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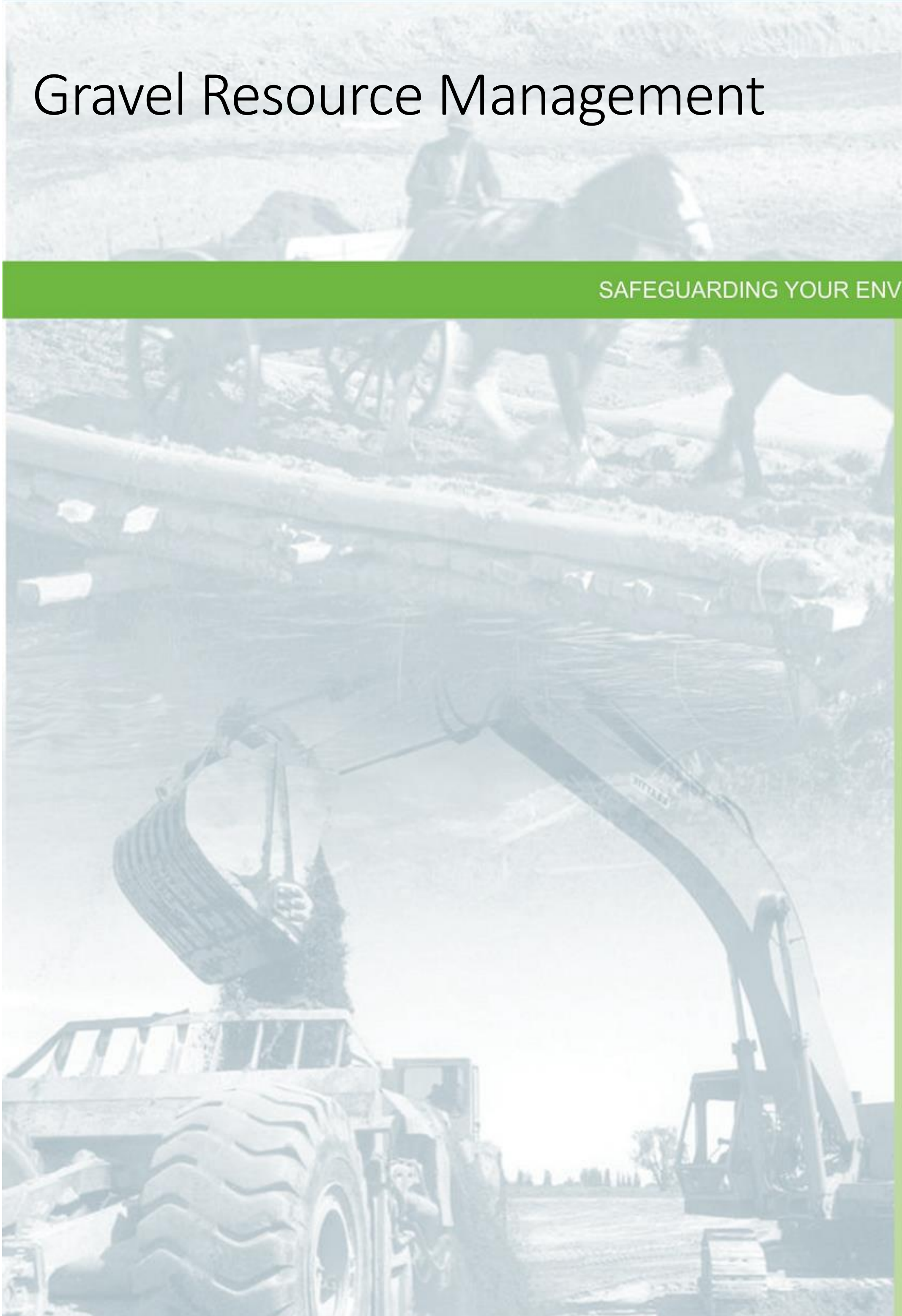
Gravel Resource Management



HAWKE'S BAY
REGIONAL COUNCIL

SAFEGUARDING YOUR ENVIRONMENT + KAITIAKI TUKU IHO

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1 Introduction

Important gravel[1] resources are available from the Hawke's Bay rivers. Gravel is produced at the sources in the upper catchments including historical deposition laid down in the river banks and floodplains and is transported through the plains to the coast by the rivers. The main gravel transporting rivers are the Ngaruroro, Tukituki, Waipawa, Tutaekuri and Esk, with most extraction occurring in the Heretaunga Plains and the Ruataniwha Plains areas. Various reaches of these rivers have been engineered to provide safety from inundation and erosion to the urban and rural communities and farms established on the flood plains.

Gravel is an important resource for the construction industry and its demand has been increasing although tied to the economic cycles (Historically in Hawke's Bay, gravel has been extracted from the main rivers as well as the coast). The last area where coastal extraction was carried out was Awatoto and this ceased in 2017.

Past and present engineering management of the rivers include:

1) Stopbanks to contain the flood waters below an average return interval (ARI) within a design floodplain (typically 100 years return period).

2) Riparian planting and clearing to stabilise the river channel and meanders within the design width.

3) Localised hard erosion protection such as groins, rip-rap or sheet piling.

4) Managed gravel extraction to keep the river bed levels near the design level thus maintaining the river channel capacity.

5) River raking consisting of ripping the upper layer of the gravel bars and beaches in order to break natural armouring and uproot vegetation to increase gravel movement.

This report includes relevant information about the gravel resources of the main Hawke's Bay rivers and it is intended to cover the sort of questions that could be raised in a consent application process. The Hawke's Bay Regional Council HBRC is applying for global gravel extraction consents in order to manage comprehensively gravel extraction in Hawke's Bay (Appendix 1). The information presented is focused mostly in the reaches and rivers where gravel extraction has been more significant and demand is greatest. Section 1 contains the present introduction. Section 2 provides a background covering geology of the plains and gravel sources, historical changes in land use, the effect of large natural events, the past and present river management techniques, the connection between the rivers and the coast, the state of the art in sediment availability quantification and the recent new analysis implemented at HBRC. Section 3 explains the analysis methodology applied in this report. Sections 4 to 10 present details about the gravel resources in the main rivers: Lower, Middle

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[1] *Note that throughout this report the terms 'sediment' and 'gravel' are used interchangeably. By definition sediment includes all alluvial material found in the active river channel and berms. Sediment consists of the broad categories of gravels, sands and silts. For convenience the term gravel is often used in this report to refer to the bed material of the active channel. Gravel makes up a high proportion of the bed material (although significant sand is also present) and is the bulk of the material extracted in most cases.*

and Upper Tukituki, Ngaruroro, Tutaekuri, Waipawa and Esk. Sections 12 and 13 present general conclusions and recommendations for future work.

Figure 1-1: Location of the main gravel extraction rivers in Hawke's Bay

2 Background

2.1 Geology and history

The geology and geomorphological evolution of the Hawke's Bay rivers and coast has been well documented by various authors including , White (1994), Komar (2005), Lee et al. (2014), Steven and Larsen (2015, 2017) and Reeves (2016) gravel raking report among many others.

Dynamic erosive and depositional processes by rivers and sea, glaciations, sea level changes and tectonic movements such as uplifting, subsidence and landslides, have formed and shaped the Heretaunga and Ruataniwha plains and the Esk Valley (Figure 2-1).

Sediment eroded from the upper catchments, old terraces and floodplains has been deposited and uplifted and subsided within the floodplains and coast for millions of years. Meandering rivers have been flooding and shifting their course allowing the formation of the plains, depositing fertile soil, gravels, sands and silts in the lower flood plains.

In the last 200 years, major floods and earthquakes, and intensive anthropic interventions after the European establishment in the 19th century, have changed the shape of the plains dramatically (Figure 2-2).

The main major natural events recorded after European arrival that significantly changed the shape of the plains and river courses are:

- The 1867 flood: Changed the course of the Ngaruroro River and deposited large amounts of sediments in the plains. The Tukituki, Ngaruroro and Tutaekuri Rivers all overflowed their banks in several locations causing extensive flooding. Floodwater was several feet deep in Clive, Papakura and Meeanee. Silt was deposited over the area to a depth of 0.3 m to 0.46 m.
- The 1931 Earthquake caused an uplift of nearly 2 m North of Napier, uplifted nearly 40 km^2 of seabed creating new land, and subsistence of about 1 m to the south of Napier and Hastings, caused coastal morphology changes including erosion in the southern part of the Hawke's Bay coast (Komar, 2010). The earthquake changed the course of the Tutaekuri River shifting its mouth from the Ahuriri Lagoon to its present location. The uplift of the Ahuriri lagoon and the shifting of the Tutaekuri mouth, (a major inflow to the lagoon), reduced the lagoon to a fraction of the original size. The uplift raised the lower reaches of the Tutaekuri, Ngaruroro and Esk Rivers, trapping the gravel so that now those rivers only deliver silt and sand to the Bay's shores. The opposite effect happened in the Tukituki River where subsidence encouraged the movement of gravel to the coast.
- 1988 Cyclone Bola: Caused extensive flooding damage and added a significant sediment load into the northern Hawke's Bay River systems.

In addition to sea level rise due to climate change, the coastal land of the Heretaunga and Ahuriri plains is in the long and short term subsiding at ~1 mm/y and ~2mm/y respectively (Beavan & Litchfield, 2012). Land slips such as the formation of Folger's Lake in 1968 in the Upper Tukituki can interrupt sediment supply for long periods of time.

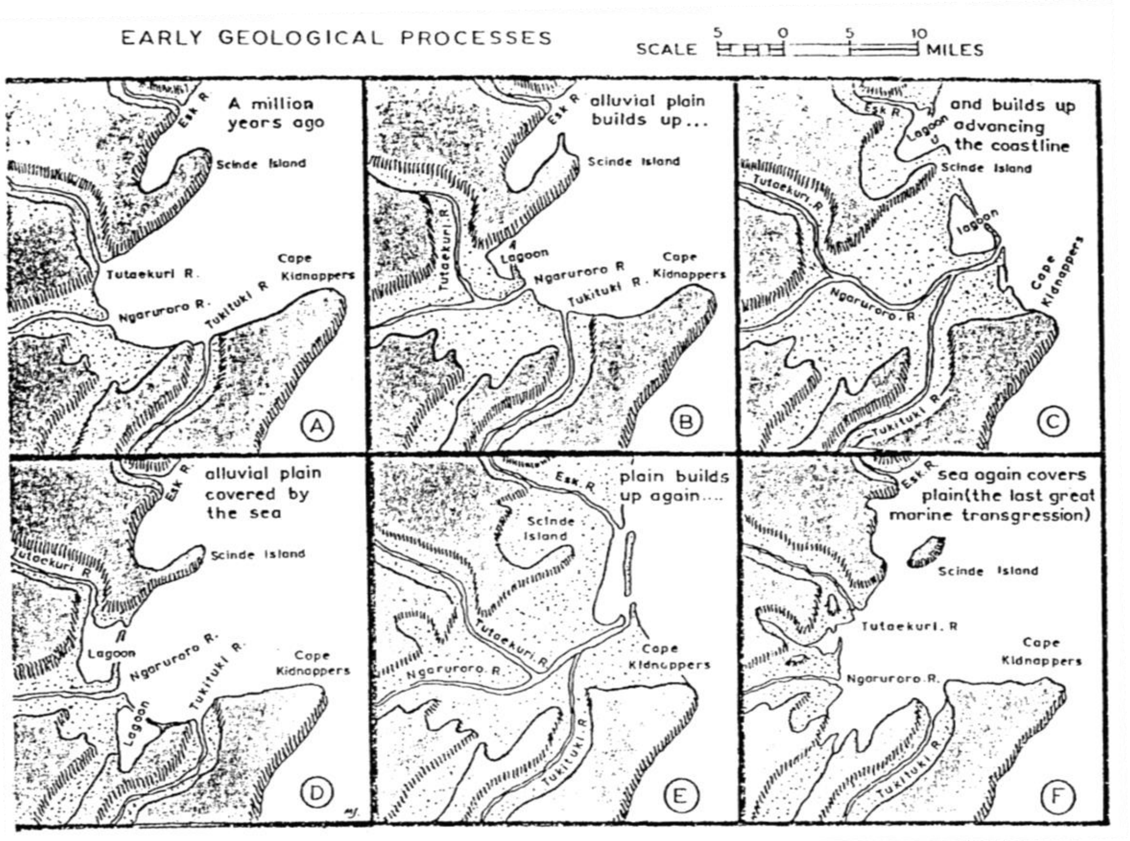


Figure 2-1: The building up of the Heretaunga plains- Early geological processes (images given to HBRC source unknown)

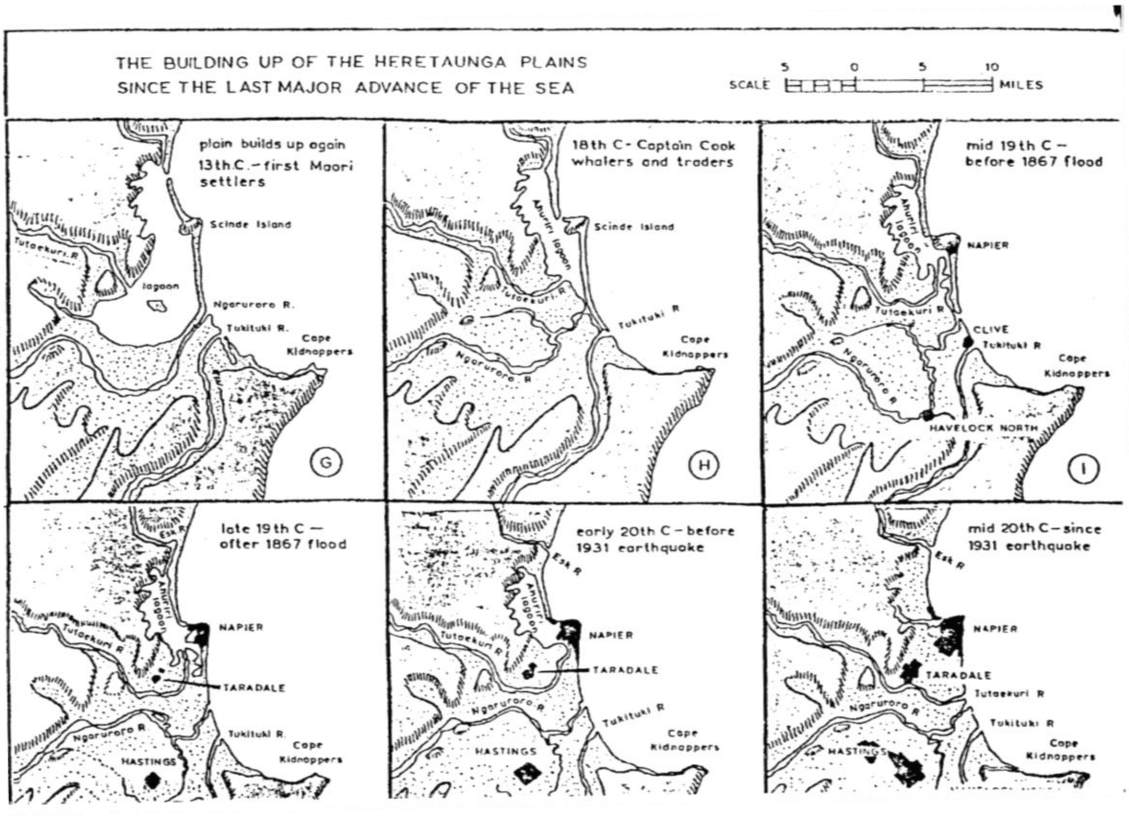


Figure 2-2: The building up of the Heretaunga plain since the last major advance of the sea (images given to HBRC source unknown)

2.2 Present gravel sources to the rivers

Present gravel supply to the rivers originates mostly from two sources:

i) erosion in the upper catchments of indurated greywacke, and

ii) gravel deposits in old terraces within the reach of the river.

Furthermore, it is important to understand that gravel moves in pulses rather than in a continuous fashion, with large amounts during extreme flood events and smaller quantities during lower flows.

2.3 River Management

River works, mainly stopbanking and planting or the clearing of willows, have been undertaken from the beginning of European settlement. Subsequent and more substantial works were carried out by the Hawke's Bay Rivers Board formed in 1910 and dissolved in 1950, The Hawke's Bay Catchment Board from 1950 to 1990, and the Hawke's Bay Regional Council (1990-to date) (Williams, 1987). An important catalyst to undertake the long liaison process prior to the main rivers flood protection schemes were the flood events in the 1930s, the changes produced by the 1931 Earthquake and the Soil Conservation and Rivers Control Act in 1941.

As more intensive development and settlement of the plains took place so did the need to provide flood protection. Thus, over the years, the plains rivers near developed areas have been confined to managed channels through construction of stopbanks and channel works to provide the high standard of flood protection expected by the population that currently live and work on the plains.

Other river management techniques carried out over the years include: river raking, gravel extraction, grazing, river mouth openings, tree removal, fencing, bank reinstatement, edge retreating and groynes, rip-rap or sheet piling among others.

2.3.1 Monitoring Programme

Cross sections surveys have been carried out periodically since approximately 1980 for the main rivers, some of the minor rivers and the coast for flood control performance reviews and gravel availability assessments (Table 2-1). However, some earlier cross sections date from the 1940s. Systematic surveys have been taken at fixed locations spaced at approximately regular time intervals since 1990. There has been exceptions where the frequency has been lowered or increased depending on the observed changes, magnitude of extraction and presence of flood protection structures. More detailed information about the survey programme for each river is presented in sections 4 to 10.

Table 2-1: Frequency of cross section measurements in the main gravel rivers.

River	Reach covered (metres)	Spatial spacing (metres)			Number of Cross sections	Cross Sections Survey Frequency (years)
		Average	Max	Min		
ESK	890 – 8,330	438	750	210	18	2
MAKARETU	400 -16,890	589	1,460	40	30	6
MANGA-O-NUKU	600 – 15,150	455	670	270	33	6
NGARURORO	491 – 37,850	743	1,800	290	46	3
TUKIPO	750 – 16,500	309	580	160	52	6
TUKITUKI - LOWER	390 – 14,870	517	1,190	350	29	3
TUKITUKI - MIDDLE	15,330 – 57,800	775	1,600	160	58	6
TUKITUKI - UPPER	57,940 – 97,870	513	980	280	79	3
TUTAEKURI	585 – 18,070	473	1,050	250	39	3
WAIPAWA	420 – 27790	517	1,140	230	55	3
COASTAL	Clifton to Mahia	x	x	x	x	1

Gravel size has been monitored sporadically. Early work in the 1980s by Williams (1985, 1986, and 1987) carried out gravel size analysis for the Ngaruroro, Esk and Upper Tukituki Flood Scheme reviews. Gravel size sampling was commenced again in the 2010s for the computer modelling work started by Measures (2012, 2018) for the Ngaruroro and Tukituki rivers.

2.3.2 River beach raking

Beach raking involves dragging a tractor-mounted ripper across exposed gravel bars during low flows (Figure 2-3). The aim is to disturb the armoured gravel layer and uproot plants before they establish and stabilise the gravel beach. This technique was developed by the HBRC Engineering team, is unique to Hawke's Bay Rivers and has been applied since 2003 to the main rivers.

River beach raking is used for two purposes:

1) Break the armour layer of the gravel deposits. This encourages gravel transport in the river (Measures, 2012; Warman & Friedrich, 2013; Reeves, 2016).
2) Remove invasive vegetation that stabilizes the gravel deposits. This also encourages gravel transport as well as helping to maintain the braided morphology of the rivers and the gravel beaches where sensitive bird species nest (Holmes, 2017).

River raking is applied to the main gravel rivers (Figure 2-4) in summer the after nesting season and when river levels are low to cover more area. Care is taken to avoid ploughing underwater and avoid increasing the suspended sediment concentration in the rivers. The raking operation (and gravel extraction) is controlled through two key documents: *The Environmental Code of Practice for River Control and Waterway Works, Clode and Groves, Feb. 2017 and the Ecological Management and Enhancement Plans, Forbes Ecology.*

Field measurements, laboratory tests and morphological modelling carried out by Reeves (2016), Warman & Friedrich (2013) and Measures (2012), provide some evidence that raking is effective in increasing gravel transport in rivers.

Measures (2012) simulated raking in a morphological model of the Ngaruroro River, representing raking 'events' by mixing the surface (armoured) and subsurface layers of the model. The morphological model showed that river raking in an idealised case, perfect mixing of the bed substrate can increase model transport rates by up to 100%. Two important conclusions can be drawn from his study. Firstly, it is clear that where raking is carried out there are lowered bed levels in the raked reaches and increased bed levels downstream of them. Secondly, the increased transport rate with raking results in increased supply to the coast and thus helps offset the loss of supply to the coast through extraction.

Warman & Friedrich (2013) laboratory tests found that raking can increase up to 30%-40% the river bed erosion during moderate river flows and that the surface gravel size increased due to the successive removal of fine material from the surface. They also found that, after raking, the bed levels in different cross sections have larger standard deviations.

Reeves (2016) analysed survey data in the Tukituki River and did not find significant differences in the erosion/deposition rates between raked and unraked reaches. However, in this type of analysis there are too many factors that cannot be isolated and it was not possible to have a control sample to compare the effect of raking alone.

Figure 2-3: River gravel beach raking (a) in the Waipawa River in Hawke's Bay and (b) a close-up view of the large metal ripping blades on the tractor and trailer unit. Rippers designed by G Clode.

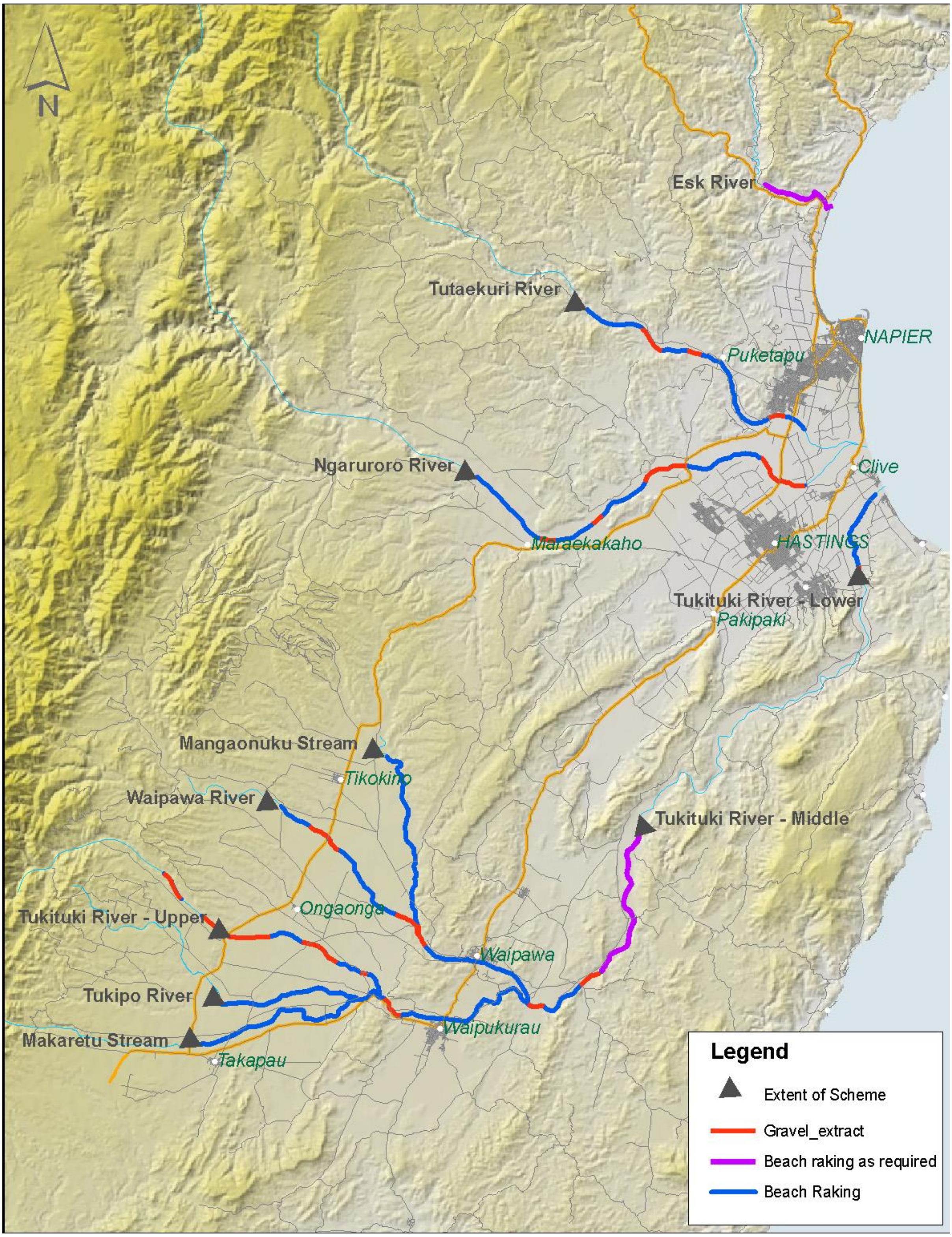


Figure 2-4: Locations of river beach raking and gravel extraction in Hawke's Bay (Note: Beach raking can also take place in the gravel extraction areas when vegetation is potentially a problem)

2.3.3 Gravel extraction and allocation

Gravel extraction is one of the management activities that allows maintaining the river capacity for floods and groundwater levels control.

The flood control schemes, developed with the purpose of maintaining the rivers within a limited fixed channel, have radically changed the natural dynamics of the rivers. Rivers that used to braid freely and change their course, in part due to localized accumulation of sediments (mainly gravel) within the active channel, are no longer allowed to do so. River braids are controlled within an active channel by vegetated edges and berms. River bed accretion (and degradation) therefore needs to be managed in order to maintain the protection against flooding. Bed degradation needs to be controlled in order to avoid the erosion of land and infrastructure, to maintain groundwater levels and to maintain gravel transport rates to downstream reaches or the coast

Gravel extraction prior to 1989 was somewhat ad-hoc and, as a result, some river reaches were over extracted with the effects still evident today. A reliable extraction record was not kept, although there is information available since 1963. In 1988 the Catchment Board placed restrictions on the quantities that could be allocated for extraction as an interim measure until a full review and management plan could be prepared. The resulting plan was the *"Heretaunga Plains Gravel Resource Management Plan, April 1989, File 7/2*". Since then, the allocation of gravel extraction volumes has been based on the definition of a fixed reference level for each cross section called the *grade line.*

The extraction records are assessed from the annual returns by gravel extractors and recorded in the HBRC database. The data is considered to be reasonably accurate although it likely has a negative bias, given that the extractor's have an incentive to under-report due to the Council's administration and monitoring charges applied on volume. The extractors currently apply for a resource consent for extraction each year and gravel is allocated considering their demands and the availability. As part of the consent requirement, gravel extraction is not permitted in the wetted channel in order to avoid discolouring the river with suspended sediments.

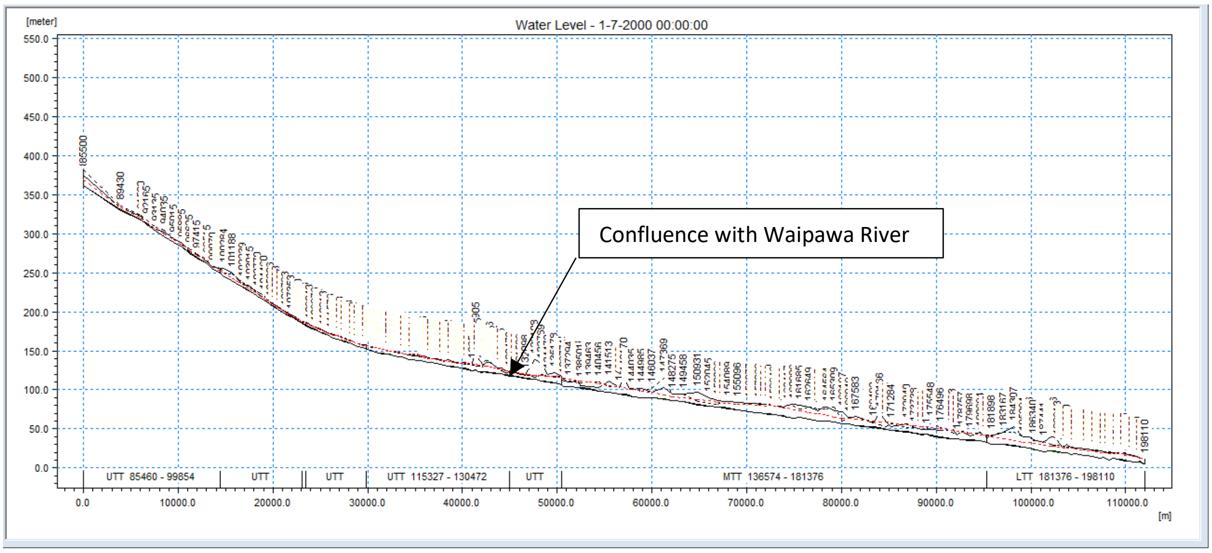
Historical sediment extraction for the different rivers in Hawke's Bay is shown in Figure 2-10 and Figure 2-11.

2.3.4 Grade line

A grade line is a concept for managing gravel extraction by providing a 'benchmark' at a given location by which the variation of sediment storage is measured and described as a surplus (positive) representing an increase in bed level or a deficit (negative) representing a decrease in bed level. Grade lines are based on design mean bed levels for which the mean annual flood (which is exceeded one every 2.3 years on average) just fits within the active channel before overflowing onto the berms (floodplain). This definition is supported by the understanding that the average yearly flood, typically estimated by the design 2.3 year return period peak flow, is the main channel forming event for mobile-bed rivers. Typically this definition applies to the managed channels within the flood protection schemes managed by HBRC. In a less controlled situation where the valley gradient can change and the river is free to adjust its channel to accommodate the change in energy gradient, a single gradient grade line may not be a sufficient benchmark requiring multiple gradients over a reach in order to best use this concept. This is not the case for the main extraction areas managed by HBRC.

While the definition of the grade level is exact, its final calculation has a qualitative component as a filtering process was used to produce a smooth line and to account for cases where levels were desired to be lower or higher for other river management purposes. By defining and trying to keep a smooth line, the natural formation of riffle-pool sequences may be disrupted. However since extraction does not take place in the channels, this disruption is reduced. Although the grade line 'benchmark' is a level for comparative purposes, it is actually based on volumes that are calculated based on average depths about the grade line and channel widths at the start of the survey period. If the channel widens during the survey period this shows up as a volume change (positive or negative).

With the Lower Tukituki River the bed grade is relatively straight and the grade line is parallel. See Figure 2-5 and also Figure 2-7 below.



Confluence with Waipawa River

Figure 2-5 Bed profile of the Tukituki River (taken from Mike 11 computer model). This shows a remarkably linear bed profile until the confluence with the Waipawa River where the profile becomes concave and then steepens. The lower gradient is 0.176% and the upper, steeper gradient is 0.758%. The Waipawa branch (not shown) is 0.603%.

In the above figure the long uniform profile is indicative of a river system that is supply limited, there being no significant inputs below the confluence with the Waipawa River and both the Waipawa and the Upper Tukituki rivers suffer from lack of significant floods in recent decades to transport the gravel downstream. As a result there are surpluses upstream.

A long uniform profile can also result from the presence of exposed bedrock. In the Tukituki River especially the papa bedrock is exposed in some locations. These reaches represent areas where sediment storage has ceased and a design grade line that is below these bedrock levels will yield a false indication of surplus.

However, in practice any allocation is also 'ground-truthed' by a site visit and such areas are avoided because the bedrock is soft papa and lumps of this mixed with the gravel is undesirable and makes the product unsuitable for many high-end usages. For example in the Lower Tukituki cross sections, XS28 and XS29 where papa bedrock is exposed in the active channel, extraction has been nil or minor for maintenance purposes for many years.

The location of exposed bedrock has been apparent to river managers but until recently it has not been accurately located on plans at HBRC. In building the morphological computer model for gravel transport in the Tukituki River, Measures, (NIWA) measured and plotted the extent and location of the bedrock in order to calibrate the model. This is discussed in the next section.

2.3.5 Bedrock

This section has been provided by Richard Measures, NIWA, as part of the morphological modelling study for the Tukituki River which is a work in progress at the time of completing this report.

Bedrock is an important control on river morphology. Although bedrock erosion is important over long timescales (hundreds to thousands of years and longer), bedrock erosion is not considered to be significant over the timescales simulated in this modelling study. As such, bedrock is included at cross-sections in the model as a level below which no erosion can occur.

In order to identify the location of bedrock outcrops affecting the Tukituki River morphology we systematically reviewed current and historic aerial imagery of the river. In many locations bedrock was visible in the river bed, either in bars or under the water surface (e.g. Figure 2-6A). In other locations the river corridor passed through narrow gaps/gorges between bedrock hills, and we assumed it likely that bedrock was present underneath the channel even though it was not necessarily visible within the channel itself (e.g. Figure 2-6B).

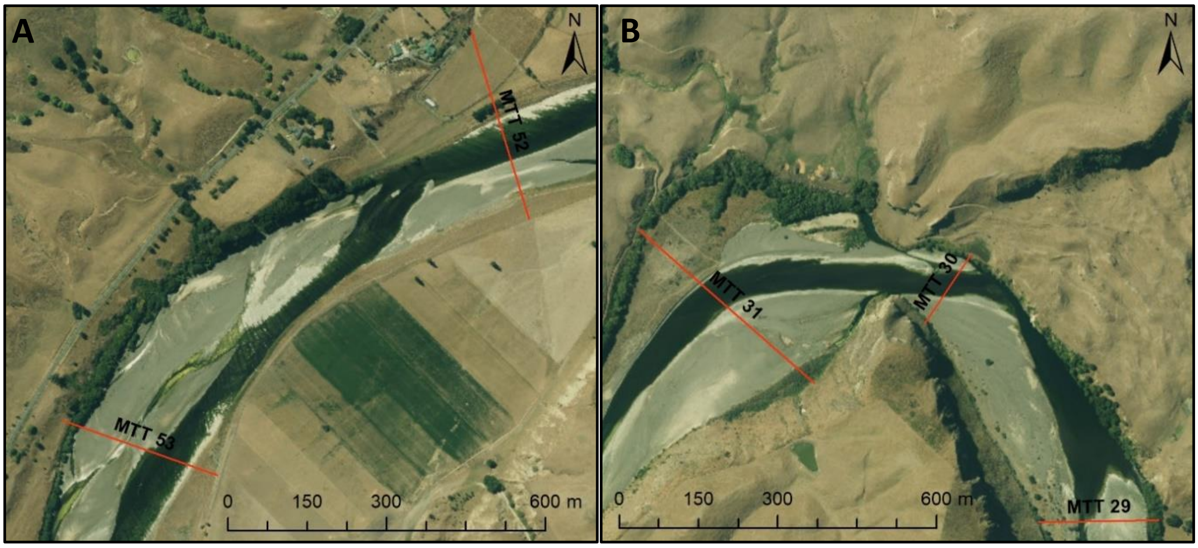


Figure 2-6: Example aerial imagery of bedrock identification. A: Bedrock visible underwater between cross-sections "MTT 53" and "MTT 54". B: Channel constricted by bedrock hills on either side so bedrock assumed to extend under river at cross-section "MTT 30". Both panels show 2014-15 aerial imagery (copyright Hawke's Bay Local Authority Shared Services (HB LASS), released under [Creative Commons Attribution 4.0 International](https://creativecommons.org/licenses/by/4.0/)).

Based on the appearance of the bedrock, we assumed a representative "depth to bedrock" at each cross-section where bedrock was identified. To simplify matters we assigned only three different depths:

- 0.2 m was assigned in areas where submerged bedrock was visible, and it is likely that little if any degradation is possible. 0.2 m is the active layer thickness of the model (see section X), as such any erosion below the initial bed elevation will start to reduce sediment availability.

- 0.5 m was assigned where bedrock was present near the cross-section (either upstream/downstream or in the banks) but none in the bed itself. This depth to bedrock allows a small amount of erosion (0.3m) before sediment availability starts to reduce.

- 5.0 m was assigned in constrictions between bedrock hills. In constrictions rivers often scour during floods and deposit on flood recessions (e.g. Carson and Griffiths 1989). Whilst bedrock is usually present, and limits the scour depth during large floods, deposition during the flood recession means that the bedrock is several metres below the surface at the time of survey.

The cross-sections where bedrock was identified, and the depth to bedrock assumed for the morphological model, are listed in Table 2-2 below. Figure 2-7 shows the bedrock locations on a long profile of the river.

Table 2-2: Assumed depth to bedrock at cross-sections where bedrock was identified. Listed from upstream to downstream.

Cross-section ID	Model chainage (km)	Assumed depth to bedrock (m)	Notes
UTT 86	85.46	0.200	Large bedrock outcrop, bedrock gorge upstream.
UTT 74	99.07	0.500	Bedrock visible on bank but none in bed
UTT 73	99.85	0.200	Bedrock visible on banks and bed
UTT 72	100.28	0.500	Bedrock visible on banks but none in bed
UTT 19	126.05	0.500	Constricted cross-section just downstream - likely bedrock present
UTT 17	126.91	0.200	Bedrock visible just downstream
UTT 16	127.58	0.200	Submerged and exposed bedrock visible
MTT 56	137.29	0.200	Submerged bedrock visible
MTT 54	138.50	0.200	“Shag Rock” bedrock visible
MTT 53	139.46	0.200	Submerged and exposed bedrock visible
MTT 52	140.46	0.200	Submerged and exposed bedrock visible
MTT 51	141.51	0.200	Submerged and exposed bedrock visible
MTT 50	142.66	0.200	Submerged and exposed bedrock visible
MTT 49	143.17	0.200	Submerged bedrock visible
MTT 48	143.75	0.200	Submerged bedrock visible
MTT 46	144.99	0.200	Submerged bedrock visible
MTT 44	147.37	0.200	Submerged bedrock visible
MTT 42	149.46	0.200	Submerged bedrock visible
MTT 32	157.93	5.000	Confined between bedrock outcrops
MTT 30	158.95	5.000	Confined between bedrock outcrops
MTT 27	160.42	0.200	Submerged bedrock visible
MTT 26	160.99	0.200	Exposed bedrock visible in bar
MTT 25	161.69	0.200	Submerged bedrock visible
MTT 24	162.65	0.200	Submerged bedrock visible
MTT 23	163.62	0.200	Bedrock cliffs on bank, submerged bedrock visible upstream
MTT 22	164.15	0.200	Submerged bedrock visible
MTT 21	164.56	0.200	Submerged bedrock visible
MTT 20	165.31	0.200	Submerged bedrock visible
MTT 13	171.28	0.500	Bedrock visible downstream but none at section itself
MTT 12	172.94	0.200	Submerged bedrock visible
MTT 11	173.74	0.200	Submerged bedrock visible

Cross-section ID	Model chainage (km)	Assumed depth to bedrock (m)	Notes
MTT 10	174.53	0.200	Submerged bedrock visible
MTT 9	175.00	0.200	Submerged bedrock visible
MTT 8	175.55	0.200	Submerged bedrock visible
MTT 7	176.50	0.500	Bedrock visible up and downstream but none at section itself
MTT 6	177.78	0.200	Exposed bedrock outcrop in channel
MTT 5	178.26	0.200	Submerged and exposed bedrock visible
MTT 4	178.76	0.200	Submerged bedrock visible
MTT 3	179.70	0.500	Bedrock visible up and downstream but none at section itself
MTT 2	180.69	0.200	Submerged bedrock visible
MTT 1	181.38	0.200	Submerged bedrock visible
LTT 29	181.90	0.200	Submerged and exposed bedrock visible
LTT 28	183.17	0.200	Submerged bedrock visible
LTT 27	184.31	0.200	Submerged bedrock visible
LTT 26	185.29	0.200	Submerged bedrock visible
LTT 25	185.92	0.200	Submerged bedrock visible
LTT 24	186.34	0.200	Submerged bedrock visible

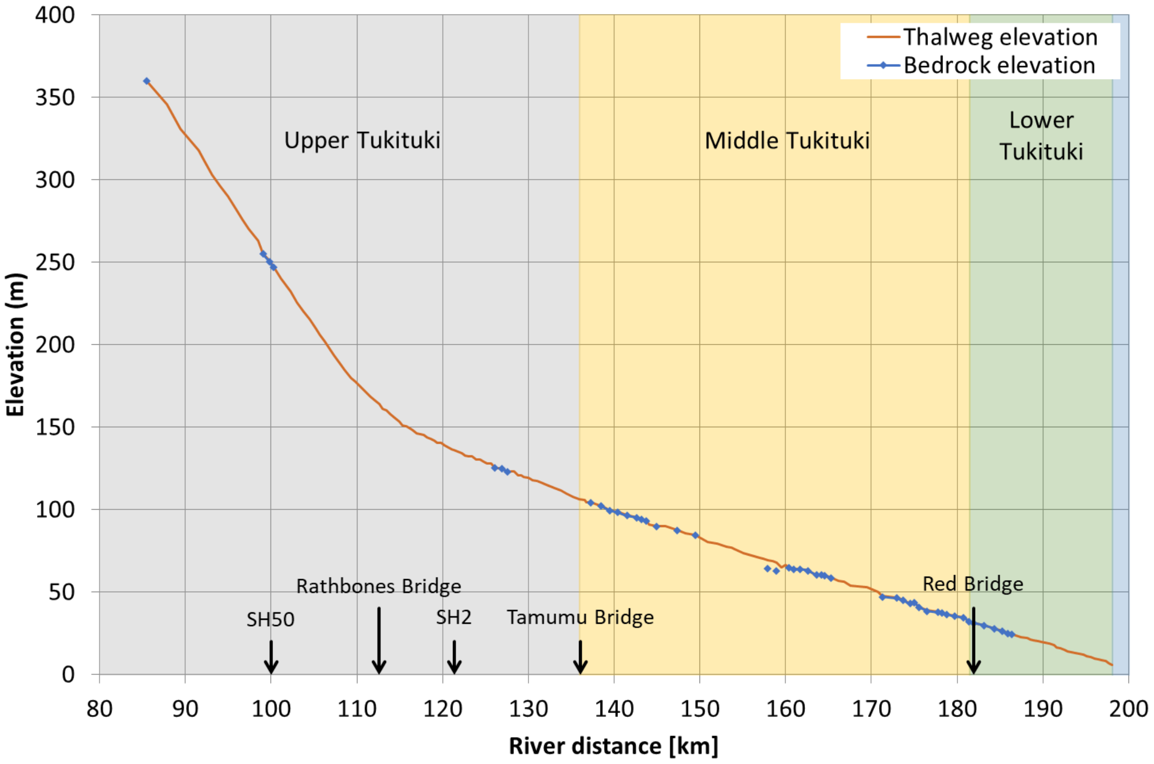


Figure 2-7 Long profile of the Tukituki GRATE model showing location of bedrock.

2.3.6 Allocation criteria

Grade lines are used as a reference level from which the measured mean bed levels are compared. Present gravel management consist of calculating - on a yearly basis – the available gravel volumes obtained from the most recent cross section surveys and reported gravel extraction data since the survey. Gravel extractors present, also on a yearly basis, an allocation request indicating their desired volumes and location. In general, if volumes are positive above the grade line, extraction, or a portion of it, is permitted. When volumes are negative, extraction is not permitted.

Extractors are encouraged to move to sections with positive volumes, making them a key part of river management. However there is a reluctance to travel too far due to high transport costs which creates aggradation issues (reduced flood capacity) in the southern rivers. Exceptions in the allocation criteria occur when bed levels are evidently high between cross sections but are not revealed by the analysis (e.g. island or bar). These exceptions are managed on a case-by-case basis. The allocation information is recorded in an internal yearly report series called Gravel Allocation.

YEAR 1		YEAR 2		YEAR 3	
Before Start	Up to year end	Before Start	Up to year end	Before Start	Up to year end
New Survey (from previous year) and analysis		New analysis, Y1 Survey plus extraction returns, plus Y1 impact effects		New analysis, Y2 Survey plus extraction returns, plus Y2 impact effects	New Survey of riverbed
Gravel requirements from extractors		Gravel requirements from extractors		Gravel requirements from extractors	
Allocation and Authorisations	Gravel returns from extractors	Allocation and Authorisations	Gravel returns from extractors	Allocation and Authorisations	Gravel returns from extractors
Visual inspections	Assess any flood changes to gravel supply	Visual inspections	Assess any flood changes to gravel supply	Visual inspections	Assess any flood changes to gravel supply
	Assess ecological impacts		Assess ecological impacts		Assess ecological impacts
	Assess erosion impacts, bed and banks		Assess erosion impacts, bed and banks		Assess erosion impacts, bed and banks

Figure 2-8: General structure of the 3 year allocation and inspection process. Currently the year starts in July and extraction returns are required together with any new survey by the end of June to enable analysis and the next year's allocation.

One concern with having riverbed surveys every three years is that the effects of floods, ecological impacts and unexpected gravel demand that should trigger a cessation of gravel extraction, gets overlooked. In practice this does not occur as all large allocations are assessed in the field prior to approving allocation. If necessary additional survey is carried out to confirm any decision.

In years with few or no floods the gravel resource still needs to be managed. As noted, allocations are prepared annually, by the process outlined in Figure 2-8. If there is a supply shortage, extraction ceases. There is regular discussion with the larger gravel extraction companies and potential supply shortages will be signalled. Extraction from rivers and reaches further from the traditional areas close to market is an option, albeit a more costly one. HBRC is using sediment modelling scenarios to gain a better insight to the supply issues over a longer time frame. This detailed work has begun and it will be a valuable management tool in the future, but it is not yet complete.

Earlier and recent work on extraction limits (Table 2-3) has provided guidance on the long-term effects of present extraction rates in the allocation process. Currently the year-to-year allocation criteria is based on frequent cross section monitoring due to the high variability and future uncertainty in the sediment supply rates to the rivers. More investigation is required to improve our understanding of the long term supply rates.

Keeping the river bed levels at or near the grade line allows managing four main issues:

i) Maintaining the capacity of the flood channel by reducing the mean bed levels where they exceed the design grade line;

ii) Maintaining a morphologically stable channel and consequently lowering the risk of scour and erosion at the active channel edge and important riverine structures such as roads, bridges and stopbanks;

iii) Maintaining river gradient such that sediment supply to downstream reaches and the coast is maintained and

iv) Maintaining the groundwater levels.

2.3.7 Gravel balance calculation

Gravel extraction limits (Table 2-3) and gravel supply rates to the river reaches and coast can be estimated from a gravel balance calculation. The gravel balance calculation separates the river into sub-reaches.

For each sub-reach (i) the gravel balance considers: the total sediment input from upstream between two survey dates ($G_{in,i}$), the total gravel extraction volume occurred between the surveys ($G_{ext,i}$), the total volume accumulated in the sub-reach between surveys ($G_{acc,i}$), and the total sediment output to downstream ($G_{out,i}$) between surveys (Figure 2-9). The distinction between G_{in} *and* G_{out} can be removed by simply having $G_{transp.i}$ representing the gravel transported to the sub-reach i from the upstream sub- reach $i-1$. Thus, there would then be $N+1$ unknowns and N equations.

$$G_{acc,i} = G_{transp.i} - G_{ext,i} - G_{transp,i+1} \qquad ; \quad i \in [1, N] \qquad [2.1]$$

$$G_{transp.i} = G_{in,i} = G_{out,i-1} \qquad [2.2]$$

Where i is the index identifying individual sub-reaches and N is the total number of sub-reaches on the surveyed length of river.

G_{acc} is obtained directly by calculating the difference in the volumes above the grade line between cross sections from two surveys. G_{ext} is obtained directly from the gravel extractors returns.

G_{transp} is unknown but has an interdependent relationship between consecutive reaches. One boundary condition is needed in order to solve [2.1]. Usually, the boundary condition is the first upstream input ($G_{in,i} = G_{transp,i}$) or the last downstream output ($G_{out,N} = G_{transp,N+1}$). These boundary conditions are not easy to estimate, although in cases such as in the Ngaruroro River where gravel does not reach the coast, a downstream boundary condition of $G_{transp,N+1}(t) = G_{out,N}(t) = 0$ can be assumed.

In order to solve [2.1] it is necessary to add additional information. The standard solution to solving gravel balance equations, which has been applied for the analysis described in this report, is to minimise $G_{transp,i}$ within the physical constraint that all transport is downstream (i.e. positive). This converts the analysis into an optimisation problem [2.3].

$$\min_{G_{transp,i}} \quad \left\{ \quad G_{acc,i} = G_{transp,i} - G_{ext,i} \qquad ; \quad i \in [1, N] \right. \qquad [2.3]$$

$$\mathit{subject\ to}: \qquad G_{transp,i} \geq 0$$

Equation [2.3] provides estimates of $G_{transp,i}$ that are a lower bound of the sediment input as at least in one of the sub-reaches it will be zero. This means that the sediment transport volumes using this method are probably underestimated (Table 2-4).

The sediment transport rates ($Q_{g,i}$) are calculated as:

$$Q_{g,i}(t) = \frac{G_{transp,i+1}}{t_{j+1} - t_j} \quad ; \quad i \in [1, N] \qquad [2.4]$$

Where t_j is the time of the earliest survey used in the analysis and t_{j+1} is the time of the latest survey used in the analysis and t is the average of t_{j+1} and t_j.

Extraction limits calculated in previous reports (Table 2-3) were set by estimates of the sediment transport rate from[2.4]. The problem with doing this is that part of the supply that goes into the sub-reach i leaves it as $G_{transp,i+1}$ and it is therefore not available for extraction. This means that extraction limits estimated using [2.4] were overestimated.

An alternative approach to estimate extraction limits is by using $G_{net,i}$ [2.5], which can be solved directly as the number of unknowns (N) is equal to the number of equations. This estimate of the supply volume only includes the sediment that would have been deposited in the river without extraction and not the sediment that passes through the sub-reach. It is simply the difference between the input and output of the reach. By taking the relative values of $G_{in,i}$ and $G_{out,i}$, $G_{net,i}$ is not sensitive to the boundary condition assumptions discussed previously. This is therefore a more conservative estimate of the sediment availability to the reach than equation [2.3], but it is still a coarse estimate, as it does not account for the complexities of the physical processes that govern sediment transport and the high future variability and uncertainty of its dominant forcings.

$$G_{net,i} = G_{in,i} - G_{out,i} = (\, G_{acc,i} + G_{ext,i} \,) \qquad ; \qquad i \in [1, N] \tag*{[2.5]}$$

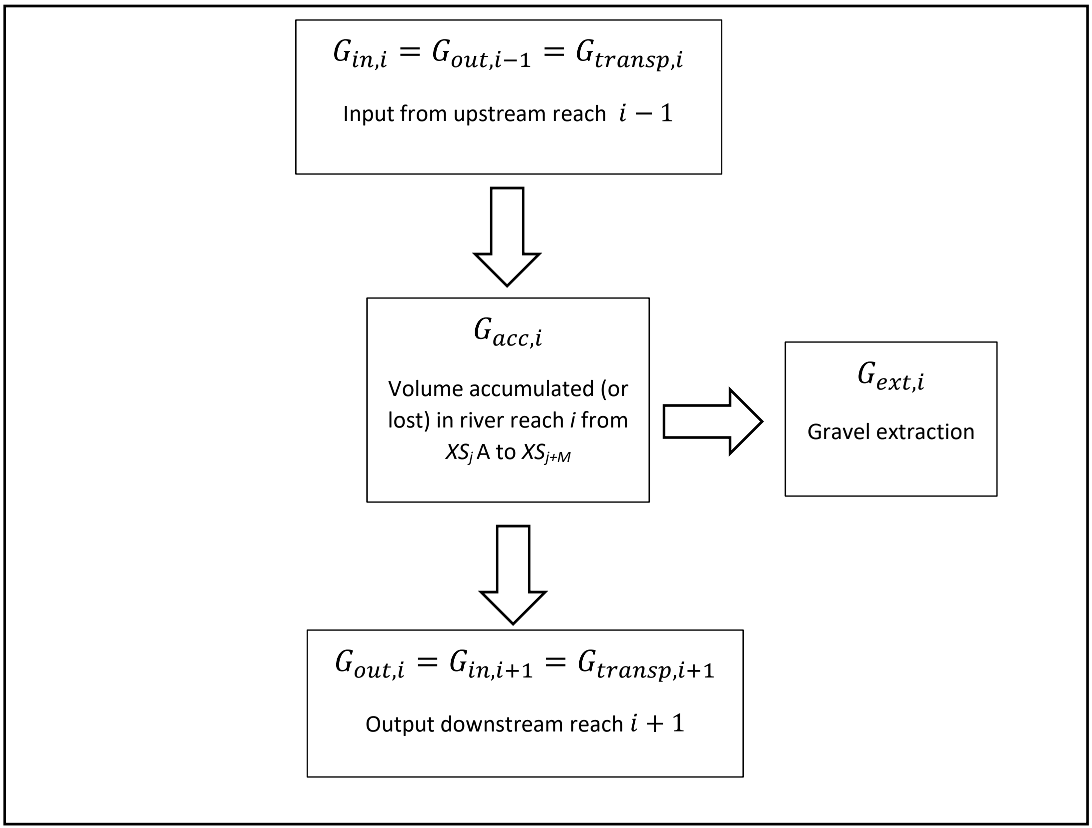


Figure 2-9: Schematic representation of the sediment balance

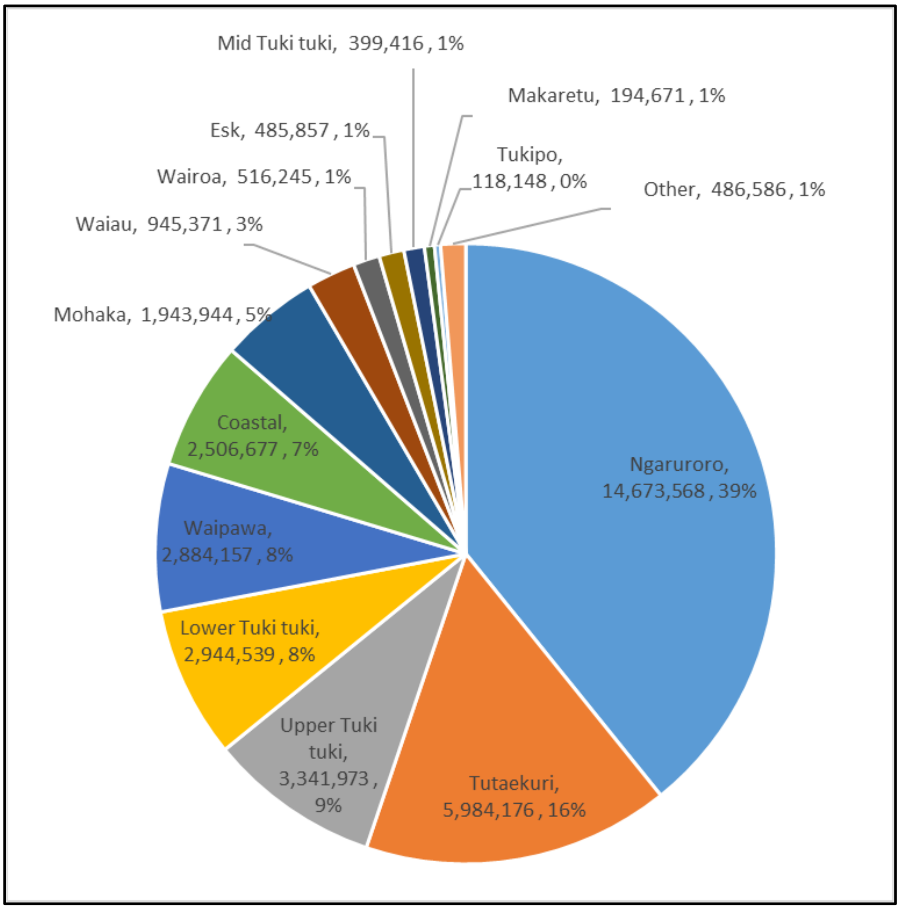


Figure 2-10: Total historical sediment extraction volumes from 1939 for all rivers and coast (HBRC, 2018).

