Dam
- Waipawa River between Makaroro confluence and SH50
- Waipawa/Tukituki Rivers downstream of SH50.

For each area the management plans detail the monitoring and management responses. In the case of the Reservoir the management options are suggested for medium-term and long-term. The management plan is high-level at this stage and requires input from others in the Scheme such as design engineers (at the detailed design stage) and ecologists. Details of the plan such as actions, measures and timing needs will be developed. The draft sediment management plan will be adaptable to respond to issues as they arise. Such an approach is necessary given the temporal variability in sedimentation. Details of the draft sediment management plan are contained in Table 9.1 below.

Implementation of the sediment management plan will be the responsibility of HBRIC or be transferred to HBRC. Where the monitoring activities are currently carried out by HBRC, such as cross-section surveys these shall continue to be the responsibility of HBRC.

Table 9.1: Draft sediment management plan

Location/ issue	Monitoring	Management
Reservoir	Cross-section/bathymetry survey to monitor sedimentation and delta development. Frequency 3 years. Flow gauging of releases from the Dam.	*Design* Include sedimentation allowances in the volume requirement of the Dam. Design of outlet structures for sedimentation. The location of recreation areas and access points to the reservoir to consider sedimentation. Land management measures including sediment management practices for forestry areas and fire protection programmes for the Ruahine Forest Park and the commercial forestry. *Medium to long-term* (not included in the Application Design) Extraction of gravel for construction industry e.g. roading aggregate Hydraulic flushing of fine sediments via low outlets (would need to be provided for at the detailed design stage). Sediment focussing by in-reservoir works to manage sediment storage within the reservoir. These can consist of training banks and similar structures to enhance flushing of sediment from live storage to dead storage, and for access up-river. *Closure* (not included in the Application Design) Dam removal is an option to consider at the end of the operating life if required. Restrictions to access (in areas where sediment has deposited) and the potential for impacts on the Dam outlets.
Reservoir dust	Dust generation should be monitored with inhabitants provided a contact number of the Dam operator if they wish to make complaints. The operator should keep a register of complaints consistent with or similar to Appendix 2 of Good Practice Guide for Assessing and Managing the Environmental Effects of Dust Emissions (MfE 2001). Copies of the register should be forwarded to HBRC for their consideration of whether further preventative action is appropriate.	Should a dust issue arise then consideration to planting additional shelter belts, noting that a 20 m planting buffer zone is proposed to offset the impact of vegetation removal within the reservoir ponding area, which will also assist with dust control.

Makaroro River downstream of the Dam	Cross-section survey at 3 year frequency to match existing HBRC monitoring programme. Maximum spacing to match existing HBRC monitoring programme of 500 m and to include Burnt Bridge. Measure particle size distribution of bed surface particle-size distribution at three year frequency at representative and accessible locations to monitor armour development.	Respond to degradation of channel at Burnt Bridge (if required). Options include grade control (rock weir) or underpinning of piers.
Waipawa River between Makaroro confluence and SH50	Cross-section survey at 3 year frequency which is a continuation of existing HBRC river monitoring. Additional cross sections to be included for Waipawa upstream of the Waipawa/Makaroro confluence including Wakarara Road Bridge and Pendle Hill Bridge (1 km upstream) with maximum spacing of 500 m. Additional cross section for the UWI.	Respond to degradation of channel at Wakarara Road Bridge (not likely, contingency only). Options include grade control (rock weir) or underpinning of piers. The long term reduction in extraction (if required) based on monitoring in accordance with current HBRC flood and sediment management practices, refer to Section 3.5 for details. This may require an extension of the gravel management areas from Caldwell Road to upstream of the UWI. Extraction of excess gravel at the irrigation intake and elsewhere in accordance with HBRC river management practices. Optional spraying and raking of gravel beds to increase the supply of gravel (if required). Significant accumulation of gravel has occurred in this reach.
Waipawa/ Tukituki Rivers downstream of SH50	Cross-section survey at existing cross section locations at 3 year frequency, which is a continuation of existing HBRC river monitoring.	Normal river management practises undertaken by HBRC. The long term reduction in extraction (if required) based on monitoring in accordance with current HBRC flood and sediment management practices, refer to Section 3.5 for details.

Coast	Cross-section surveys at existing cross section locations, which is a continuation of locations and frequency of existing HBRC coastline monitoring.	Beach nourishment of 3,400 m^3/year comprising of 1700 m^3/year of river sediment placed within the Coastal Marine Area directly along the barrier beach between Richmond Road and School Road extension and an additional 1,700 m^3/year to the south along the spit. The sediment would be extracted from upstream of Black Bridge or other locations in the Tukituki/Waipawa Rivers. The extraction of sediment would be in accordance with HBRC's river management practices (refer Section 3.5). The beach nourishment will carried out around October/November after the winter storms. Review the beach nourishment requirements based on updated assessments of reduction in capacity (and renourishment needs) due to the Scheme using the consented reservoir operating regime. Review to be based on monitoring and modelling at year 3 and at subsequently at nine year intervals. Changes in beach nourishment to be approved by HBRC manager.
Tukituki River basin	Cross-section monitoring (as above), selected PSD sampling, sediment and flow gauging.	Morphological model be developed for the Tukituki River basin including Waipawa and Makaroro Rivers. Model to simulate the balance between sediment supply and transport capacity can only be fully described by a detailed morphological transport modelling. It will have its greatest value if developed and calibrated to observed changes resulting from the Dam. In particular the model can simulate the dynamic effects of immediate changes to sediment transport capacity all the way to the coast (albeit with diminishing influence as flow enters from tributaries), versus the longer term interruption of sediment from the Dam which will require many years to propagate all the way to the coast.

10 References

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11 Applicability

This report has been prepared for the benefit of Hawke's Bay Regional Investment Company Limited with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

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