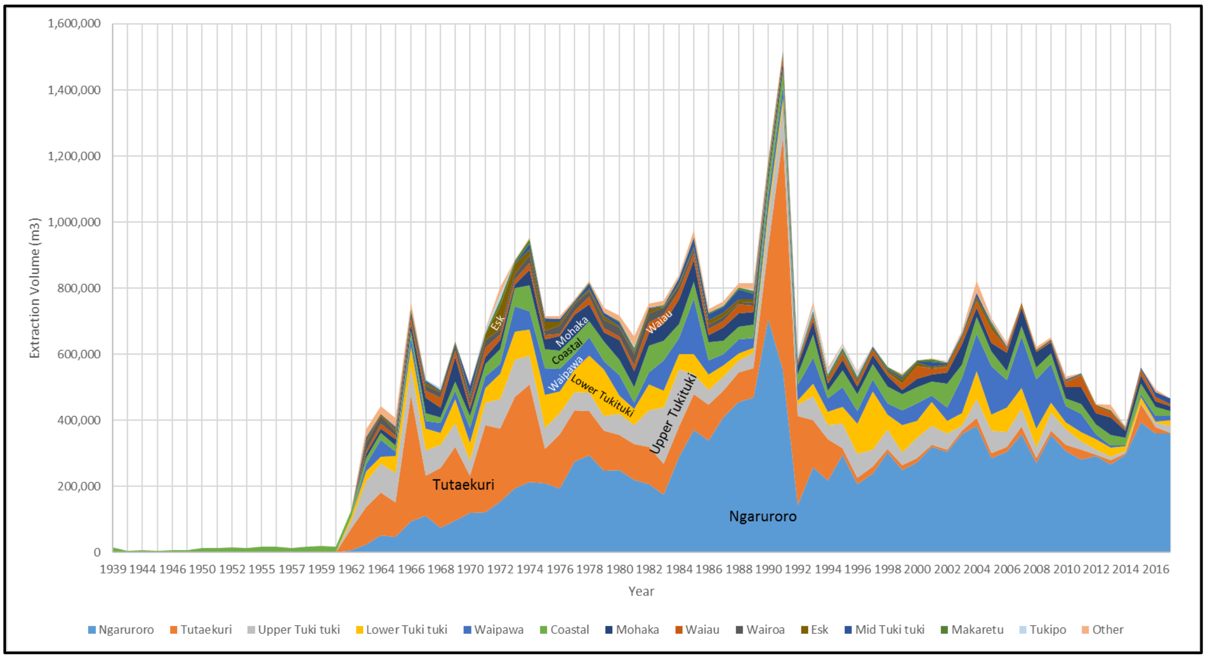


Figure 2-11: Total yearly sediment extraction volumes in Hawke's Bay rivers (Stack area plot; HBRC, 2018).

Table 2-3: Extraction limit rate set by earlier work and the latest estimates.

River	Supply rate by earlier work (m3/y)	Earlier work reference	Long term net-supply rate (Beya & Byrne, 2018)	Net-supply rate in the latest observed period (Beya & Byrne, 2018)
Ngaruroro	170,000	Williams (1997)	271,935	317,326
Lower Tukituki	7,000; 45,000	HBRC (1989); Edmondson (2001b)	-11,763	16,760
Tutaekuri	36,000; 28,000	HBRC (1989); Edmondson (2001a)	38,080	20,236
Esk	7,000	HBRC (1989)	2,033	-18,440
Upper Tukituki		N/A	51,167	48,773
Waipawa		N/A	26,543	53,030

2.4 Environmental effects of river management

Some of the environmental effects that can be identified as a result of river management are:

- Stopbanks increase the flood levels within the confined design flood plain, decrease of floodplain area and increase of peak flows caused by the restriction of the channel within the stopbanks limits. The subsequent increase of the velocities within the channel is generally thought to increase sediment transport rates and coarse sediment yields to the coast. However, there is evidence from some rivers outside the region (e.g. Davies and McSaveney, 2006) that confinement can decrease transport capacity and cause increased aggradation. Overall the effects of confinement on bedload transport rate in braided rivers is not well understood.
  Ref:Davies T.R.H., McSaveney M.J. (2006) Geomorphic constraints on the management of bedload-dominated rivers. J Hydrol New Zeal 45(2):111–130.
- Gravel extraction to maintain a relatively stable river morphology has the potential to decrease overall sediment and supply to the coast but increase local sediment transport to the area extracted. The overall effects to the coast may be experienced over hundreds of years in the case of coarse sediment, if land movements do not dramatically change the river morphology.
- Holmes (2017) indicates that morphological changes induced by gravel extraction and other management activities may change pool-riffle frequency and other morphological characteristics that affect the aquatic river ecology. However, at this time, there is no quantitative information to prove these possible effects and something that needs further study.
- Riparian and berm planting decreases erosion and can aid sediment deposition in the design flood plain. This decreases suspended sediment yields to the coast and may

increase coarse sediment transport volumes as the main channel has higher velocities. Vegetation provides shading and habitat for aquatic and terrestrial ecologies.

- River beach raking encourages coarse sediment transport to the coast and has the potential of disturbing sensitive bird nesting areas if carried out without monitoring. Raking has been blamed for causing the decrease of the depth of fishing holes (CHB Anglers' Club, 2017). More investigation is required to more fully understand what is happening here.

2.5 Coastal Sediments

The coast of Hawke Bay is characterized by alternating stretches of rocky shores and embayments that contain its principal beaches. The rocky portions, the Mahia Peninsula, the high cliffs north of Tangoio, Bluff Hill within the city of Napier, and Cape Kidnappers at the south all represent prominent headlands that limit or entirely prevent the passage of beach sediments around them, confining the sand and gravel to within the individual embayments. These features create two well defined and semi-independent systems:

1) The northern cell called the Bay View Littoral Cell (Tangoio to the Napier Port), and;

2) The southern cell called the Haumoana Littoral Cell (Napier Port to Cape Kidnappers) (as defined by Komar, 2005).

The beaches of Hawke's Bay are composed of mixtures of gravel and sand. The pebbles and cobbles are derived from the erosion of Mesozoic rocks found within the Kaweka Mountain Range, a greywacke that originated in the deep ocean as deposits of fine-grained silt but were later metamorphosed by heat and pressure during mountain building, yielding the most resistant rocks in the Range. The gravel barrier beach that formed along the present day shoreline was largely formed from landward movement of gravels lain down on the seafloor since the last marine transgression during the Holocene period.

The interaction between sediment supplies from the region's rivers has been studied in detail by Komar (2005). In particular section 7 of Komar's report covers beach sediment budgets. This work includes the results of model studies by Gibb (2003) and Tonkin and Taylor (2005) and presents current knowledge on the subject of sediment supply and coastal interaction.

The Lower Tukituki River is recognised as one of the main supplies of gravel to the coast at least since the 1931 earthquake. Presently, the Ngaruroro and the Tutaekuri rivers contribute sands and silts to the coast but no gravel. The amount of gravel on the barrier beach is affected by the wave climate, river and coastal cliffs supply, and beach extraction (ceased in 2017). Measurement of sediment volumes in the Tukituki River is crucial in order to manage extraction and not unduly affect coastal delivery while maintaining the flood capacity of the channel within the flood control scheme.

For the Bay View Littoral Cell only a very small amount (if any) of gravel is supplied to the coast and gravel extraction is likewise minimal. Any negative impact is compensated by the 15,000 m^3/y average sediment supply from the Westshore nourishment scheme since 1987.

Komar (2005) compiled a coastal sediment budget from previous work (Tonkin & Taylor, 2005; Gibb, 2003) over the years for the two littoral cells. These authors give an estimate of the net gains and losses balanced by the abrasion losses. Tonkin & Taylor (2012) updated their 2005 estimates but the high variability of the volume assessments over time makes it not possible to obtain reliable estimates of coastal annual supply rates. See the figure below and (Table 2-4).

There remains uncertainty concerning the conditions under which sediments from the lower Tukituki River are transmitted to the coast and thus there is uncertainty regarding the bed-level threshold that would allow commercial extraction to take place. Extraction for flood control and maintaining channel capacity will most likely be an over-riding consideration, given the infrastructure and assets protected by the scheme works.

Clearly more investigation and research is required to understand the conditions under which sediments transmit to the coast and importantly the quantum that end up supplying the barrier beach. Currently channel capacity is based on a grade line as explained previously, but the definition (how this line is determined) may need to be reconsidered following further research. Meanwhile, until this process is understood a precautionary approach is required that balances the competing requirements of reducing the flood risk and maximising the throughput of material to the coast (barrier beach).

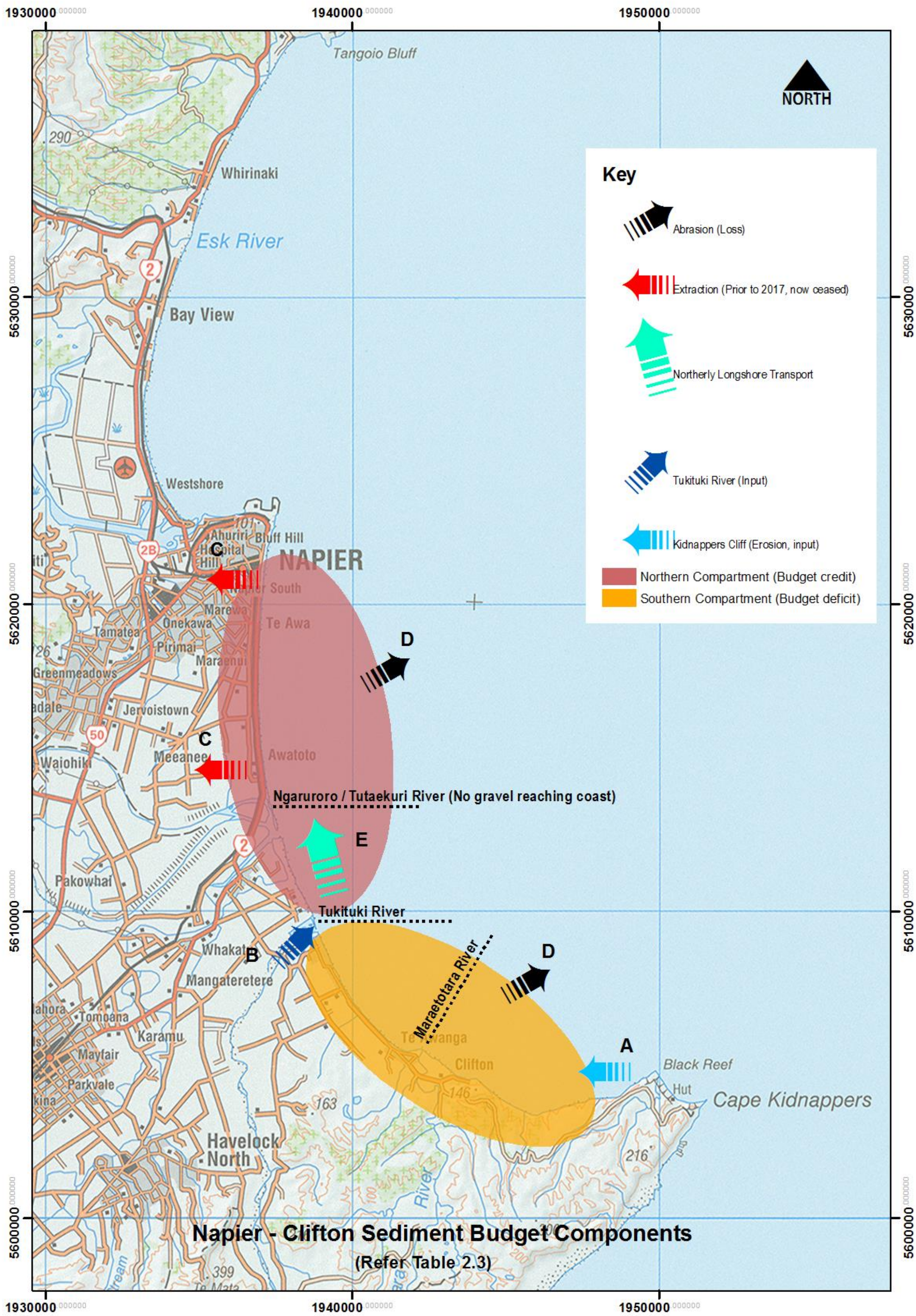


Figure 2-12: Components that make up the Napier-Clifton sediment budget. Table 2-4 shows the estimated values for the components by different researchers at different times in the past.

Table 2-4: Sediment sources and losses in the Haumoana littoral cell with ranges from various research and estimates.

Location of source (credit) or sink point (loss)	Estimated Long term Average Annual Sediment Supply Rate (m^3/year)	Comments
Cape Kidnappers and possibly the Maraetotara Stream.	18,000	Tonkin & Taylor (2005). Calibration of their UNIBEST shoreline evolution model. This value was determined based on the erosion rates on the southern beaches.
	13,000 to 20,000	Cliff face erosion estimates by Tonkin & Taylor (2005).
Tukituki River Mouth	8,000 to 13,000	Tonkin & Taylor (2005). Smaller than originally estimated
	16,000	Measures (2018). Tukituki river morphological model.
	3,000	Tonkin & Taylor (2012). Ruataniwha report.
	>28,000	Edmondson (2001b) and Gibb (2003)
	>37,580	Gravel balance 1978 to 2015
	>44,446	Gravel balance 2000 to 2015
	>Zero	Gravel balance 2012 to 2015
Coastal Extraction	Zero	After 2017
	32,137	Average extraction rate from 1939 to 2017 (HBRC, 2018)
	43,367	Average extraction rate from 1980 to 2017 (HBRC, 2018)
Abrasion loss	-9,800 to -32,400	Tonkin & Taylor (2005). Calibration of their UNIBEST shoreline evolution model.
	-30,400	Komar (2005). This value derived from the sediment budget for the Haumoana Littoral Cell and the best estimates for the debits and credits.
Net-average longshore transport	70,000-80,000	Gibb (2003)
	61,000-68,000	Inferred by Komar (2005) from Tonkin & Taylor (2005).
Sediment Balance (Gain or loss at the beach)	-45,000	Inferred by Komar (2005) from Tonkin & Taylor (2005). This number is composed of -48,800 m^3/s south of the Tukituki mouth and 3,800 m^3/y north of the Tukituki mouth.
	21,912	Calculated from data by Carruth & Cave (2016) beach profile monitoring programme (1980-2016). This is composed of -9,009 m^3/y south of the Tukituki mouth and 30,921 m^3/y north of the Tukituki mouth.

2.6 Recent advances implemented by HBRC

2.6.1 Modelling

Measures (2012, 2018) has undertaken morphological models of the Ngaruroro and Tukituki River using GRATE v3.50 (Gravel Routing and Textural Evolution), a one-dimensional sediment transport model (Walsh, 2014). GRATE allows modelling coarse-sediment transport rates and bed level changes on braided rivers, including the ability to manage multiple grain size fractions, gravel extraction, river beach raking and distributed shear stress.

The modelling for the Ngaruroro was calibrated for the period between year 1979 and 2005 and used to study the effects of different extraction and raking scenarios and climate change. These scenarios included, no extraction, no river raking, site-specific changes in extraction, increased extraction, climate change and changes in gravel supply.

The Ngaruroro modelling study showed that if no extraction had taken place, flood capacity would be significantly lower than present. Gravel extraction has not affected the total gravel supply rate but has changed the distribution of deposition, focusing it around Fernhill where the highest extraction rates have occurred. Gravel extraction has reduced the propagation towards the coast but not prevented gravel reaching it. For that to happen, significant aggradation of the bed will need to occur in order to increase the slope of the reach upstream of the coast. Beach raking increases the transport rate significantly. Future sea level rise and river flow reduction expected from climate change are likely to reduce sediment supply to the coast.

A similar work-in-progress model study of the Tukituki River is currently being completed. When available the key findings of the Tukituki Gravel report will be included as an addition to this report.

In the Tukituki modelling carried out to date the sediment transport rate in general decreases with no extraction but increases in the last 3km towards the sea. This change is a result of historic extraction from the Lower Tukituki. In general the modelled transport rates are approximately 50% lower compared to the estimates with the gravel balance approach over the period 1978 to 2015. This indicates that further model calibration is necessary in this reach to match the gravel balance approach rates, however the trends are still evident. The most significant changes in transport rate occurred between the mouth and 15 Km upstream, while the middle Tukituki is practically unaffected by extraction.

2.6.2 LiDAR Survey

The use of LiDAR surveys has being explored for improving the accuracy of gravel availability estimates. The assessment method used currently includes cross section data spaced every 500 m approximately (Table 2-1) while LiDAR has the potential to include data at a much better spatial resolution.

Present day LiDAR surveys are carried out with an aeroplane-mounted sensor and a GPS and are significantly more expensive than the conventional cross section surveys. This implies that, at present and in practical terms, LiDAR surveys can be undertaken at a lesser frequency than the cross sections. Flying a meandering river corridor is more complicated due to the various flight paths, and hence, more costly. Another disadvantage in the use of present LiDAR technology is the inability to obtain riverbed levels in the portions covered by water.

Nevertheless, it is likely that future developments can significantly reduce the cost of LiDAR. Technological advances including the use of drone mounted LiDAR, drone photography survey, water depth measurement from photography and shallow water LiDAR bathymetry are promising and likely to be at accessible costs in the near future.

Recent LiDAR surveys have been carried out for the Lower Tukituki and Tutaekuri rivers in 2003, the Waipawa and Middle Tukituki rivers in 2004 and the Ngaruroro and Upper Tukituki rivers in 2005 (Figure 2-15).

Hall and Clode (2018) carried out a comparison between gravel availability estimates (volumes) from cross sections and LiDAR data for the whole Lower Tukituki River reach. The results showed a difference of 10% in the estimated volumes, indicating that, overall, gravel availability estimates obtained from cross section data is adequate. Difficulties in areas with heavy vegetation and differences between cross section benchmark levels and survey data were detected. Also the underwater portion of the river needed to be estimated to complete the LiDAR survey.

Despite the latter, LiDAR surveys can provide more detailed insight on availability in specific locations for gravel extraction allocation. The figures below provide an indication of the type of information that HBRC is developing, using LiDAR as part of managing the river sediments.

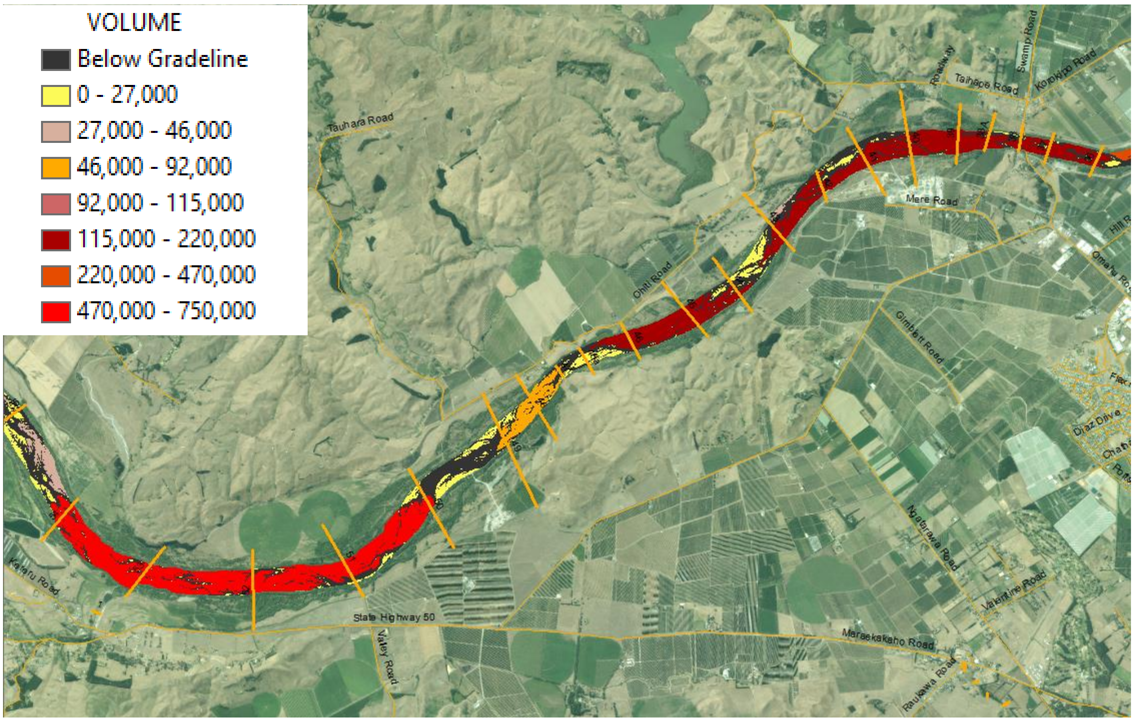


Figure 2-13 Ngaruroro River XS 36 to XS 55 gravel volumes above the grade line (2003 LiDAR data). Volumes are cubic metres relative to the grade line. Each colour represents a contiguous area over which the volume is within the range associated with the colour. Although the red area (470,000 – 750,000 m3) is adjacent to the yellow area (0 – 27,000m3) for example, it is consistent as it is indicating that in the contiguous yellow area there is much less gravel available than in the contiguous red area. This corresponds to a reach where there is a fixed gravel plant operating.

In the future the use of Lidar techniques will provide better information to link decision-making and management of the gravel resource.

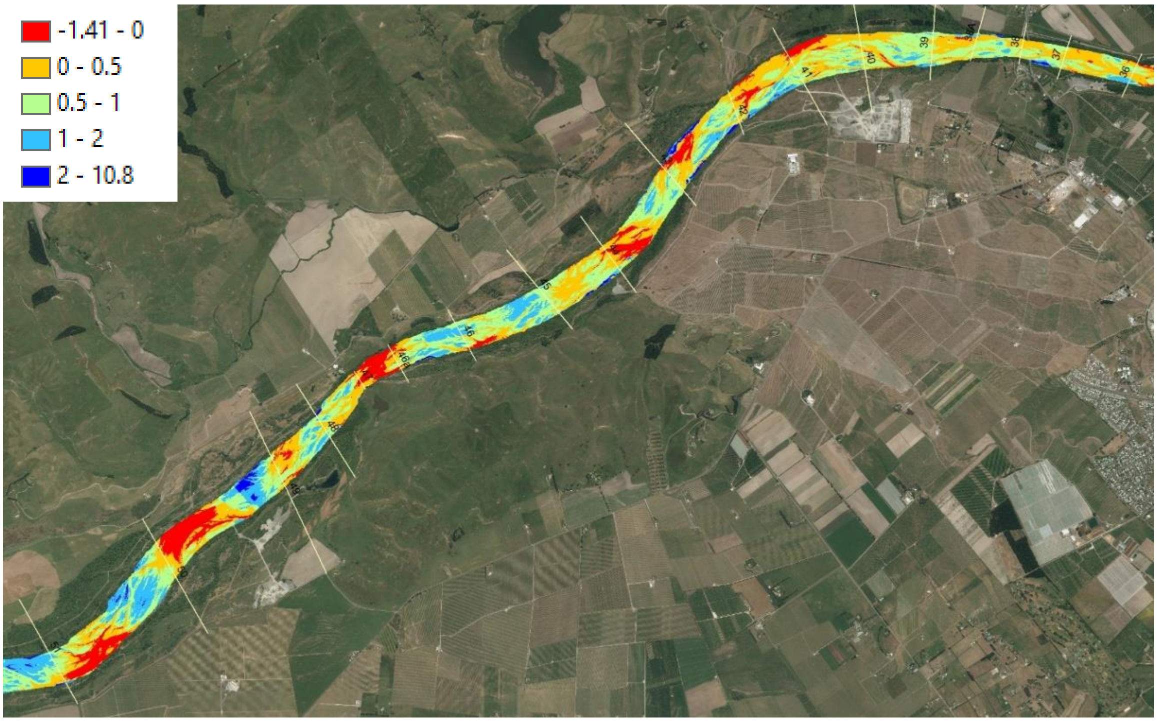


Figure 2-14 Ngaruroro River XS 36 to XS 51 showing bed levels relative to the grade line. Red areas represent locations where gravel extraction is not currently permitted. The image readily shows areas of aggradation and degradation to provide a visual guide to extraction locations.

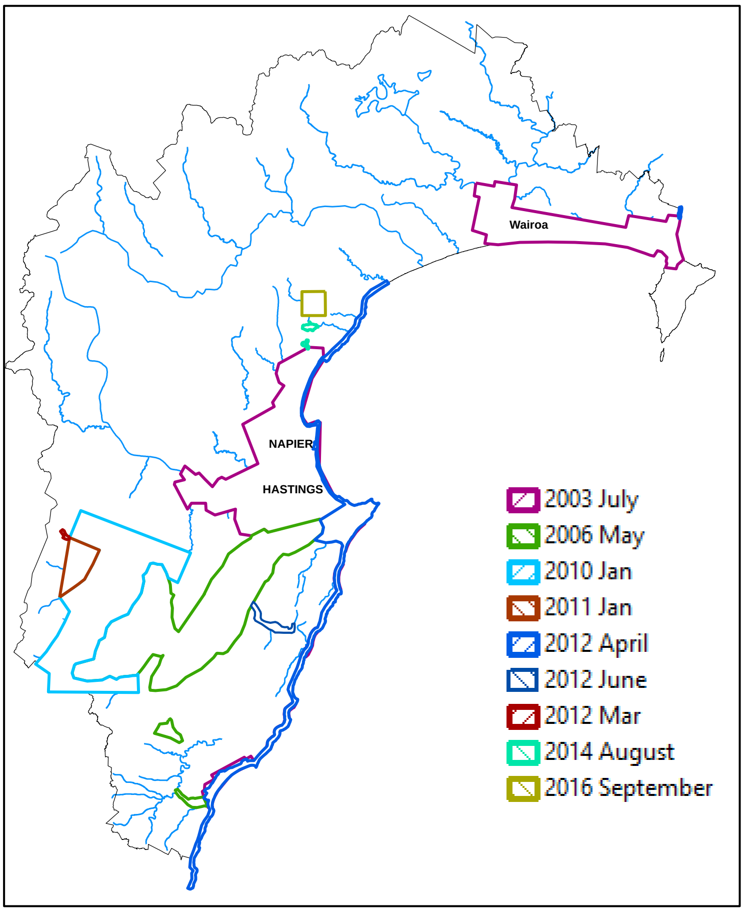


Figure 2-15: LiDAR Coverage for Hawke's Bay region

3 Methodology

This section explains how the cross section data was analysed for each of the rivers in the following sections of the report. The cross section data corresponds to the reaches where extraction has taken place. The following morphological parameters were calculated with the data.

The mean bed levels (MBL) were calculated within the active channel as:

$$MBL = \frac{\int_{x_{min}}^{x_{max}} z^a dx}{x_{max} - x_{min}} \qquad [3.1]$$

Where z^a is the vertical cross section data within the active channel, x_{min} and x_{max} correspond to the left and right limits of the active channel were obtained from aerial photographs and during survey by noting the areas where gravel was exposed.

The minimum bed levels were calculated as:

$$minBL = min(z^a) \qquad [3.2]$$

The active channel width was calculated as:

$$AChW = x_{max} - x_{min} \qquad [3.3]$$

The mean bed level slope was calculated as:

$$S_{MBL} = \frac{MBL_{j+1} - MBL_j}{Y_{j+1} - Y_j} \qquad [3.4]$$

Where Y_j is the river distance at cross section *j* measured from the river mouth.

The relative maximum depth was calculated as:

$$RMD = MBL - minBL \qquad [3.5]$$

This parameter represents the depth of the lowest point with respect to the mean bed level at each cross section location and is a representation of channel depth relative to the tops of bars (i.e. channelization). It may be useful to provide a rough indication of the changes of the fishing holes depths in time and along the river but really only accurate if there happens to be a hole located where the cross section crosses the channel.

The volume of gravel available above the grade line was calculated as:

$$V_j = \frac{(MBL_{j+1} - GL_{j+1}) \cdot AChW_{j+1} + (MBL_j - GL_j) \cdot AChW_j}{2} \cdot (Y_{j+1} - Y_j) \qquad [3.6]$$

Where GL_j is the grade line level at the location of river cross section *j*.

The uncertainty for these morphological parameters produced by the sample size and variability is represented by the *standard error of the mean* (DeCoursey, 2003):

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{N_s}} \qquad [3.7]$$

Where σ is the standard deviation and N_s the number of samples.

4 Lower Tukituki River

4.1 Background

The Lower Tukituki River covers the reach from the river mouth (downstream XS 1, Km 0) to Red bridge (XS 29), Km 14.87). The reach has 18.5 Km of stopbanks protecting Havelock North and the surrounding farmland. Willow planting has been applied along the berms to stabilize the active channel width, although, width changes have occurred due to loss of edge protection during floods. Gravel extraction and river raking have been regularly applied along the reach (Clode, 1996; *Figure 4-1*).

Cross section data has been systematically measured in 29 cross sections (XS 1 to XS 29) along the river since 1990, with non-systematic records dating from 1947 (Figure 4-2). The analysis in this chapter includes survey data from 2000 onwards.

Gravel extraction was significantly decreased after 2009. For the present year, gravel extraction has ceased due to river bed reaching levels below the grade line (Figure 4-3 and Figure 4-4). Reduction in gravel extraction is also, in part, due to an increased concern about the impact in coastal erosion. As explained in section 2.5, the Tukituki River is the only supply of river gravel to the southern littoral cell.

Floods capable of mobilizing significant amounts of gravel have occurred regularly in the river. However, there has been a high variability in the frequency of these type of events with 5 events above the 2 year return period between 2008 and 2018 and 3 events in the period from 1998 to 2008 (Figure 4-5).

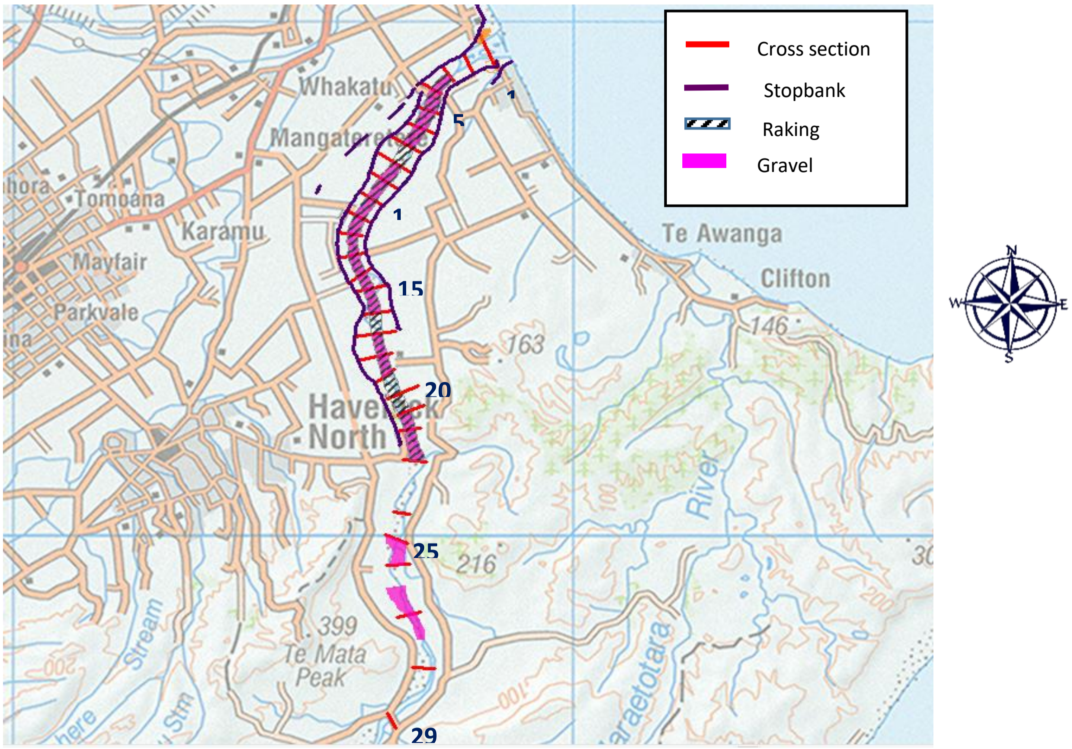


Figure 4-1: Location of the Lower Tukituki River and an indication of cross sections, stopbanks, raking and gravel extraction. Blue numbers indicate XS numbers.

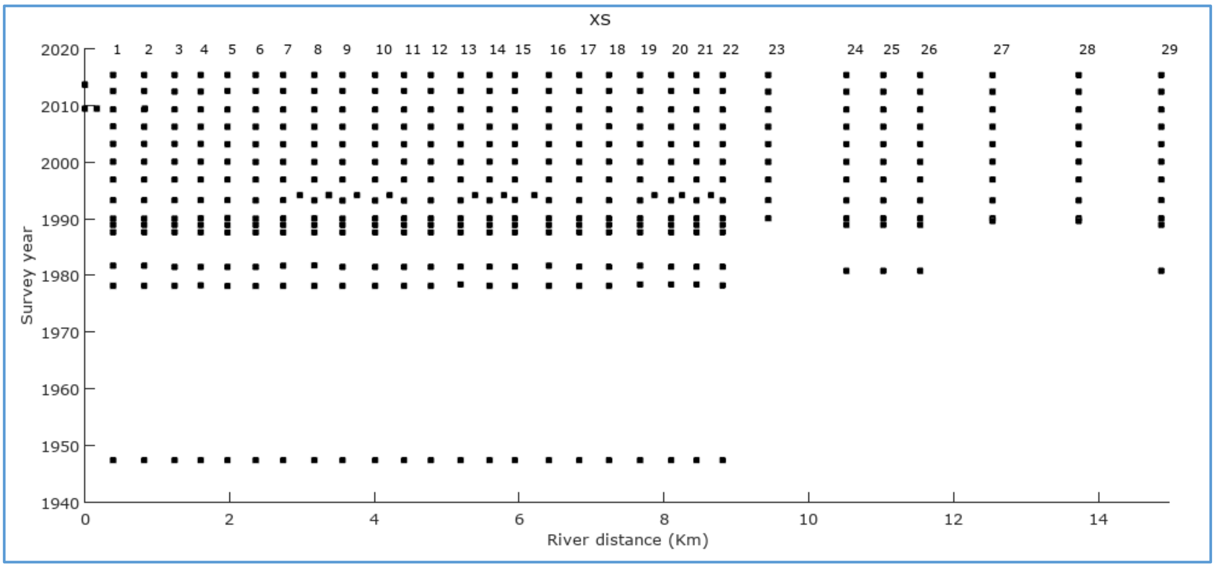


Figure 4-2: Cross section data availability for the Lower Tukituki River. Each black dot represent a cross section survey.

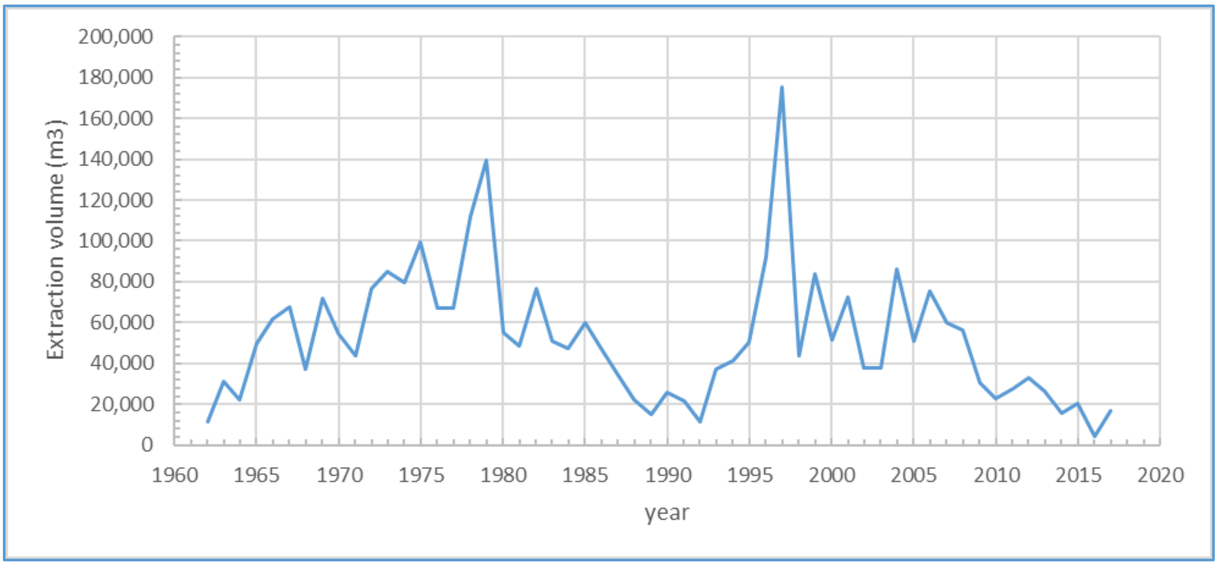


Figure 4-3: Time series of total gravel extraction volumes in the Lower Tukituki River.

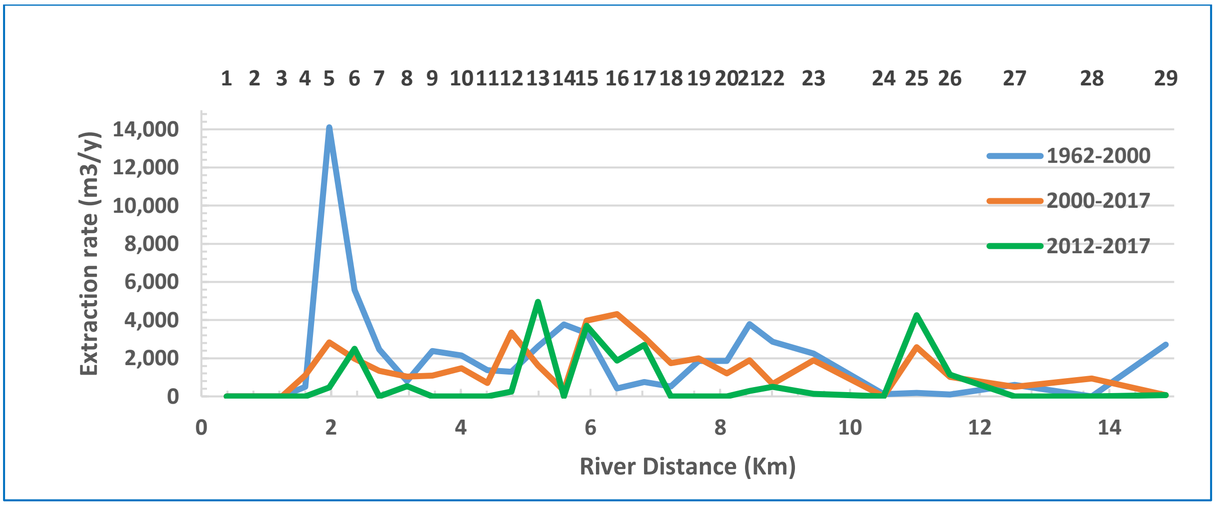


Figure 4-4: Average gravel extraction rates along the Lower Tukituki River for three different periods.

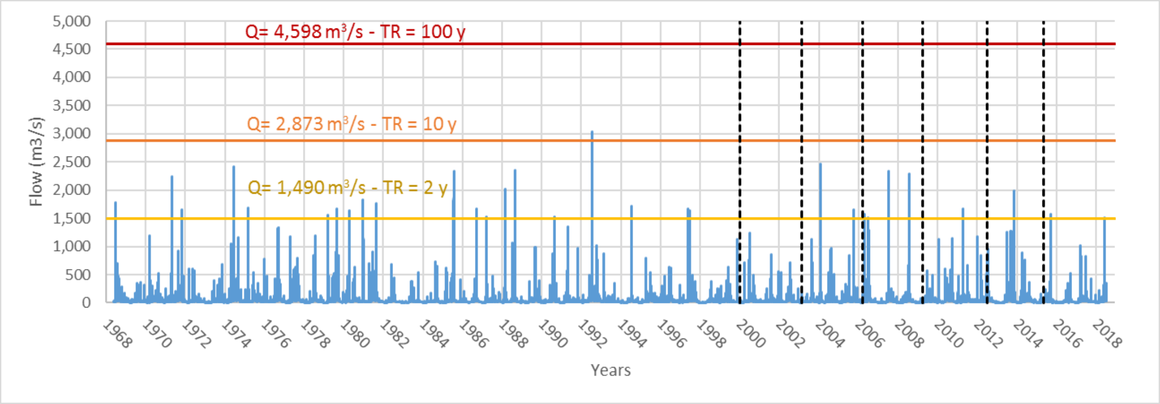


Figure 4-5: Tukituki River hourly flows at Red Bridge. Return values from Carruth (2015a). Vertical black dashed lines indicate the survey dates used in the analysis in this chapter. Earlier dates have not been considered in the analysis.

4.2 Observed Morphological Changes

4.2.1 Summary

Table 4-1: Average historical and latest rates of change of morphological parameters in the Lower Tukituki River. The period of analysis is indicated in brackets. The parameters definition is outlined in section 3.

Symbol	**Parameter name**	**Historical best fit trend (2000-2015)**	**Average of historical rate of change (2000-2015)**	**Average of Latest rate of change (2012-2015)**	**Units**
MBL	Mean bed level (-ve below grade line)	-0.024	-0.018	0.043	m/y
S_{MBL}	Mean bed level slope	$-7.2\text{x}10^{-5}$	$-8.0\text{x}10^{-6}$	$9.0\text{x}10^{-4}$	%/y
$AChW$	Active channel width	-0.51	-0.42	2.01	m/y
RMD	Relative maximum depth (+ve deepening)	0.0047	0.0057	0.042	m/y

4.2.2 Active channel mean bed level

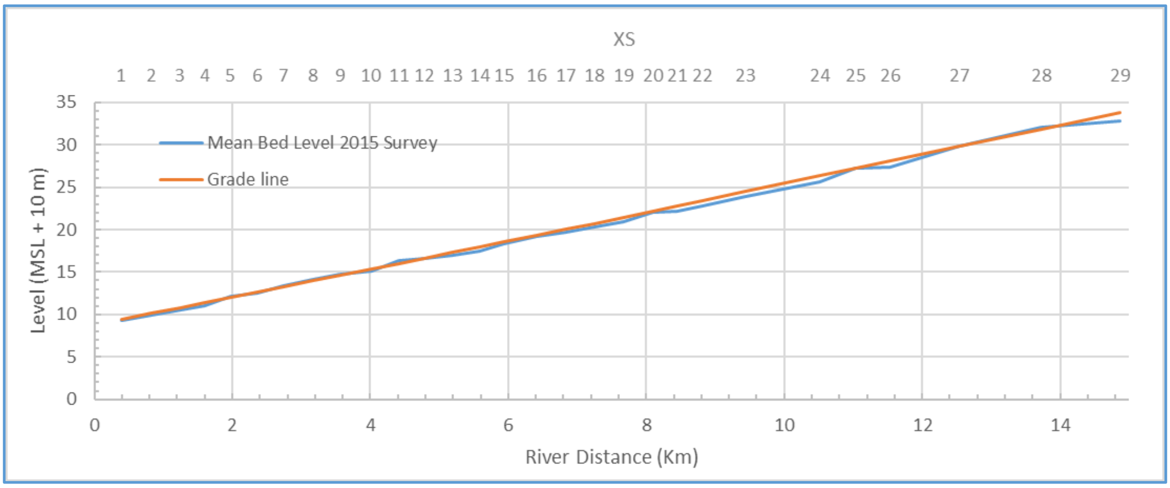


Figure 4-6: Mean bed level and design grade-line

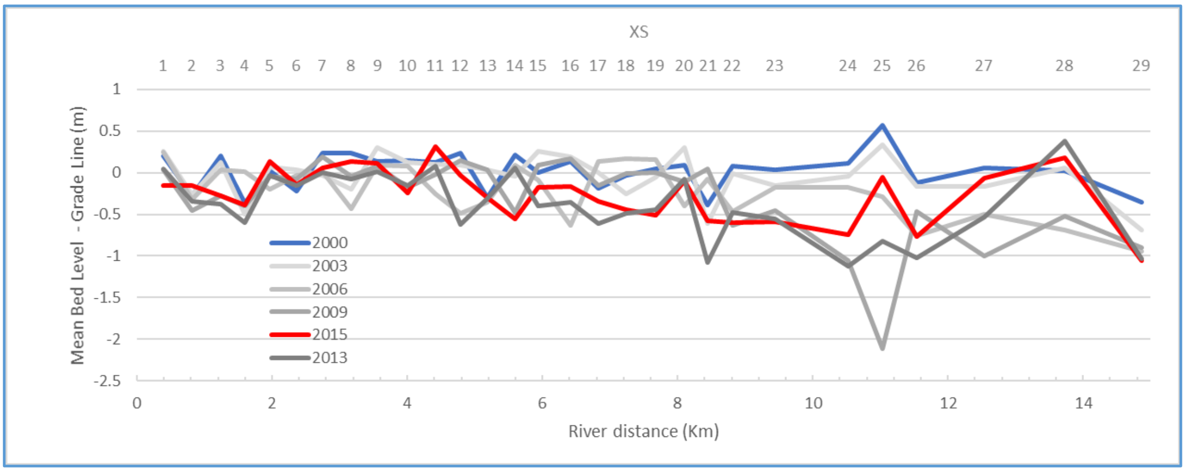


Figure 4-7: Change in time of the mean bed level relative to the grade line level along the Lower Tukituki River.

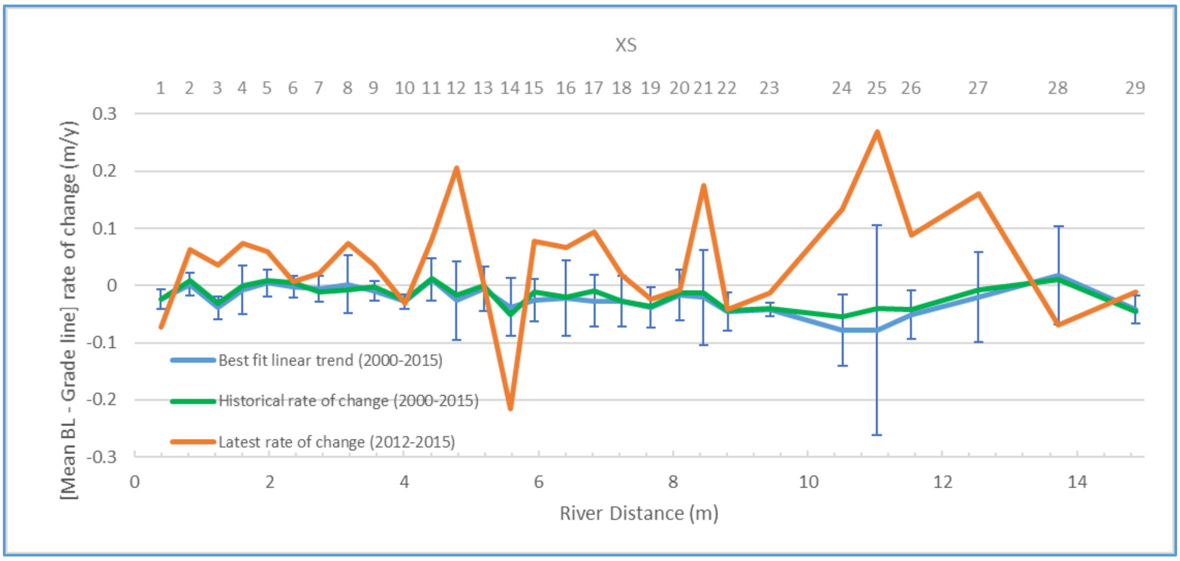


Figure 4-8: Rate of change of the mean bed level relative to the grade level along the Lower Tukituki River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

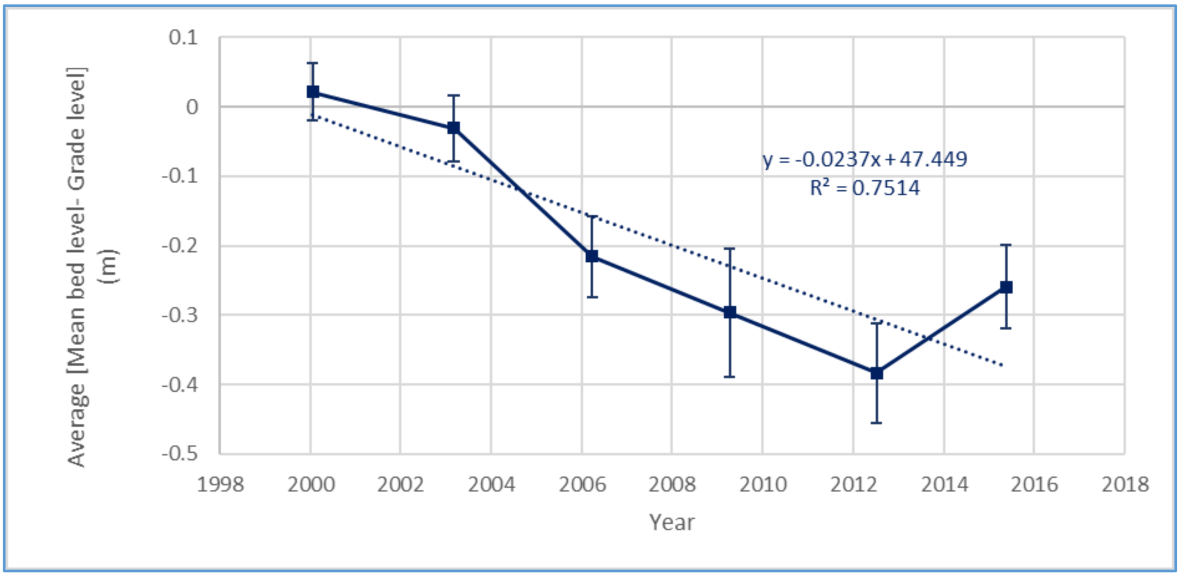


Figure 4-9: Change in time of the average mean bed level relative to the grade level along the Lower Tukituki River. Error bars indicate the standard error of the mean.

4.2.3 Active channel mean bed level slope

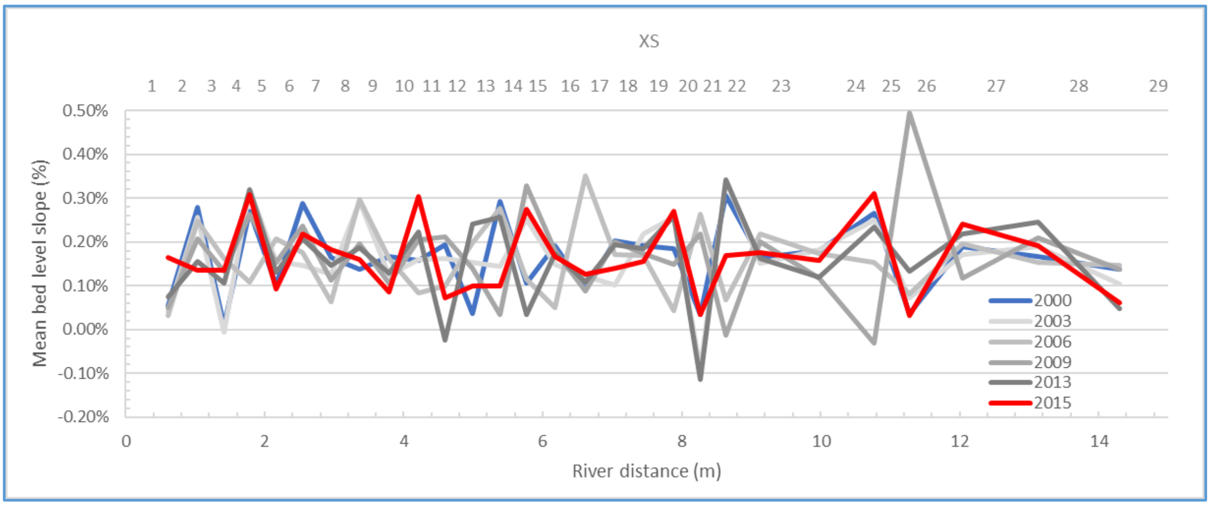


Figure 4-10: Change in time of the mean bed level slope along the Lower Tukituki River.

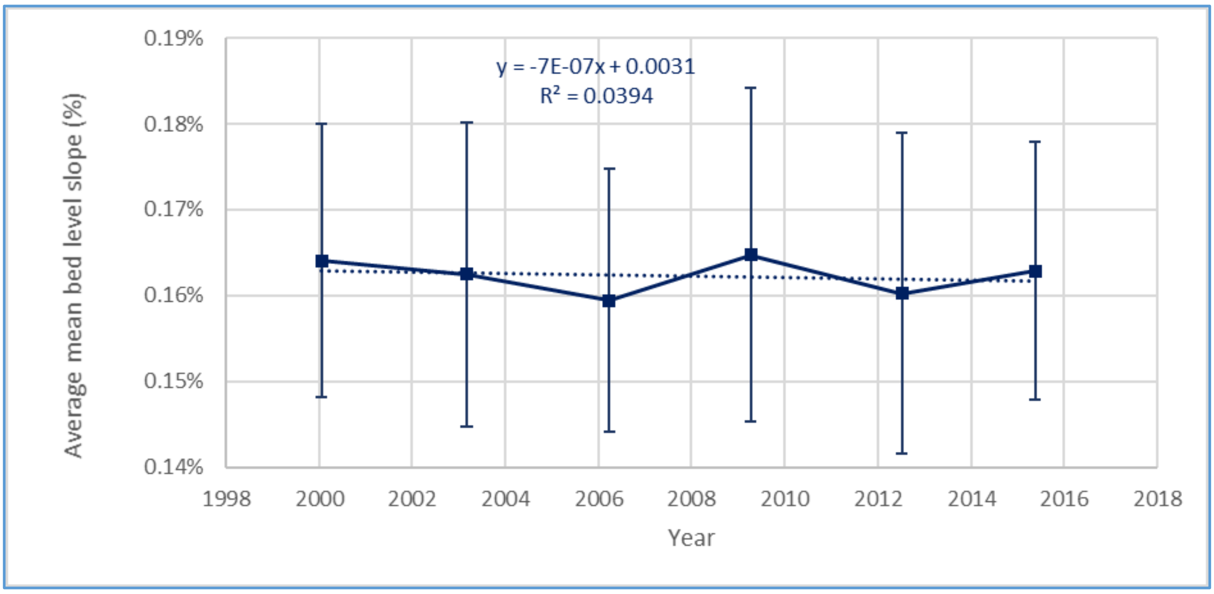


Figure 4-11: Change in time of the average mean bed level slope along the Lower Tukituki River. Error bars indicate the standard error of the mean.

4.2.4 Active channel width

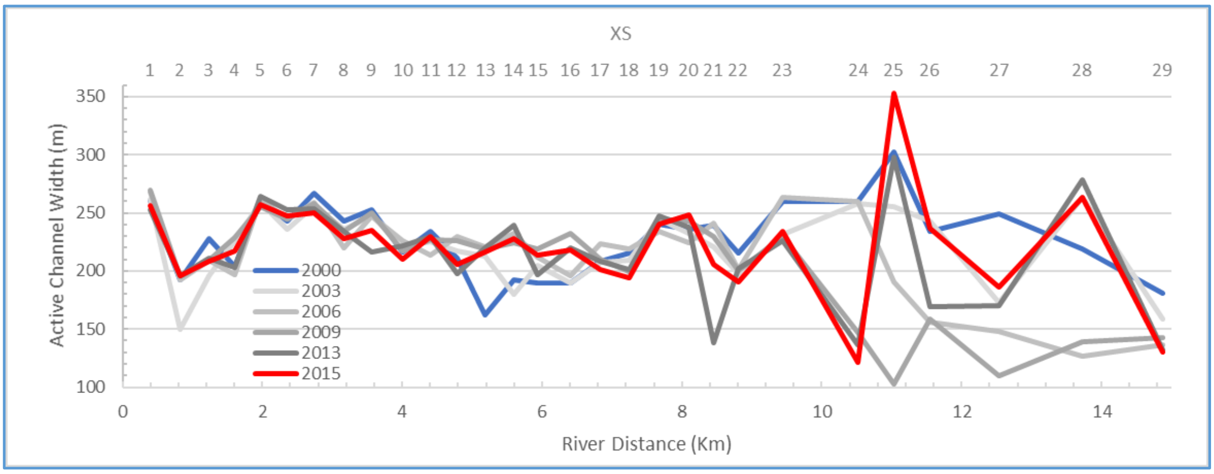


Figure 4-12: Change in time of the active channel width along the Lower Tukituki River.

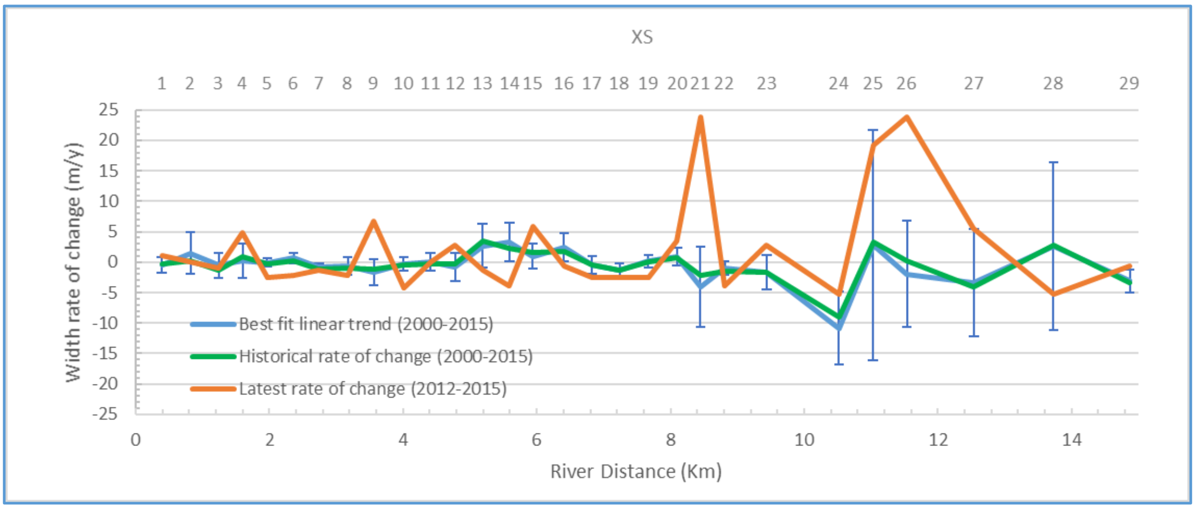


Figure 4-13: Width rate of change along the Lower Tukituki River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

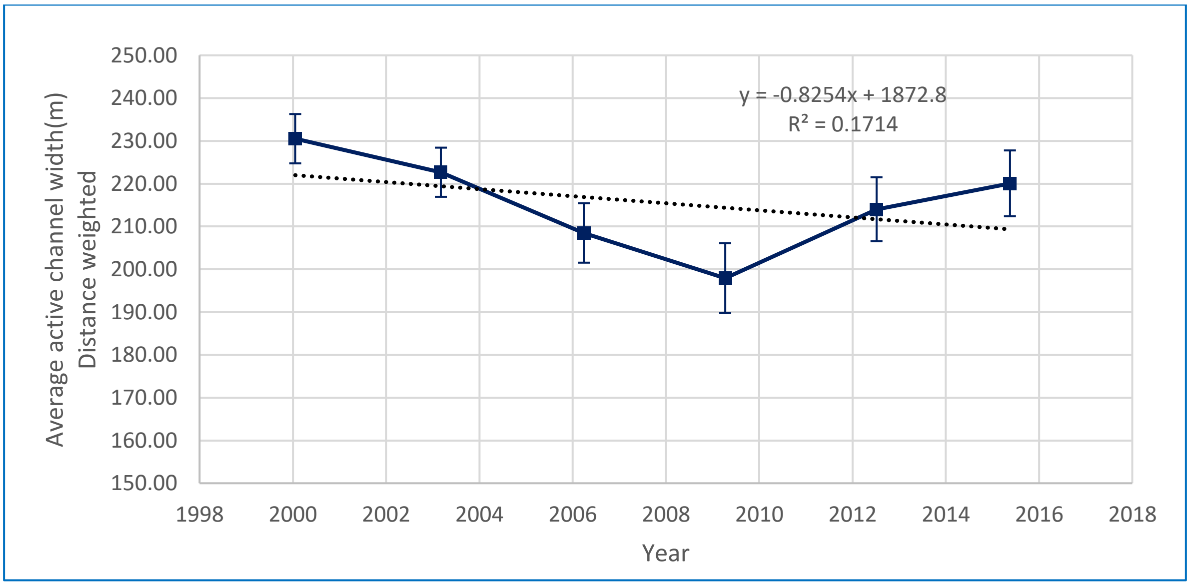


Figure 4-14: Change in time of the average active channel width along the Lower Tukituki River weighted by reach length. Error bars indicate the standard error of the mean cross section width.

4.2.5 Relative maximum depth

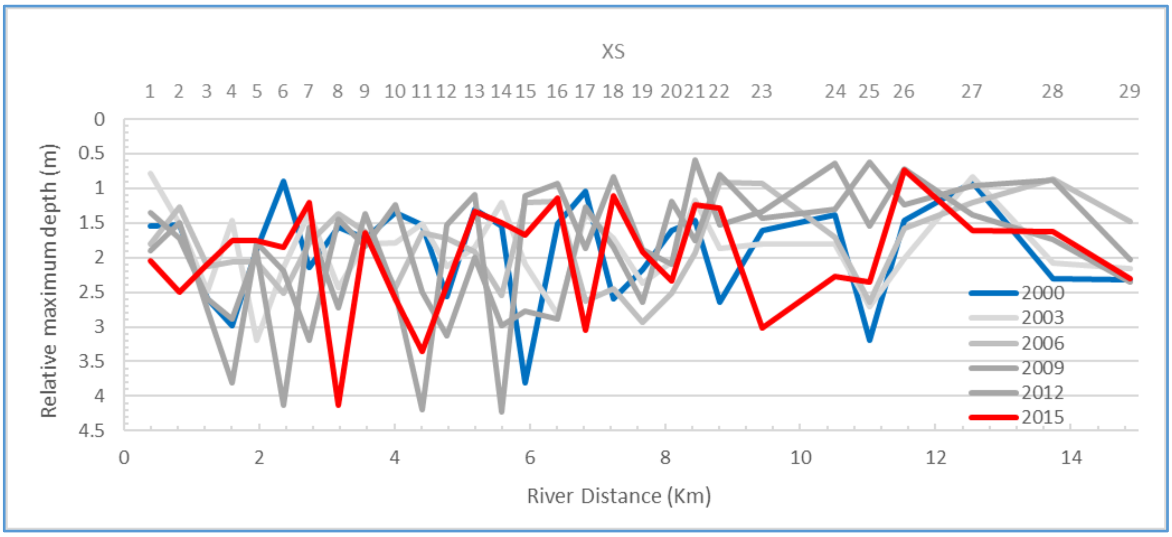


Figure 4-15: Change in time of the Relative Maximum Depth (Mean Bed Level – Min Bed Level) along the Lower Tukituki River. Note that the vertical axis is reversed for a more intuitive visualization of (water) depth.

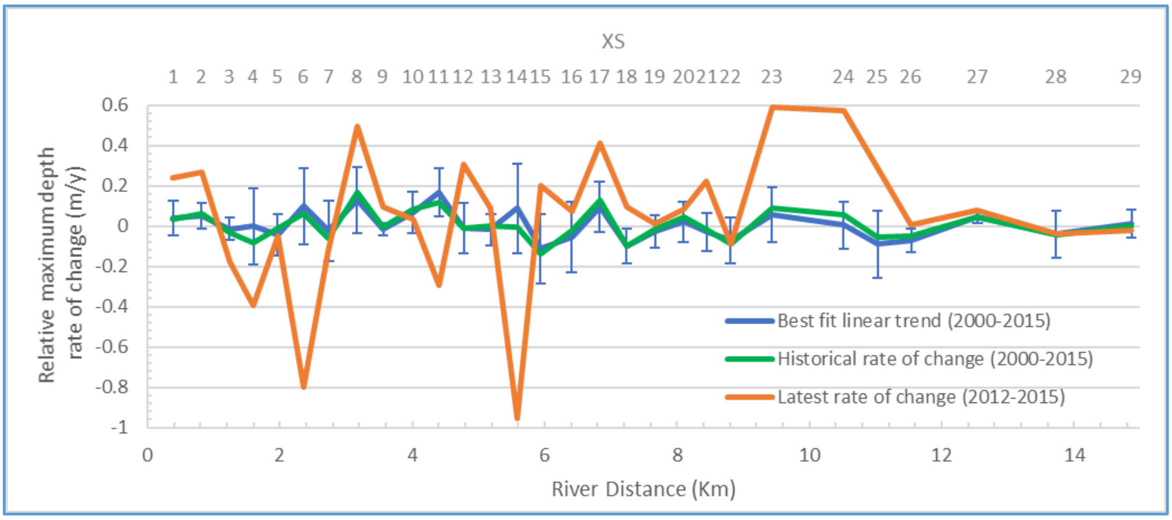


Figure 4-16: Relative Maximum Depth (Mean Bed Level – Min Bed Level) rate of change along the Lower Tukituki River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

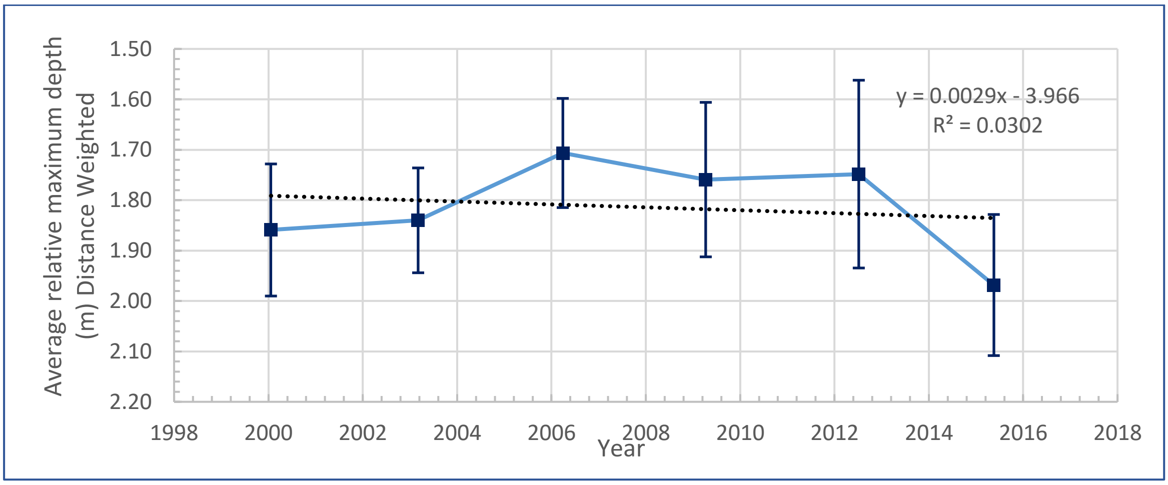


Figure 4-17: Change in time of the average the Relative Maximum Depth (Mean Bed Level – Min Bed Level) along the Lower Tukituki River. Error bars indicate the standard error of the mean at each cross section. Note that the vertical axis is reversed for a more intuitive visualization of (water) depth.

4.3 Gravel Availability

4.3.1 Present

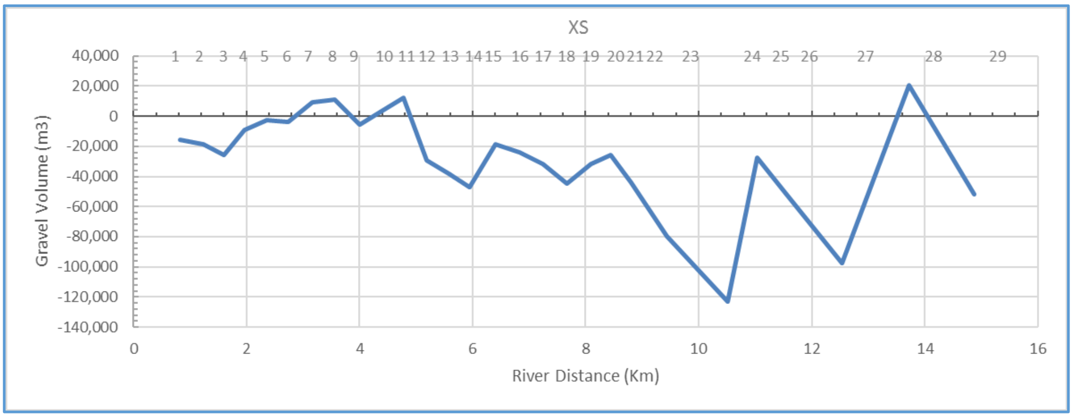


Figure 4-18: Estimated gravel availability for 2018 in the Lower Tukituki River (Beya & Byrne, 2018). This is the volume measured above the grade line

4.3.2 Historical change

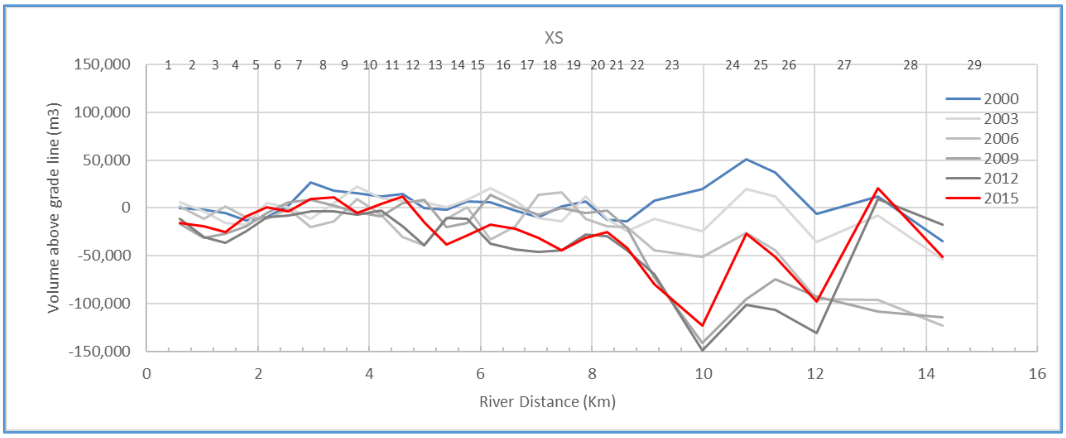


Figure 4-19: Historical change in measured gravel availability (Volume above the grade line)

4.3.3 Cumulative volume analysis

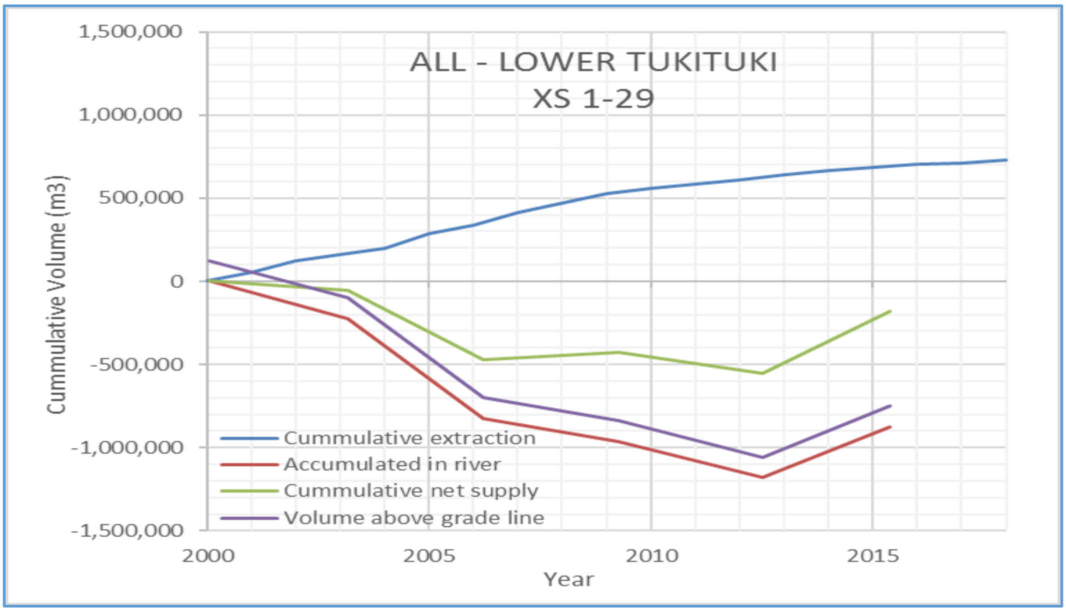


Figure 4-20: Lower Tukituki cumulative volume analysis for the entire river

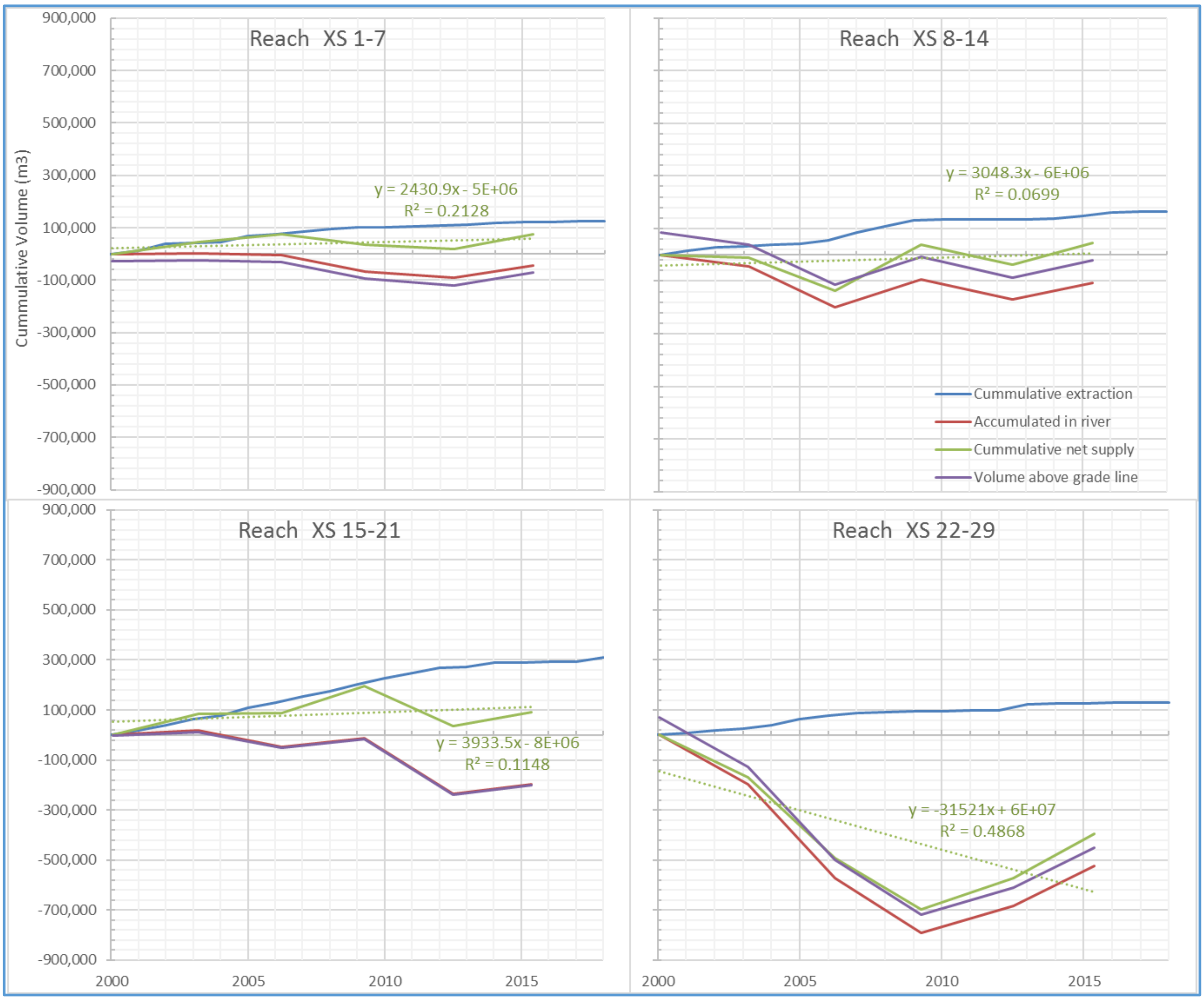


Figure 4-21: Lower Tukituki cumulative volume analysis for different river reaches

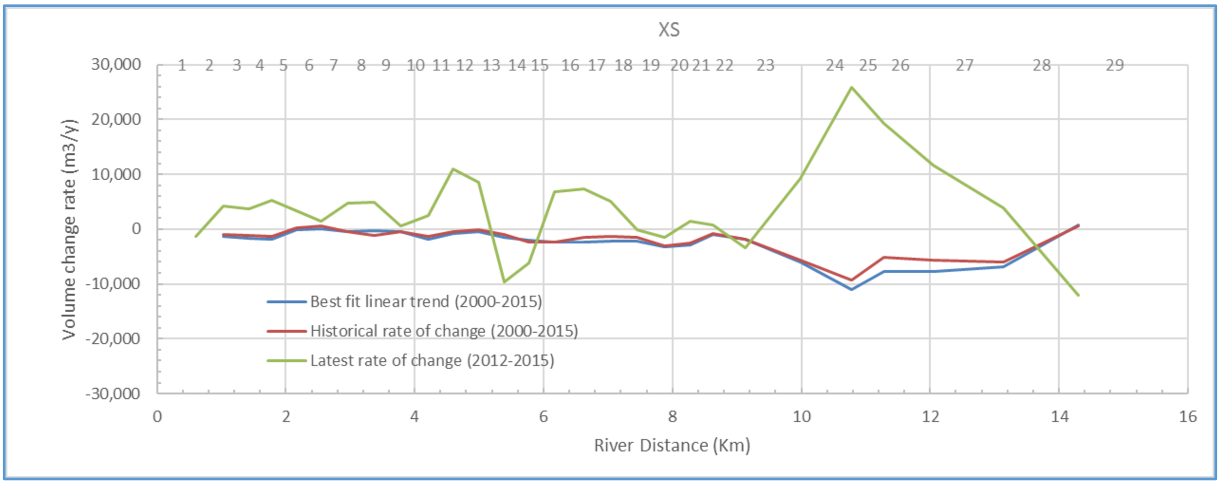


Figure 4-22: Volume change rates and trends along the Lower Tukituki River.

4.3.4 Net-supply rates

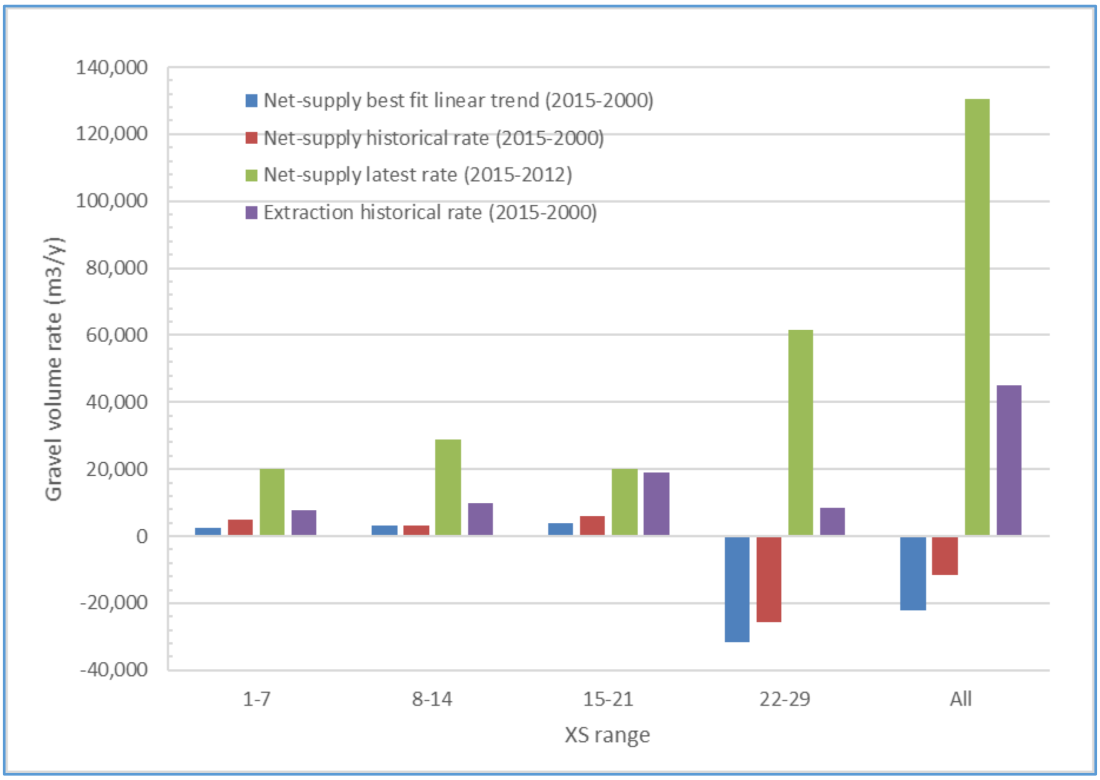


Figure 4-23: Gravel net-supply and extraction rates for different reaches.

4.4 Discussion

The analysis based on cross section survey data shows a long-term decrease in mean bed levels and widths in the Lower Tukituki. However, the latest data shows that these trends are being reversed. The relative maximum depth has been increasing in the long and short term. Future surveys will confirm if the latest trend changes will continue in the long term and this should be the case with no extraction currently allocated.

Mean bed levels are overall below the grade line level. Although, the latest survey showed a change in the historical decreasing trends due to the decrease in gravel extraction experienced since 2006. Mean bed levels upstream XS 14 are recovering but relatively slowly.

The river width has been relatively stable in the downstream half (below XS 12) and has shown more variability in the upstream part from XS 13 to XS 16 and from XS 21 to 29. The long-term trends reveal a narrowing of the river, but data after 2010 shows the contrary, with the most significant changes occurring upstream of XS 20.

The relative maximum depth (RMD) shows large variability between surveys and along the river. The RMD trend analysis indicates a relatively steady increase of nearly 5 mm/y.

There is presently very little gravel available for extraction. However, in most parts of the river, mean bed levels are increasing but are still below the grade line. Long-term net-supply rates are low or negative while the latest rates are positive and significantly higher.

The most important gravel deficit is in the reach between XS 15 and 21 where the most significant gravel extraction has occurred. Although, the reach upstream XS 22 shows the greatest latest net-supply rates.

The next survey is due in 2018 and it will provide updated information about changes to the gravel supply resulting from the events in July and September 2018 that exceeded the 2 year return period.

Balance between gravel removal in the upper / middle reaches and the lower reach.

There is a surplus of gravel in the upper reaches that is causing flood risk and drainage issues for some of the Upper Tukituki Scheme landowners. In the HBRC report *"Middle Tukituki River Scheme Works Proposal, June 1991, TS 91-6"* over the decade 1980 to 1990 there was a net aggradation of 22,000 m3/km or just over 1 million m3 over the middle Tukituki reach. No further assessment has been made in the intervening years, and anecdotally it could be assumed that there are significant volumes that are not moving through the system at any significant rate due to a dearth of significant floods. There is supply available to re-stock the lower reaches, it is just not being transported.

For gravel extraction purposes replenishment is not a concern in the Lower Tukituki because extraction is managed around the design grade line and extraction ceases once there is no surplus. Currently there is no extraction from the Lower Tukituki and for the short term extraction will only be where necessary to help protect or maintain the active edge if this is threatened. Raking of the gravel beaches to break up the armour layers and encourage gravel transport will continue, despite ceasing extraction.

Sediment supply rates to the coast are not yet fully understood, and neither is the way in which sediment delivery contributes to the development of the coastal barrier. These matters require further study which HBRC is committed to do, within financial constraints that might be imposed by the Council. Part of this knowledge gap is being addressed through on-going morphological modelling of the Tukituki River.

Due to concerns around delivery of sediment to the coast, any proposed extraction activities should be directed towards making the coastal situation no worse than present. Potentially, with the current 'no extraction and continued beach' raking situation the delivery to the coast could potentially improve.

5 Ngaruroro River

5.1 Background

The Ngaruroro River has 46 Km of stopbanks protecting farmland and settlements between Napier and Hastings. Willow edge protection has been applied along the berms to stabilize the active channel width. Gravel extraction and river raking have been regularly applied along the reach to maintain the active channel near the design parameters. (Refer Figure 5-1).

Cross section data has been systematically measured in 45 cross sections (XS 13 to XS 55) along the river since 1990, with non-systematic records dating from 1941 (Figure 5-2). The analysis in this chapter includes survey data from 2000 onwards.

Gravel extraction has been progressively increasing in time with a major peak between 1985 and 1991 (Figure 5-3). The Ngaruroro River is currently the most important gravel resource in the region with a present production rate of 360,000 m^3/y. There is a significant amount of gravel above the design grade line and recent estimates indicate that the present allocation rates could be maintained for the next 14 years if the historical supply rates are maintained (EMS, 2016; Beya & Byrne, 2018).

The location of the extraction has changed in time. In earlier periods, extraction from XS 13 was intense and recently it has decreased significantly while it has intensified upstream around XS 45 (Figure 5-4).

As explained earlier in section 2.6.1, gravel in the Ngaruroro River does not reach the coast after the major landscape changes caused by the 1931 earthquake and the following man-made modifications that diverted the Ngaruroro by an artificial straight channel joining the Tutaekuri at the mouth (Williams, 1985). The gravel front is currently at XS 13 and in a slow process of moving towards the coast. Today only fine sand and cohesive sediments are able to reach the sea (Measures, 2012).

Smaller floods can move significant amounts of gravel due to their greater frequency of occurrence. Significant floods larger than the 2 year return event have occurred regularly in the river. However, there has been a high variability in the frequency of these type of events with prolonged periods with small or nil number of floods (e.g. period from 1999 to 2005) followed by 12 events occurred since then (Figure 5-5).

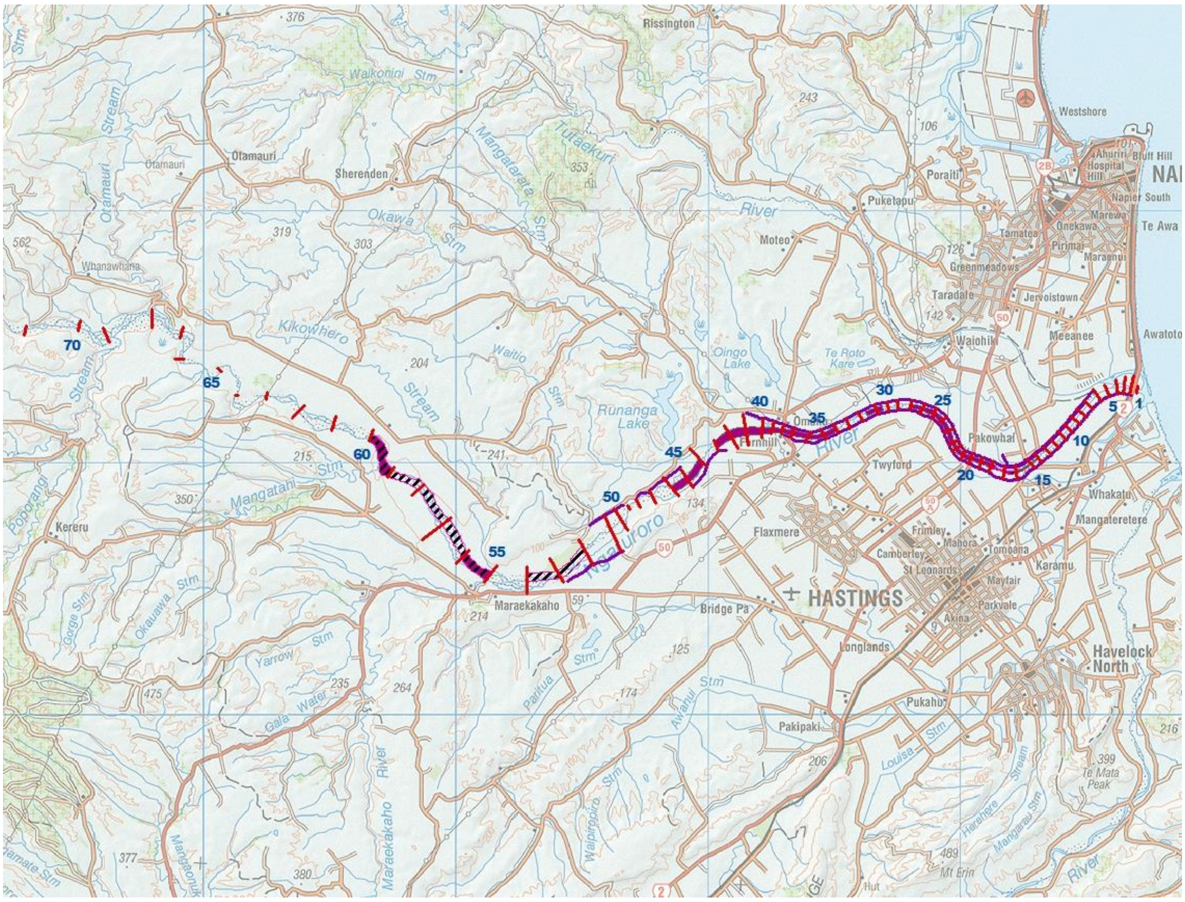


Figure 5-1: Location of the Ngaruroro River and an indication of cross sections, stopbanks, raking and gravel extraction. Blue numbers indicate XS numbers.

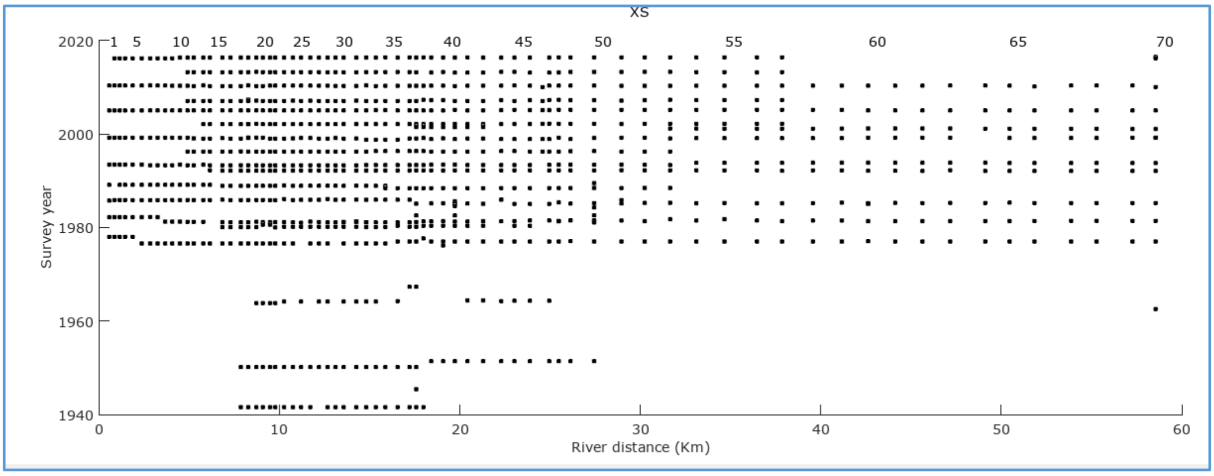


Figure 5-2: Cross section data availability for the Ngaruroro River. Each black dot represent a cross section survey.

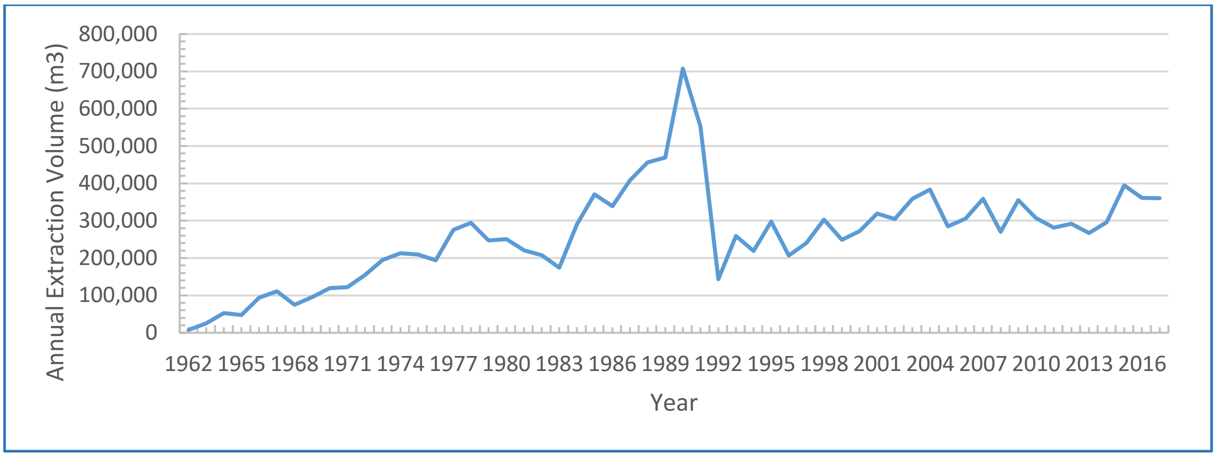


Figure 5-3: Time series of total gravel extraction volumes in the Ngaruroro River.

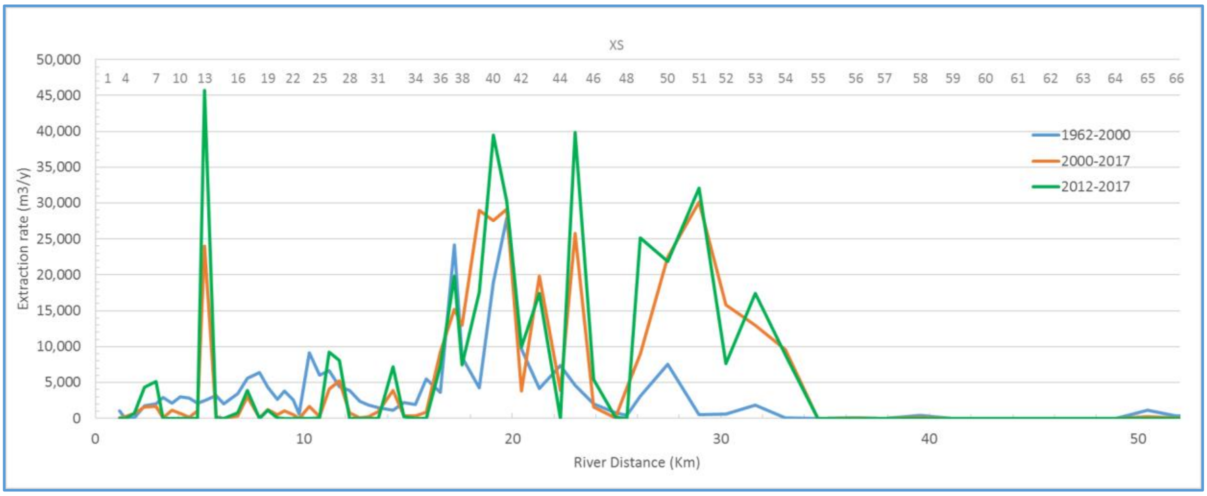


Figure 5-4: Sediment extraction rates in the Ngaruroro River for three different periods. Note that only silt extraction occurs downstream of XS 12 as there is no gravel in that reach.

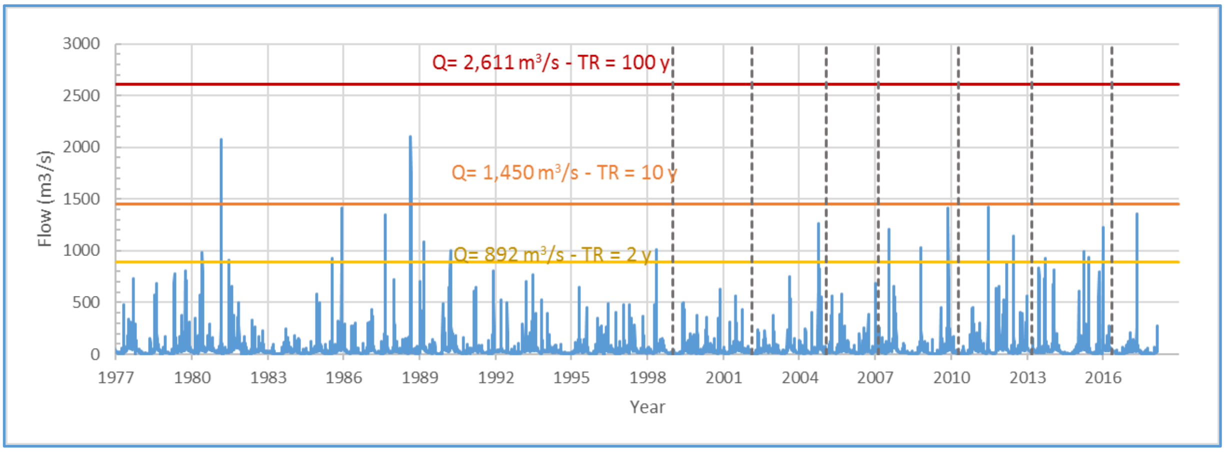


Figure 5-5: Ngaruroro River flows at Chesterhope. Return values from calculated from peaks over a threshold of 750 m³/s and a GEV best-fit analysis. Data is from 1977 to 2018 and therefore does not include historical data from the full series. Return periods shown are those that apply to this limited data set and should not be used for design purposes. Vertical grey dashed lines indicate average survey dates.

5.2 Observed Morphological Changes

5.2.1 Summary

Table 5-1: Average historical and latest rates of change of morphological parameters in the Ngaruroro River. The period of analysis is indicated in brackets. The parameters definition is outlined in section 3.

Symbol	**Parameter name**	**Historical best fit trend (2000-2015)**	**Average of historical rate of change (2000-2015)**	**Average of Latest rate of change (2012-2015)**	**Units**
MBL	Mean bed level (-ve below grade line)	-0.0083	-0.0094	0.0017	m/y
S_{MBL}	Mean bed level slope	-2.3x10^{-4}	-2.7x10^{-4}	-6.7x10^{-4}	%/y
$AChW$	Active channel width	0.16	0.22	1.01	m/y
RMD	Relative maximum depth (+ve deepening)	0.023	0.013	-0.026	m/y

5.2.2 Active channel mean bed level

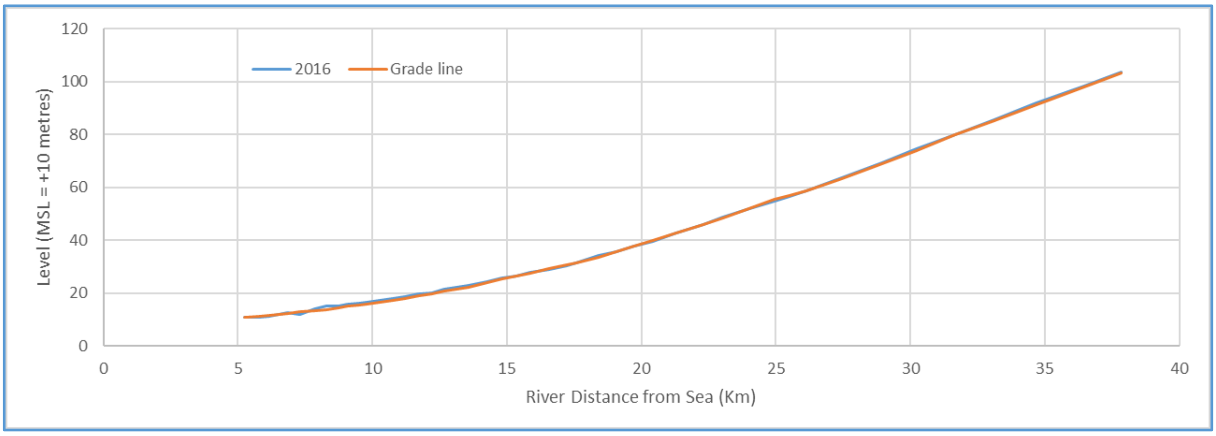


Figure 5-6: Mean bed level and design grade line for the Ngaruroro River.

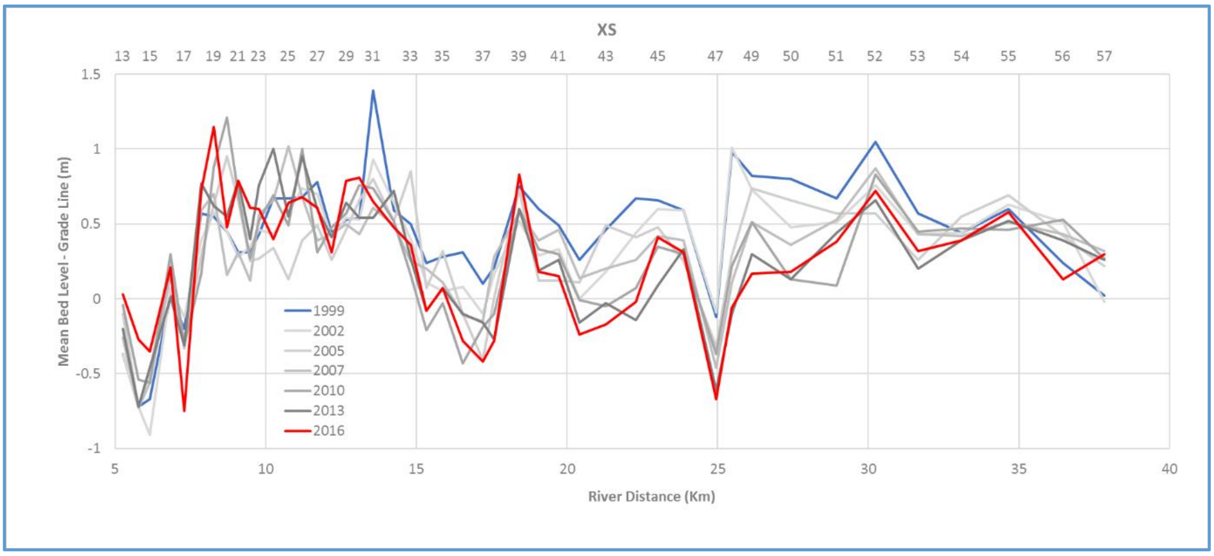


Figure 5-7: Change in time of the mean bed level relative to the grade line level along the Ngaruroro River.

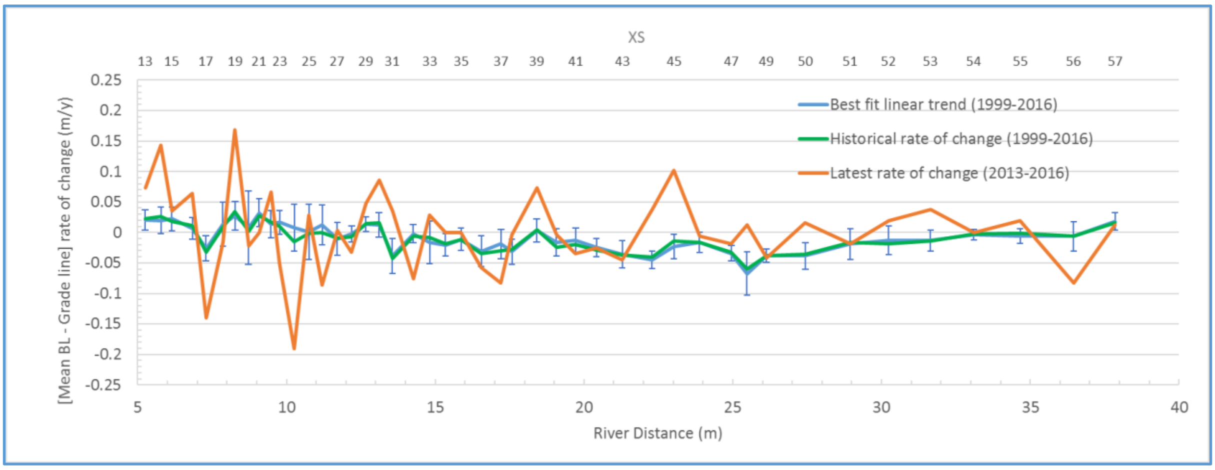


Figure 5-8: Rate of change of the mean bed level relative to the grade level along the Ngaruroro River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

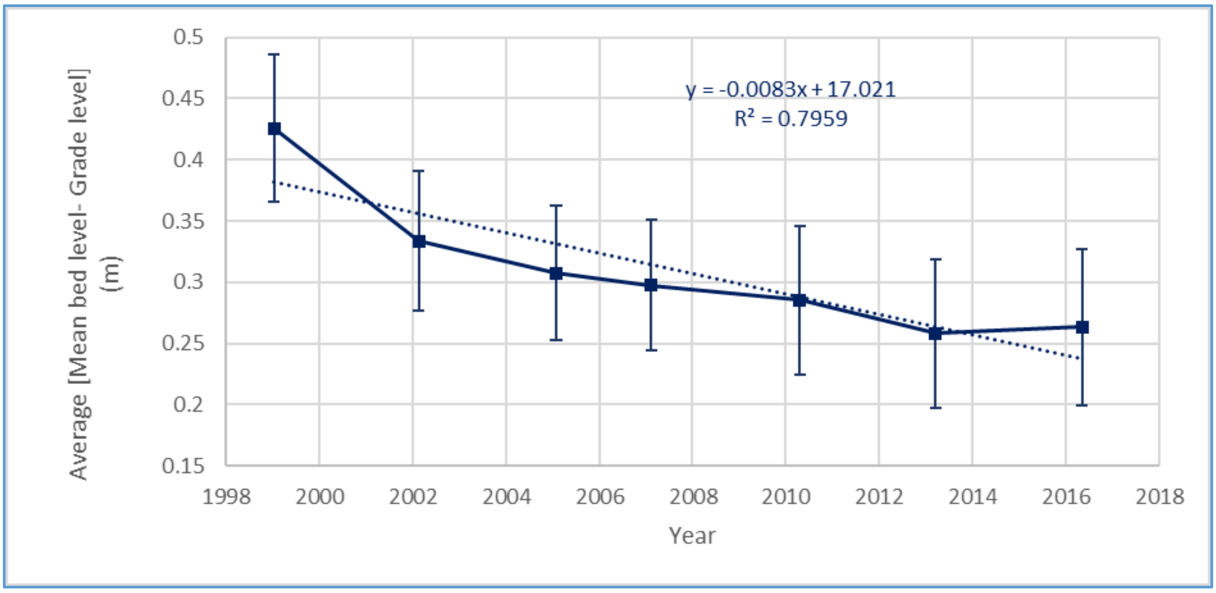


Figure 5-9: Change in time of the average mean bed level relative to the grade level along the Ngaruroro River. Error bars indicate the standard error of the mean.

5.2.3 Mean bed level slope

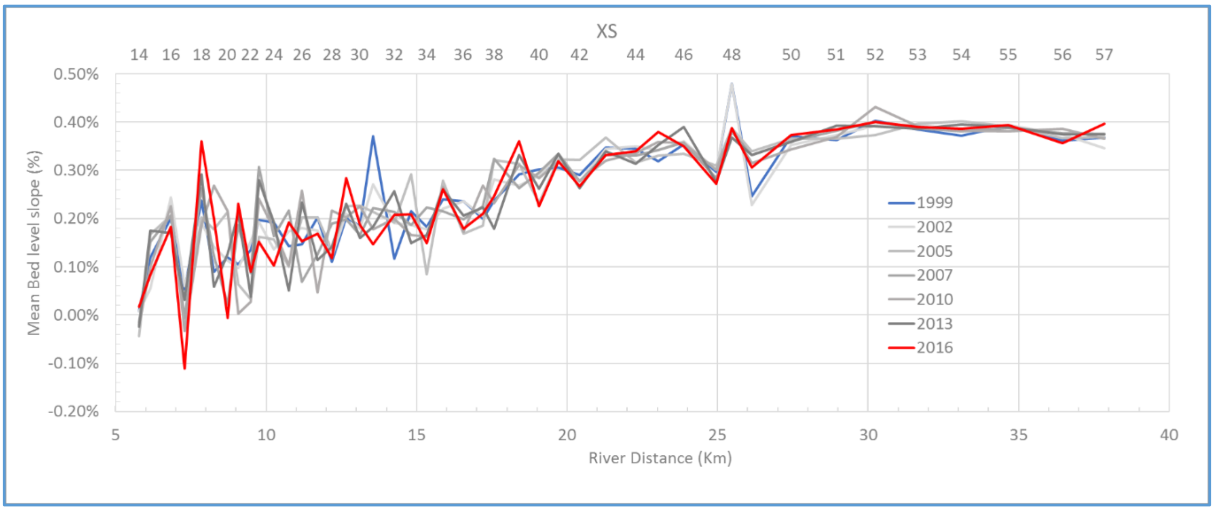


Figure 5-10: Change in time of the mean bed level slope along the Ngaruroro River.

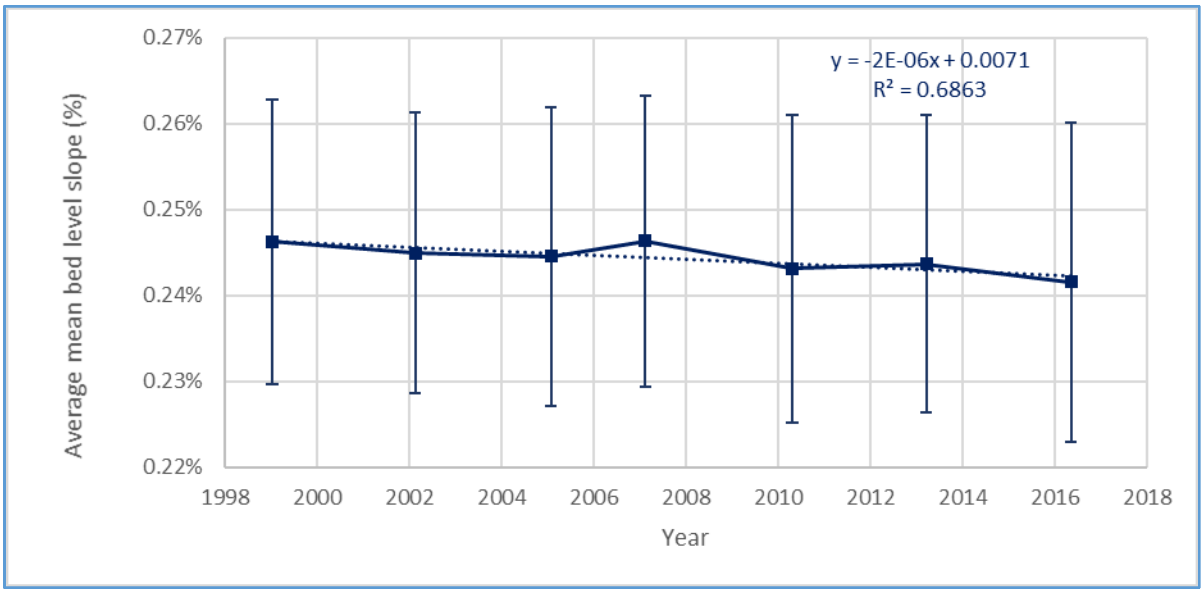


Figure 5-11: Change in time of the average mean bed level slope along the Ngaruroro River. Error bars indicate the standard error of the mean.

5.2.4 Active channel width

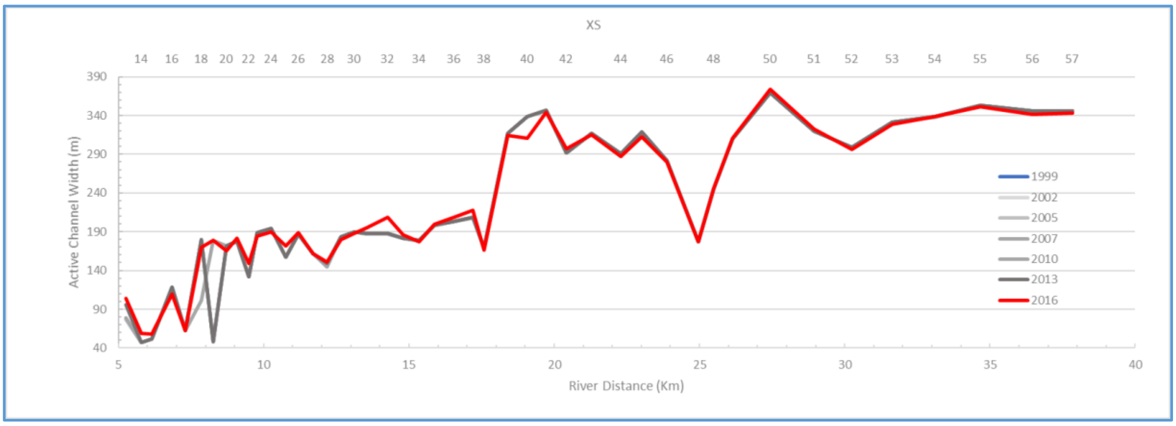


Figure 5-12: Change in time of the active channel width along the Ngaruroro River. (Note there appears to be some isolated errors in the data (XS18 for example) which have not been able to be verified).

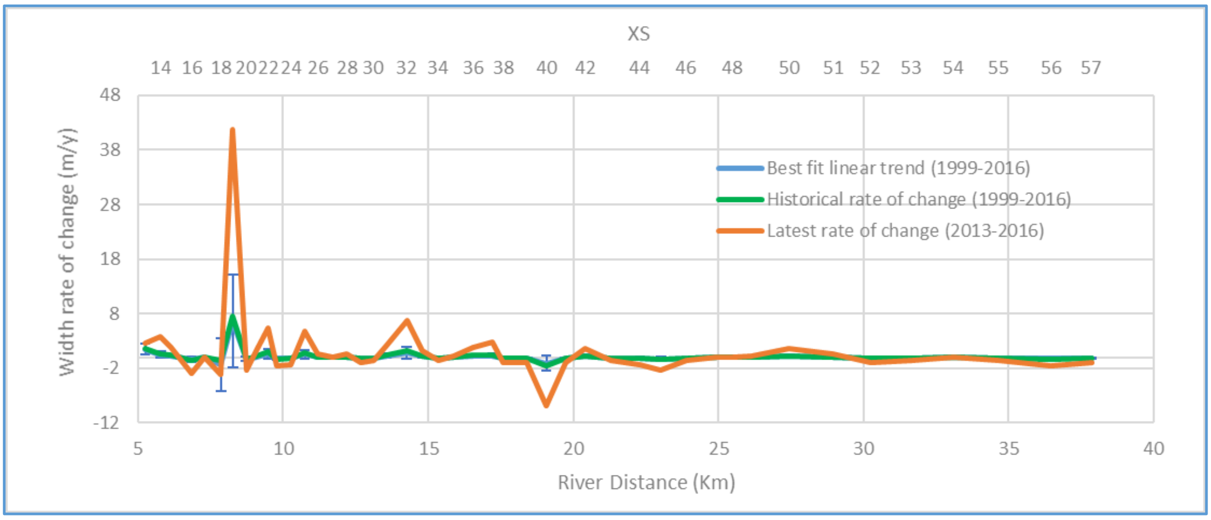


Figure 5-13: Rate of change of the active channel width along the Ngaruroro River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

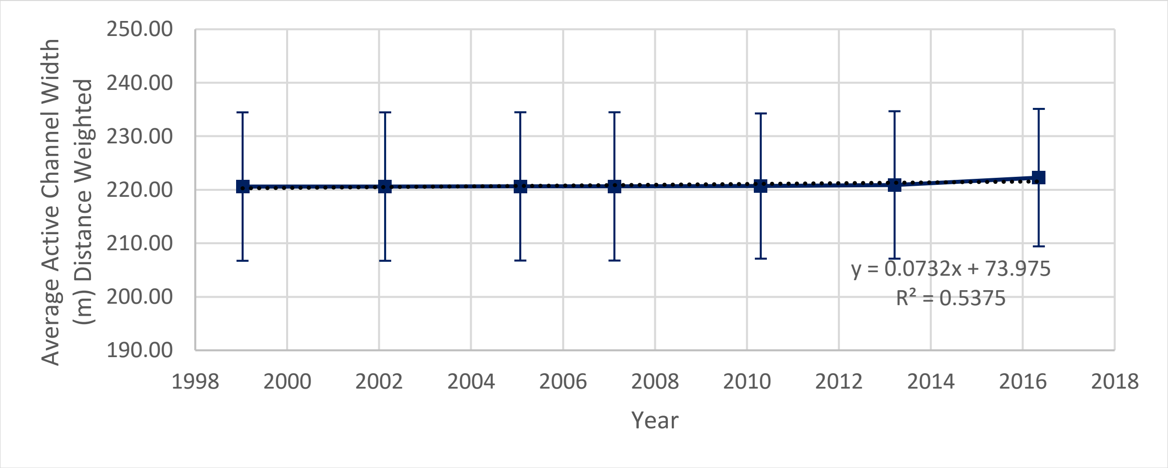


Figure 5-14: Change in time of the average active channel width along the Ngaruroro River weighted by reach length. Error bars indicate the standard error of the mean cross section widths.

5.2.5 Relative maximum depth

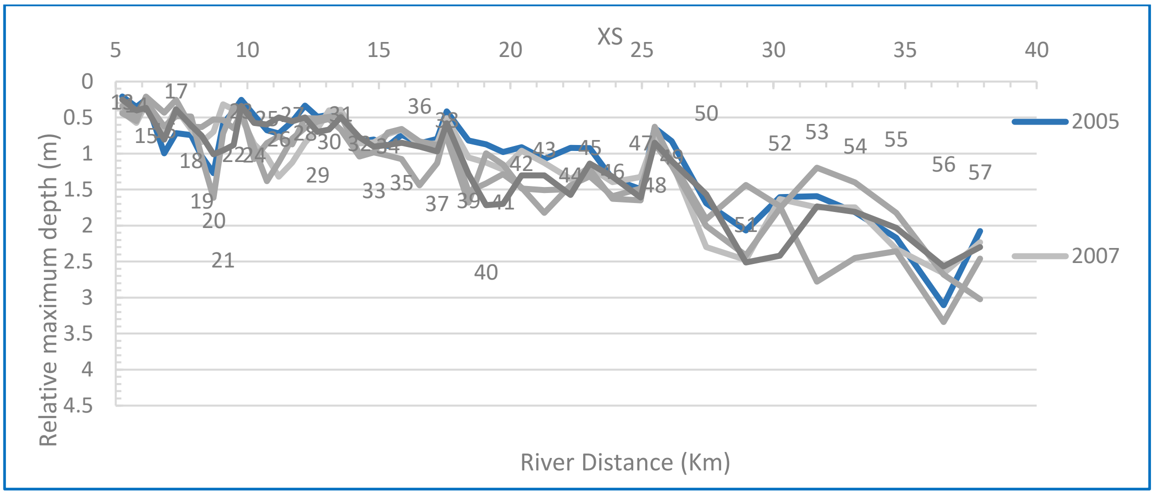


Figure 5-15: Change in time of the Relative Maximum Depth (Mean Bed Level – Min Bed Level) along the Ngaruroro River. Note that the vertical axis is reversed for a more intuitive visualization of (water) depth.

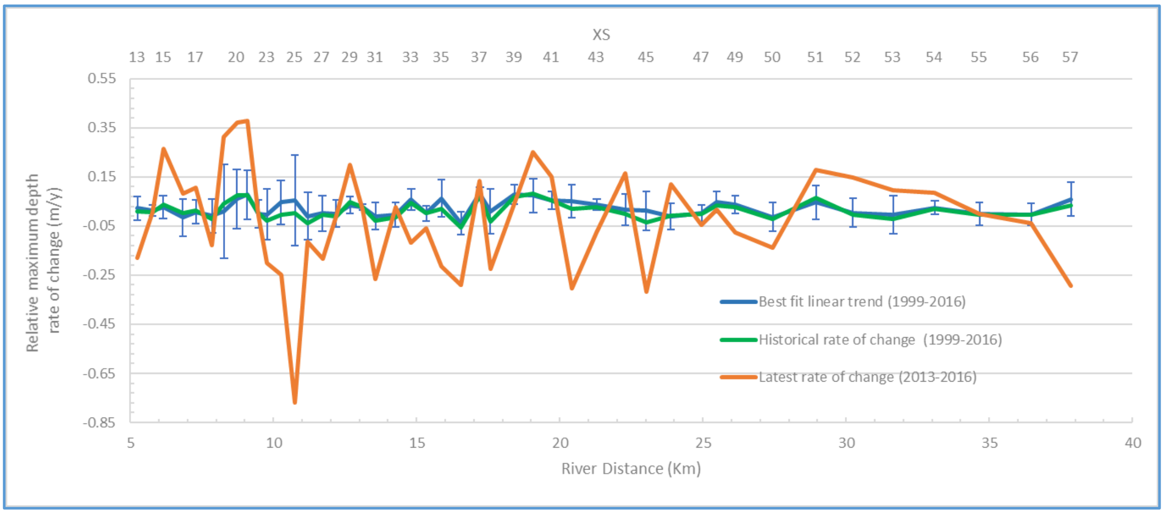


Figure 5-16: Relative Maximum Depth (Mean Bed Level – Min Bed Level) rate of change along the Ngaruroro River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

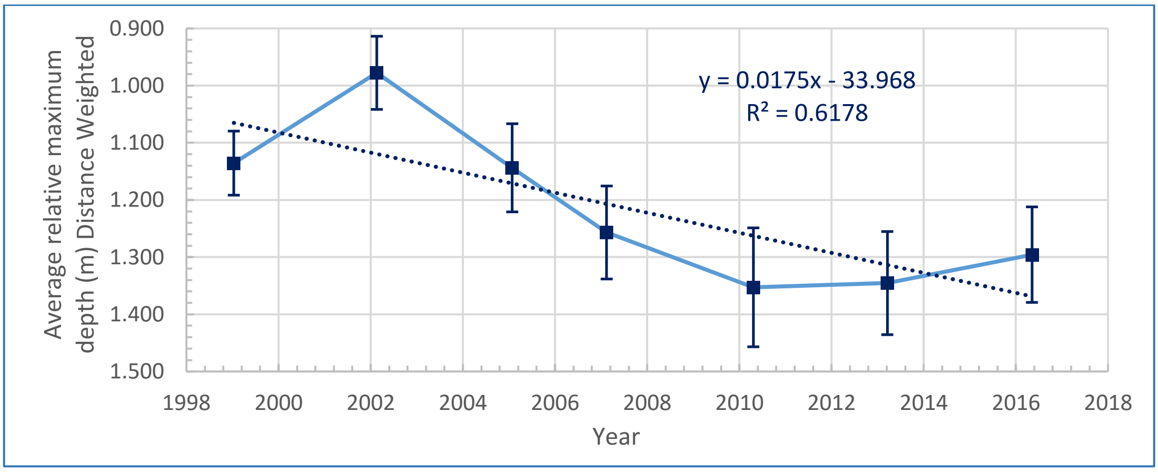


Figure 5-17: Change in time of the average the Relative Maximum Depth (Mean Bed Level – Min Bed Level) distance weighted along the Lower Tukituki River. Error bars indicate the standard error of the mean at the cross section. Note that the vertical axis is reversed for a more intuitive visualization of (water) depth.

5.3 Gravel Availability

5.3.1 Present

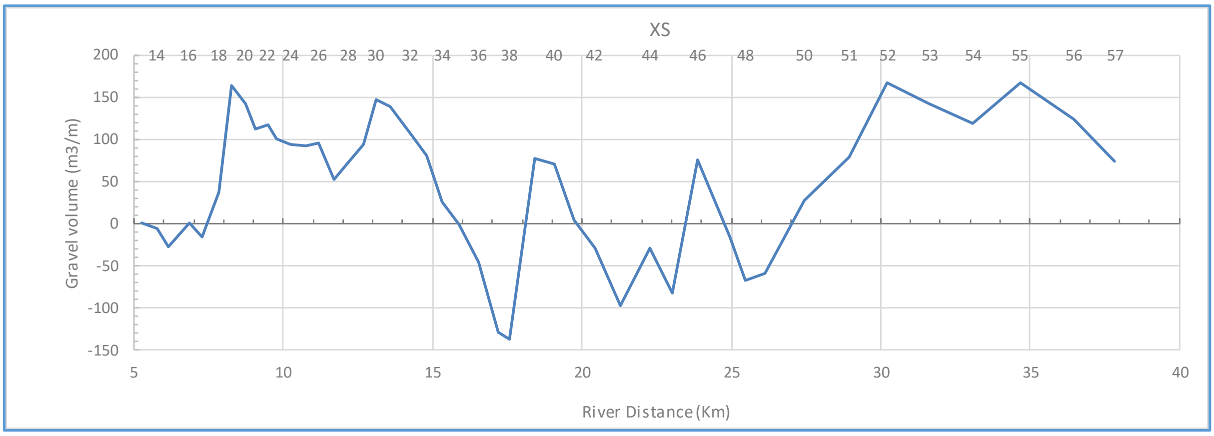


Figure 5-18: Estimated gravel availability for 2018 in the Ngaruroro River.

5.3.2 Historical change

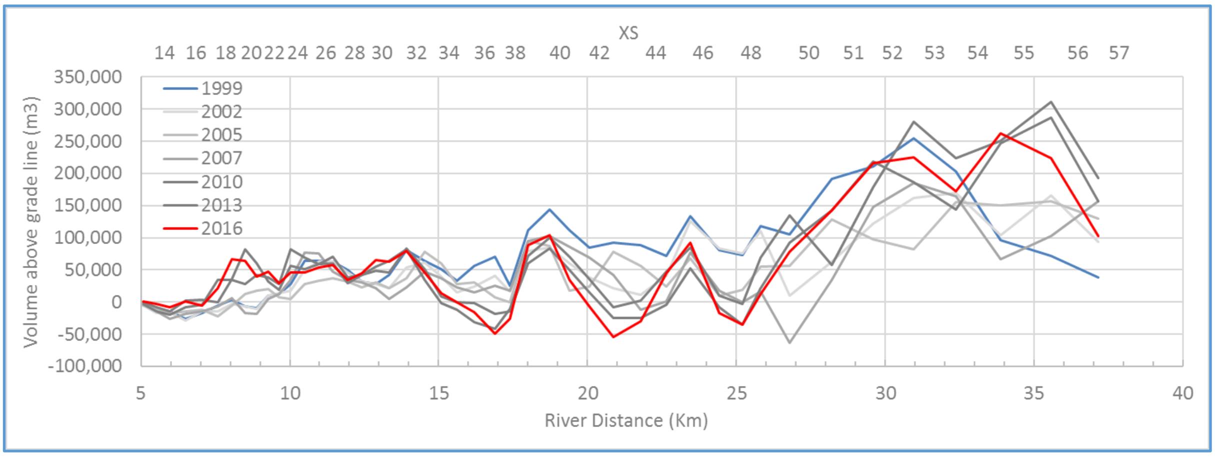


Figure 5-19: Historical change in measured gravel availability in the Ngaruroro River

5.3.3 Cumulative volume analysis

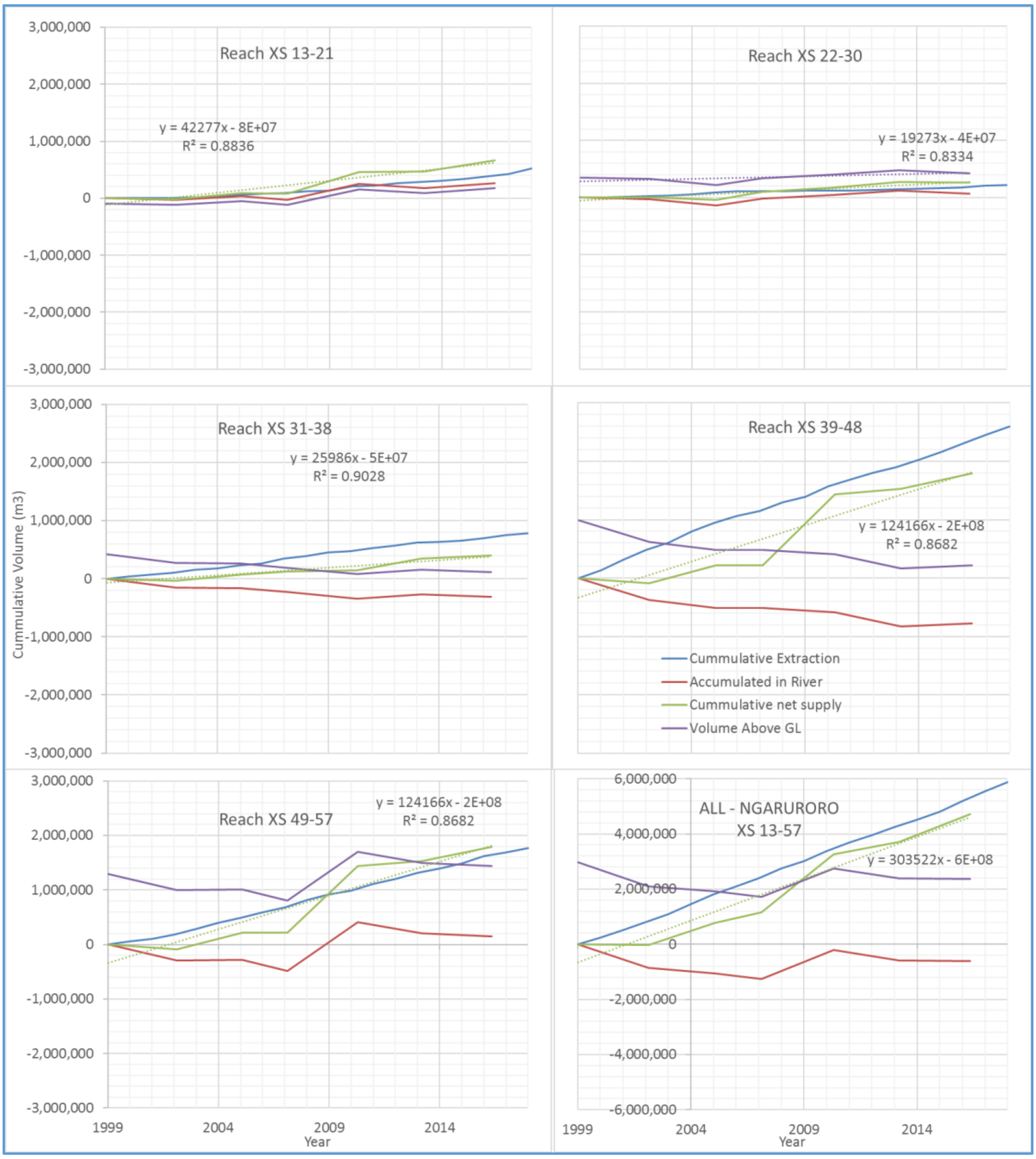


Figure 5-20: Cumulative volume analysis for the entire Ngaruroro River

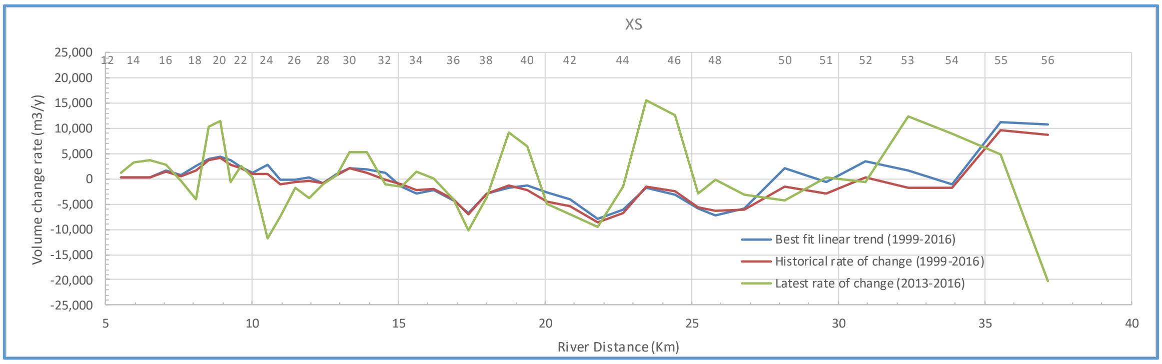


Figure 5-21: Volume rates of change and trends along the Ngaruroro River

5.3.4 Net-supply rates

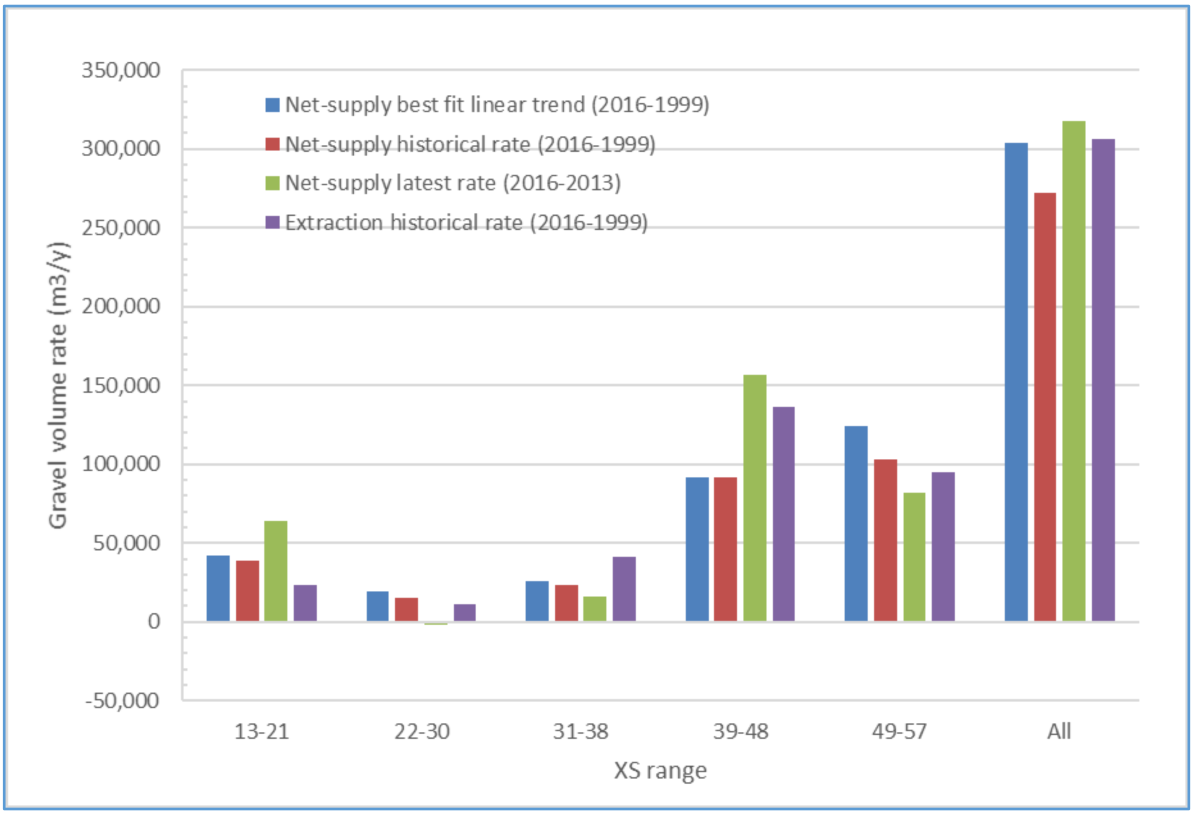


Figure 5-22: Gravel volumes net-supply long term and latest rates and best-fit trend and historical extraction rate in the Ngaruroro River.

5.4 Discussion

Generally speaking, the grade line is below the present mean bed level (*MBL)* with a maximum difference of 1.15 m and an average difference of 0.26 m. Historical overall *MBL* rates of change are negative (-8 mm/y and -9 mm/y) meaning a steady lowering of the bed towards the grade line, and the latest rate is positive (2 mm/y). The *MBL's* have been relatively maintained from XS 29 downstream. Upstream of XS 29 there is some evidence of progressive degradation, possibly explained due to the increased extraction rates in that reach. Historical *MBL* rates of change are negative throughout the river with the lowest values reaching 60 mm/y in XS 48. The latest rates show high variability and slightly higher values especially from XS 43 to 55.

Historical and latest rates of change in the mean bed level slopes are negative. The latest surveys show a faster decrease in slopes. Along the reach, slopes appear to be more or less stable in time but showing high variability.

Active channel widths (*AChW*) are increasing and the latest rate of change is significantly higher (1.01 m/y) compared to the historical rate (0.22 mm/y). Nevertheless, these changes are a small fraction of the width (less than 1%) and are within the detection error of the measurement. XS 18 shows the greatest changes but this could be data error in the set (refer Figure 5-12). Future work should review the historical estimates of MBL and widths.

The relative maximum depth *(RMD)* historical rates of change show an increase (0.013 m/y) but latest rate shows a decrease of a similar magnitude (-0.026 m/y).

There is presently substantial gravel resources available from XS 18 to XS 34 and 50 to 57. The cumulative analysis show net positive gravel supply to the reaches that are close to the current extraction volumes. The reach from XS 39 to XS 48 shows the highest extraction but also the highest net-gravel supply. The reaches from XS 31 to XS 38 and from XS 39 to XS 48 show a progressive depletion of the gravel resource. Overall, historical extraction and net-supply seem to be in balance.

5.5 Ngaruroro Morphological Report (refer Section 14 References)

The following section contains the executive summary of the Ngaruroro River Morphological Modelling taken directly from the report to provide the reader with a summary of the procedure and essential results.

Executive summary

A calibrated one-dimensional morphological model of the Ngaruroro River was constructed to simulate gravel transport and bed level change. The modelling had two main aims:
a) Inform better understanding of the gravel transport processes on the river and investigate the impact of different drivers including gravel extraction, beach raking, changes in supply and climate change.

b) Pilot the application of calibrated morphological models for informing gravel management in the Hawkes Bay Region. The process developed for modelling the Ngaruroro River should be applicable to other rivers in the region including the Tukituki River which is significantly more complex.

Surveyed cross-section data and sampled grain size data were used to construct the model which was then hydraulically calibrated against observed levels for two flood events. After hydraulic calibration, the model was run for the period 1977-2012, using flow and tide data for that period and incorporating the gravel extraction and beach raking which occurred during those years. The sediment transport rate, bed surface composition and bed level changes were calibrated against previous estimates of average annual transport rate, sampled bed surface composition and surveyed bed level changes. The calibration adjustments involved altering the supply rate and grading of the gravel feed. No adjustments were made to the transport equations. After an initial period of “bedding-in” the model replicated observed bed level change and surface composition and the pattern of transport rate along the length of the river reasonably well. The model values of average annual transport rate were approximately 30-40% lower than estimates derived from previous gravel balance analyses.

This calibration result demonstrates that the model results can be applied with a reasonable degree of confidence.
Once calibrated, various scenarios were simulated in order to investigate the response of the river to different drivers. Key results of the scenario modelling are:

1. Gravel transport in the Ngaruroro is highly variable year to year (varying from one third to three times the average annual load in any given year).

2. There is significantly more inter-annual variability in the amount of gravel transported past Ohiti than past Fernhill.
3. Natural aggradation is occurring from Ohiti down to the limit of the gravel. The fastest aggradation is occurring around Fernhill and averages more than 30 mm/year.
4. The model shows some gravel does propagate downstream of the current limit of gravel on the bed but this is very variable over time and none propagates closer than 1.9 km from the sea.
5. If no extraction had taken place since 1977, bed levels would be one to two meters higher than they are now from Maraekakaho to Chesterhope.
6. Historic gravel extraction has not affected the total gravel supply rate into the extraction reaches.
7. Gravel extraction does reduce the propagation of gravel into the coastal reach. However, even with no extraction, no gravel propagates closer than 1.8 km from the sea.
8. Individual extractions influence bed levels within approximately 5 km upstream and downstream of the limits of the extraction.
9. It is possible to control aggradation between Maraekakaho and Ohiti with extraction downstream of Ohiti, but it is not possible to control aggradation downstream of Ohiti by upstream extraction.
10. Beach raking does significantly increase gravel mobility.
11. A 5% reduction in flow, as expected with future climate change, causes a 6-10% reduction in gravel supply into the extraction reaches.
12. A 0.8 m sea level rise causes aggradation of bed levels up to 15 km from the coast and reduction in sand delivery to the coast.

Morphological modelling generally has a high amount of uncertainty associated with it, but through careful use of historic data to calibrate/validate the model this study demonstrates the confidence that can be placed in the model results. Overall the morphological modelling has performed well, replicating historic river conditions and providing insight into the gravel transport processes in the Ngaruroro River. It is concluded that one-dimensional morphological modelling is a suitable tool for informing gravel management decisions on the rivers in Hawkes Bay Region.

5.6 Impacts on Reach Sediment Storage

Model results indicate that the extraction from the Ngaruroro River has little impact on bedload transport rates, although there is a question that arises around the impacts on reach sediment storage and active alluvial width, and thus habitat and the longer-term trajectory of the river.

The extraction reach of the Ngaruroro River is a heavily modified reach and extraction activities do affect both the storage and active alluvial width. Figure 5-12, Figure 5-13and Figure 5-14 show the results of the change in active channel widths over time. There are no apparent impacts based on this work, however if there are others that we have not studied for this application then they could be included as part of future studies. Recently completed Ecological Management and Enhancement Plans for the major rivers are considered to thoroughly address the ecological issues. (Reference: Tukituki Catchment Rivers, Ecological

Management and Enhancement Plan, May 2017 AM 17-05; Tutaekuri River Ecological Management and Enhancement Plan, June 2015 AM 15-13; Ngaruroro River Ecological Management and Enhancement Plan, May 2017 AM 17-06.)

5.7 Gravel deficit

It is noted that the ‘extraction’ reaches (sections 36-51) Figure 5-18 show a gravel volume deficit at 13 of 16 sections, raising the question: why do extraction works continue here as this seems to violate conditions for sustainability?
Although the observation of a gravel deficit in the selected reach is correct it is not correct to assume that extraction is allowed to continue in this reach, the situation changes from year to year. For example there were 13 sections in deficit for 2015, in 2017 the deficit locations over the same reach numbered eight. Extraction is not permitted in areas where the cross section location shows a deficit. Occasionally areas between cross sections that are not reflected in the normal volume estimates are extracted, but these are first subject to on-site verification (visual inspection and survey) that there is a surplus and that removal is necessary for river management.

5.8 When to cease extraction

Forecast demand continues at 250,000-300,000 m3·yr-1 based on extrapolation of Figure 5-3, and the question arises as to where is the ‘red line’ for ceasing operations?
In the annual allocation process operations cease at locations where survey indicates a deficit. In terms of longer term sustainable supply and allocation this is determined by gravel volume trends over the years of record. Current gravel balance cumulative volume plots indicate a supply volume to the reach of 320,000 m3/year (from 2013 to 2016 data) and an average of 273,000 m3/ (1999 to 2016). The extraction volume gradient for the corresponding periods is 323,000 m3/year and 315,000 m3/year. Overall, historical extraction rates and net supply appear to be in balance. By managing the extraction there is no concern that this balance will not be achieved in future. The ‘red line’ referred to above is a limit on extraction not a point where extraction ceases. Extraction ceases when there is no surplus above the design grade line.

The Allocation Report outlines the approach for directing more extraction to the southern region, prior to any extraction from the Heretaunga Plains rivers. There is also scope to direct extraction further upstream (in the Ngaruroro River) beyond current extraction areas. Although modelling shows that the river above the current extraction reach (Maraekakaho) is approximately in equilibrium there is considerable volume above design grade in storage that could be extracted. For example in the three cross sections above the current limit reach of extraction there is an aggradation of 600,000 m3. Further upstream there is similar aggradation. There has been no need to consider these upstream reaches to date.

6 Esk River

6.1 Background

The Esk river reach analysed in this section covers from the, XS1 mouth downstream (Km 0) to XS 11 (Km 8.3). Large amounts of gravel were extracted in the 1970s which together with extensive river channel works (mainly clearing & widening) undertaken in the late 1980s led to significant channel degradation. Following this an ongoing edge protection planting programme started. The river has currently 1.7 Km of stopbanks protecting the Whirinaki Pan Pac Pulp Mill and surrounding area (Figure 6-1).

Cross section data has been from 18 cross sections spaced along the river since 2000. Although systematic records of fewer cross sections date from 1975 (Figure 6-2). The analysis in this chapter includes survey data from 1997 onwards.

Due to past over extraction (Figure 6-3, Figure 6-4), presently only minor extraction takes place at the Whirinaki pulp mill water intake (XS 5) with the exception of very small amounts taken further upstream.

Important flood events (above 10 y return period) have occurred in the river since the start of the record. An unrecorded event in 1938 was estimated to have peaked at 2,000 m^3/s (Williams, 1986). There has been a high variability in the frequency of events with prolonged periods with small or nil number of floods (e.g. from 1997 to 2008) and periods with large amount of significant flood events such as 1984 to 1988, 2009 to 2012 and the events of the present year (Figure 4-5).

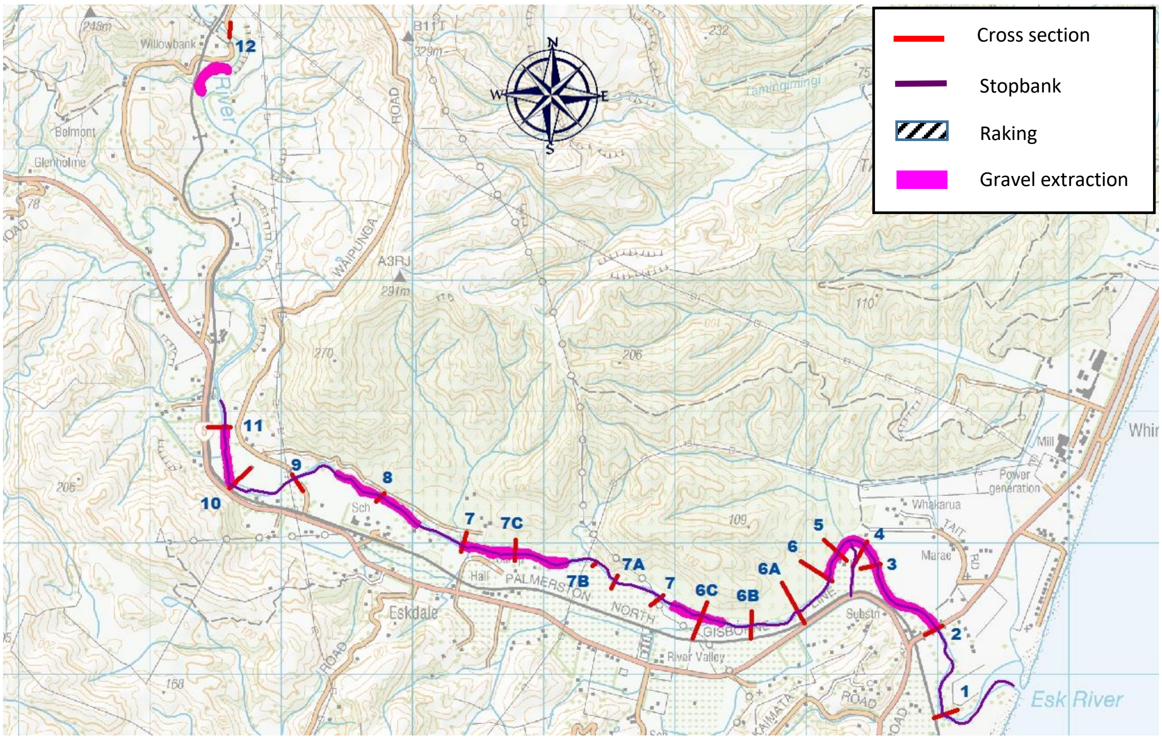


Figure 6-1: Location of the Esk River and an indication of cross sections, raking and gravel extraction. Blue numbers indicate XS numbers.

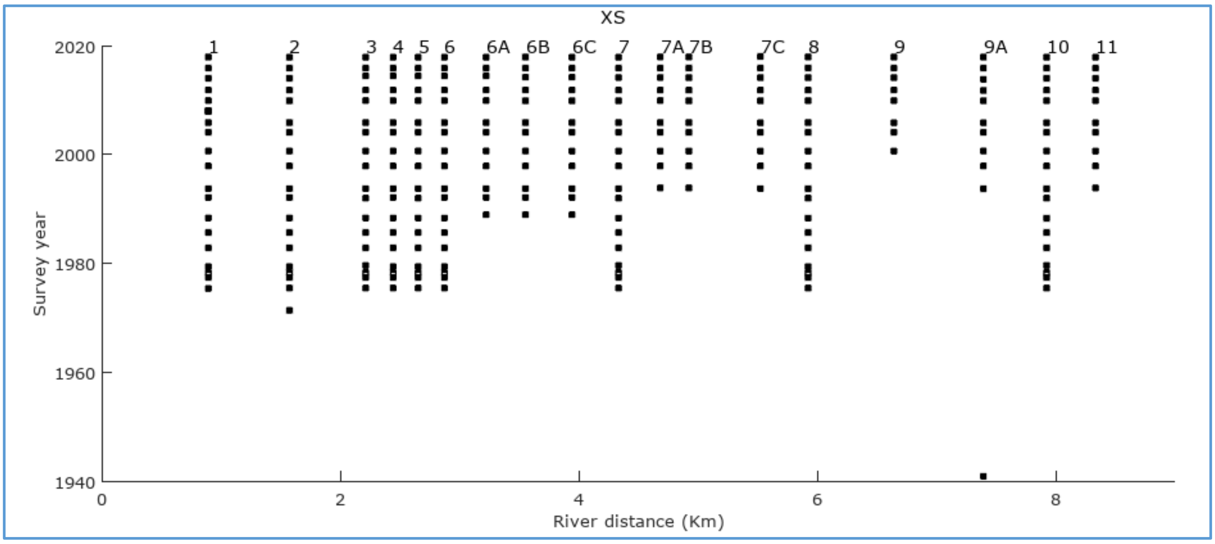


Figure 6-2: Cross section data availability for the Esk River. Each black dot represent a cross section survey.

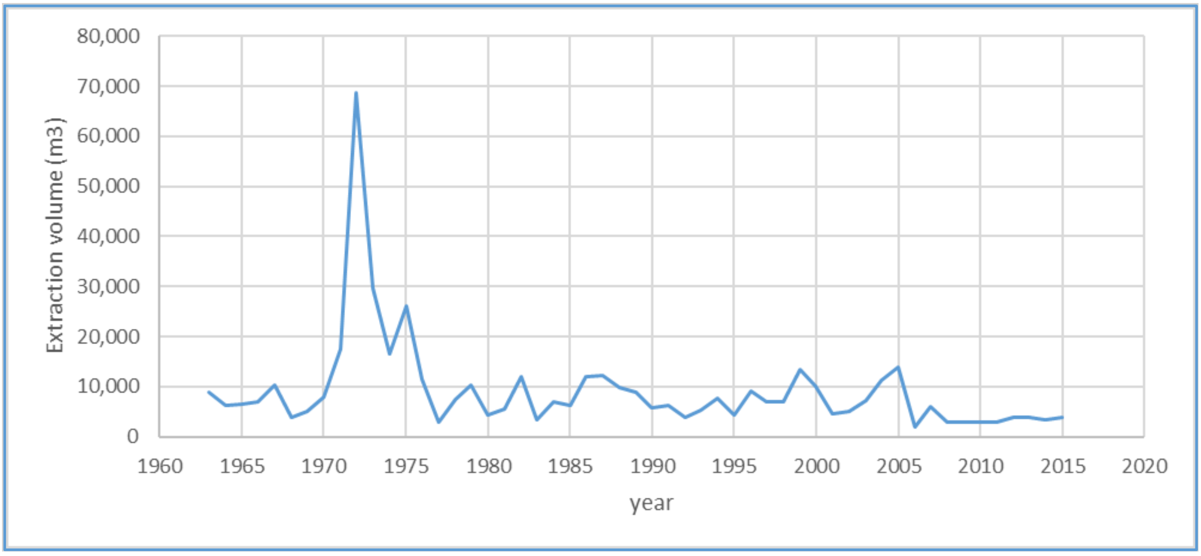


Figure 6-3: Time series of total gravel extraction volumes in the Esk River.

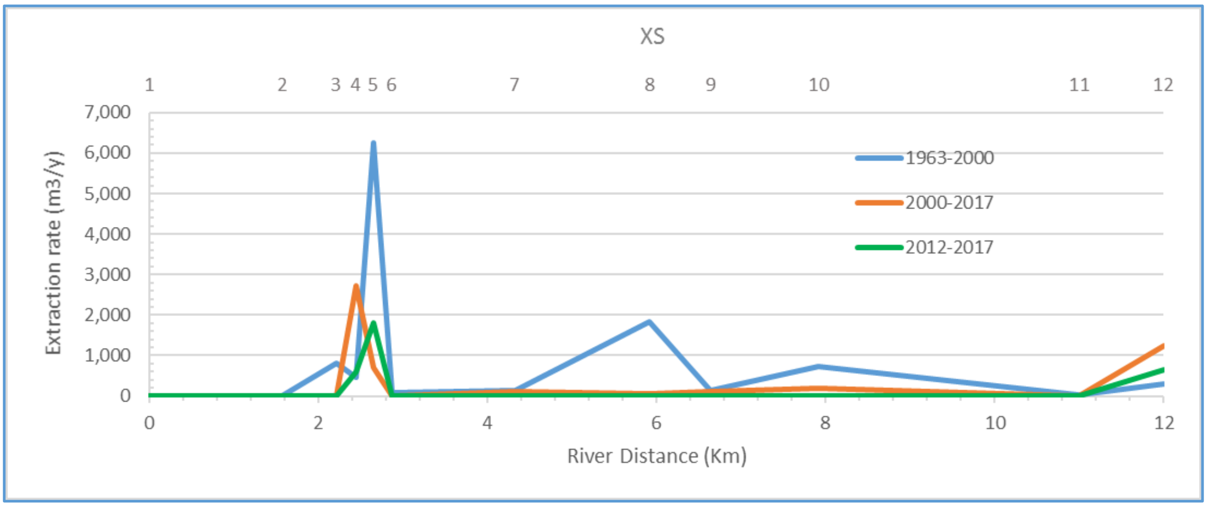


Figure 6-4: Average gravel extraction rates along the Esk River for three different periods.

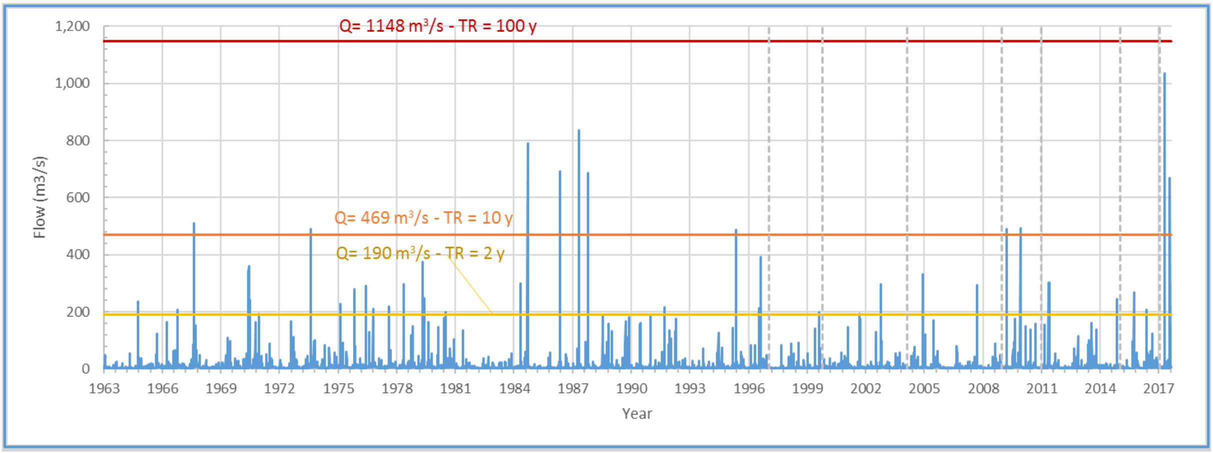


Figure 6-5: Esk River hourly flows at Waipunga Bridge. Return values from Carruth (2018). Vertical grey dashed lines indicate the survey dates used in the analysis in this section. Earlier dates have not been considered in the analysis.

6.2 Observed Morphological Changes

6.2.1 Summary

Table 6-1: Average historical and latest rates of change in morphological parameters. The period of analysis is indicated in brackets. The parameters definition is outlined in section 3.

Symbol	**Parameter**	**Historical best fit trend (1997-2017)**	**Average of historical rate of change (1997-2017)**	**Average of Latest rate of change (2015-2017)**	**Units**
MBL	Mean bed level (-ve below grade line)	-0.009	-0.015	-0.073	m/y
S_{MBL}	Mean bed level slope	$-4.6\text{x}10^{-4}$	$-4.0\text{x}10^{-4}$	$-2.8\ \text{x}10^{-4}$	%/y
$AChW$	Active channel width	-0.126	-0.119	0.310	m/y
RMD	Relative maximum depth (+ve deepening)	0.001	-0.001	-0.073	m/y

6.2.2 Active channel mean bed level

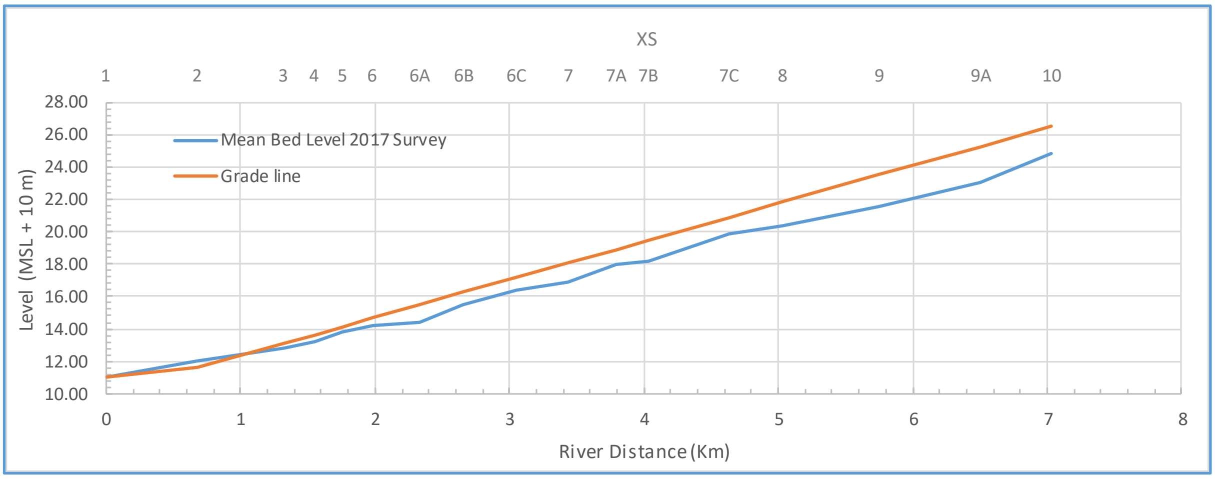


Figure 6-6: Mean bed level and design grade-line

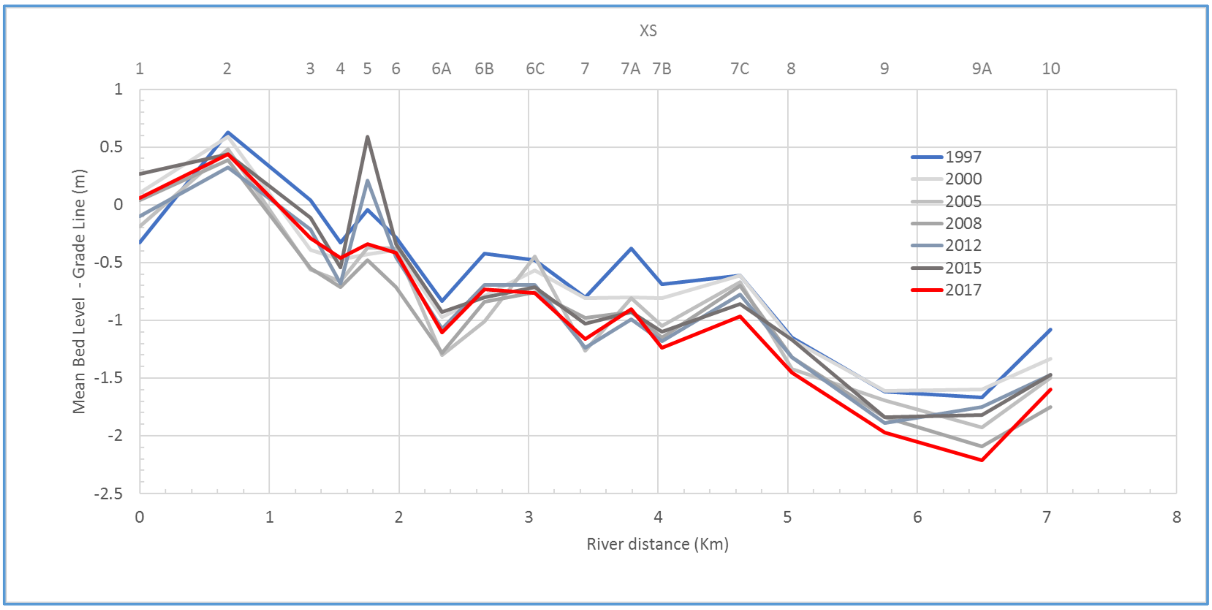


Figure 6-7: Change in time of the mean bed level relative to the grade line level along the Esk River.

Figure 6-8: Rate of change of the mean bed level relative to the grade level along the Esk River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

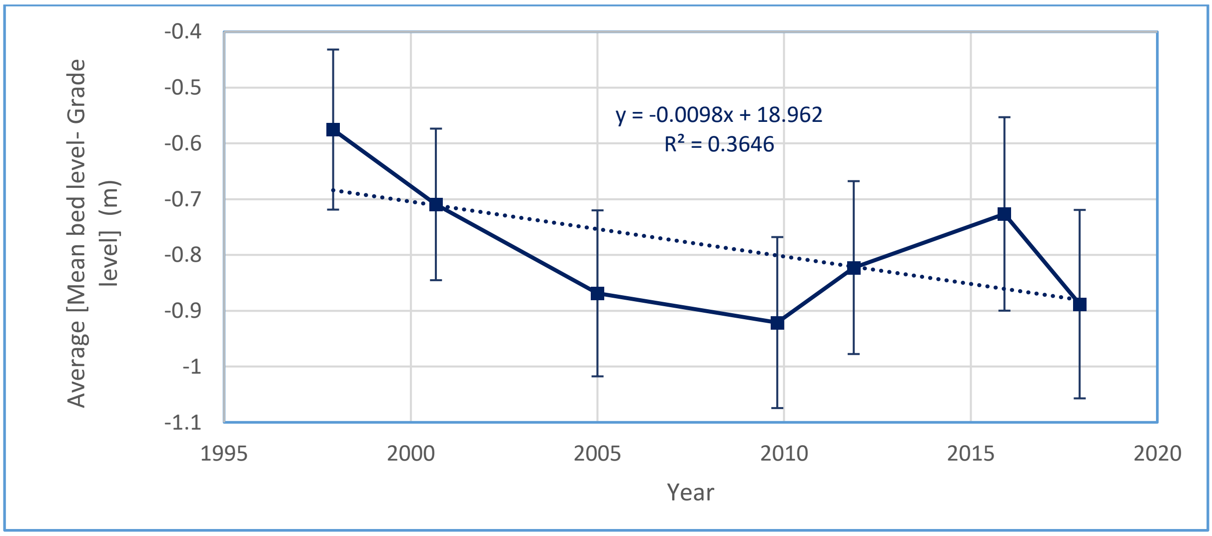


Figure 6-9: Change in time of the average mean bed level relative to the grade level along the Esk River. Error bars indicate the standard error of the mean.

6.2.3 Active channel mean bed level slope

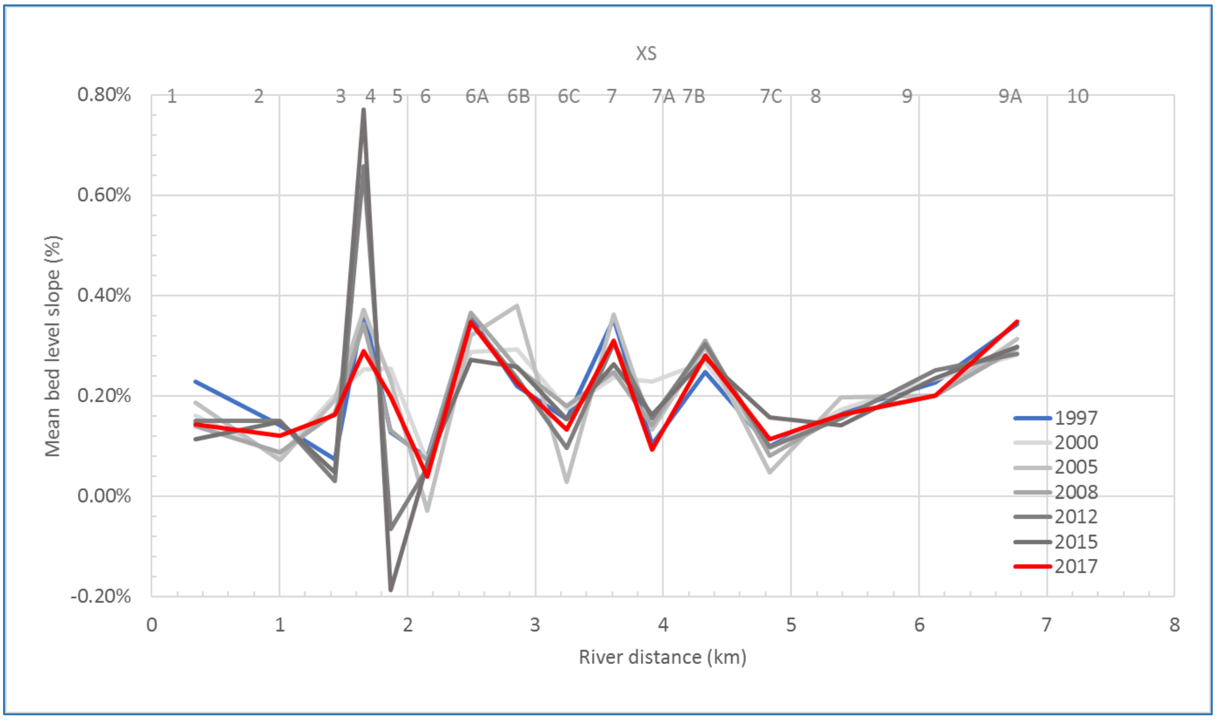


Figure 6-10: Change in time of the mean bed level slope along the Esk River.

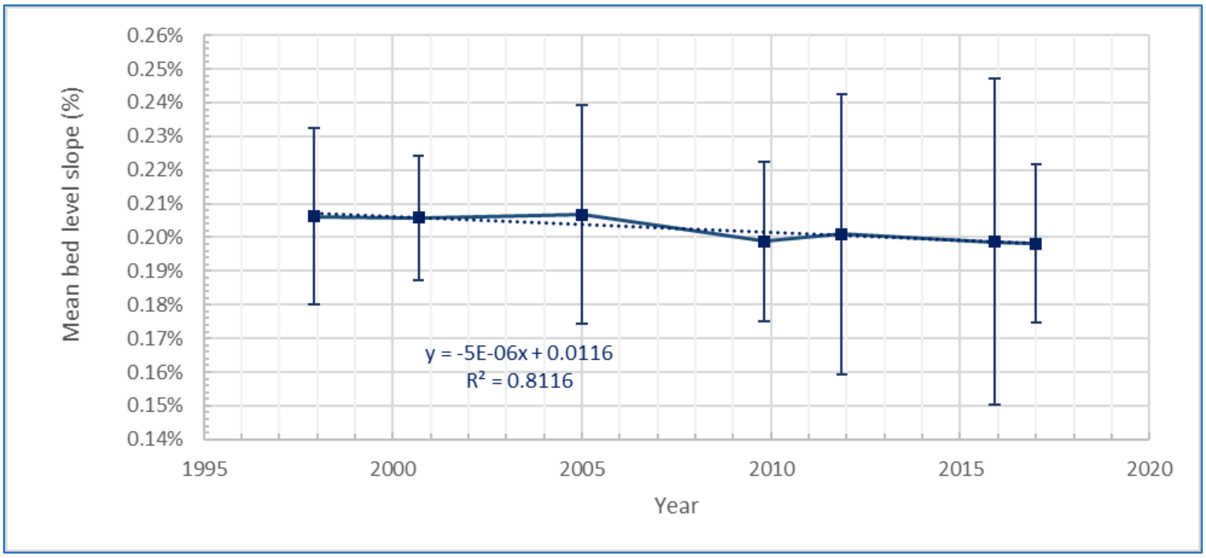


Figure 6-11: Change in time of the average mean bed level slope along the Esk River. Error bars indicate the standard error of the mean.

6.2.4 Active channel width

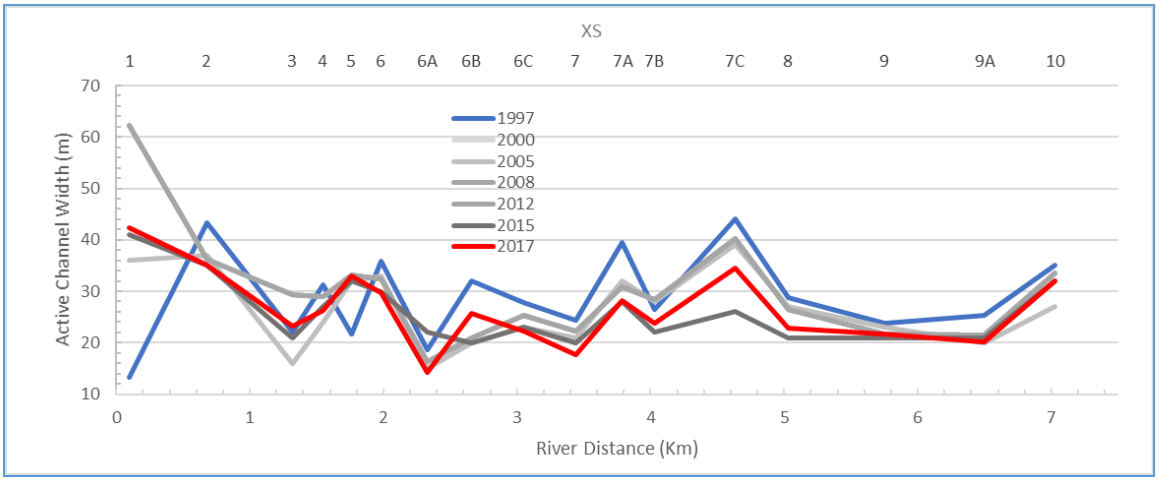


Figure 6-12: Change in time of the active channel width along the Esk River.

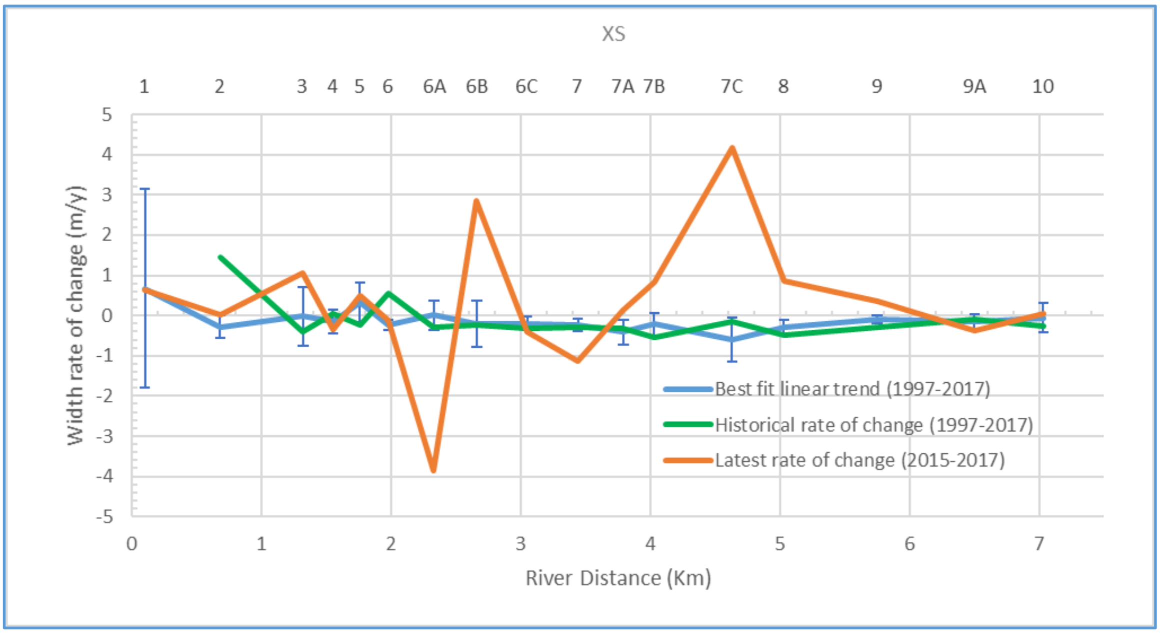


Figure 6-13: Rate of change of the active channel width along the Esk River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

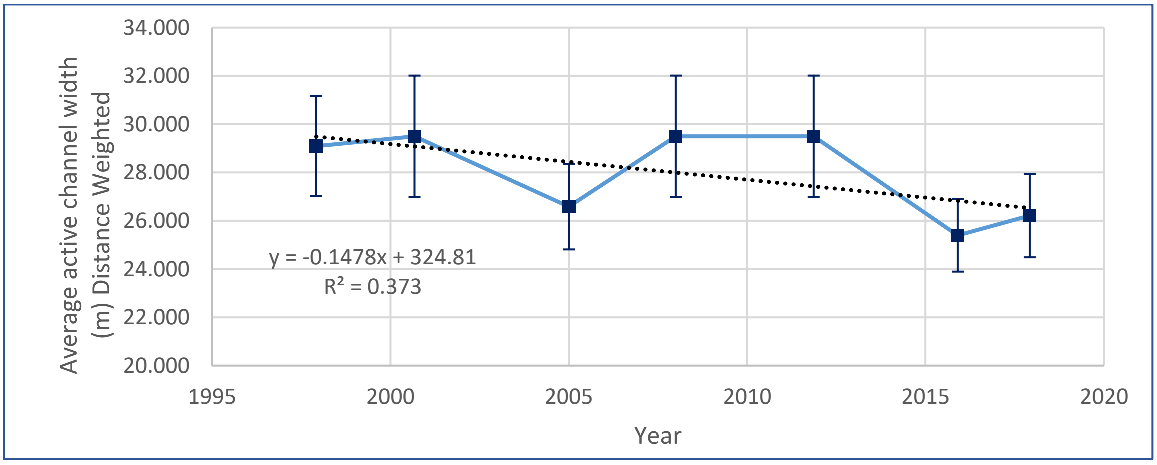


Figure 6-14: Change in time of the distance weighted average active channel width along the Esk River. Error bars indicate the standard error of the mean cross section width.

6.2.5 Relative maximum depth

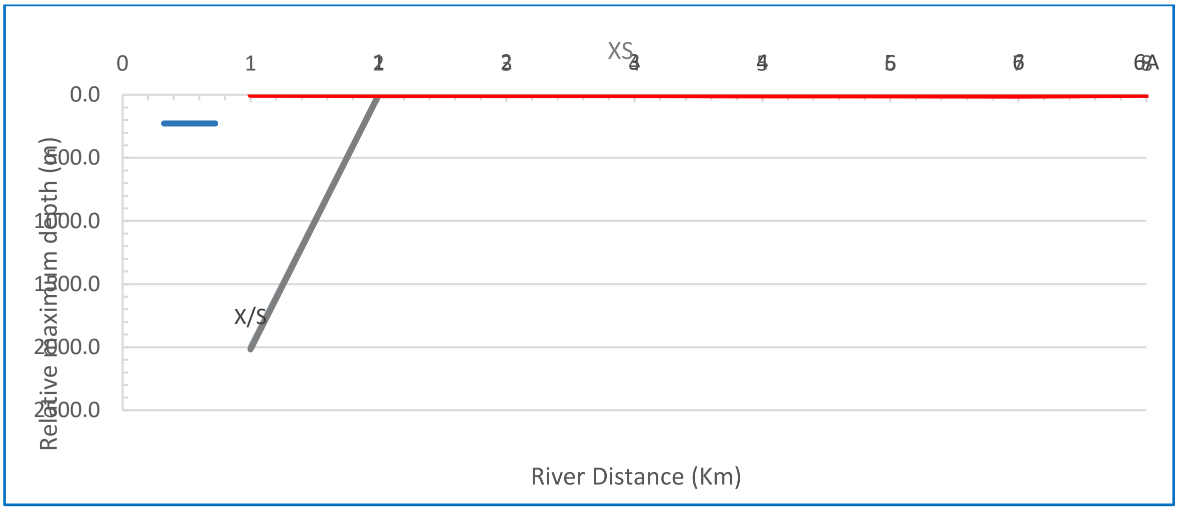


Figure 6-15: Change in time of the Relative Maximum Depth (Mean Bed Level – Min Bed Level) along the Esk River. Note that the vertical axis is reversed for a more intuitive visualization of (water) depth.

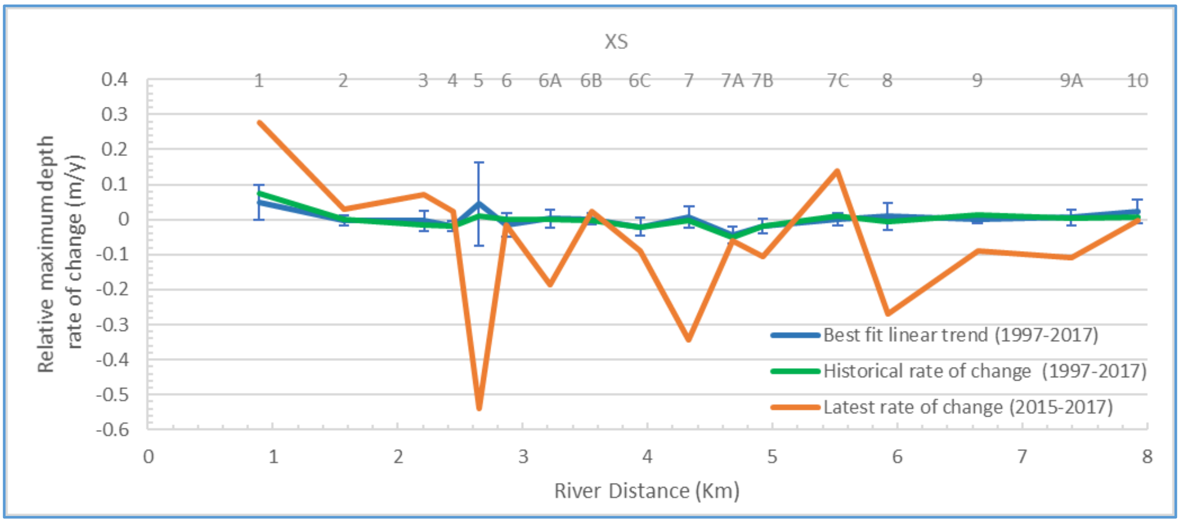


Figure 6-16: Relative Maximum Depth (Mean Bed Level – Min Bed Level) rate of change along the Esk River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

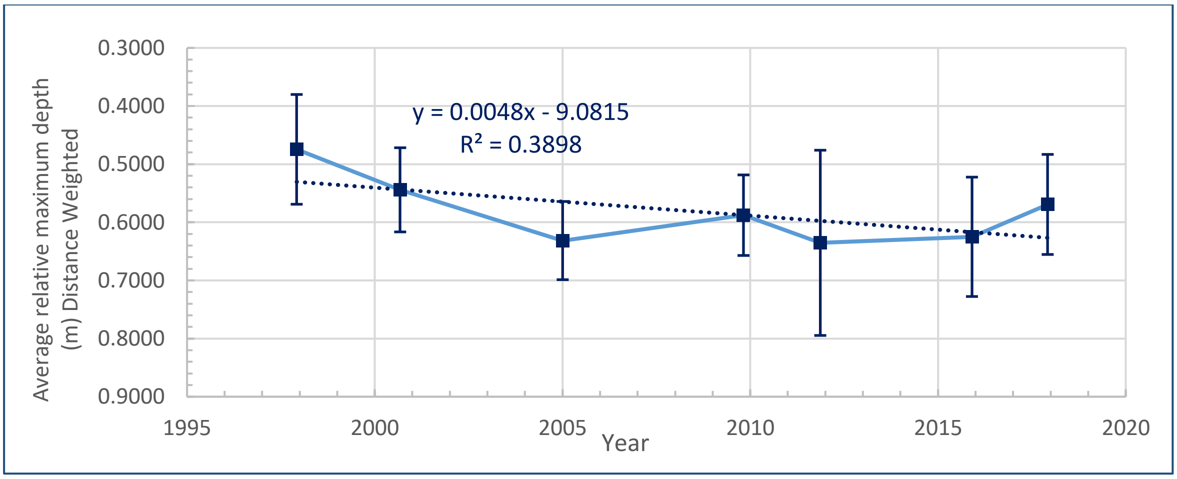


Figure 6-17: Change in time of the average the Relative Maximum Depth (Mean Bed Level – Min Bed Level)distance weighted along the Esk River. Error bars indicate the standard error of the mean at the cross section. Note that the vertical axis is reversed for a more intuitive visualization of (water) depth.

6.3 Gravel Availability

6.3.1 Present

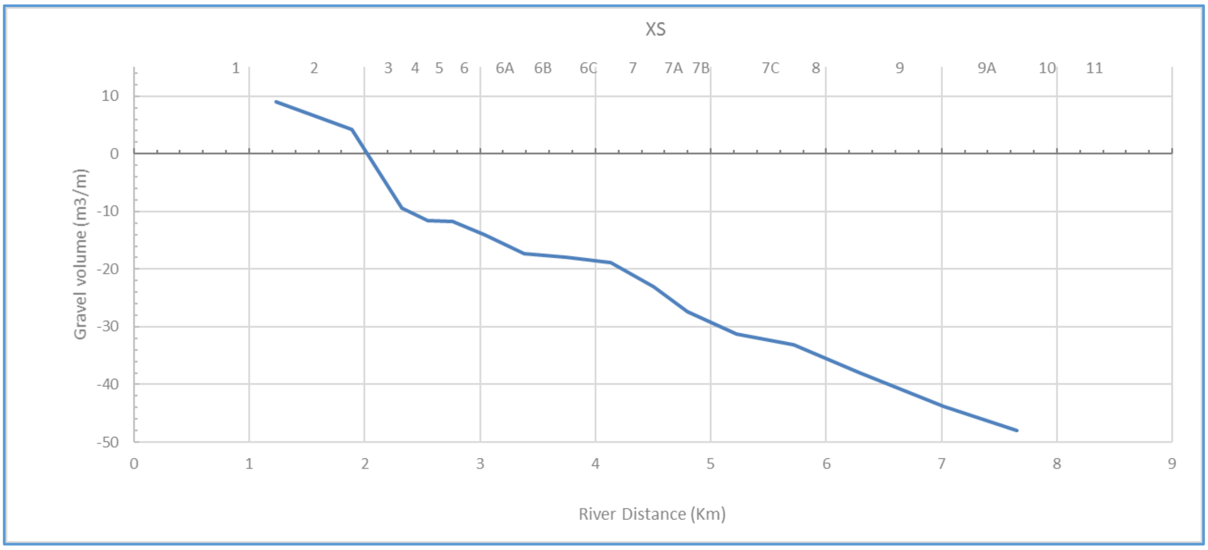


Figure 6-18: Estimated gravel availability for 2018 in the Esk River (Adapted from Beya & Byrne, 2018).

6.3.2 Historical change

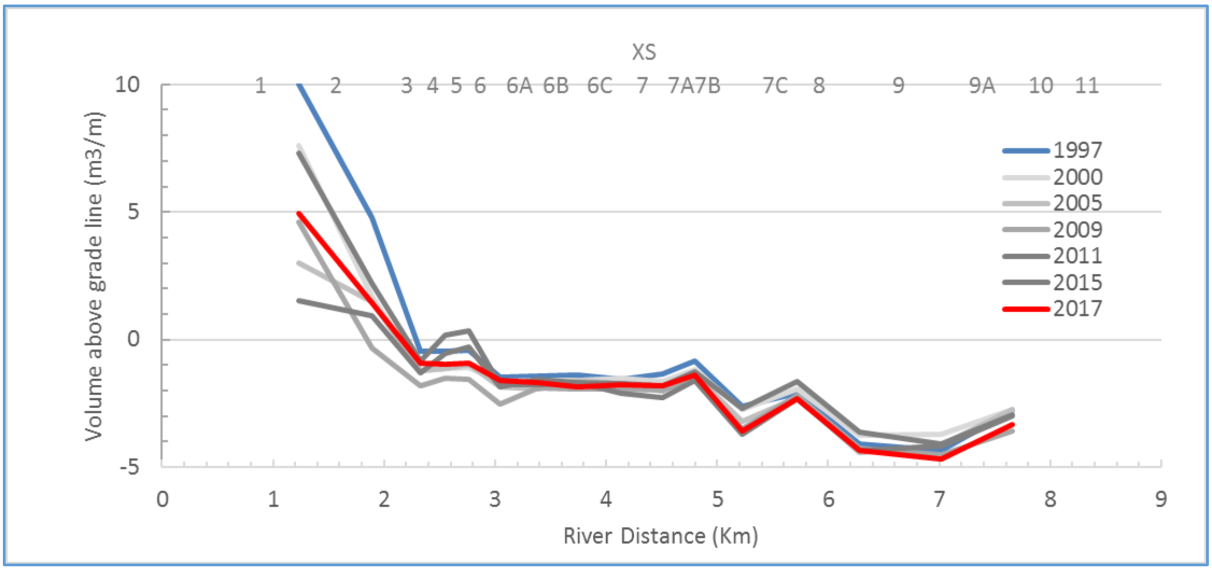


Figure 6-19: Historical change in measured gravel availability

6.3.3 Cumulative volume analysis

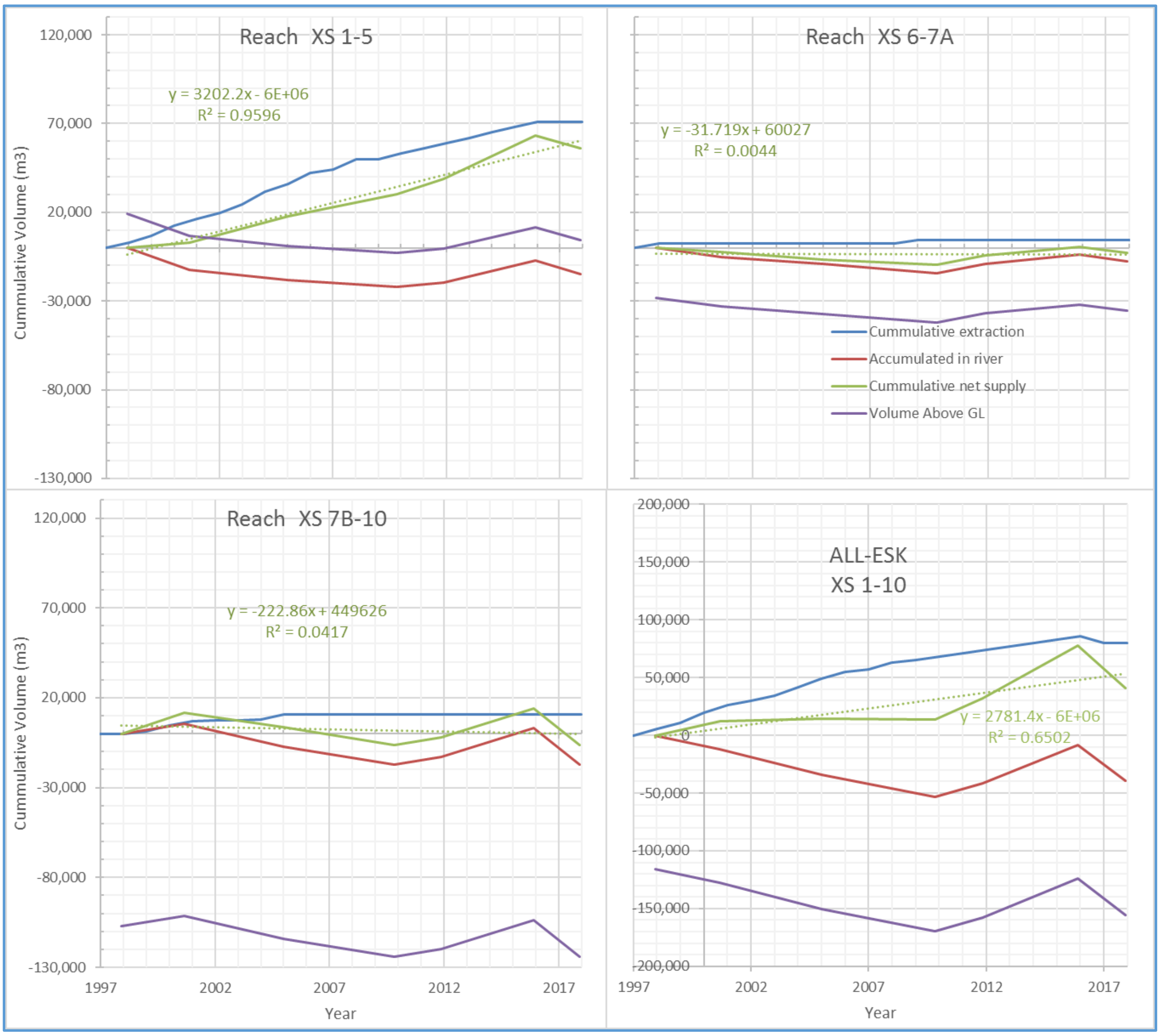


Figure 6-20: Cumulative volume analysis for all and different reaches in the Esk River

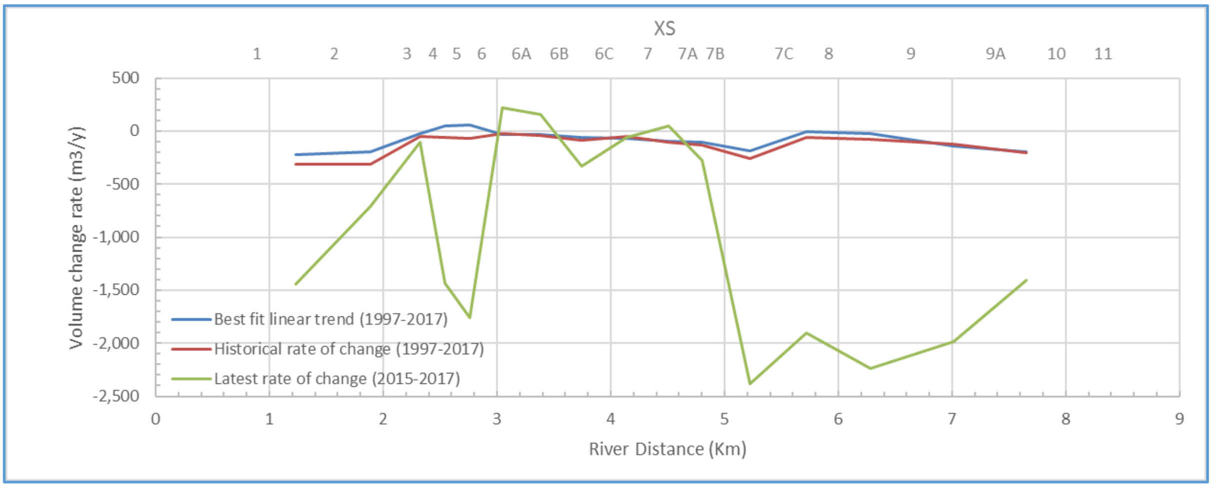


Figure 6-21: Volume change rates and trends along the Esk River.

6.3.4 Net-supply rates

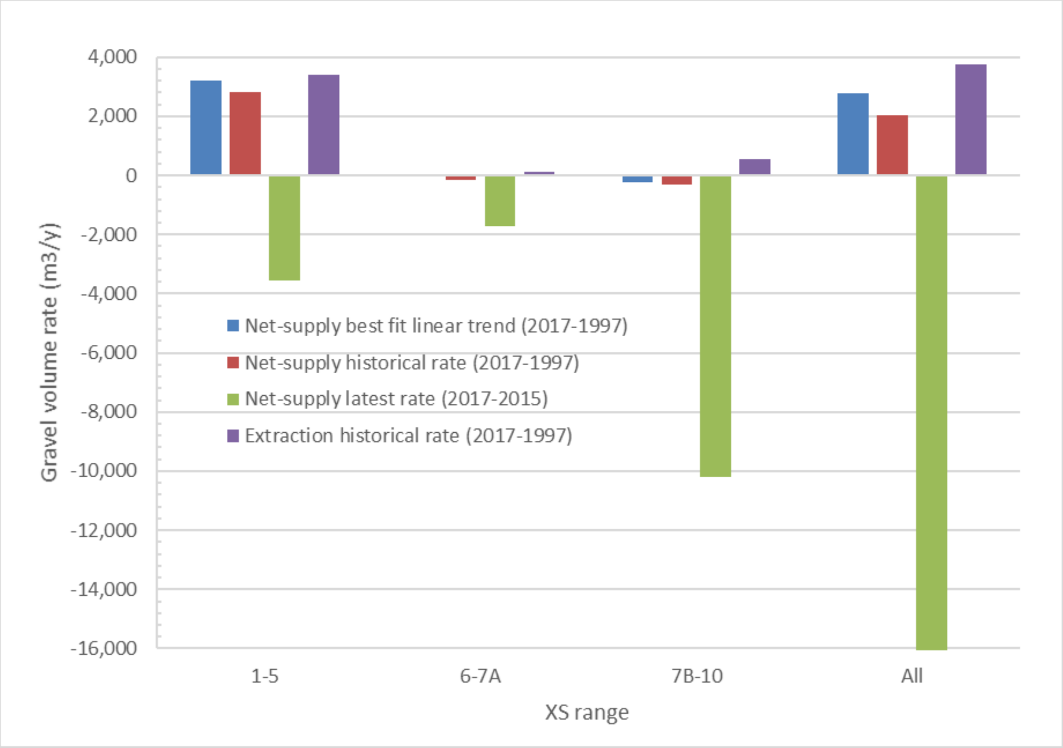


Figure 6-22: Gravel net-supply long term and latest trends.

6.4 Discussion

The overall mean bed level (*MBL*) historical rate of change indicates a generalized degradation over the measured reach with intensified values for the latest period. There is presently significant bed degradation with an average value of 0.880 m below grade line and the upstream section shows degradation up to 2.21m below the grade line. In general, since 1997 *MBLs* steadily decreased in time except during 2009 and 2015.

MBL decreasing trend from 1997 to 2009 is likely influenced by the lack of significant floods with only four events above the 2 year return value. The increase shown from 2009 to 2015 was probably caused by two important floods above 10 year return value and a significant decrease in extraction since 2006. The latest period shows a decreasing trend and the occurrence of two minor flood events. It is likely that the next survey will show significant changes in the *MBLs* after two major floods have occurred in 2018, where one of them almost reached the 100 year return value.

In general, the mean bed level slope has been decreasing relatively steadily. The average active channel width (*AChW*) has been decreasing in time but the latest trend is positive. The channel has narrowed upstream XS 6 and widened importantly in XS 1. The latest historical rate of change shows important variations along the river. There is an overall decrease at a rate of 0.13 m/y with cycles of relative increase (years 2000, 2008-2013, and decrease (years 2005, 2015, 2017).

The relative maximum depth (*RMD*) is relatively stable. There is a slight historical decrease in values but a stronger variability during the different years, especially after 2005. XS 11 shows the highest historical decreasing trend while XS 1 shows the highest increasing trend. The largest variability between surveys is observed between 2009 and 2011.

Gravel availability is below the grade line above XS 3 with the deficit increasing upstream. Historical volumes show a slight decreasing trend in time as levels showed already a large deficit from the start of the analysed period. A small variability is observed during the different surveys.

The cumulative analysis shows that, overall, the river has a positive net-supply, although, lower than the extraction. The latest rates of change show a negative net-supply with most of the degradation occurring upstream XS 7B. The reach from XS 6-7A shows small amounts of extraction but negative cumulative net-supply rates and a historical decrease in volume availability with a stable trend in the last period.

Despite the historical river degradation below the grade line, there are no apparent issues identified with infrastructure at risk. Therefore a new grade line lower than the existing, could potentially be established. However, the effects on the coastal supply need to be carefully analysed. The Esk river mouth is located up-drift of Whirinaki in terms of the along-shore net coastal sediment transport. Important coastal line retreat occurred from the mid-1980s to the mid-1990s which could be due in part to the large amounts extracted during the 1970s. Since the mid-1990s the coast line has been maintained in a dynamic equilibrium with signs of a faint recovery (Carruth & Cave, 2016).

The large floods in March and June 2018 may have changed significantly gravel availability and the river morphological parameters. A new survey is scheduled for this year to measure the changes.

7 Tutaekuri River

7.1 Background

The Tutaekuri River has 39.3 Km of stopbanks protecting farmland and settlements around South of Napier, Taradale and Puketapu. Live edge protection (willows) has been applied along the berms to stabilize the active channel width. Gravel extraction and river raking have been regularly applied along the reach to maintain the active channel near the design parameters, although some reaches currently do not meet the specifications. (Figure 8-1).

Cross section data has been systematically measured in 39 cross sections (from XS 17 to XS 55) along the river since 1988, with non-systematic records dating from 1951 (Figure 8-2). The analysis in this chapter includes survey data from 2000 onwards.

Gravel extraction was significantly decreased after 1995 after extraction peaked in the early 1990s. In the later years extraction has been maintained at a relatively stable rate (Figure 8-3). Presently, there is little gravel above the grade line downstream XS 40 (Beya & Byrne, 2018) due to intensive gravel extraction prior 2000 (Figure 8-4).

As explained earlier in section 2.5, gravel in the Tutaekuri River does not reach the coast after the major landscape changes caused by the 1931 earthquake and following the man-made modifications that diverted the Ngaruroro and Tutaekuri rivers at their downstream reaches and joined their mouths (Williams, 1985). The gravel front is currently at XS 9 and in a slow process of moving towards the coast. Today only fine sand and cohesive sediments are able to reach the sea.

Floods capable of mobilizing gravel have occurred regularly in the river. However, since 1989, there have not been floods above the 10 year return period. In general, there has been two floods above the 2 year return value between surveys with the exception of the period between 1999 to 2002 (Figure 8-5).

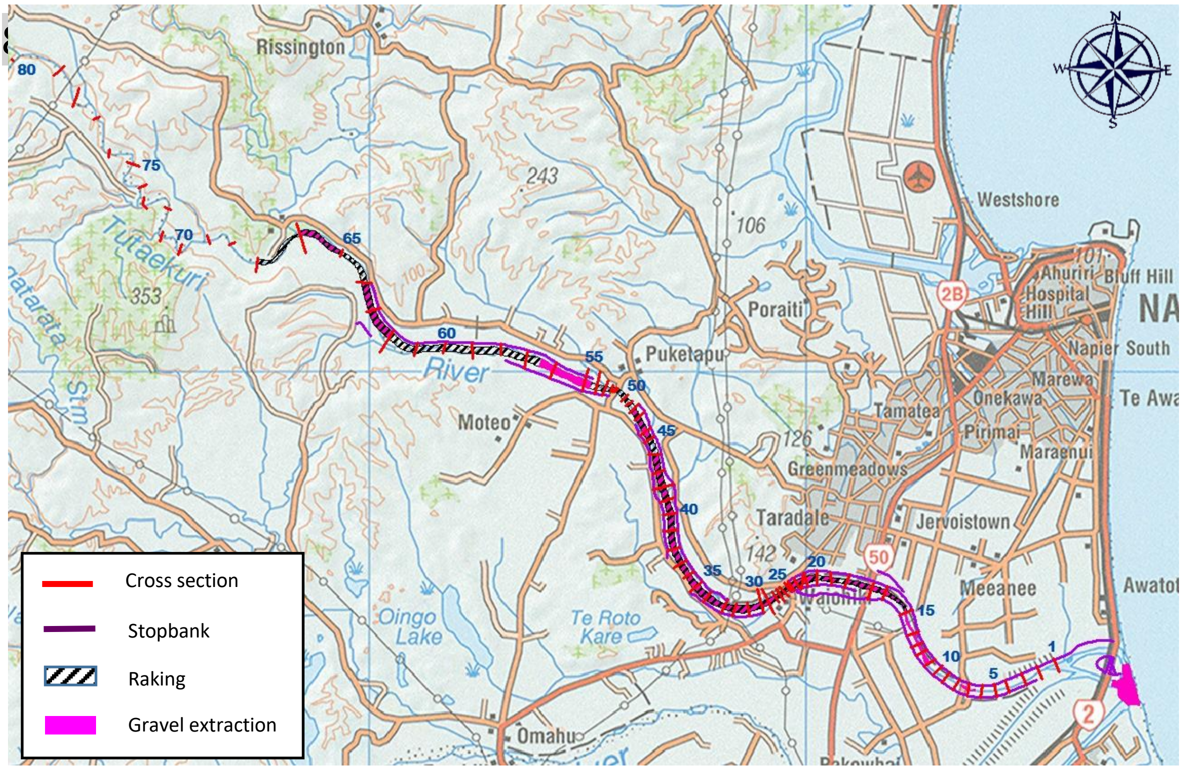


Figure 8-1: Location of the Tutaekuri River and an indication of cross sections, stopbanks, raking and gravel extraction. Blue numbers indicate XS numbers.

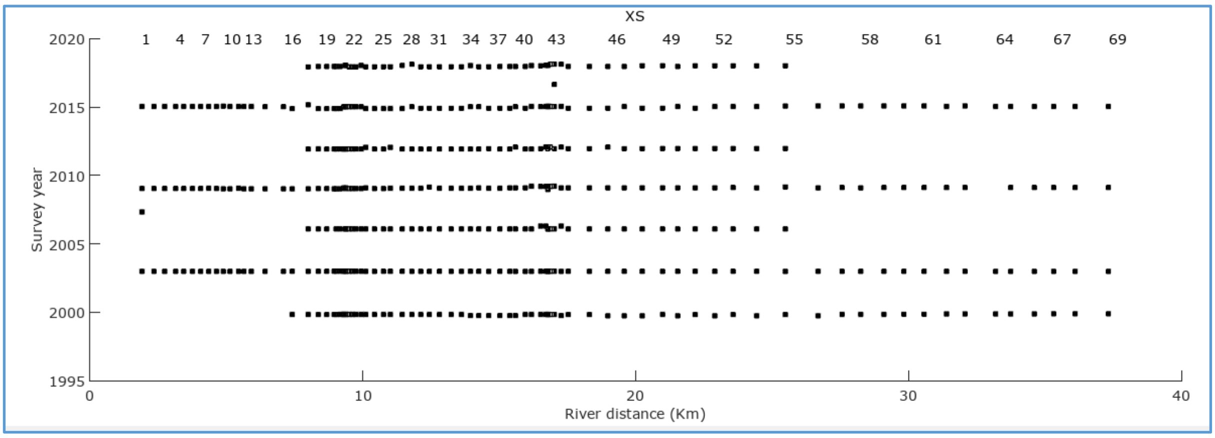


Figure 8-2: Cross section data availability for the Tutaekuri River. Each black dot represent a cross section survey.

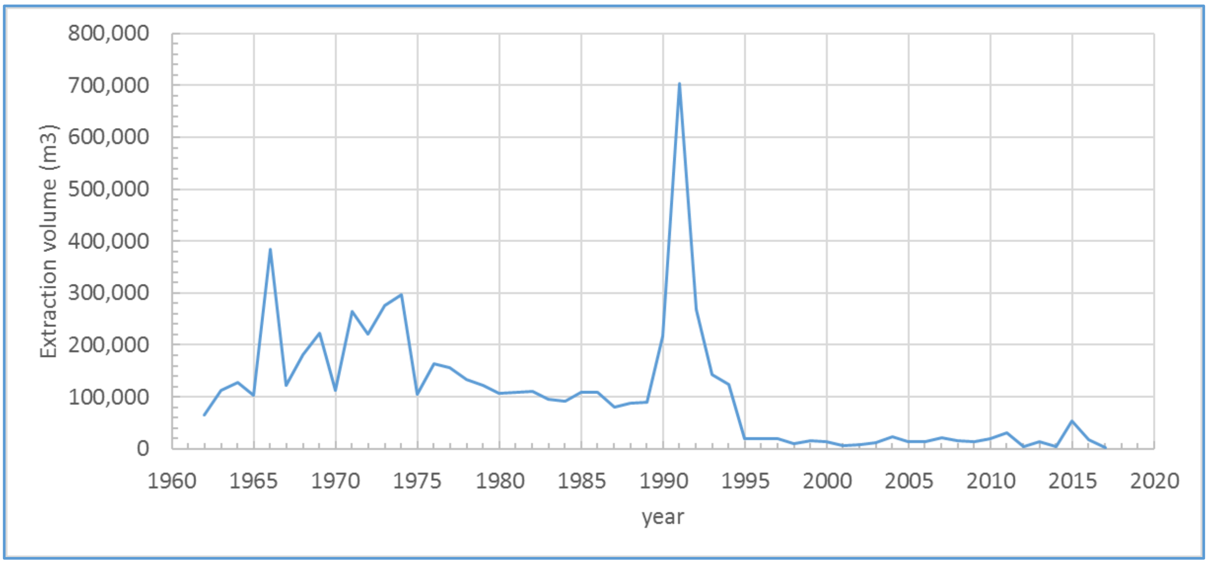


Figure 8-3: Time series of total gravel extraction volumes in the Tutaekuri River.

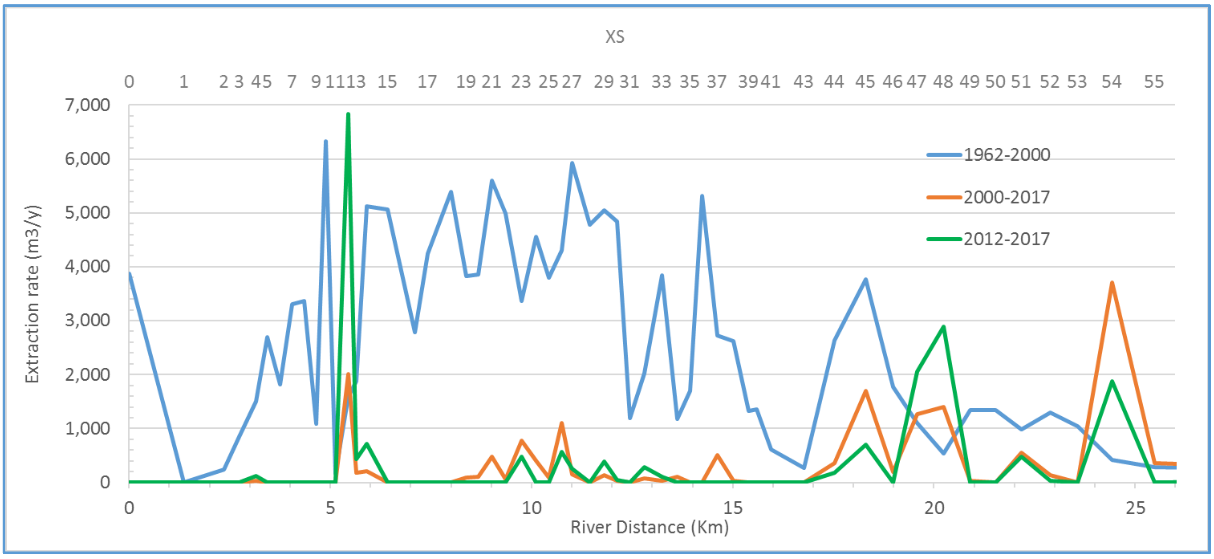


Figure 8-4: Average gravel extraction rates along the Tutaekuri River for three different periods.

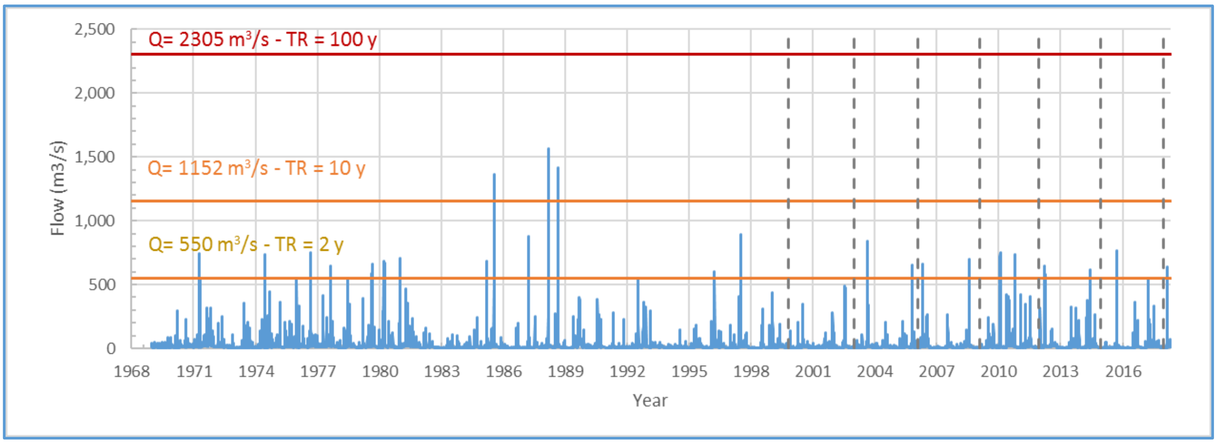


Figure 8-5: Tutaekuri River hourly flows at Puketapu HBRC site. Return values from Carruth (2015b). Vertical black dashed lines indicate the survey dates used for the analysis in this chapter. Earlier dates have not been considered in the analysis.

8.1 Observed Morphological Changes

8.1.1 Summary

Table 8-1: Average historical and latest rates of change of morphological parameters in the Tutaekuri River. The period of analysis is indicated in brackets. The parameters definition is outlined in section 3.

Symbol	**Parameter**	**Historical best fit trend (2000-2015)**	**Average of historical rate of change (2000-2015)**	**Average of Latest rate of change (2012-2015)**	**Units**
MBL	Mean bed level (-ve below grade line)	0.014	0.019	0.059	m/y
S_{MBL}	Mean bed level slope	-4.2x10^{-4}	-5.0x10^{-4}	-5.8x10^{-4}	%/y
$AChW$	Active channel width	-0.16	-0.19	-0.58	m/y
RMD	Relative maximum depth (+ve deeper)	0.0014	0.0079	0.0350	m/y

8.1.2 Active channel mean bed level

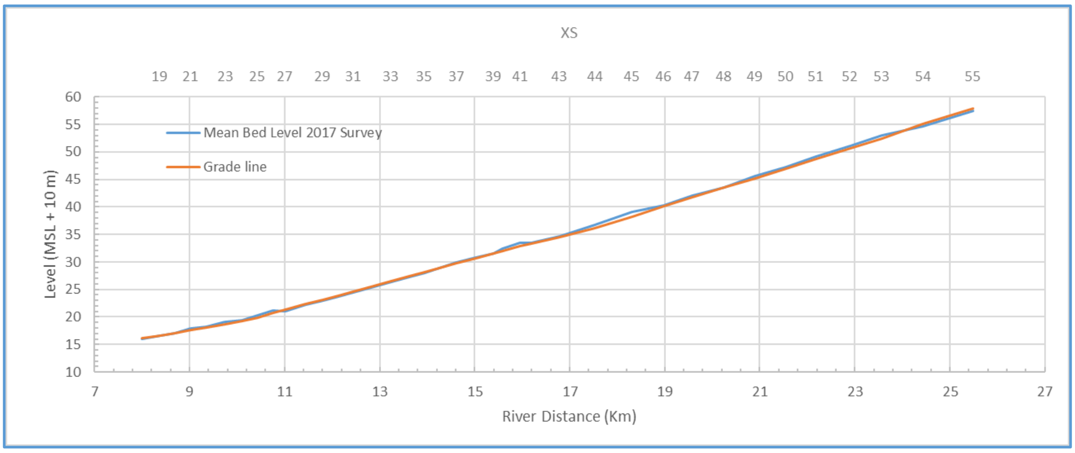


Figure 8-6: Mean bed level and design grade-line for the Tutaekuri River

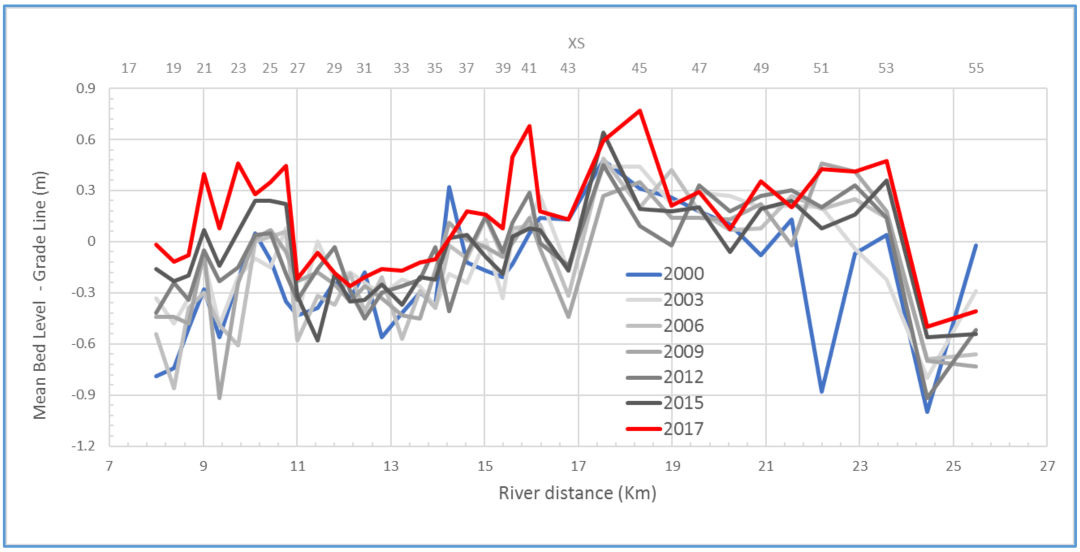


Figure 8-7: Change in time of the mean bed level relative to the grade line level along the Tutaekuri River.

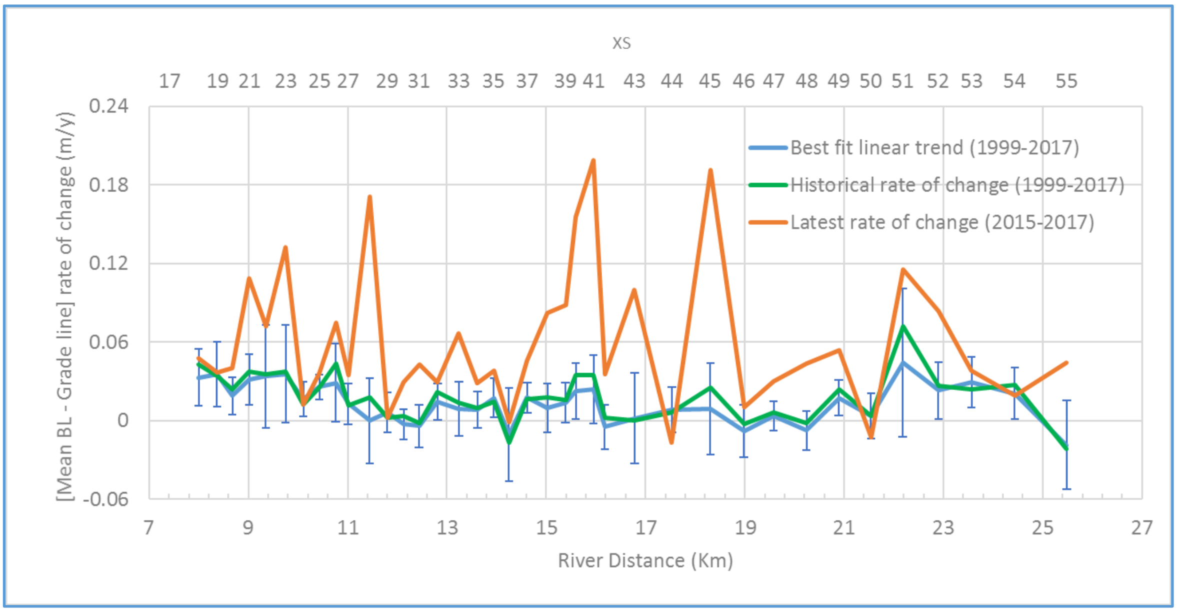


Figure 8-8: Rate of change of the mean bed level relative to the grade level along the Tutaekuri River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

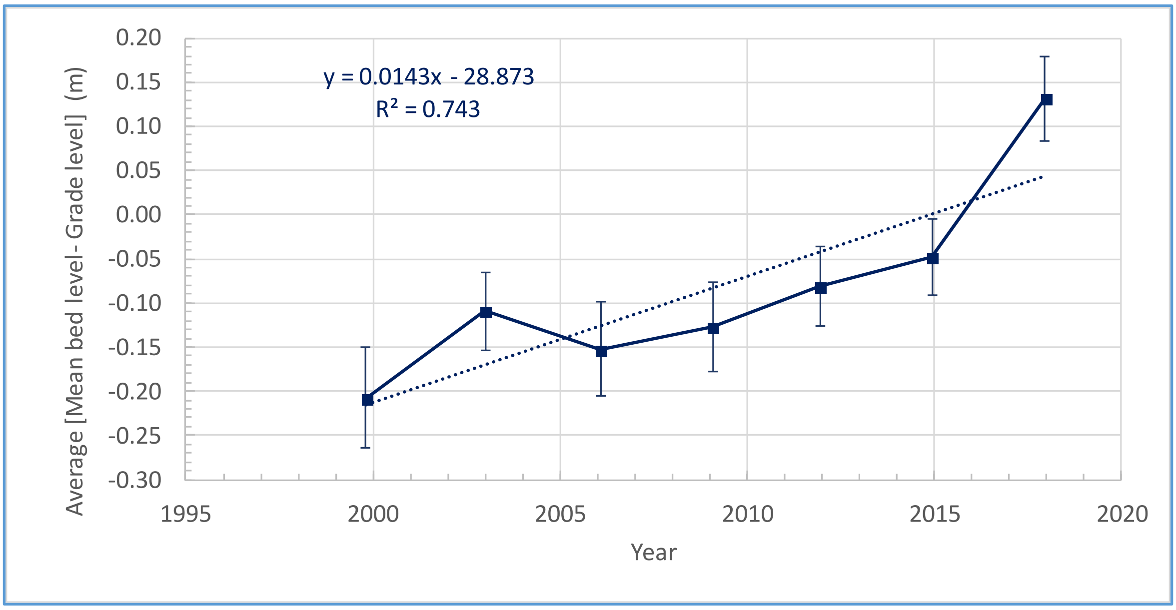


Figure 8-9: Change in time of the average mean bed level relative to the grade level along the Tutaekuri River. Error bars indicate the standard error of the mean.

8.1.3 Active channel slope

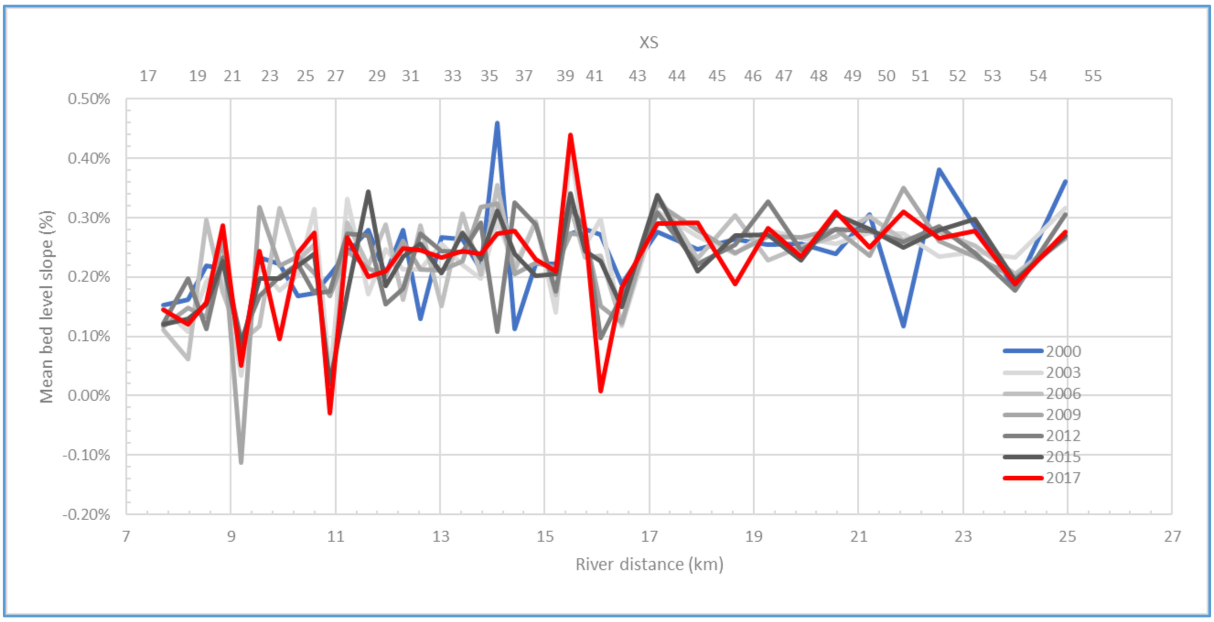


Figure 8-10: Change in time of the mean bed level slope along the Tutaekuri River.

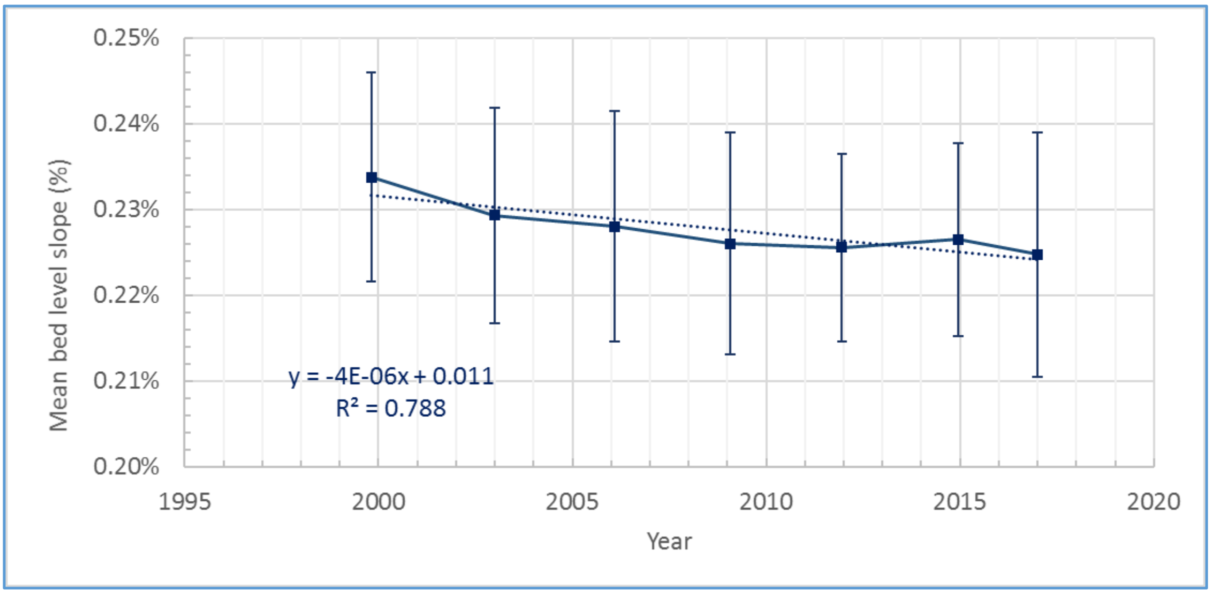


Figure 8-11: Change in time of the average mean bed level slope along the Tutaekuri River. Error bars indicate the standard error of the mean.

8.1.4 Active channel width

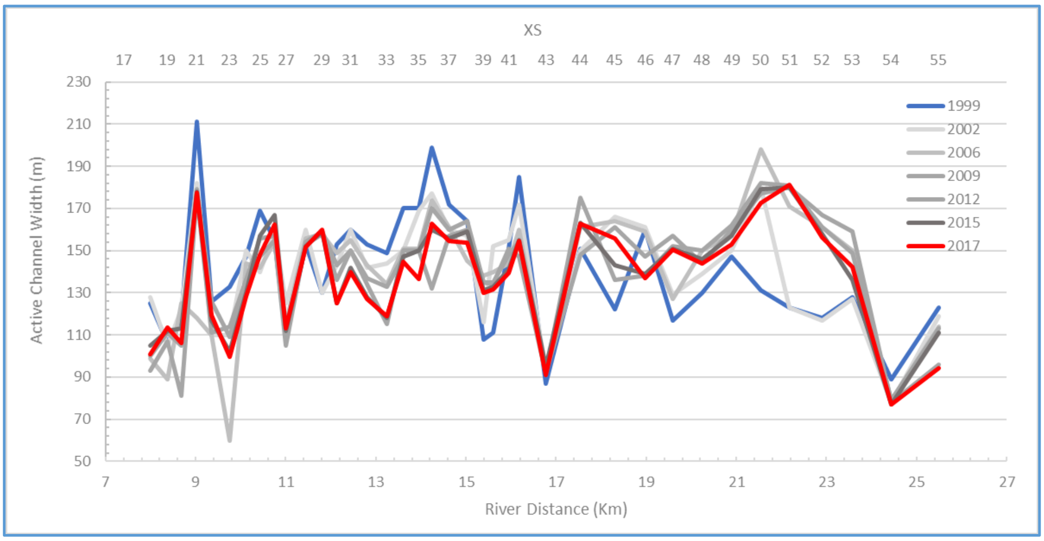


Figure 8-12: Change in time of the active channel width along the Tutaekuri River.

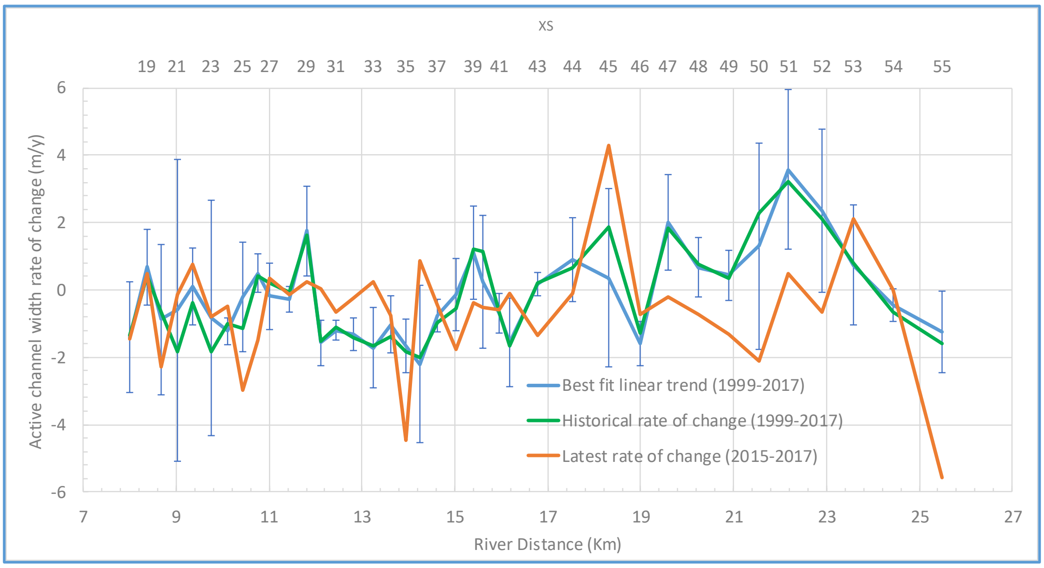


Figure 8-13: Rate of change of the active channel width along the Tutaekuri River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

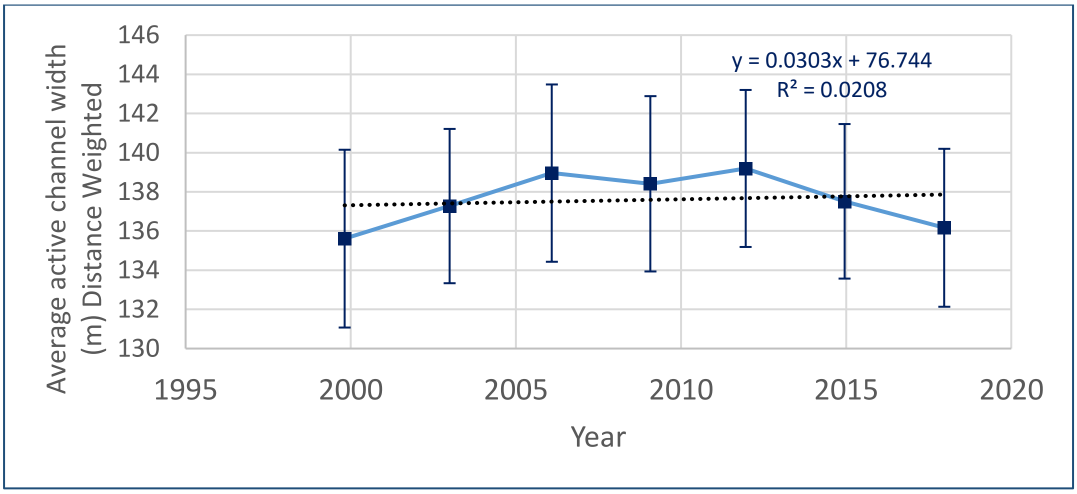


Figure 8-14: Change in time of the average active channel width distance weighted along the Tutaekuri River. Error bars indicate the standard error of the mean at the cross section.

8.1.5 Relative maximum depth

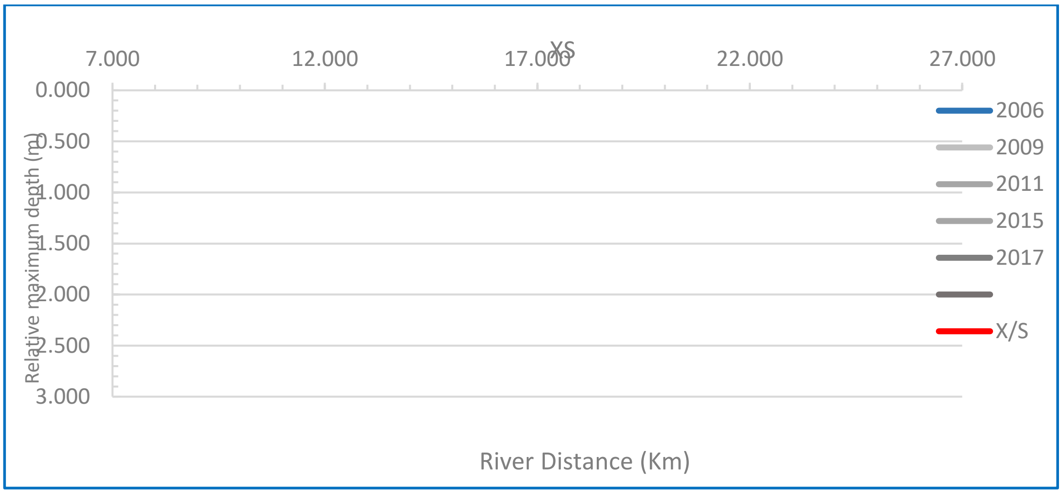


Figure 8-15: Change in time of the Relative Maximum Depth (Mean Bed Level – Min Bed Level) along the Tutaekuri River. Note that the vertical axis is reversed for a more intuitive visualization of (water) depth.

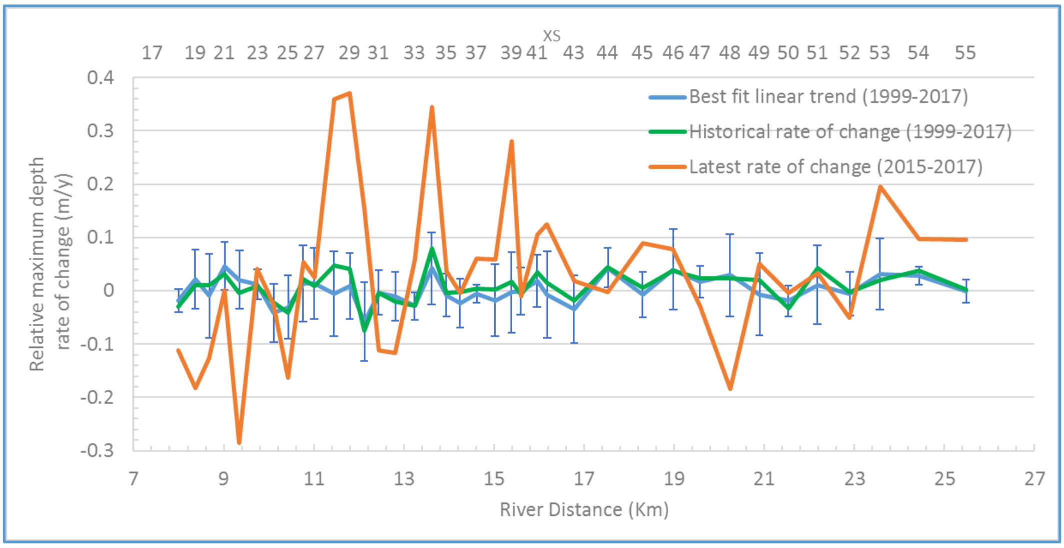


Figure 8-16: Relative Maximum Depth (Mean Bed Level – Min Bed Level) rate of change along the Tutaekuri River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

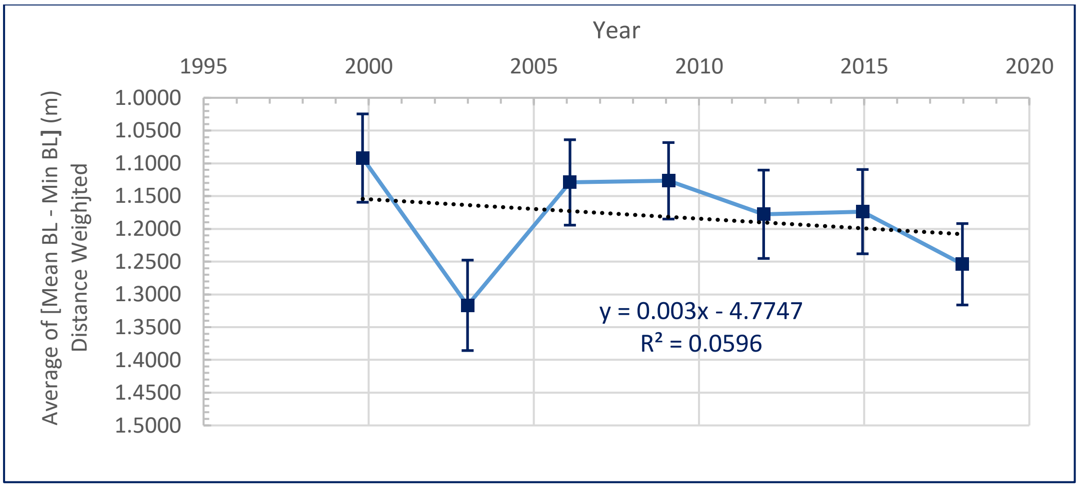


Figure 8-17: Change in time of the average the Relative Maximum Depth (Mean Bed Level – Min Bed Level) along the Tutaekuri River distance weighted. Error bars indicate the standard error of the mean at the cross section. Note that the vertical axis is reversed for a more intuitive visualization of (water) depth.

8.2 Gravel Availability

8.2.1 Present

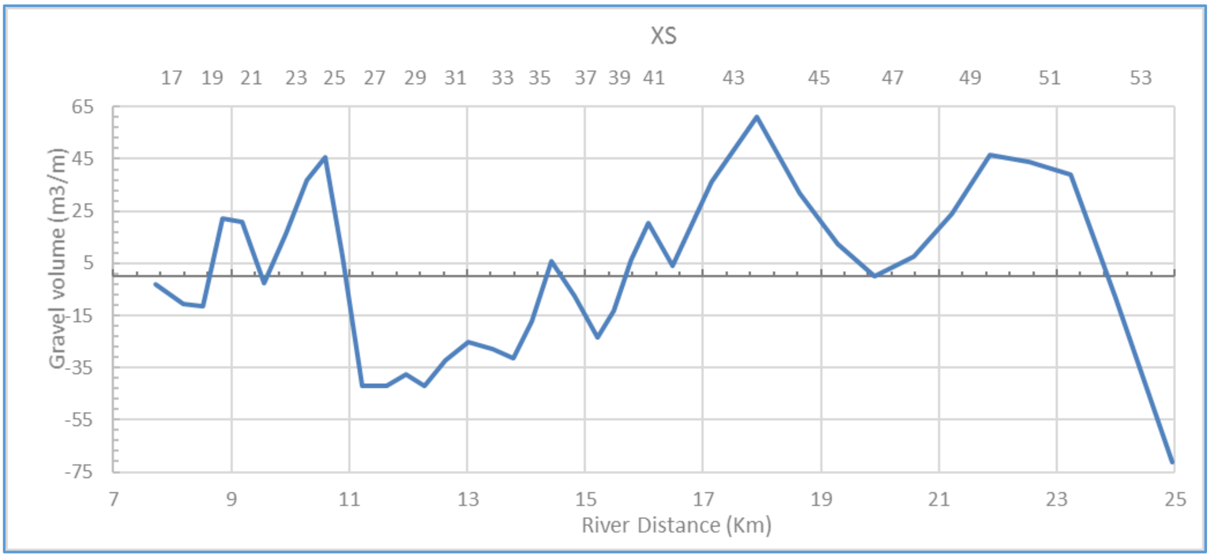


Figure 8-18: Estimated gravel availability for 2018 in the Tutaekuri River (adapted from Beya & Byrne, 2018).

8.2.2 Historical change

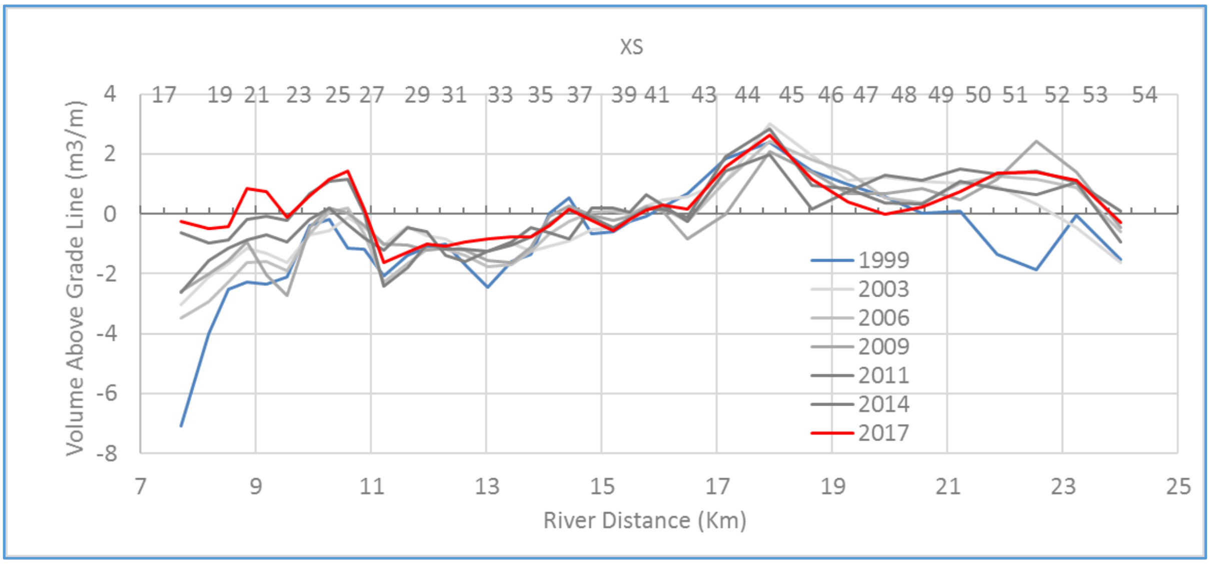


Figure 8-19: Historical change in measured gravel availability in the Tutaekuri River

8.2.3 Cumulative analysis

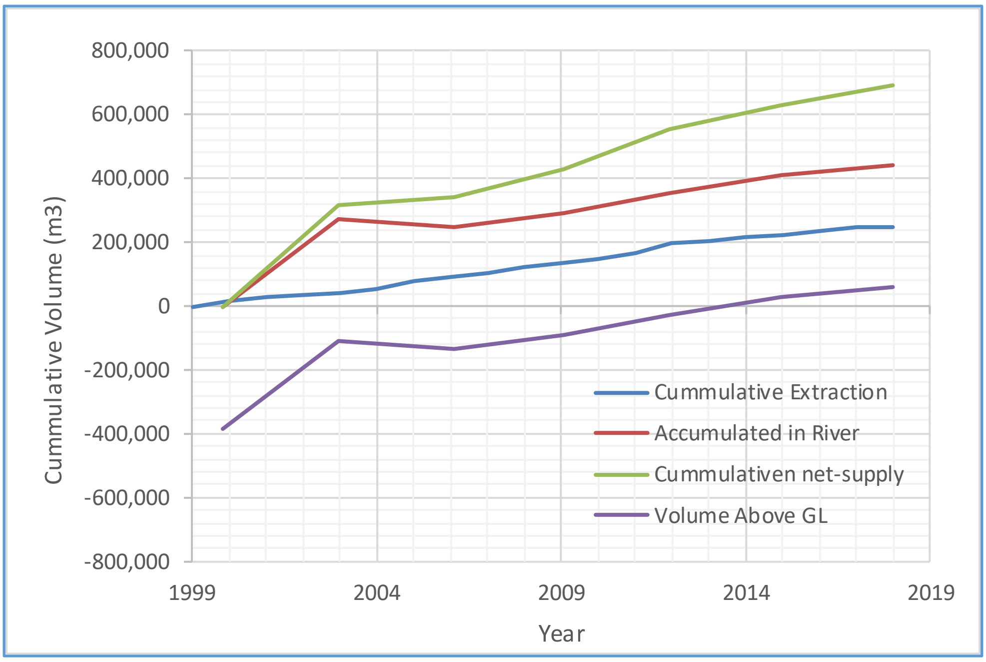


Figure 8-20: Cumulative volume analysis for the entire Tutaekuri River

Figure 8-21: Cumulative volume analysis for different reaches in the Tutaekuri River

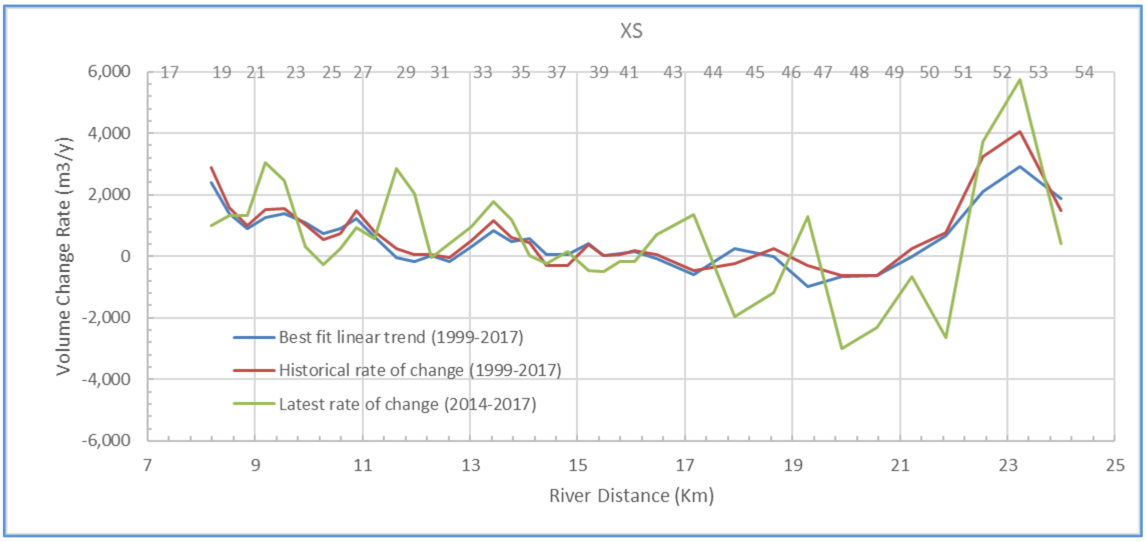


Figure 8-22: Volume change rates and trends along the Tutaekuri River

8.2.4 Net-supply rates

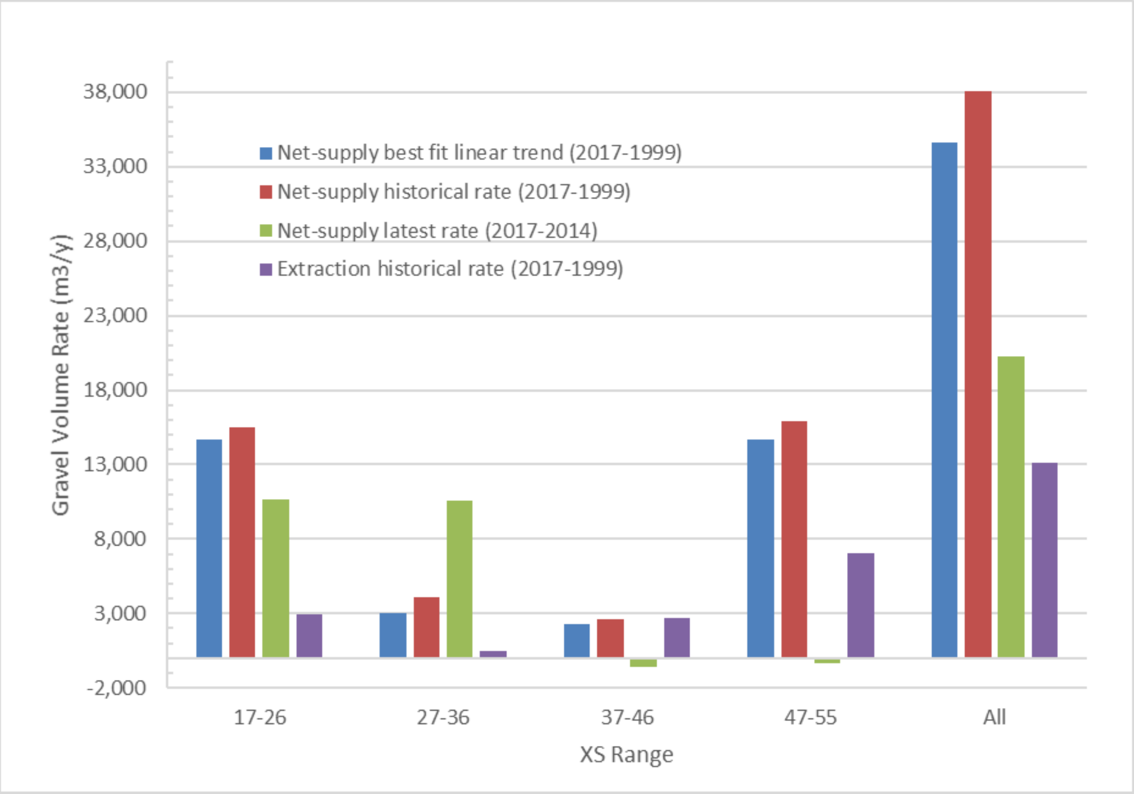


Figure 8-23: Gravel volumes net-supply long term and latest rates and best-fit trend and historical extraction rate in the Tutaekuri River.

8.3 Discussion

MBL is increasing at 19 mm/y with the latest survey indicating an increase rate of 59 mm/y. Increase is more noticeable from XS 17 to XS 27 and from XS 49 to XS 55. Rates are almost all positive (or negative but near zero) except at XS 36 and XS 55 where values of historical rates of change are 17 mm/y and 21 mm/y respectively. Overall increase has been steady with an accelerated rate between the last surveys and with a decrease from 2003-2006. Only the last survey showed that the mean bed levels are on average above the grade line.

The MBL slope is decreasing steadily in time at a rate of 0.00049 %/y.

The width is decreasing with intensification in the latest survey. Decrease is dominated by the reach downstream of XS 43. Upstream of XS 43 there is a general increase in *AChW*.

The relative mean depth, RMD is increasing and is more significant in the latest survey. There is some variability with time especially the increase shown in 2003 survey.

Present gravel availability is above grade line except in XS 17, 18 and from XS 26 to XS 34 and XS 35 XS 39 and XS 53. Volumes have increased downstream XS 27 and XS 32 and upstream XS 48 while in the rest of the river volumes have been relatively stable.

The cumulative analysis shows that the net-supply has been substantially greater than the extraction and that gravel has been accumulating in the river bed. This scenario is enhanced in the first reach from XS 18 to XS 26 and gradually softens upstream. The upstream reach from XS 47 to XS 55 shows greater net-supply than extraction but the first shows a decrease since 2012 while extraction shows an increase. Consequently gravel availability in the reach also shows a decrease in the latter years.

As part of the ongoing study into understanding of the gravel resource and response times of gravel stores, a morphological model similar to the Ngaruroro Model is planned for the Tutaekuri River.

9 Upper Tukituki River

9.1 Background

The Upper Tukituki River covers from XS 1 (Km 57.94 from the mouth) to the upper catchment. The reach has 42.2 Km of stopbanks protecting Waipukurau and the surrounding farmland. The Tukipo and Waipawa are major tributaries that join the river at XS 25 and XS 10 respectively, both contributing important gravel sources for the Tukituki River. As part of river management willows have been planted along the berms to stabilize the active channel width. Gravel extraction and river raking have been carried out along the reach (Figure 9-1).

Cross section data has been systematically measured in 79 cross sections (XS 1 to XS 80, XS 57 is missing) along the river since 1990, with non-systematic records dating from 1944 (Figure 9-2). The analysis in this chapter includes survey data from 2002 onwards.

Gravel extraction has been gradually decreasing in time, with the exception of a major peak in the early 1970s. After 2010 the extraction has decreased dramatically (Figure 9-3). Before year 2000 extraction was more intense below XS 37 and after year 2000 extraction has been focused between (XS 47 and XS 65) (Figure 9-4). Reduction in gravel extraction has been due to the lack of demand in the area, consequently the river has aggraded significantly in some areas.

A small number of floods capable of mobilizing gravel have occurred in the river with only 5 events above the 2 year return value in 30 years of record (Figure 9-5).

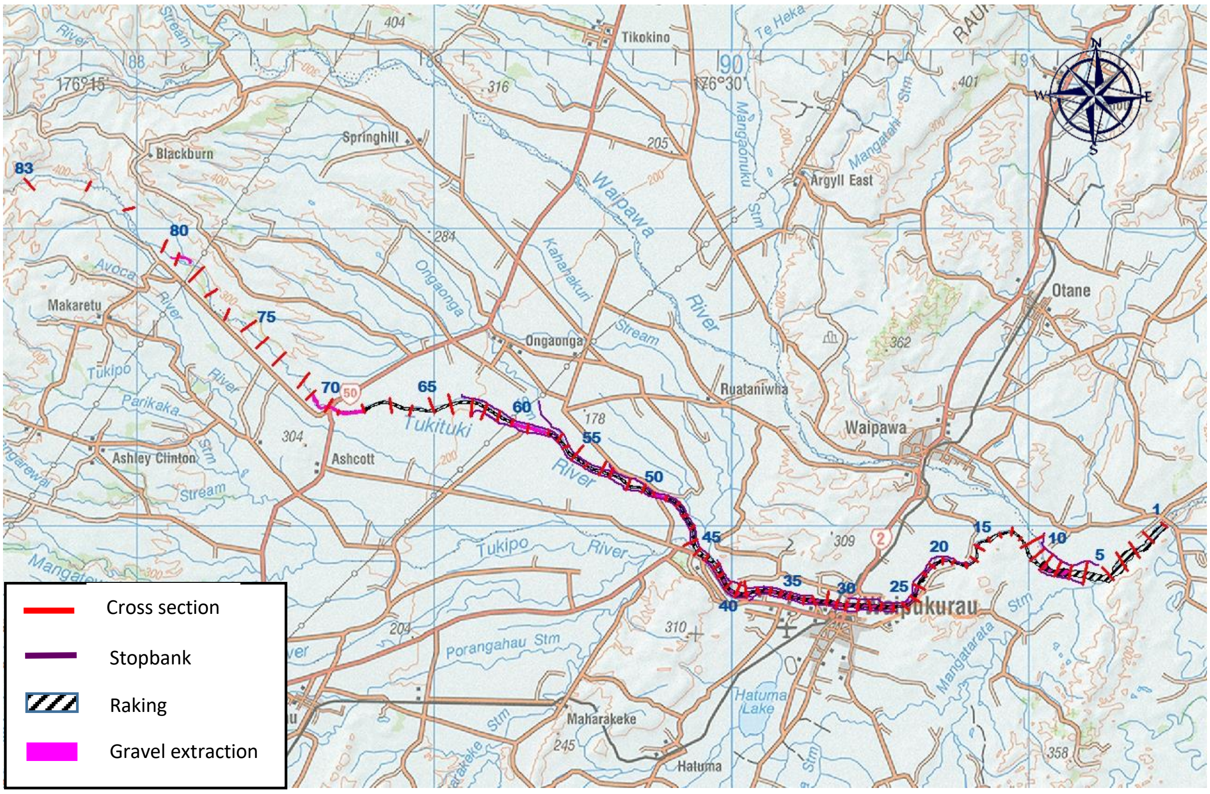


Figure 9-1: Location of the Upper Tukituki River and an indication of cross sections, stopbanks, raking and gravel extraction. Blue numbers indicate XS numbers.

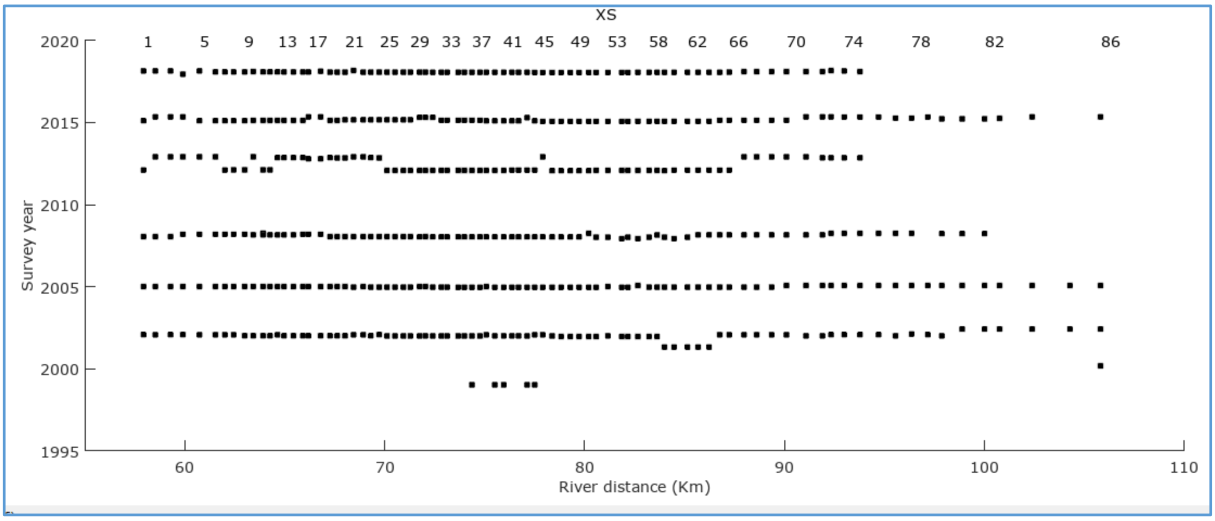


Figure 9-2: Cross section data availability for the Upper Tukituki River. Each black dot represent a cross section survey.

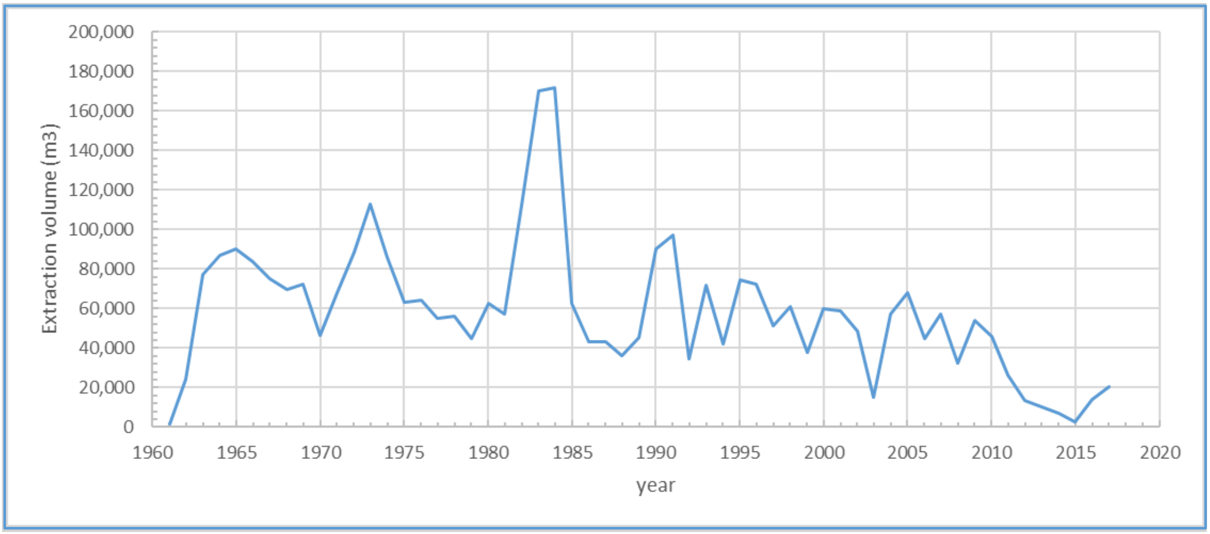


Figure 9-3: Time series of total gravel extraction volumes in the Upper Tukituki River.

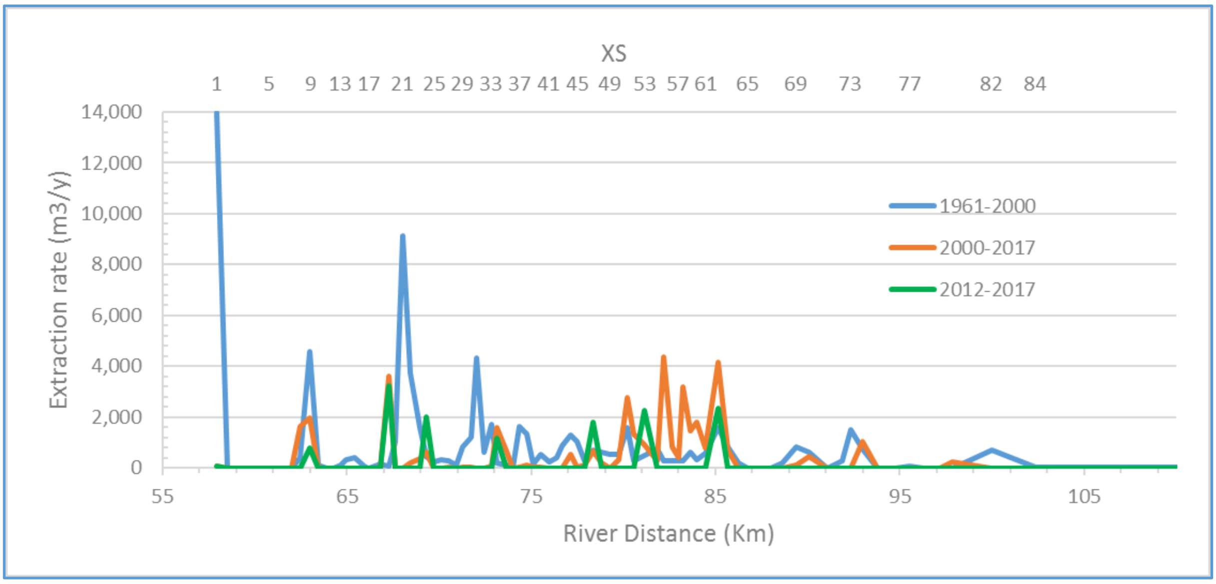


Figure 9-4: Average gravel extraction rates along the Upper Tukituki River for three different periods.

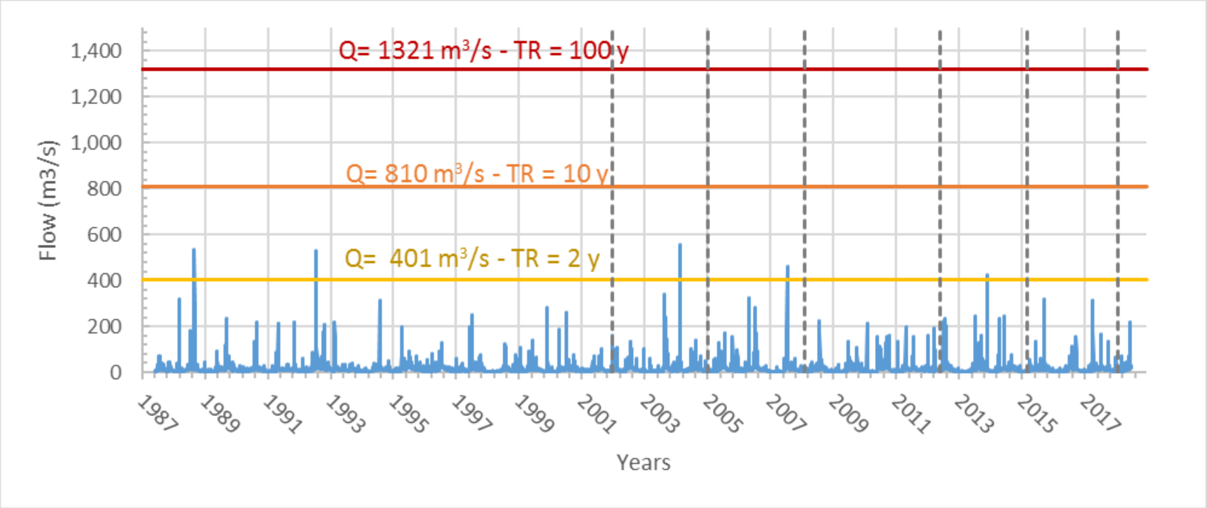


Figure 9-5: Tukituki River hourly flows at Tapairu Rd. Return values from Carruth (2015a). Vertical grey dashed lines indicate the survey dates used for the analysis in this chapter. Earlier dates have not been considered in the analysis.

9.2 Observed Morphological Changes

9.2.1 Summary

Table 9-1: Average historical and latest rates of change of morphological parameters in the Upper Tukituki River. The period of analysis is indicated in brackets. The parameters definition is outlined in section 3.

Symbol	**Parameter**	**Historical best fit trend (2000-2015)**	**Average of historical rate of change (2000-2015)**	**Average of Latest rate of change (2012-2015)**	**Units**
MBL	Mean bed level (-ve below grade line)	0.00057	0.00051	-0.00019	m/y
S_{MBL}	Mean bed level slope	$2.2\text{x}10^{-4}$	$1.8\ \text{x}10^{-4}$	$6.9\ \text{x}10^{-4}$	%/y
$AChW$	Active channel width	0.067	-0.010	-0.758	m/y
RMD	Relative maximum depth (+ve deepening)	0.0036	0.0040	0.0108	m/y

9.2.2 Active channel mean bed level

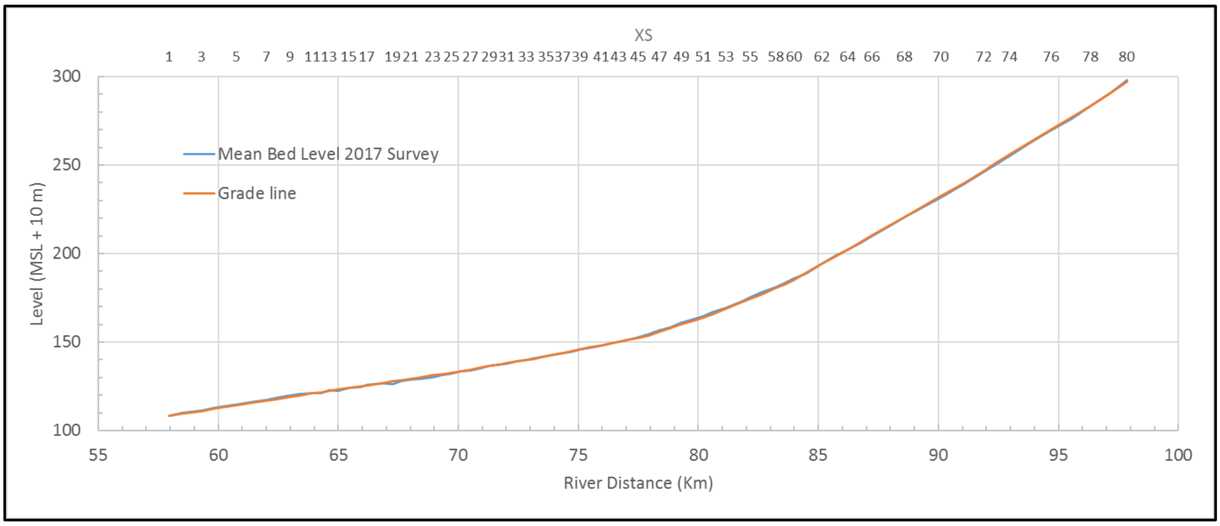


Figure 9-6: Mean bed level and design grade-line for the Upper Tukituki River

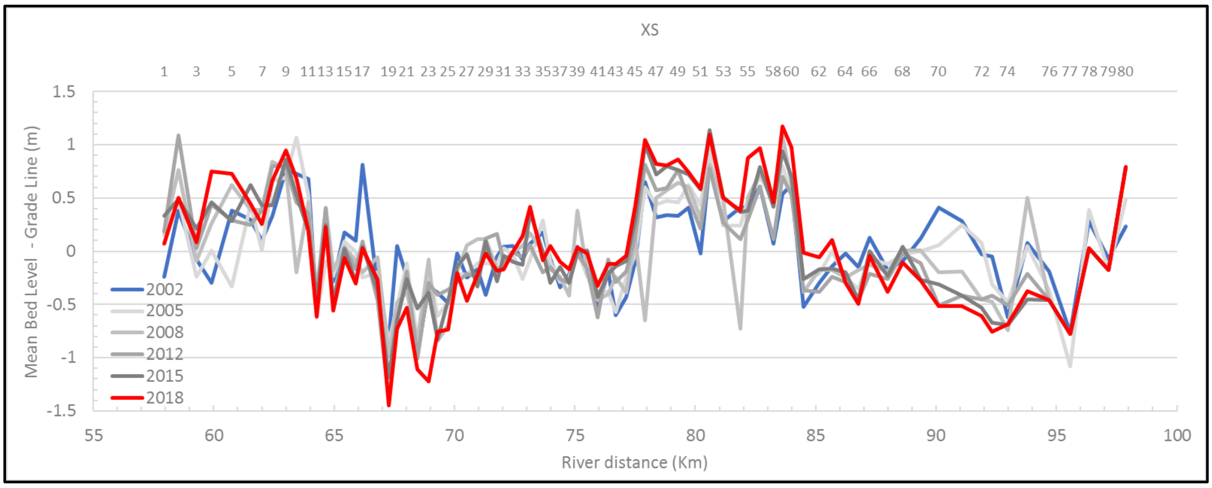


Figure 9-7: Change in time of the mean bed level relative to the grade line level along the Upper Tukituki River.

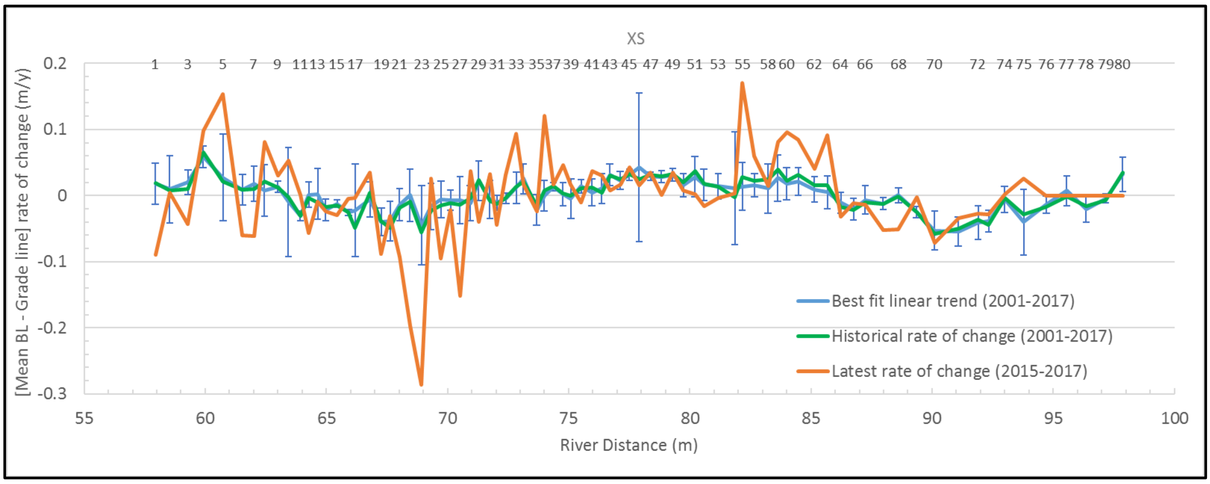


Figure 9-8: Rate of change of the mean bed level relative to the grade level along the Upper Tukituki River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

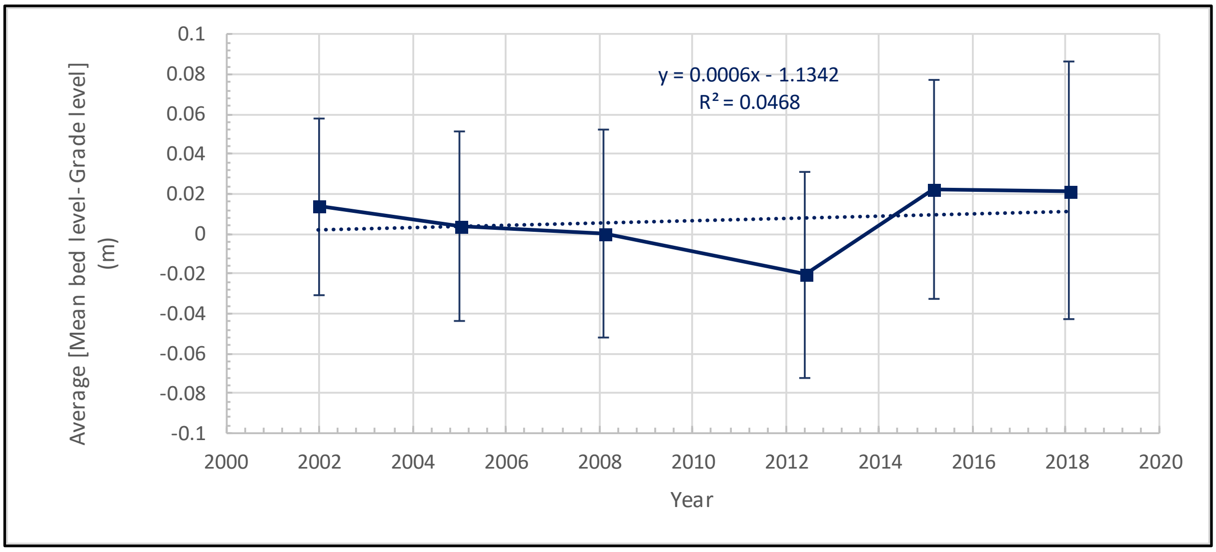


Figure 9-9: Change in time of the average mean bed level relative to the grade level along the Upper Tukituki River. Error bars indicate the standard error of the mean.

9.2.3 Active channel slope

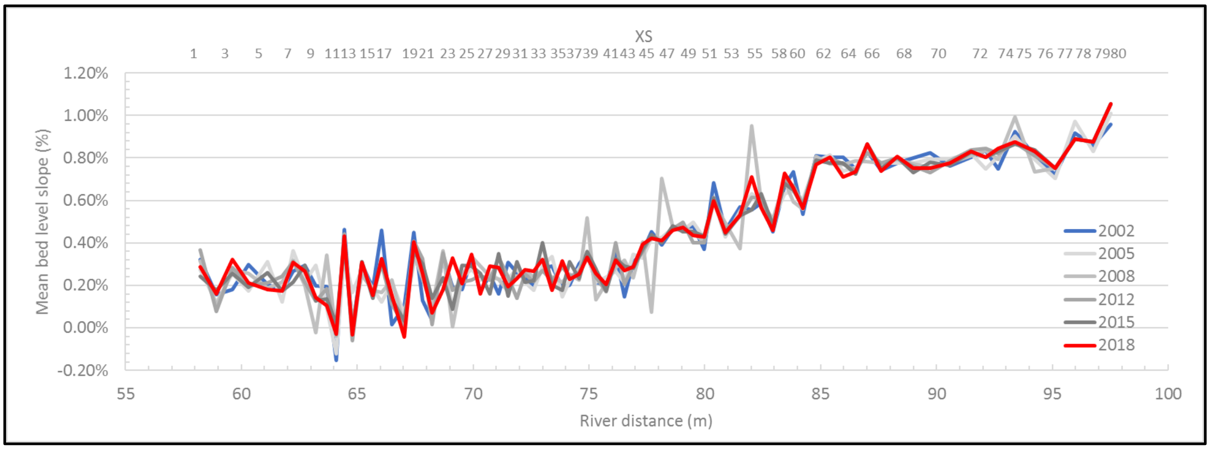


Figure 9-10: Change in time of the mean bed level slope along the Upper Tukituki River.

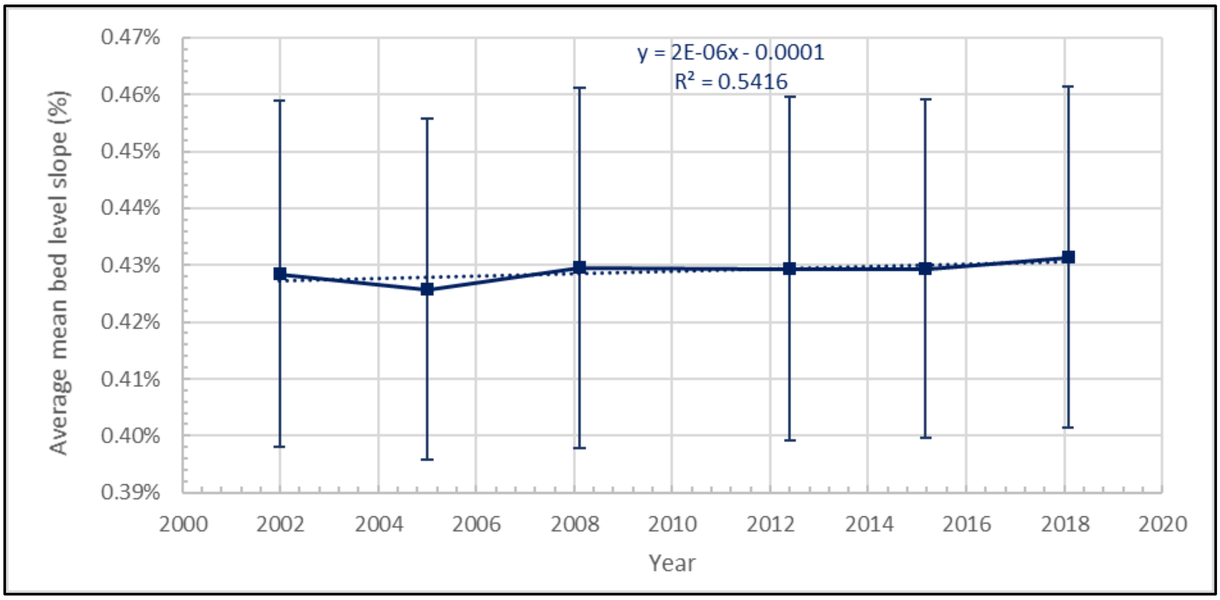


Figure 9-11: Change in time of the average mean bed level slope along the Upper Tukituki River. Error bars indicate the standard error of the mean.

9.2.4 Active channel width

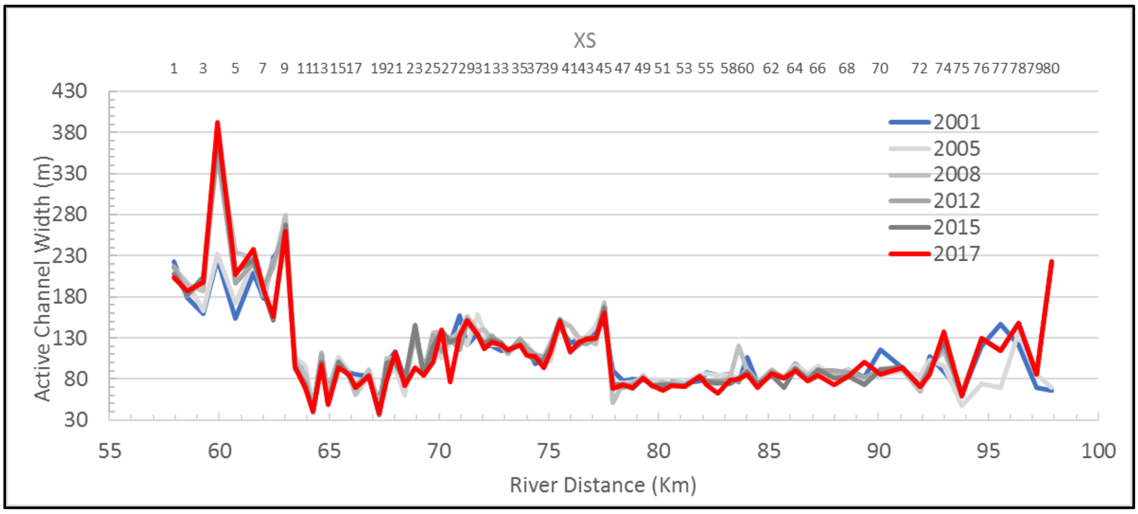


Figure 9-12: Change in time of the active channel width along the Upper Tukituki River.

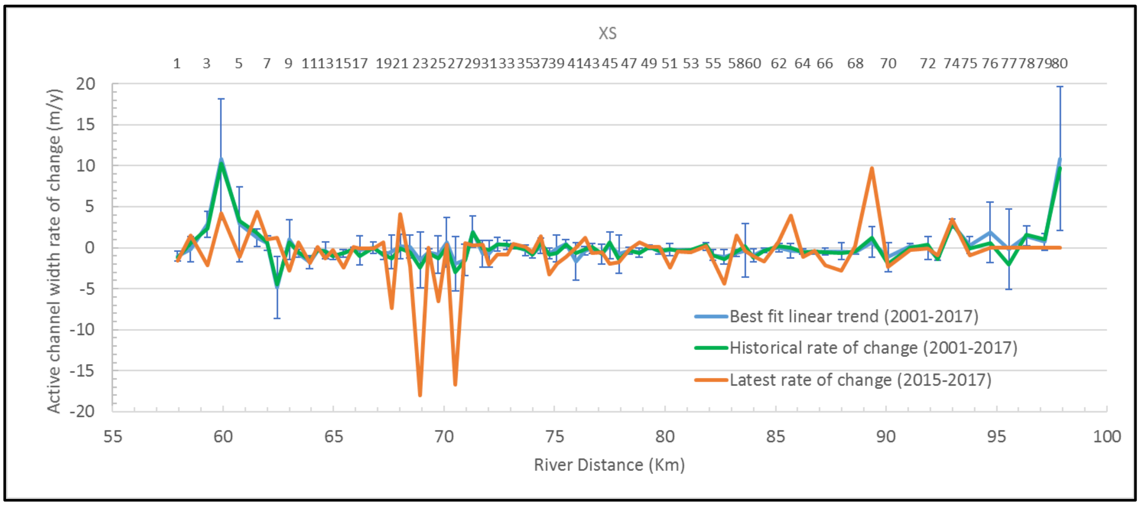


Figure 9-13: Rate of change of the active channel width along the Upper Tukituki River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

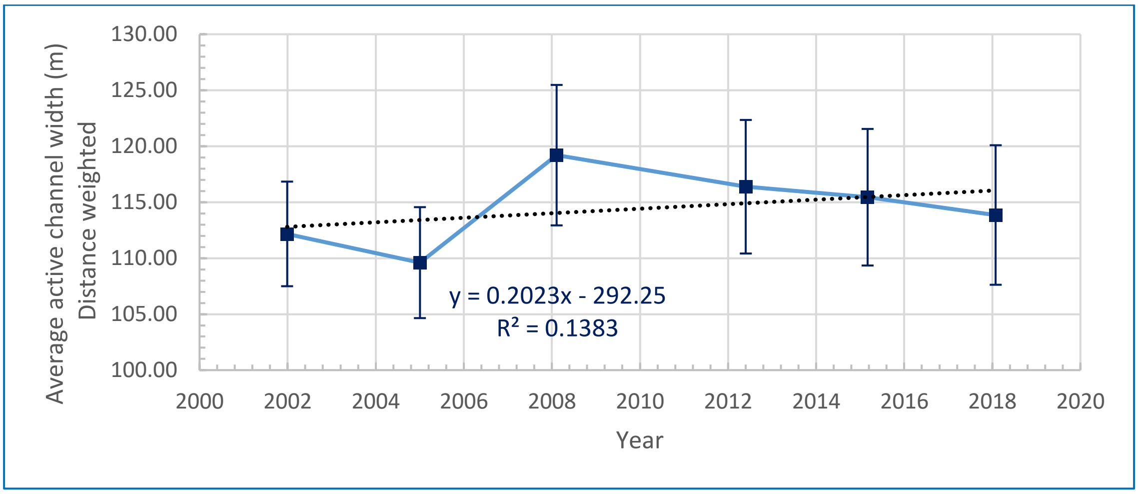


Figure 9-14: Change in time of the average active channel width distance weighted along the Upper Tukituki River. Error bars indicate the standard error of the mean at the cross section.

9.2.5 Relative maximum depth

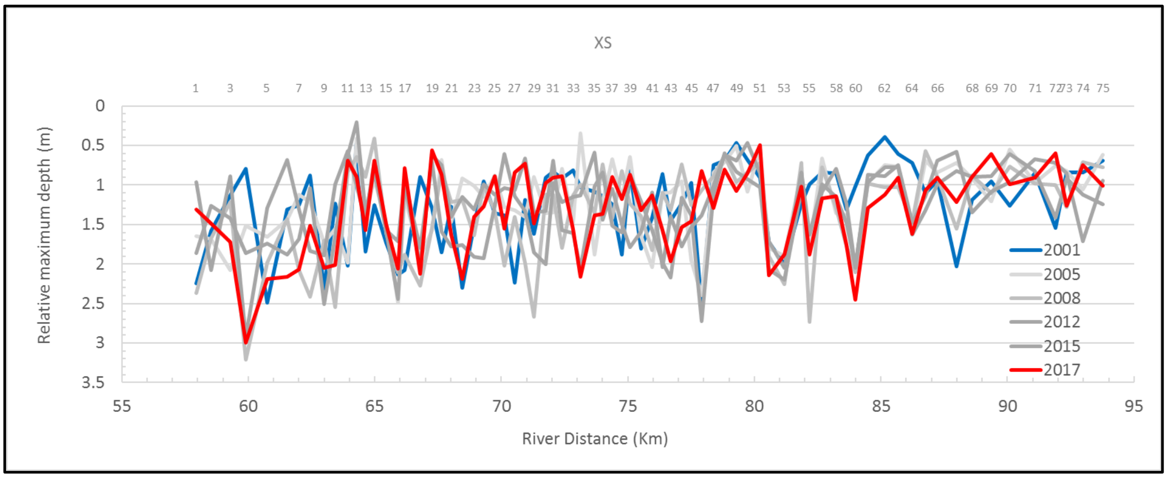


Figure 9-15: Change in time of the Relative Maximum Depth (Mean Bed Level – Min Bed Level) along the Upper Tukituki River. Note that the vertical axis is reversed for a more intuitive visualization of (water) depth.

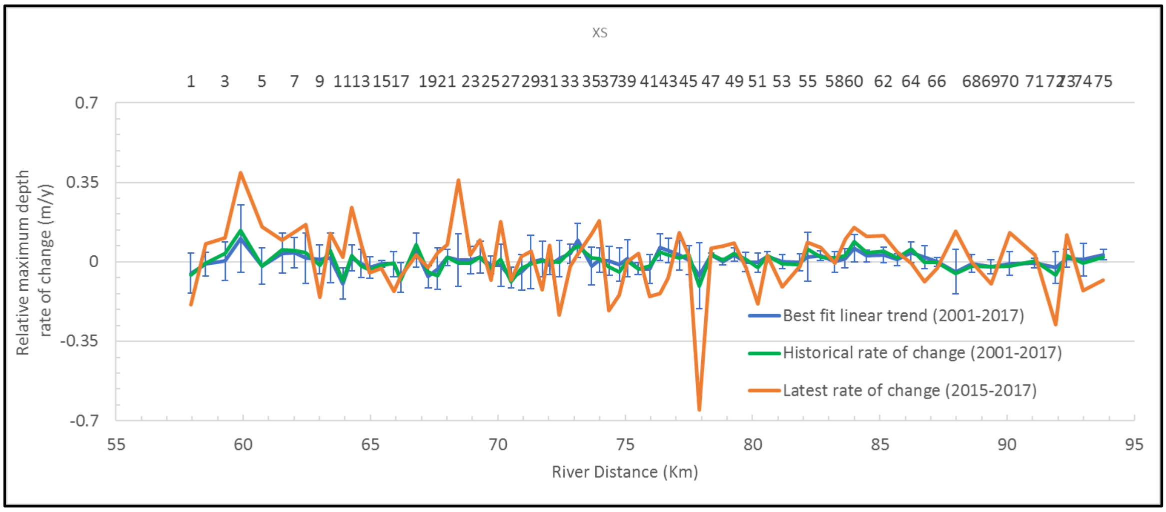


Figure 9-16: Relative Maximum Depth (Mean Bed Level – Min Bed Level) rate of change along the Upper Tukituki River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

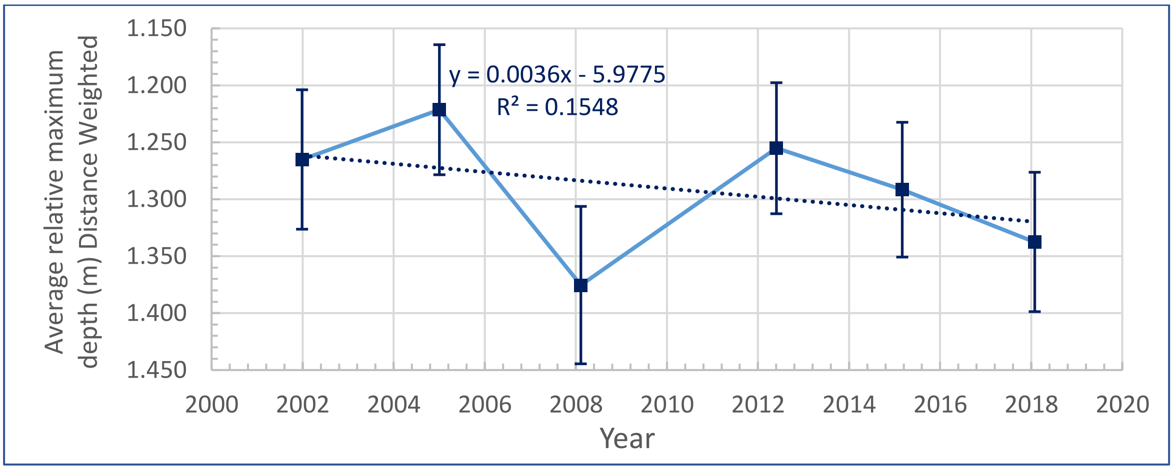


Figure 9-17: Change in time of the average the Relative Maximum Depth (Mean Bed Level – Min Bed Level) along the Upper Tukituki River. Error bars indicate the standard error of the mean. Note that the vertical axis is reversed for a more intuitive visualization of (water) depth.

9.3 Gravel Availability

9.3.1 Present

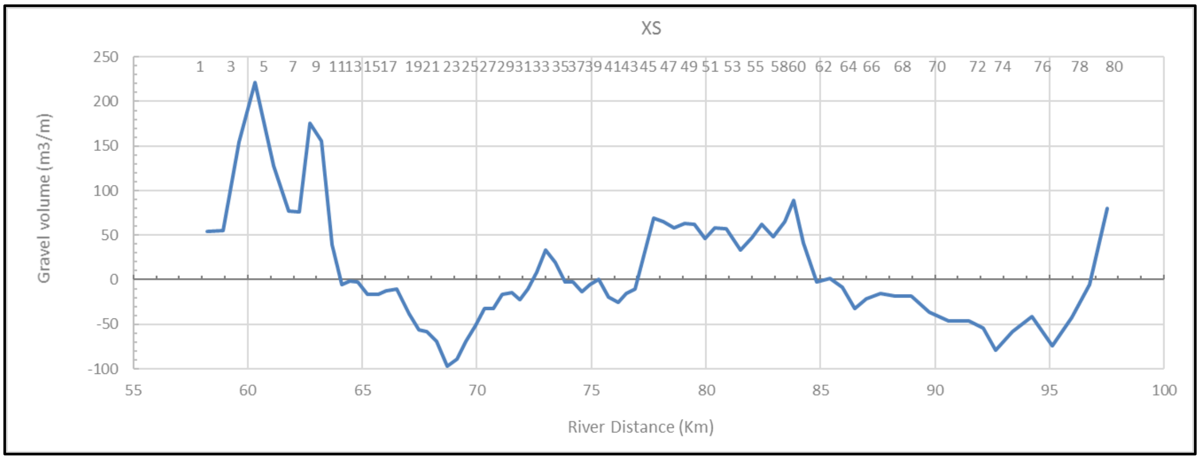


Figure 9-18: Estimated gravel availability for 2018 in the Upper Tukituki River (adapted from Beya & Byrne, 2018).

9.3.2 Historical change

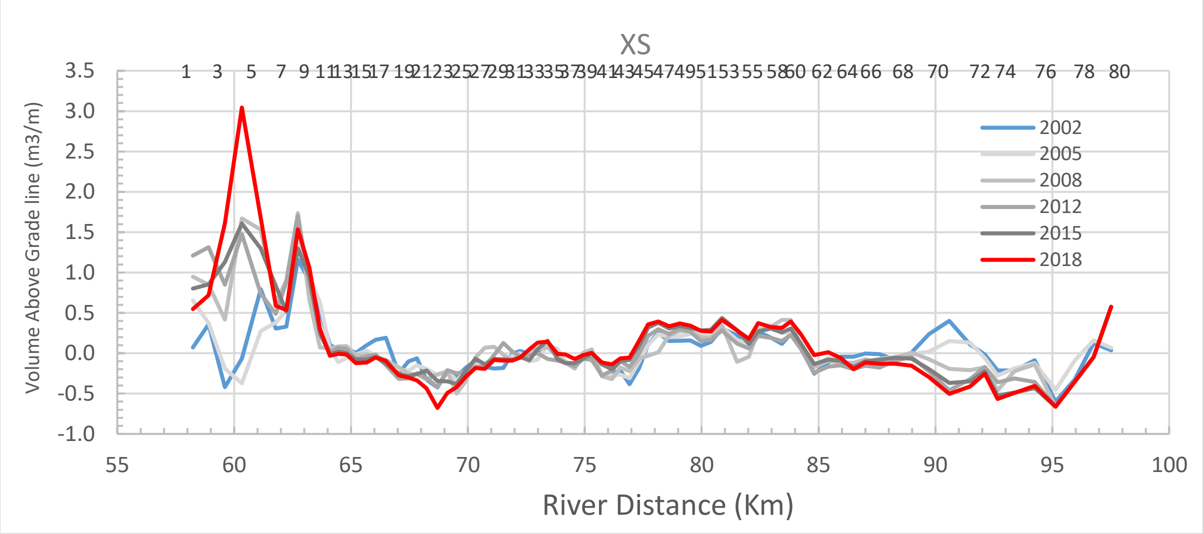


Figure 9-19: Historical change in measured gravel availability in the Upper Tukituki.

9.3.3 Cumulative analysis

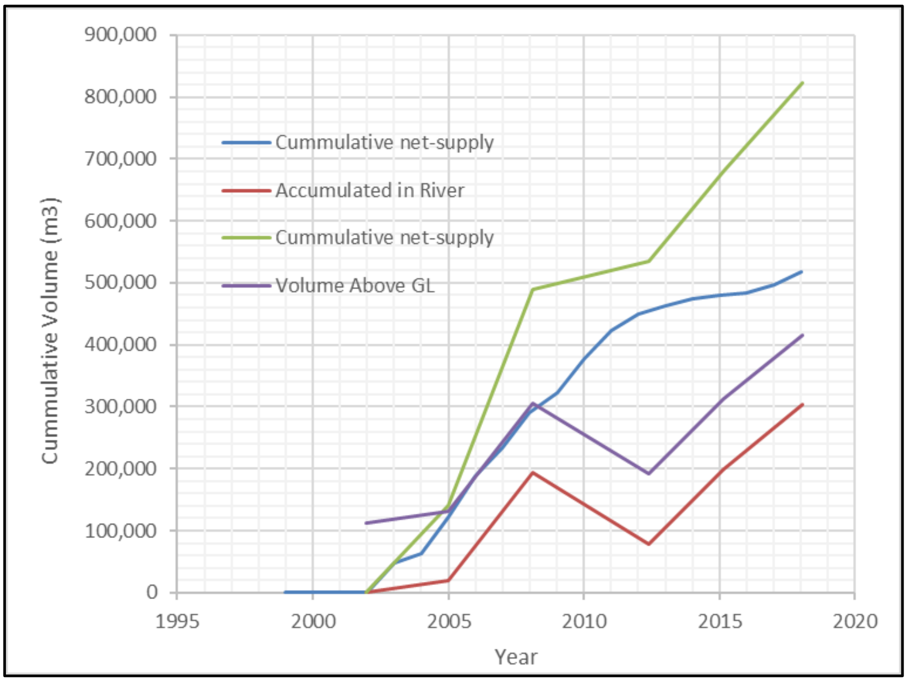


Figure 9-20: Cumulative volume analysis for the entire Upper Tukituki River

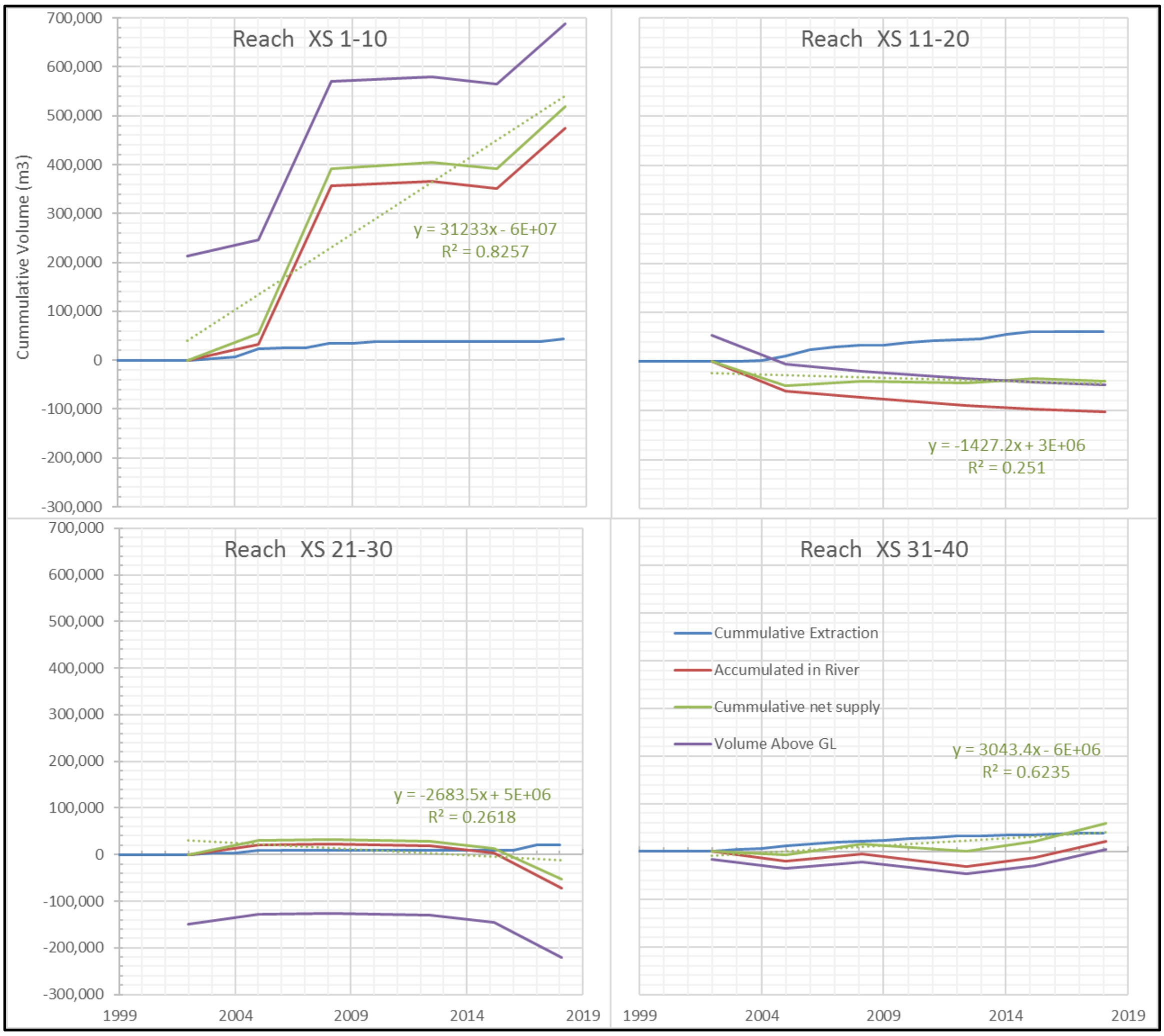


Figure 9-21: Cumulative volume analysis for different reaches between XS 1 and XS 40 in the Upper Tukituki River

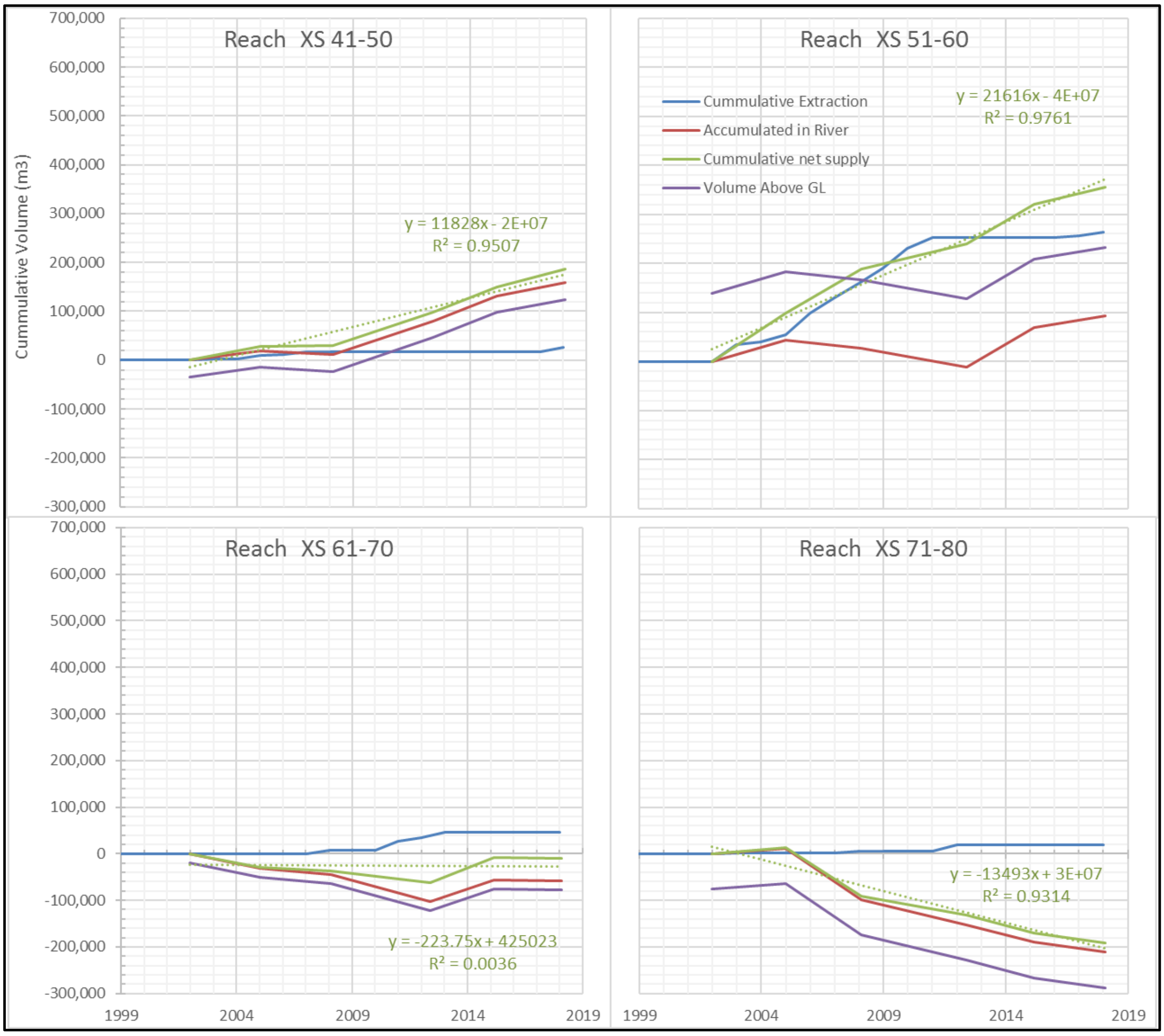


Figure 9-22: Cumulative volume analysis for different reaches between XS 41 and XS 80 in the Upper Tukituki River

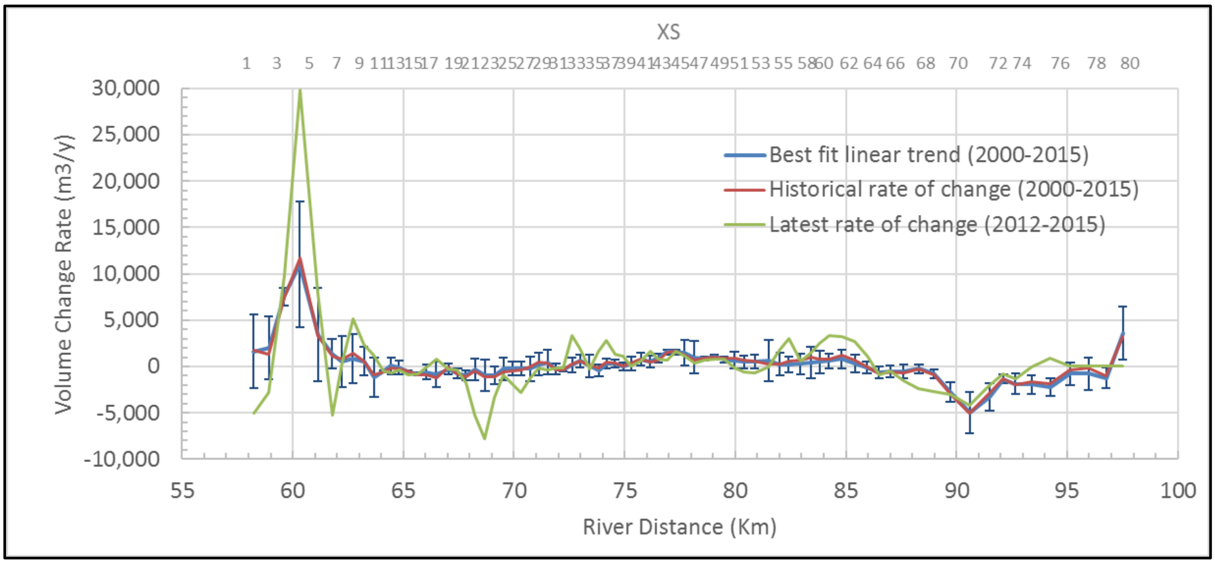


Figure 9-23: Volume change rates and trends along the Upper Tukituki River

9.3.4 Net-supply rates

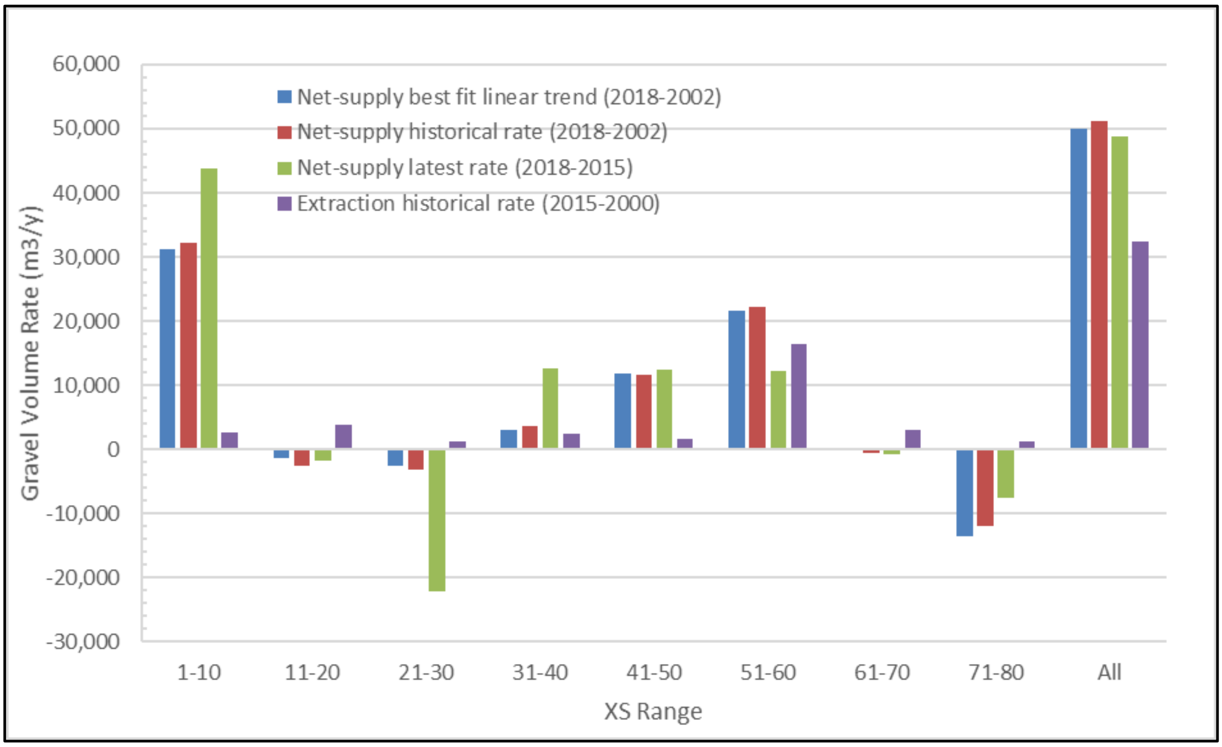


Figure 9-24: Gravel volumes net-supply long term and latest rates and best-fit trend and historical extraction rate in the Upper Tukituki River.

9.4 Discussion

MBL shows signs of stability, historically mildly increasing (0.5 mm/y) but latest trend shows a small decreasing trend (0.2 mm/y). The reach from XS 12 to XS 29 and from XS 64 to XS 79 show degradation up to 1.5 m and 0.7 m below the grade line respectively. On the other hand, the reaches from XS 1 to XS 11 and XS 45 to XS 61 show important aggradation greater than 1 m above the grade line. Overall, the surveys showed signs of degradation from 2002 to 2012 followed by aggradation from 2012 to 2015 and stability from 2015 to 2017. This observation shows a strong correlation with the extraction activity in the river with extraction locations centred about the main roads crossing the river.

Active channel slope has been increasing and the latest period has seen a steeper rise. The river appears to have three markedly distinct reaches with different slopes: from XS 1 to XS 40 an average slope of 0.23 %, from XS 41 to XS 61 slopes increasing upstream from 0.25 % to 0.80%, from XS 62 to XS 76 an average slope 0.80 % and from XS 77 to XS 80 slopes from 0.80 % to 1.1 %. Overall, the average river slope has mildly but steadily increased in time.

Active channel width shows a historical increase trend but the latest period shows a stronger decrease. Along the river, the largest changes have occurred between XS 3 and XS 5 and XS 74 and XS 80. The rest of the river has remained relatively stable. Although, the historical average trend indicates a mild widening of the channel, from 2008 onwards, there has been some decrease in the average channel width.

The relative mean depth, RMD shows an increasing trend which has been enhanced in the latest period. Along the channel, RMD appears to decrease upstream and show high variability between surveys.

There is presently substantial gravel resources above the grade line between XS 1 and XS 12, XS 44 and XS 62 and upstream XS 78.

The cumulative analysis for the entire river indicates that the net supply has been significantly greater than the extraction and therefore gravel has been accumulating in the river. However, this is only true for the reaches with gravel above the grade line, for the others it has been the opposite.

In the Upper Tukituki in particular gravel extraction can assist with sediment transport through the river system. Gravel aggradation of the main channel results in a local bed grade change (flattening) and reduction in transporting power. Extraction is effectively a manipulation of the main channel resulting in a deeper cross section. It was shown in the Ngaruroro modelling that with extraction, bedload transport rate increased due to a steepening of the bed gradient upstream of the extraction site with the opposite effect downstream.

10 Waipawa River

10.1 Background

The Waipawa River is an important tributary of the Tukituki River. The river has 22.2 Km of stopbanks protecting Waipawa and the surrounding farmland. The Mangaonuku is an important tributary that joins the river between XS 25 and XS 26 providing an important gravel supply for the Tukituki River. Willows have been planted along the berms to stabilize the active channel width. Gravel extraction and river raking have been regularly carried out along the reach (Figure 10-1).

Cross section data has been systematically measured in 55 cross sections (XS 1 to XS 54 including XS 27A) along the river since 1991, with non-systematic records dating from 1944 (Figure 10-2). The analysis in this chapter includes survey data from 1997 onwards.

Gravel extraction has been variable in time, with two important peaks in 1985 and from 2002 to 2009. Since 2014 extraction has been significantly reduced (Figure 10-3). Extraction location has changed over time. Prior to 2000 gravel extraction was located mainly between XS 8 and XS 17. After 2000 extraction was located at three preferential locations: from XS 9 to XS 13, from XS 23 to XS 27 and from XS 35 to XS 47 (Figure 10-4), related to road access.

A significant number of floods capable of mobilizing gravel have occurred in the river at relatively regular intervals but with a higher concentration from 2013 to 2018 (Figure 10-5).

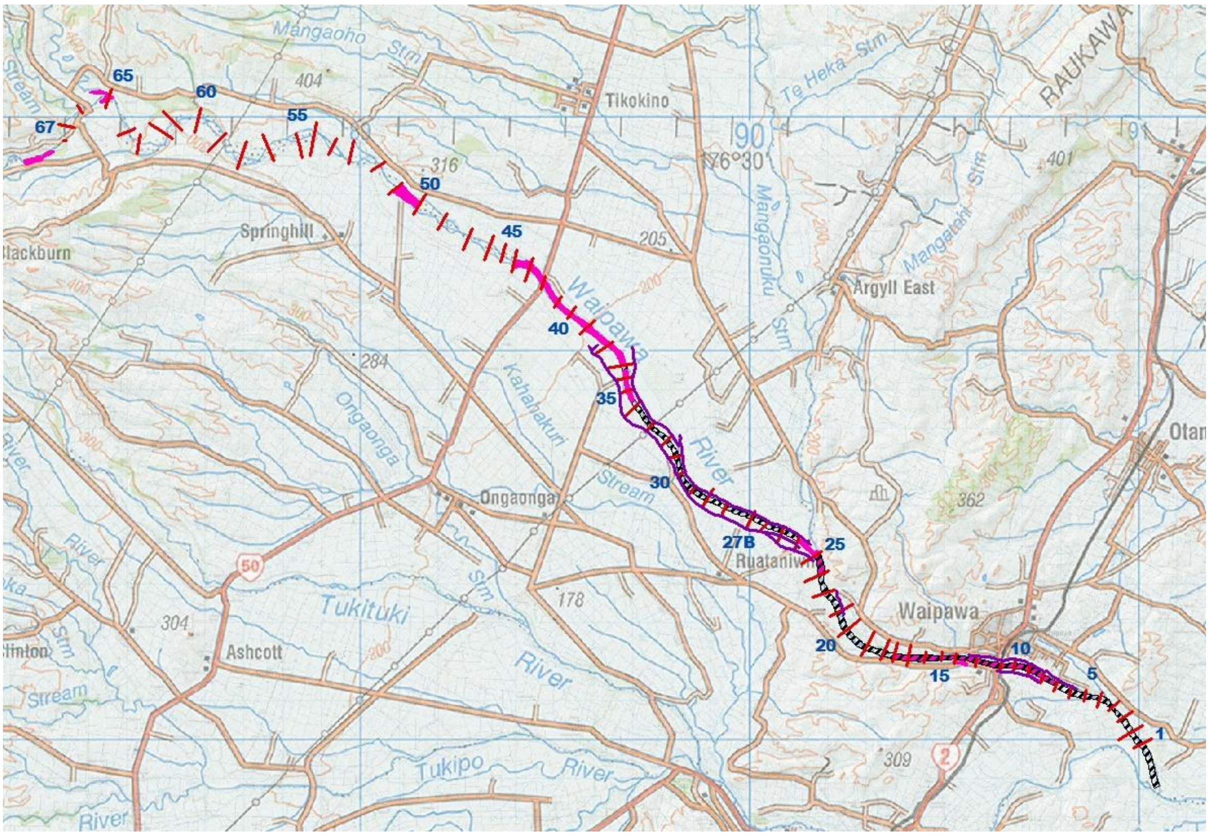


Figure 10-1: Location of the Waipawa River and an indication of cross sections, stopbanks, raking and gravel extraction. Blue numbers indicate XS numbers.

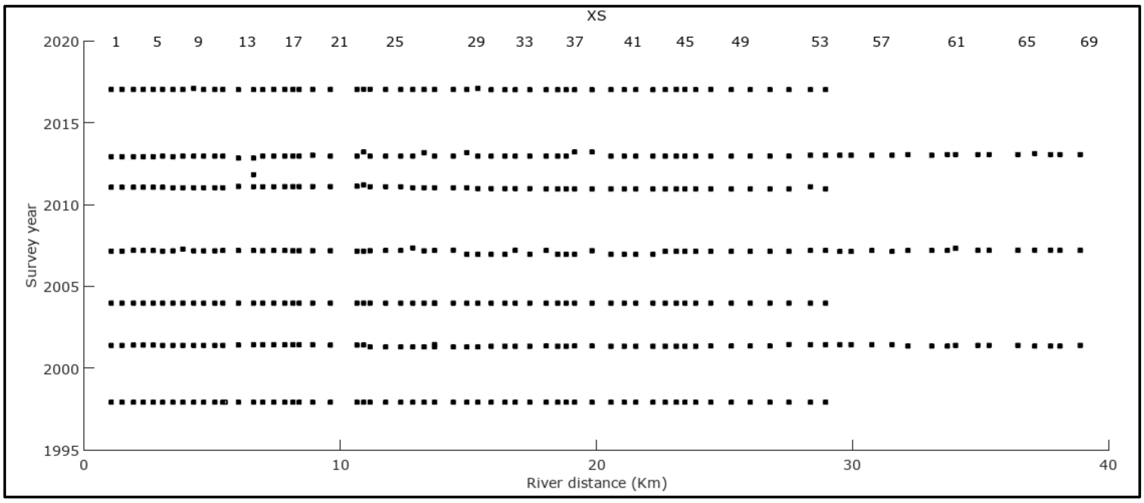


Figure 10-2: Cross section data availability for the Waipawa River. Each black dot represent a cross section survey.

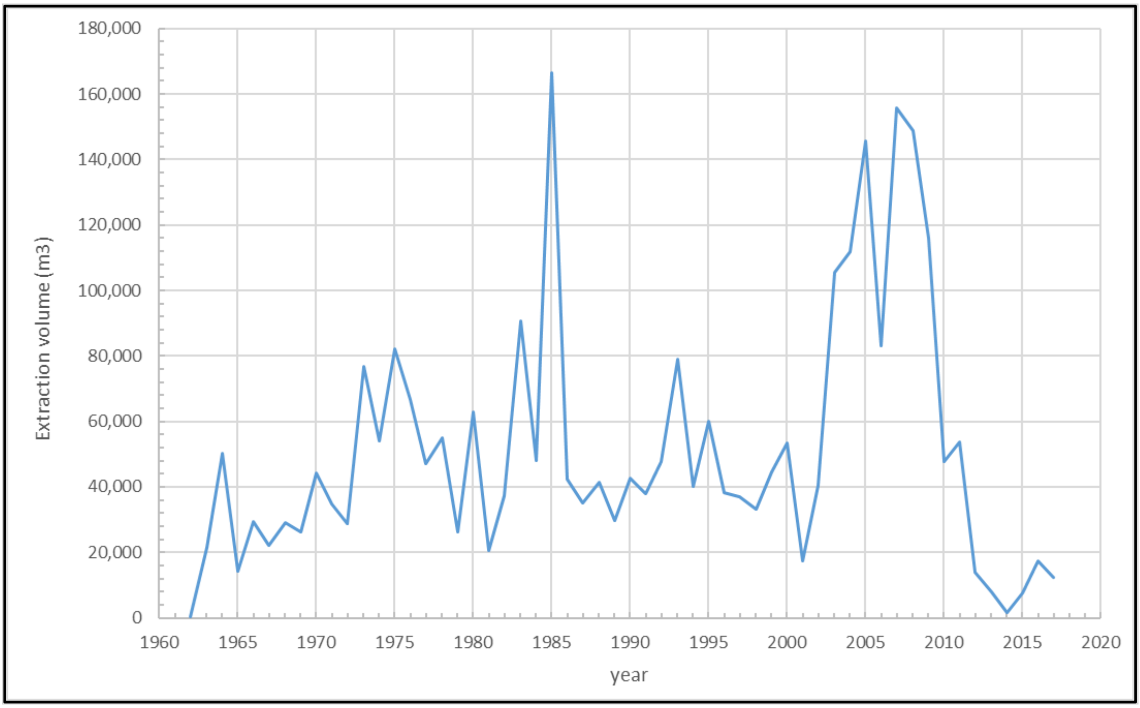


Figure 10-3: Time series of total gravel extraction volumes in the Waipawa River.

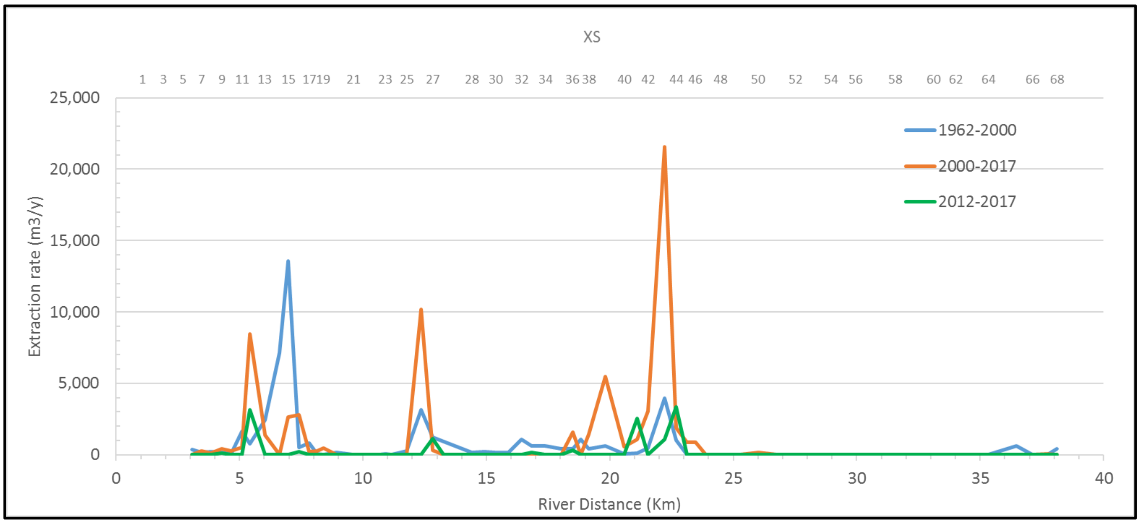


Figure 10-4: Average gravel extraction rates along the Waipawa River for three different periods.

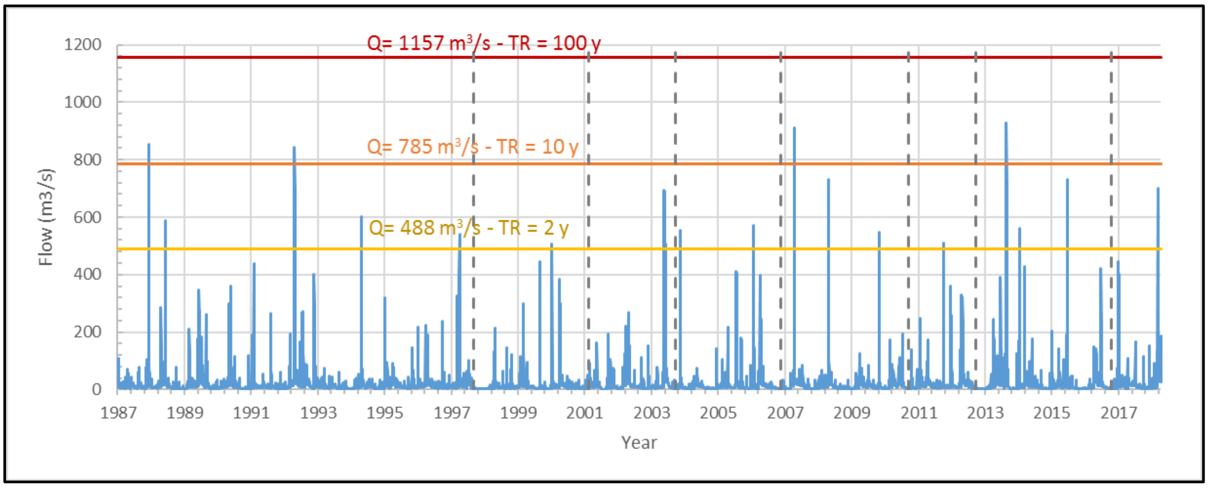


Figure 10-5: Waipawa River hourly flows at RDS/SH2. Return values from Carruth (2015a). Vertical grey dashed lines indicate the survey dates used for the analysis in this chapter. Earlier dates have not been considered in the analysis.

10.2 Observed Morphological Changes

10.2.1 Summary

Table 10-1: Average historical and latest rates of change of morphological parameters in the Waipawa River. The period of analysis is indicated in brackets. The parameters definition is outlined in section 3.

Symbol	**Parameter**	**Historical best fit trend (2000-2015)**	**Average of historical rate of change (2000-2015)**	**Average of Latest rate of change (2012-2015)**	**Units**
MBL	Mean bed level (-ve below grade line)	-0.0039	-0.0010	0.0190	m/y
S_{MBL}	Mean bed level slope	$-8.8\text{x}10^{-6}$	$5.4\ \text{x}10^{-6}$	$1.6\ \text{x}10^{-6}$	%/y
$AChW$	Active channel width	-0.89	-1.19	0.00	m/y
RMD	Relative maximum depth (+ve deeper)	-0.00015	-0.00272	0.00654	m/y

10.2.2 Active channel mean bed level

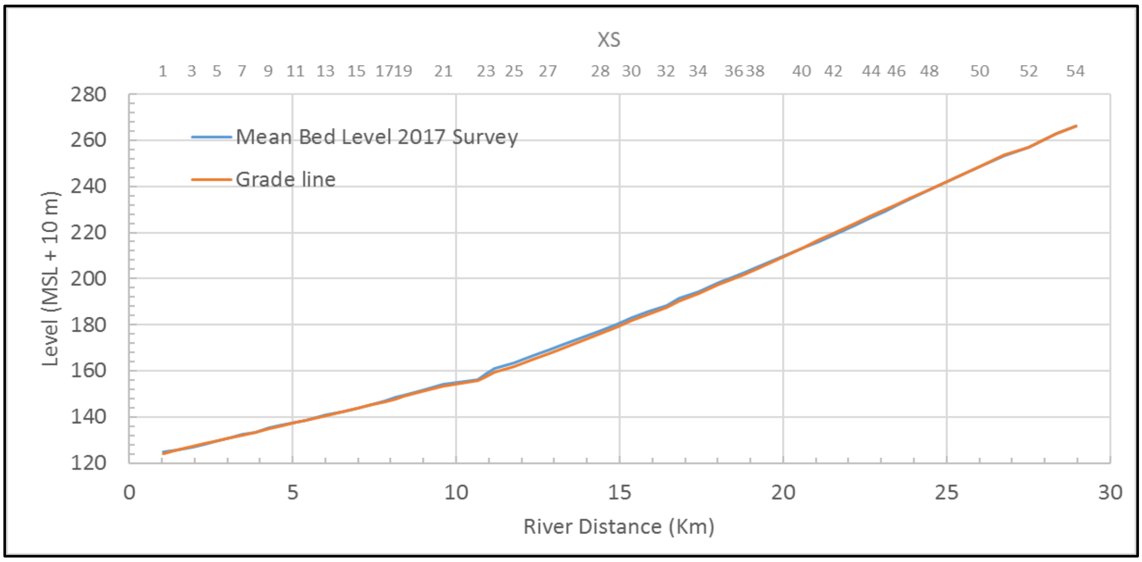


Figure 10-6: Mean bed level and design grade-line for the Waipawa River

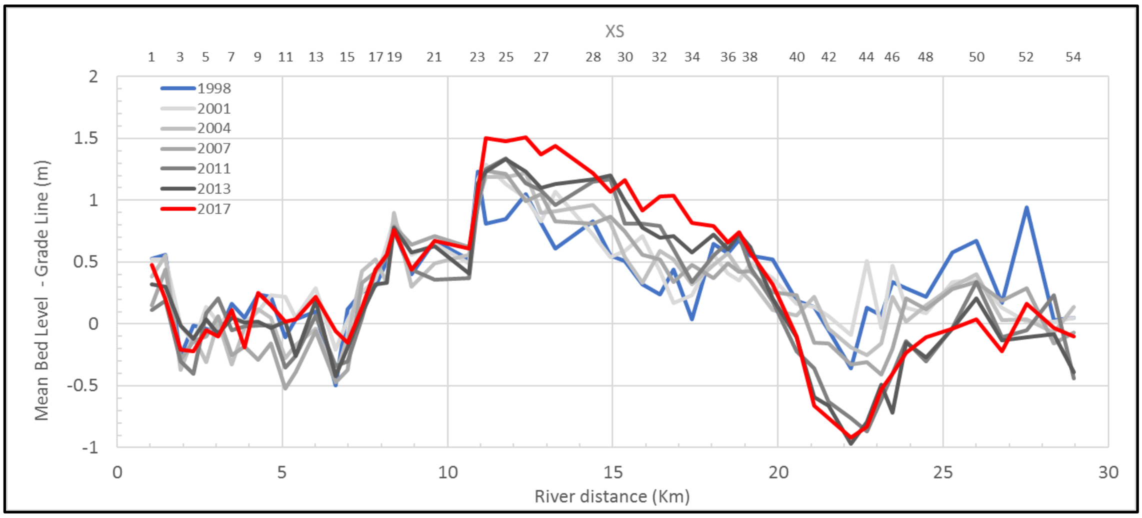


Figure 10-7: Change in time of the mean bed level relative to the grade line level along the Waipawa River.

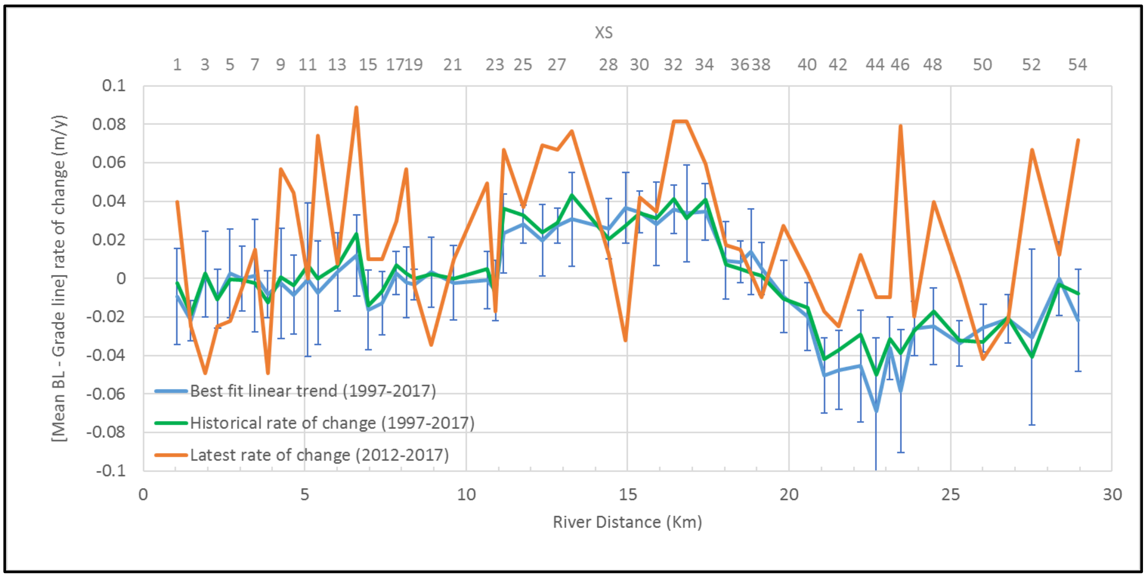


Figure 10-8: Rate of change of the mean bed level relative to the grade level along the Waipawa River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

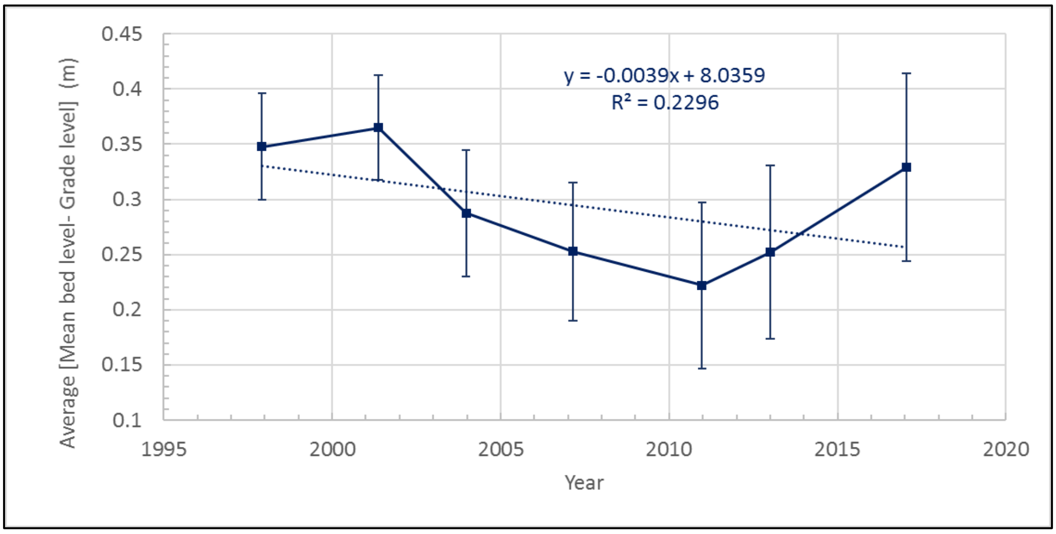


Figure 10-9: Change in time of the average mean bed level relative to the grade level along the Waipawa River. Error bars indicate the standard error of the mean.

10.2.3 Active channel slope

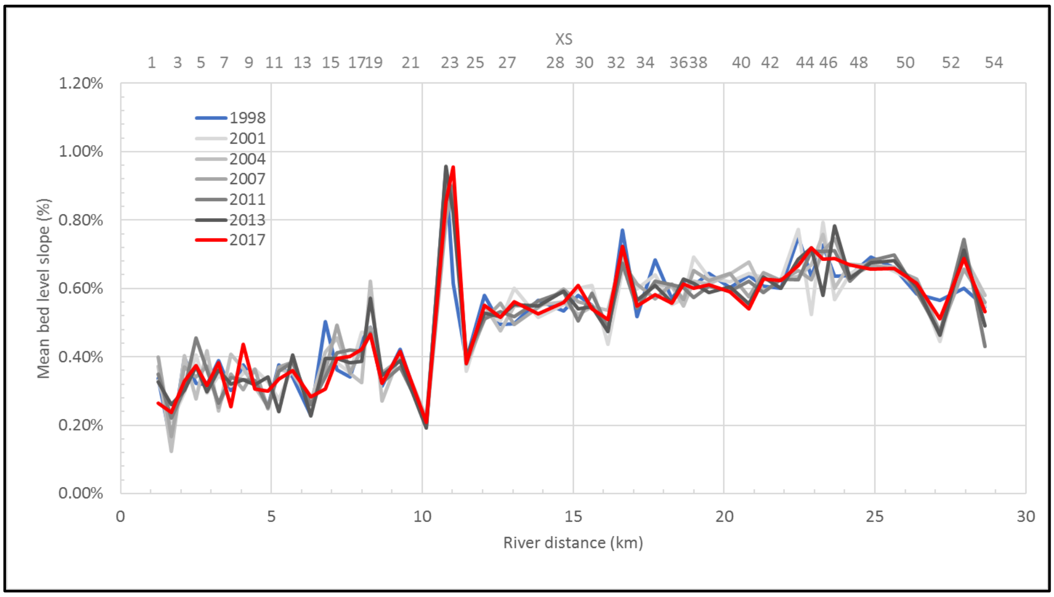


Figure 10-10: Change in time of the mean bed level slope along the Waipawa River.

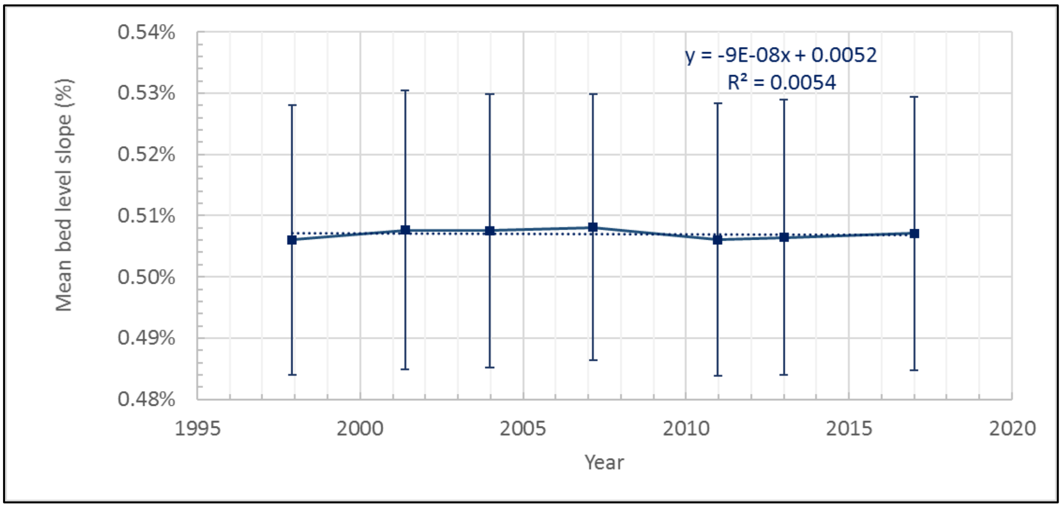


Figure 10-11: Change in time of the average mean bed level slope along the Waipawa River. Error bars indicate the standard error of the mean.

10.2.4 Active channel width

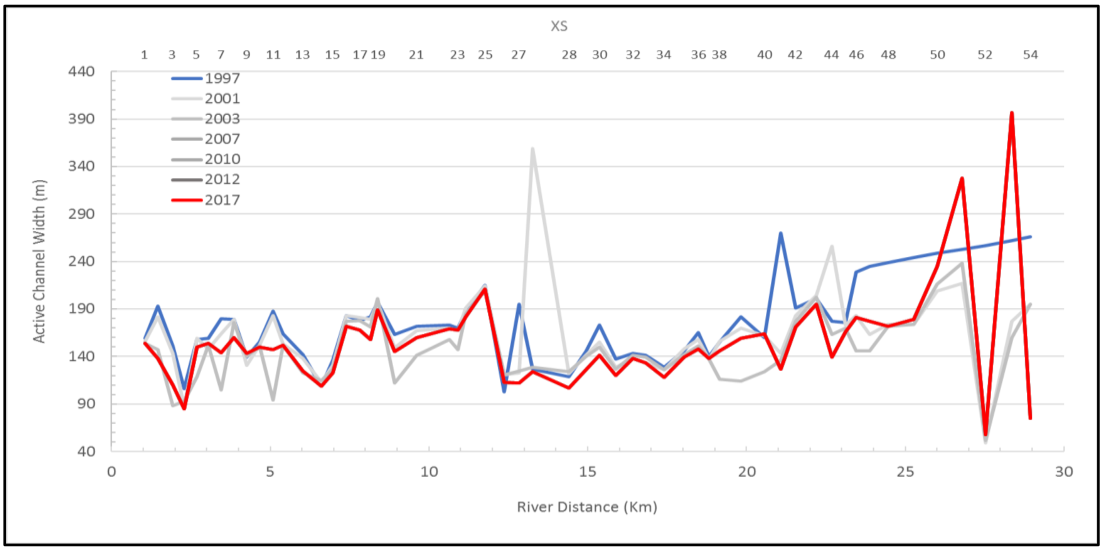


Figure 10-12: Change in time of the active channel width along the Waipawa River.

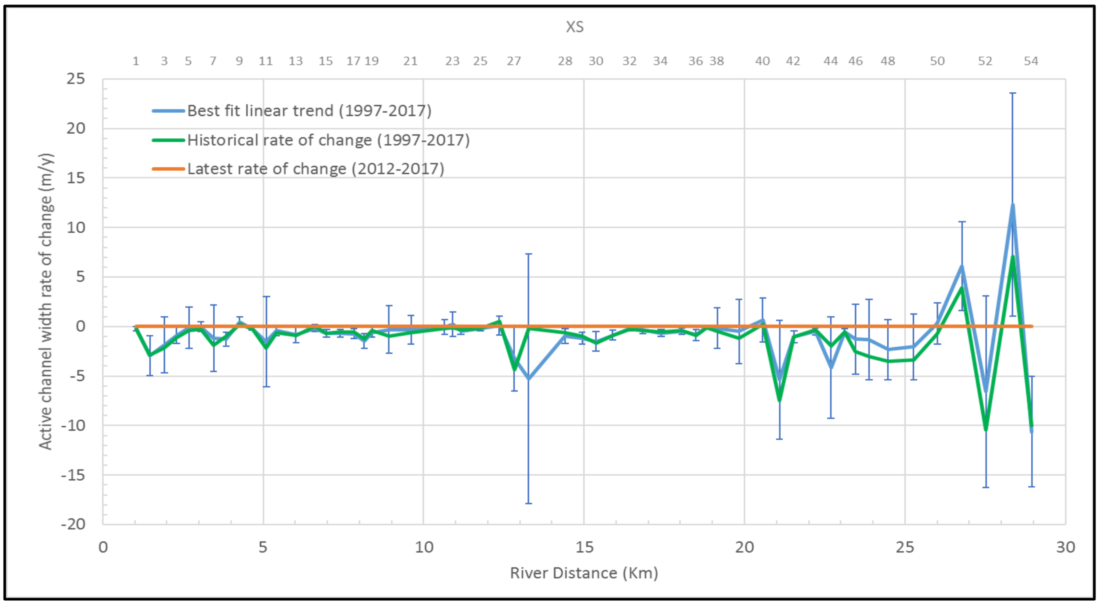


Figure 10-13: Rate of change of the active channel width along the Waipawa River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

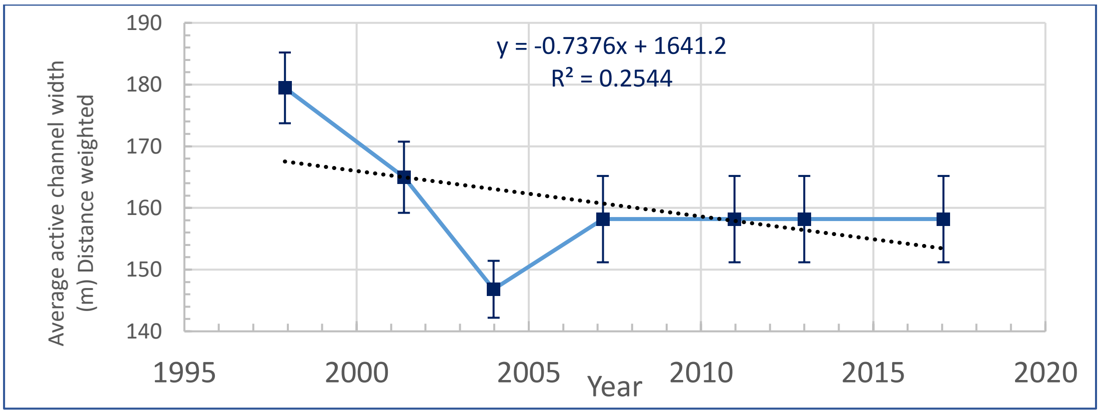


Figure 10-14: Change in time of the average active channel width distance weighted along the Waipawa River. Error bars indicate the standard error of the mean at the cross section.

10.2.5 Relative maximum depth

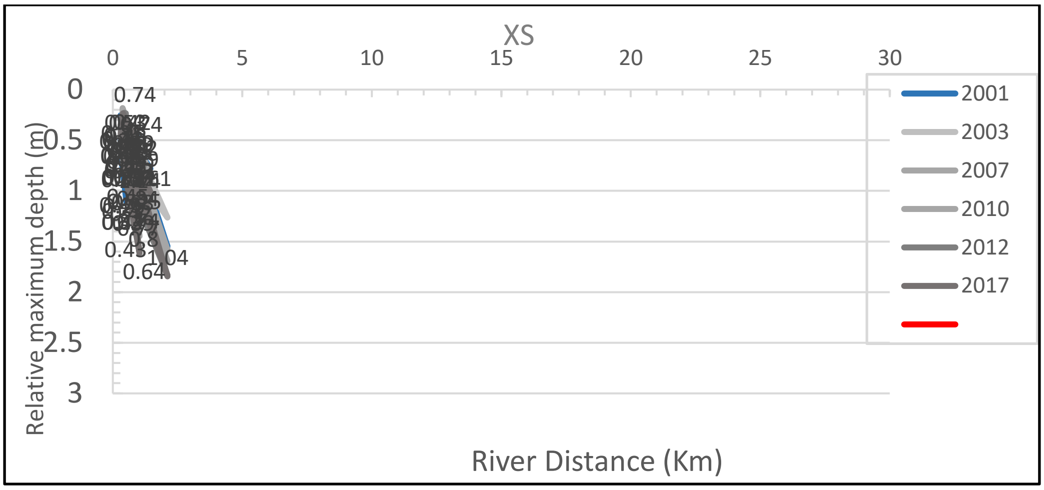


Figure 10-15: Change in time of the Relative Maximum Depth (Mean Bed Level – Min Bed Level) along the Waipawa River. Note that the vertical axis is reversed for a more intuitive visualization of (water) depth.

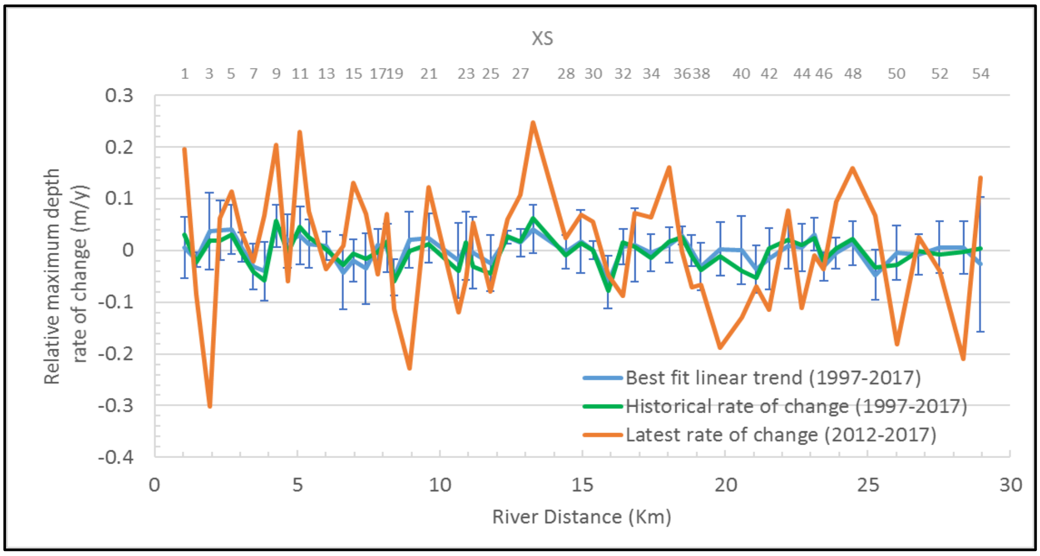


Figure 10-16: Relative Maximum Depth (Mean Bed Level – Min Bed Level) rate of change along the Waipawa River. Error bars indicate the 95 % confidence intervals obtained from best-fit analysis.

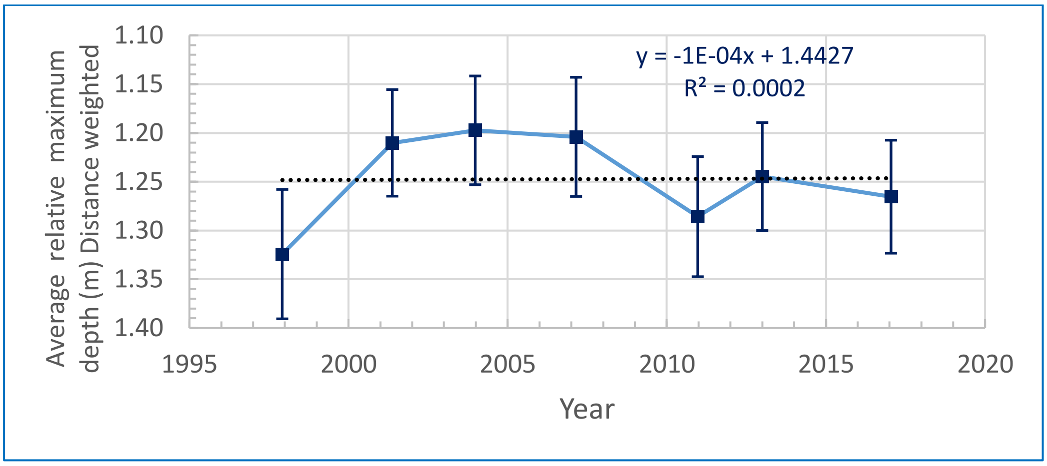


Figure 10-17: Change in time of the average the Relative Maximum Depth (Mean Bed Level – Min Bed Level) distance weighted along the Waipawa River. Error bars indicate the standard error of the mean at the cross section. Note that the vertical axis is reversed for a more intuitive visualization of (water) depth.

10.3 Gravel Availability

10.3.1 Present

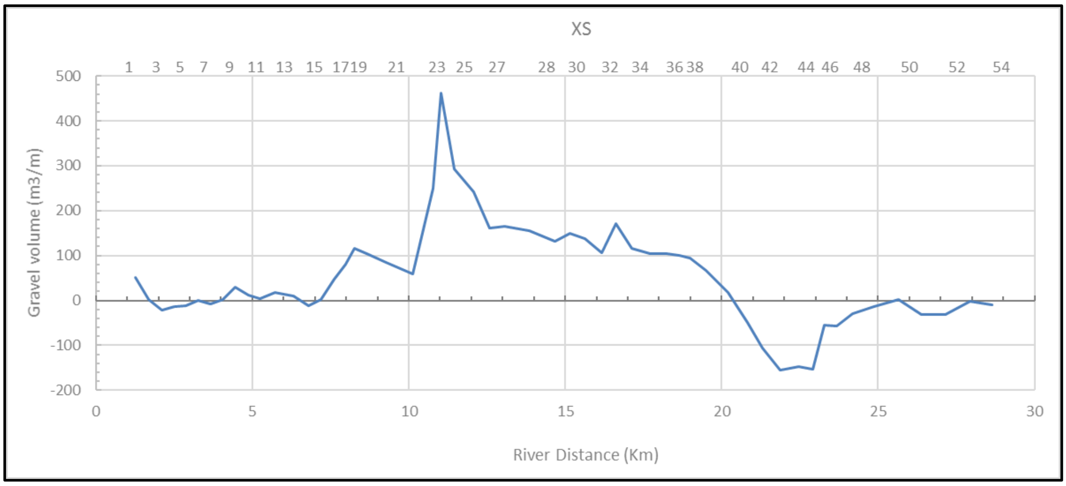


Figure 10-18: Estimated gravel availability for 2018 in the Waipawa River (adapted from Beya & Byrne, 2018).

10.3.2 Historical change

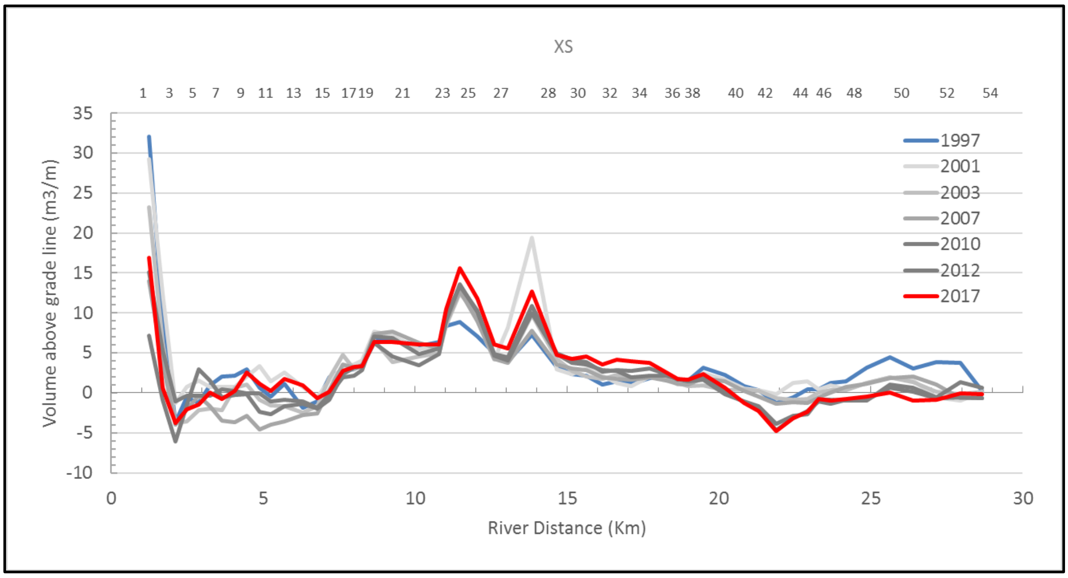


Figure 10-19: Historical change in measured gravel availability in the Waipawa.

10.3.3 Cumulative analysis

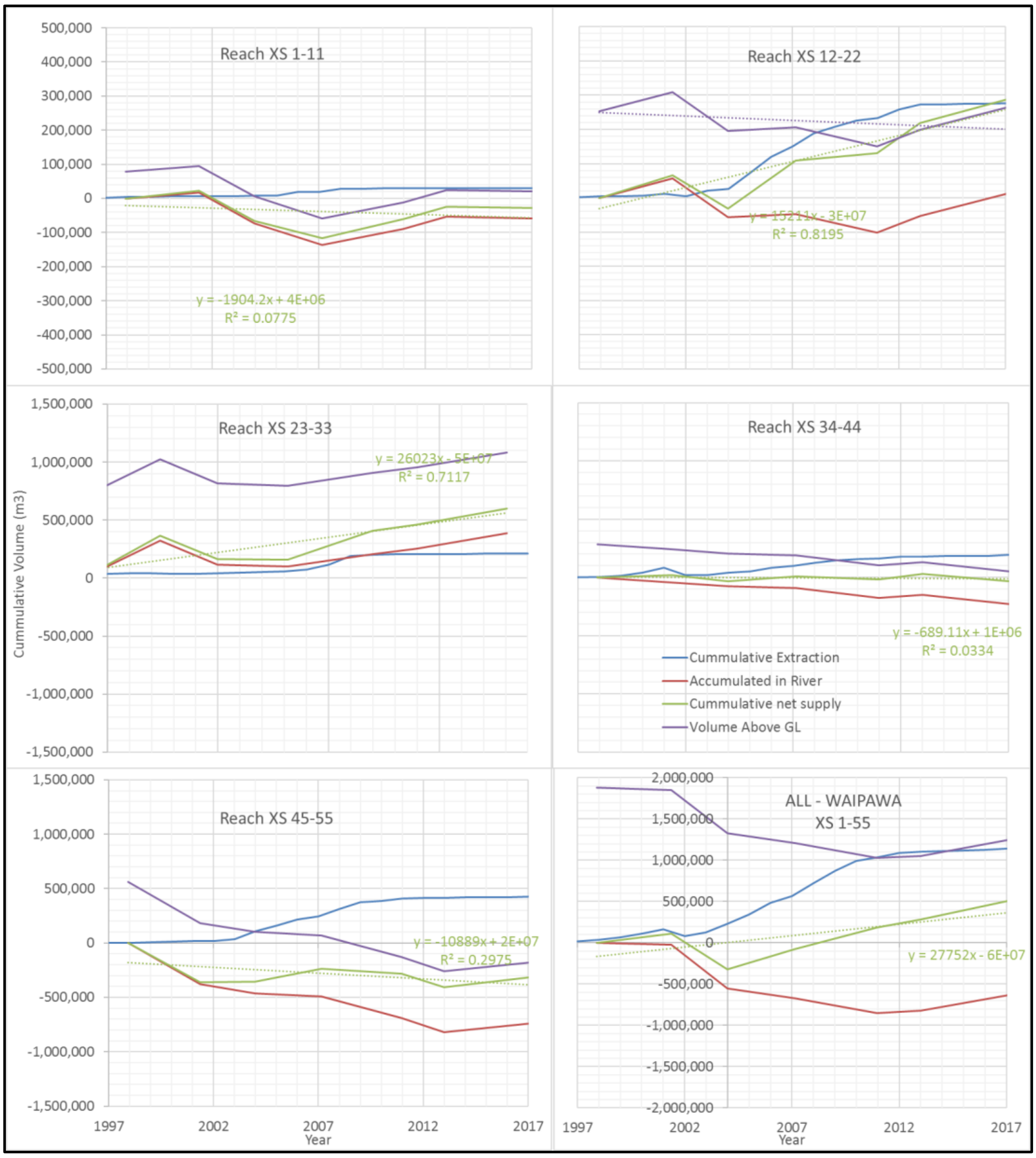


Figure 10-20: Cumulative volume analysis for different reaches in the Waipawa River

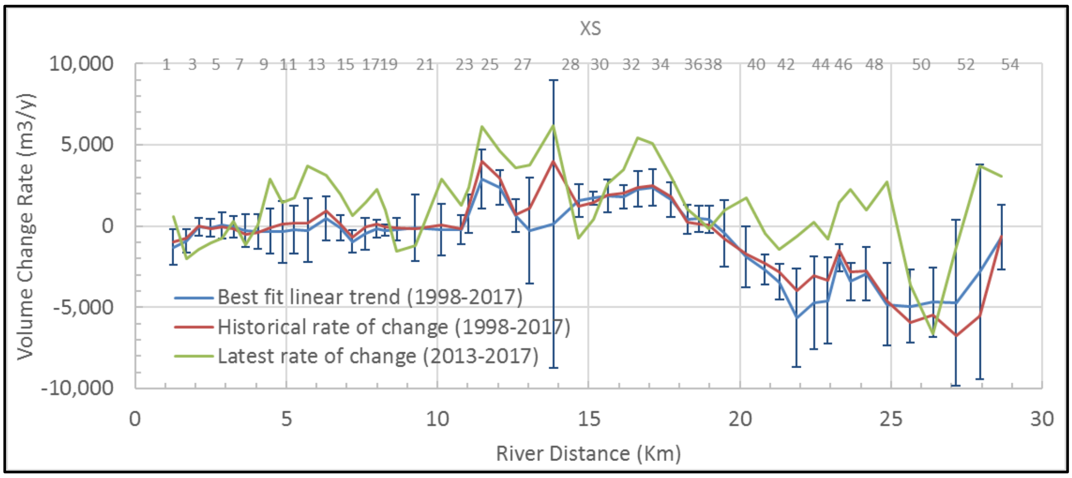


Figure 10-21: Volume change rates and trends along the Waipawa River.

10.3.4 Net-supply rates

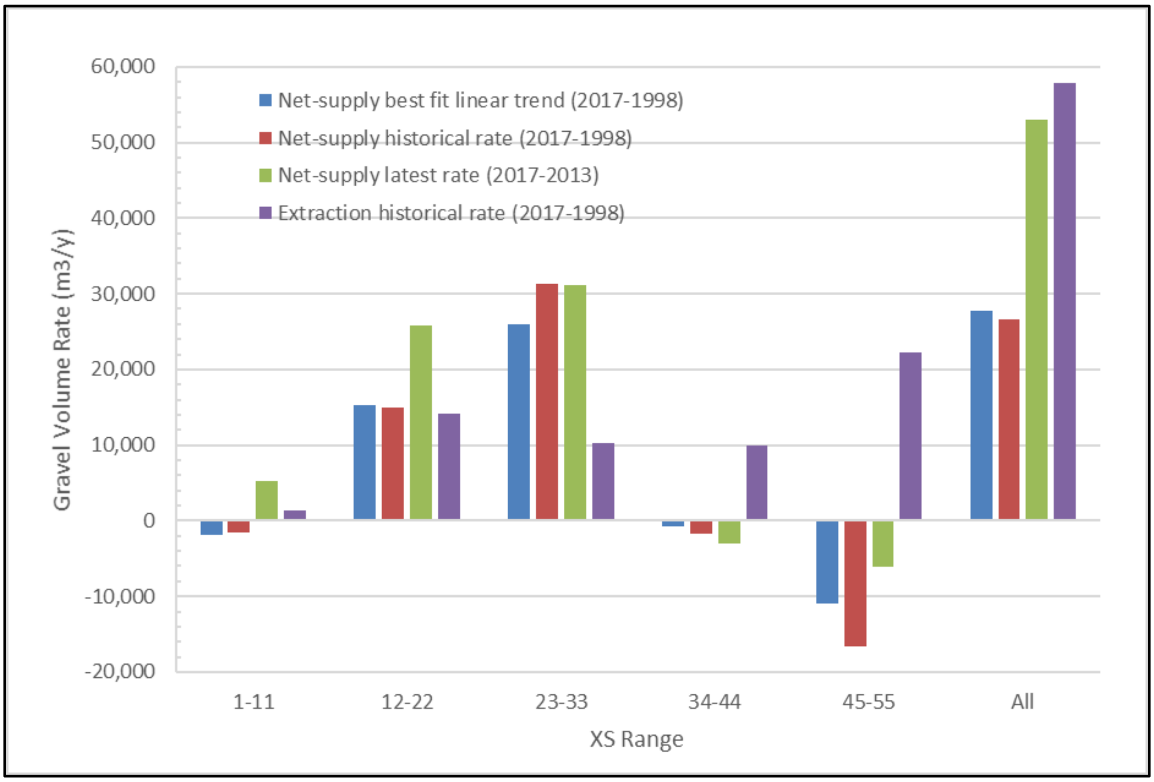


Figure 10-22: Gravel volumes net-supply long term and latest rates and best-fit trend and historical extraction rate in the Waipawa River.

10.4 Discussion

MBL decreasing historically (1 mm/y) but increasing in the latest period (19 mm/y). MBL are significantly higher than the grade line. The river is mostly aggraded or at the grade line from XS 1 to XS 40. Upstream XS 40 the river is significantly degraded up to 1 m below the grade line. From XS 23 to XS 38 the river bed has risen significantly by more than 0.5 m since 1997. From XS 38 to XS 55 the bed has degraded by approximately a similar amount. Overall in time, there is a decreasing trend, although, from 2012 onwards there has been a steep rise of the average MBL. This is strongly correlated with the significant decrease in gravel extraction after 2011.

Slope shows a slightly decreasing trend but net historical and latest rates of change are positive. Along the reach there is high variability but in general the slope increases upstream. From XS 0 to 25 there is a high variability in the slopes where the highest (0.96%) and lowest (0.21 %) slopes are found. In general in time the average slope has been maintained relatively stable near 0.51%.

AChW is decreasing in time and the latest period shows negligible change. However, the data used has been assumed equal to the previous measurement after 2007. Future work needs to be undertaken to complete this assessment. Nevertheless, there is a noticeable decrease in AChW over time prior 2007 probably caused by vegetation growth.

The relative maximum depth, RMD has been decreasing slightly historically but the latest rate of change indicates an increase. There is a high variability during surveys and along the river. This parameter has been on average relatively stable in time and along the river.

There is presently significant amount of gravel available downstream of XS 40 probably due to the relatively little extraction in the latter years. Upstream of XS 40 there is a deficit that may have been caused due to increased transport to the sections downstream which have been heavily extracted during the 2000s.

The cumulative analysis indicates that overall, the extraction has been greater than the net-supply which was due to the initial large availability gravel above the grade line. There is still a large supply that needs to be extracted at a higher rate than the net-supply in order to bring the bed levels near the design.

11 Lower Tukituki 1978 to 2015

This section examines a longer time period than the previous work in earlier sections of this report which was based mainly on the past two decades where there is consistent data for all the rivers. It has been carried out just for the Lower Tukituki River because this is the main river supplying gravel to the coast. The analysis is based on the gravel balance equations described in Section 2.3.7

11.1 Sediment Volume Plots

Figure 11-1 and Figure 11-2 below are graphs of the sediment volumes, extraction and supply to the chosen reach over the survey period. The survey period is 1978 to 2015 (37.2 years).

- The supply volume reaching the coast, taken as the average supply of the inter-survey periods, is 123,244 m^3 /survey period. The average annual rate is 37,580 m^3/year transport to the coast.
- It was found in the modelling work (GRATE) for the Ngaruroro River (*Modelling of Gravel Transport and Bed Level change in the Ngaruroro River by NIWA 2012),* that even though the extraction reduced the amount of gravel propagating downstream, for significant amounts to reach the coast, it was likely that major aggradation of the bed would first have to occur in order to increase the slope of the downstream reach and hence the transport rate.
- Although still under development, preliminary results from the lower Tukituki modelling indicate that historic gravel extraction in the lower Tukituki has increased transport rates within the extraction reach, but reduced transport out of the extraction reach to the coast by approximately 20%. These changes have been caused primarily by reduced bed levels in the extraction reach (increasing slope upstream of the reach and decreasing slope downstream), as well as by removing/breaking up the armour layer within the extraction reach (promoting increased transport).
- The model also shows that extraction in the middle and upper Tukituki has no significant effect on coastal supply. Even after 100 years of simulation extraction in these reaches has no significant effect on the coast.
- Ceasing gravel extraction will likely allow bed levels to gradually recover, increasing transport rates back toward their natural level over time.
- In the upper reach XS 22-29 the grade-line is at or near bedrock (papa) in some places. Gravel extraction from this reach has been minimal and for the no-extraction case the supply to the reach is zero until the 2009-2012 and later surveys.
- Gravel transport rates are very dependent on the time period chosen for analysis. Supply to any reach over time is sporadic, with significant movement during floods and very little movement during low flow stages. Although more frequent floods increase the supply of gravel to the coast, there is a lag between events and actual transport to the coast.

Table 11-1 *Reference reaches and distance from the coast. XS 4 is at Black Bridge, XS 29 is at Red Bridge*.

Reference Reach	Distance from Coast (km)
XS 1 – 4	0.39 - 1.6
XS 4 - 16	1.60 - 6.41
XS 16 - 22	6.41 - 8.81
XS 22 - 29	8.81 – 14.87

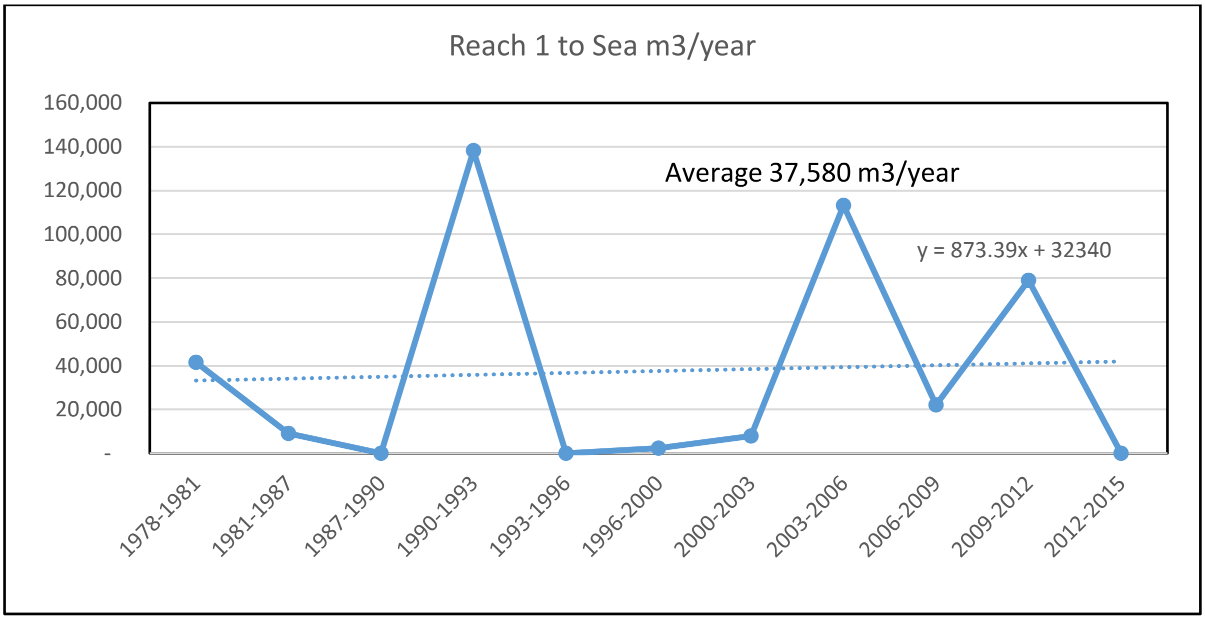


Figure 11-1 Average Supply to coast m3 / year over survey period

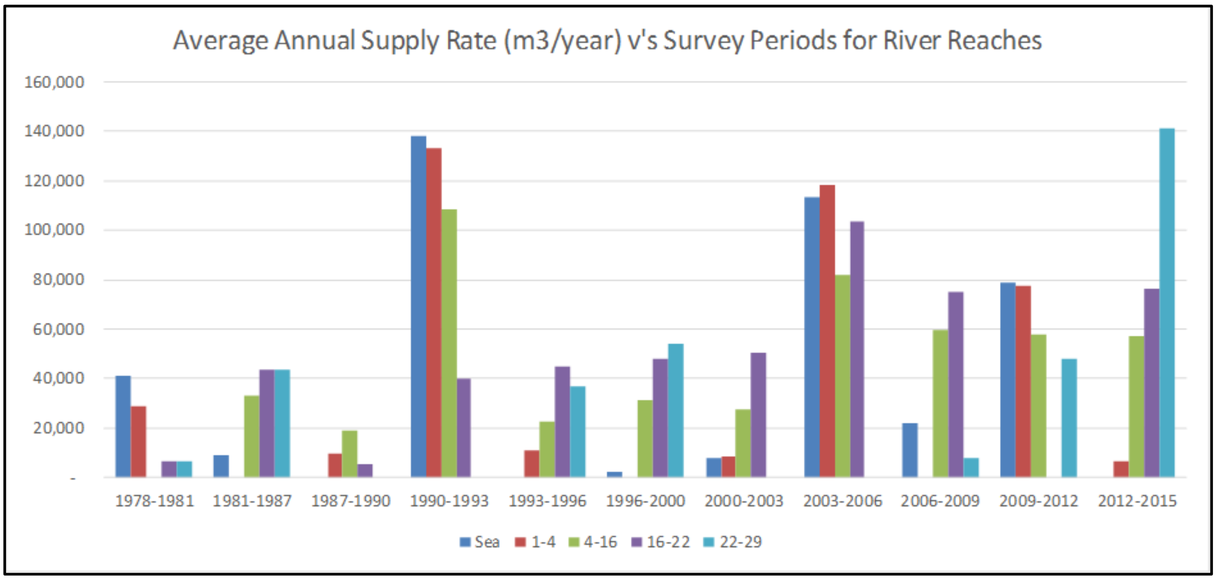


Figure 11-2: Average annual supply rates m3/year v's the survey periods for the river reaches.

Supply rates are quite variable over the survey periods. There is some correlation with floods in the lower Tukituki. For example there was a significant flood (30 year return period) in 1992 and this correlates to a peak transport rate in 1990-1993.

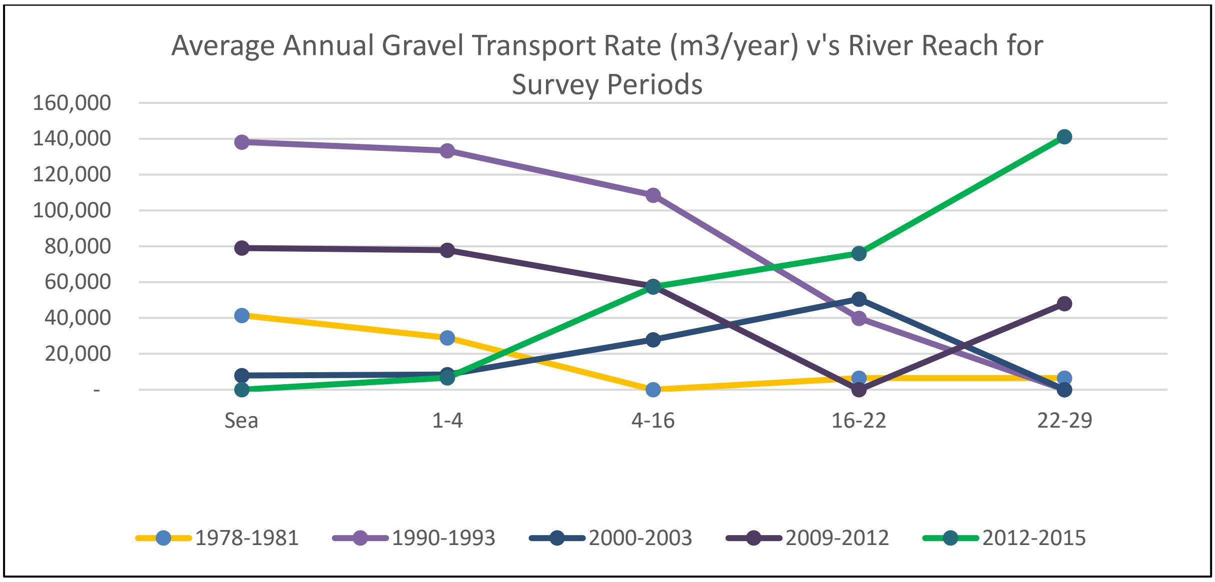


Figure 11-3: Average annual gravel transport rate (m3/year) v's river reach for selected survey periods.

Figure 11-3 above shows the wide variation of gravel transport rate with the chosen time period at various reaches along the river. It is important to note that the gravel transport rates are the minimum in order for transport to be non-negative and actual transport rates are likely to be higher than this. The high transport rate for the 1990-1993 period to the sea and lower reaches corresponds with the 1992 flood event. At the upper reach of the river XS 22-29 the transport rate for the same period is very low, probably reflecting the fact that the bedrock (Papa) is exposed in this location hence gravel is transported through the reach and not reflected in any change in bed level. In quieter years this trend reverses with the bed aggrading above the grade-line, flattening the grade and reducing the transport to the sea.

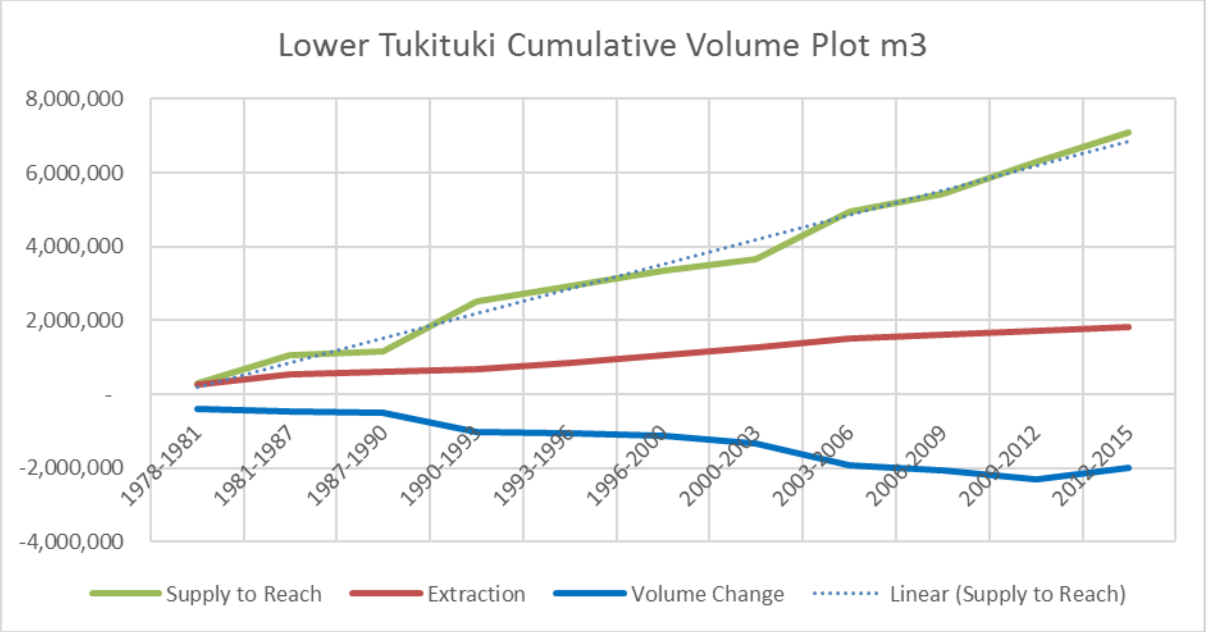


Figure 11-4: Cumulative volume plot from 1978 to 2015 (37.2 years) Average supply rate is 190,961 m3/year

In Figure 11-4 above there is a steady increase of balancing supply volume to each downstream reach with the rate increasing slightly over the past decade. This corresponds with the flattening (reduction) of the extraction volumes and with the change of slope of the volume change line. Putting this into perspective, averaged over the whole reach length from XS 1 to 29 (distance = 15400m and distance averaged active channel width = 191.2m) the current uniformly distributed deficit would be 0.679 mm. This over-extraction situation is mainly historical (pre 1989) when there was a fixed extraction plant located on the river. This has now gone and extraction has been wound back over the years and since 2017 ceased altogether to allow further recovery.

11.2 Summing up

As seen in the information above there are relatively small amounts of sediment supply to the coast from the river systems. In the Ngaruroro River gravels are not present in the lower 1.8 km of the river system, therefore removing gravels from the mid reaches of this river will have no material effect on gravel supply to the coast. It is estimated that the Tukituki River has provided an average of 37,500 m3/year of the gravel to the Haumoana Littoral Cell coastal budget north of the river and probably zero or insignificant supply south of the river. This supply is only affected by extraction in the lower reach. Preliminary modelling results indicate that extraction reduces the sediment transport rate to the coast by about 20%.

On the other hand beach raking has been shown to increase sediment transport (ref: *Reeves M. (2016). Impact of gravel raking on surface grain size and channel morphological change: Tukituki River, Hawke's Bay, New Zealand. Thesis Dissertation - Master of Science in Geography, University of Auckland.)* and as such will likely mitigate the effect of historic extraction. Currently extraction from the Lower Tukituki has ceased but beach raking continues. As such it is anticipated that bed levels and transport rates will start to recover naturally.

The effect of extraction from the lower reach on how much gravel then accretes on the beach is not able to be quantified at present.

12 Conclusions

Rivers, plains and coasts are naturally very dynamic and experience significant changes during major earthquakes and floods. In the last 150 years the Heretaunga plains have suffered several changes in river courses and coastal uplift. River management consisting mainly of stopbank construction, bank stabilization by willow planting, river beach raking and gravel extraction has enabled the safe establishment of communities in the Heretaunga, Ahuriri, Esk Valley and Ruataniwha plains by restricting the river to a fixed stable channel alignment.

On the other hand, river management has led to significant changes to the natural river sediment transport, morphology and coastal sediment supply rates. Sediments that used to be freely spread across the floodplains are now confined to move within the design river channel and expelled towards the sea. Local aggradation of the river channels leads to reduction in the flood capacity which needs to be managed by extraction and raking in order to maintain the flood capacity of the engineered river channel.

The gravel allocation methodology practiced by HBRC from 1990 to date has proven adequate and adaptive to the observed changes in the rivers. Note that while over extraction has occurred in localised reaches, notably in the Tutaekuri and Lower Tukituki, this was largely resulting from extraction prior to this period.

Gravel supply and transport is a highly unpredictable and variable process which is very difficult to accurately measure in natural rivers, even with the state-of-the-art technology. Numerical models and transport formulae can produce results that can vary in orders of magnitude depending on which sets of equations and input data are used. Boundary conditions are difficult to measure and estimate; especially during the high yield events, and monitoring of sediment availability and transport is costly, uncertain and cannot be practically undertaken at high frequencies. Comparison of the gravel supply rates by previous work and the recent work reveals significant differences and a low confidence and variability that these estimates can have (Table 2-3).

Modelling sediments for future scenarios has an even greater degree of uncertainty including:
i) climate change scenarios affecting rainfall and thus erosion and flows, sea levels, wind and waves;
ii) future changes in the land-use;
iii) future earthquakes and land movements that can dramatically change the dynamics and supply;
iv) future demand for gravel extraction;
v) future socio-politico-economic conditions.
Regarding the impacts on the coast, even if future research finds that river management causes a significant negative effect in coastal erosion, mitigation actions are limited as the affected area protected by the river flood protection schemes is significantly larger than the area likely to be affected by coastal erosion solely related to sediment supply from the rivers.

With all the difficulties and uncertainties in estimating sediment movement, the way gravel extraction has been managed by an active adaptation to the observed available volumes, grades and mean bead levels is considered adequate. The grade line approach to managing gravel extraction has the capability to adapt to future changes or increased understanding by reviewing the design grade line.

Forecasts obtained from trend analysis of observations and modelling are used as a guidance and warning of possible future scenarios. However, the final actions are undertaken on a case-by-case relatively short term basis.

HBRC is up to date with the state-of-the-art and the state-of-the-practice techniques and it is undertaking important efforts improving monitoring and forecasts of future effects. As stated in its Long Term Plan, HBRC has a commitment to continue exploring and implementing new methods and techniques. These new insights are expected to be of use as an extended guidance but they are not expected to be a replacement for the present case-by-case active and adaptive allocation process.

13 Recommendations and future work

- Continue with the active-adaptation allocation process based on frequent monitoring and on a case-by-case basis.
- Continue with the survey and gravel size sampling monitoring programme.
- Carry out a historical grain size analysis.
- Extend back and review historical cross section data analysis. In particular, review the active channel widths and associated parameters.
- Continue exploring Lidar data, Drone surveys, Quad bike surveys
- Analyse river morphology changes using existing aerial and satellite imagery.
- Continue to undertake morphological modelling studies in order to assess the effects of current river management practices and forecast future scenarios including changes in: gravel extraction, climate, multi-year-decadal climate cycles, land use, land movements due to tectonics.
- Carry out an assessment of river response times to over-extraction.
- Examine climate change scenarios showing potential impacts on gravel supply.
- Examine the sustainable supply of sediment required to reach the coast from the Tukituki River to nourish the barrier beach and mitigate erosional trends.
- Investigate the maintenance and persistence of scour pools (fishing holes) and morphologic patterns (ie pool-riffle) where gravel extraction is carried out.
- Undertake geological studies to estimate the (very) long-term effects and the depth of the bed rock under the river beds.
- Include in levels of service reviews a study of options to increase flood capacity by raising stopbanks or widening the flood channel in order to allow more gravel to migrate towards the coast.

The above list of recommendations and future work is extensive and will be ongoing while data is gathered and better understanding together with improved modelling techniques is gained. Improved surveying techniques using Lidar at affordable costs show much promise and will improve the assessment of the gravel budget for allocation decision-making.

While these recommendations are being implemented over time, the adaptive management approach of allocation and resurvey with field checks and careful observation of river behaviour by river managers will continue. This will ensure sustainable gravel supplies that satisfy the gravel extraction industry and balance the river and flood protection requirements.

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15 Appendix

This section covers the peer review and request for further information following the initial application. In response to this request considerable additional information was provided and the process followed to provide this information is described herein.

Gravel Extraction Consent Application: Section 92 Request

Introduction:

A request for further information to support the global gravel consent application CL170122E, LU170121E, LU170123E, CL170124E, LU170125E and CL170126E was received on 11 January 2018. This report provides additional information and discussion in response to the request. Where it is considered that the information requested is out of the scope of the application or we have insufficient information available to provide a complete answer, this will be discussed and reasons given.

The Review:

The review has been presented as a request for further information in a letter from HBRC Consents (Sven Exeter, Mott MacDonald) based on technical reports from The University of Auckland (Dr. John Tunnicliffe and Prof. Paul Kench) and HBRC (Dr Andy Hicks). Our response will follow the order of the items outlined in the letter from HBRC.

Process:

For ease of reference the order of the review document has been followed, although the work stream to answer the points raised will follow a different order. To assist with the process two additional reports are provided. These are:

1. **Allocation Process**. This report outlines the rationale behind the gravel allocation and provides protocols or guidelines as to how longer term Gravel Authorisation under the Hawke's Bay Riverbed Gravel Management Plan (2017) will operate. This includes how multiple extraction operations will be managed and how sustainable extraction volumes will be protected over the period of the Gravel Authorisation and beyond.

2. **Gravel Resource Management (***Gravel Resource Report)***:** This report covers the assessment of gravel supply and extraction availability over the current extraction reaches of the main rivers. It sets out the logic for decision making based on data collection, design grade-lines and current river management techniques. Climate change and sustainability of future gravel supplies are discussed.

In answering the review queries, reference is made to these two reports as many of the review queries had a similar theme and are thus more easily answered with reference to a report.

Response:

1. **Timing and Amenity**

a) *Please confirm the general timing for the proposed activities. Would the activities occur during weekends and public holidays***?** *i.e. note the standard construction work hours: 7am to 7pm Monday to Friday, 8am to 4pm Saturday and no work Sunday and public holidays. Would the proposed activities occur during the summer school holidays (mid-December to*

late-January/ early February)? We assume it would and we note the restrictions during nesting seasons.
Reply: The general timing is standard construction work hours 7am to 7pm Monday to Friday, 8am to 4pm Saturday and no work Sunday and public holidays. The proposed activities will occur during school holidays. Work during nesting seasons is covered in the Ecological Management Plans for the rivers where extraction is carried out.

b) *Given the above, could you proffer a condition that further mitigates and manages effects on amenity and recreation by way of general controls on timing and proximity to public access points?*
Reply: Given the nature of the work it relies on good weather conditions and particularly good river conditions to be carried out. The effects on amenity and recreation are minimal in the context of the overall river corridors. Public access to the larger extraction sites is already restricted. Work is currently underway on planning and providing for public use of the river-berm land which will cater for the public amenity and recreation with separation from commercial activities.

1. **Tukituki River**

a) *Given that the upper and middle Tukituki River are the only sources to re-stock the lower Tukituki River with gravels, how is the balance to be struck between gravel removal in the upper/middle sections and replenishment to the lower sections?*
Reply: There is a surplus of gravel in the upper reaches that is causing flood risk and drainage issues for some of the Upper Tukituki Scheme landowners. In the HBRC report *"Middle Tukituki River Scheme Works Proposal, June 1991, TS 91-6"* over the decade 1980 to 1990 there was a net aggradation of 22,000 m3/km or just over 1 million m3 over the middle Tukituki reach. No further assessment has been made in the intervening years, and anecdotally it could be assumed that there are significant volumes that are not moving through the system at any significant rate due to a dearth of significant floods. There is supply available to re-stock the lower reaches, it is just not being transported. For gravel extraction purposes replenishment is not a concern in the Lower Tukituki because extraction is managed around the design grade line and extraction ceases once there is no surplus. Currently there is no extraction from the Lower Tukituki and for the short term extraction will only be where necessary to help protect or maintain the active edge if this is threatened. Raking of the gravel beaches to break up the armour layers and encourage gravel transport will continue, despite ceasing extraction.

b) *How will the applicant manage the gravel resource and extractors in years with few or no floods?*
Reply: Refer also to the Gravel Resource Report. Allocations are prepared annually, if there is a supply shortage, extraction ceases. There is regular discussion with the larger gravel extraction companies and potential supply shortages will be signalled. Extraction from rivers and reaches further from the traditional areas close to market is an option, albeit a more costly one. HBRC is using sediment modelling scenarios to gain a better insight to the supply issues over a longer time frame. This detailed work has begun and it will be a valuable management tool in the future, but it is not yet complete.
c) *How will the applicant manage the cumulative impacts of multiple operators at various locations along the river? There is also the problem of lack of access to some of*

the aggrading sections, which could result in impacts from localised over-extraction in a section that is otherwise balanced or aggrading. How best to deal with local discontinuities in the downstream balance of aggradation and degradation?

Reply: Refer to the Allocation Process.

i) Managing Cumulative impacts: By managing to a grade line this accumulates impacts from all extractions (and natural variations) which affect a given location. Thus using a grade line approach to determine total availability inherently manages cumulative impacts.

ii) Managing Local Impacts: Operators are aware that they need to share access and access tracks. Extraction fees help pay for access tracks and these are provided to get access to aggrading reaches of the rivers. This is considered in the allocation process as it does not matter whether there is one or many operators, the allocations are granted per river sections on a yearly basis in the reaches where gravel is available. LIDAR mapping provide a good visual indication of local discontinuities and these maps guide allocation areas. Extraction is managed in such a way that significant discontinuities do not occur by undertaking periodic monitoring by staff responsible for river management.

d) *The applicant has not provided any rationale for setting the river extraction rates other than local mean river bed level should be maintained, in relation to some local design datum. This does not take any direct account of the actual gravel fluxes reaching the coast, time lag effects, and cumulative impacts from multiple operations. Please provide details on these matters.*

Reply: The rationale for setting the river extraction rates using mean bed level and design grade line has been used successfully and it is intended to continue with this method. The key means of measuring the success of this method other than maintaining flow capacity is that the vegetative edge protection does not become undermined by flood events. If this was happening regularly or on a large scale it would be indicative of an extraction red-line that was too low. The Gravel Resource Report has more detail about this and alternative analysis using relative mean bed level for comparison. Actual gravel fluxes reaching the coast are unknown although estimates are made using gravel balance methods. The morphological model of the Tukituki River (not yet complete) will also yield an estimate of supply to the coast. Based on similarity with the already completed Ngaruroro model the effects of gravel extraction on the propagation of gravel downstream are to reduce the amount of gravel propagating downstream. Morphological modelling studies for all rivers with important gravel extraction will be developed within the next 5 years. Time lag effects relating to extraction and gravel availability are managed through regular survey and analysis of trends. The cumulative effects from multiple operators would be little different from a single operator carrying out the same extraction volume.

e) *The criteria for siting extraction locations presented in Section 3.2 requires some further contextualisation. It is not clear how gravel extraction "aids transport of sediment through the river system" – presumably this refers to artificial manipulation of channel depths or river course alignment?*

Reply: The bullet point referred to relates to the Upper Tukituki in particular where gravel aggradation of the main channel results in local bed grade change (flattening) and reduction in transporting power. Extraction is effectively a manipulation of the main channel resulting in a deeper cross section. It was shown in the Ngaruroro modelling that with extraction, bedload transport rate increased due to a steepening of the bed gradient upstream of the extraction reach, with the opposite effect downstream.

f) *We note in Section 4.2 (page 34) that the applicant intends to "continue to investigate and utilise where appropriate new modelling and LIDAR techniques to improve volume estimates". Can the applicant proffer a consent condition that commits to modelling and use of LIDAR?*
Reply: HBRC is part of an international team[1] which aims to develop a high resolution survey and analysis method (GeoTERM) to improve the estimation of gravel sediment budgets and transport rates in braided rivers. This effort is aimed at the development of a software tool to help management agencies use LIDAR and similar data to inform their management practices and strategy. This work is well advanced and HBRC has committed to partake in the study and seeing it completed. This is an indication that HBRC is keeping abreast with best practice and the development and application of the state-of-the-art, thus a consent condition is considered unnecessary.

Note 1: The GeoTERM project is headed by Professor James Brasington, previously Queen Mary, University of London, UK now the University of Waikato.
With project partners: PP Wheaton (JW) from Utah State University, USA; and PPs Hoyle (JH) and Hicks (MH), from NIWA, NZ.

2. Ngaruroro River

a) *Please detail the modelling assumptions for the rates of upstream gravel supply and transfer from lateral sources (tributaries, mass wasting, bank failure, etc.) that support the model formulation.*
Reply: Refer to *"Measures R. (2012): Modelling of gravel transport, extraction and bed level change in the Ngaruroro River, October 2012, NIWA report."* The model description and input parameters are described in the report. Distributed lateral sources (mass wasting, bank failure) have been assumed nil as the gravel production occurs in the upper catchment while the banks of the river reach modelled are stabilised with vegetation and the outer banks are the stopbanks or do not contain significant amounts of gravel. The Poporangi Stream is the only tributary contributing a significant gravel input within the modelled reach and it has been included in the model. The main gravel sources have been included in the upstream boundary condition.

b) *While model results indicate that the extraction from the Ngaruroro River has little impact on bedload transport rates, a key question is: what are the impacts on reach sediment storage and active alluvial width, and thus habitat and the longer-term trajectory of the river?*
Reply: Noting that the extraction reach of the Ngaruroro River is a heavily modified reach, extraction activities do affect both the storage and active alluvial width. The Gravel Resource Report includes results of the change in active channel widths over time. There are no apparent impacts based on this work, however if there are others that we have not studied and if it serves any purpose in terms of this application then we are prepared to include future study as part of a consent condition. We have Ecological Management and Enhancement Plans for the major rivers that we consider thoroughly address the ecological issues. (Reference: Tukituki Catchment Rivers, Ecological Management and Enhancement Plan, May 2017 AM 17-05; Tutaekuri River

Ecological Management and Enhancement Plan, June 2015 AM 15-13; Ngaruroro River Ecological Management and Enhancement Plan, May 2017 AM 17-06.)

c) *The 'extraction' reaches (sections 36-51) for 2015 in Figure 15 (p.28) show a gravel volume deficit at 13 of 16 sections, raising the question: why do extraction works continue here? This seems to violate conditions for sustainability set out in point 2 of the application (Part A), and in paragraph 3 above the figure.*
Reply: The observation of a gravel deficit in the selected reach is correct. However it is not correct to assume that extraction is allowed to continue in this reach. The figure 15 in question is for 2015, the situation changes from year to year. In 2017 the deficit locations over the same reach numbered eight. Extraction is not permitted in areas where the cross section location shows a deficit. Occasionally areas between cross sections that are not reflected in the normal volume estimates are extracted, but these are first subject to on-site verification (visual inspection and survey) that there is a surplus and that removal is necessary for river management.

d) Forecast *demand continues at 250,000-300,000 m3·yr-1 (Section 3.3, Figure 11), so where is the 'red line' for ceasing operations?*
Reply: In the annual allocation process operations cease at locations where survey indicates a deficit. In terms of longer term sustainable supply and allocation this is determined by gravel volume trends over the years of record. Current gravel balance cumulative volume plots indicate a supply volume to the reach of 320,000 m3/year (from 2013 to 2016 data) and an average of 273,000 m3/ (1999 to 2016). The extraction volume gradient for the corresponding periods is 323,000 m3/year and 315,000 m3/year. Overall, historical extraction rates and net supply appear to be in balance. By managing the extraction there is no concern that this balance will not be achieved in future. The 'red line' referred to above is a limit on extraction not a point where extraction ceases. Extraction ceases when there is no surplus above the design grade line.

e) *Evidently there is a substantial supply in the upstream sections, but how long will a deficit be allowed (i.e. before reductions in extraction allowances are made)?*
Reply: Answered in d) above. The Allocation Report outlines the approach for directing more extraction to the southern region, prior to any extraction from the Heretaunga Plains rivers. There is also scope to direct extraction further upstream (in the Ngaruroro River) beyond current extraction areas. Although modelling shows that the river above the current extraction reach (Maraekakaho) is approximately in equilibrium there is considerable volume above design grade in storage that could be extracted. For example in the three cross sections above the current limit reach of extraction there is an aggradation of 600,000 m3. Further upstream there is similar aggradation. There has been no need to consider these upstream reaches to date.

3. Tutaekuri River

a) *Can the applicant proffer a consent condition that commits to modelling the response times for replenishment of gravel stores, based on this case study? With suitable scaling to account for flows and sediment storage, this should provide some criteria for allowing a recovery phase, following over-extraction in other rivers.*
Reply: Yes we can commit to modelling response times. The NIWA report noted in section 2.a) above for the Ngaruroro, examined spatial and temporal impacts of specific short duration gravel extractions for recovery periods of 1 to 20 years post extraction. It

also examined the effects of substantial extra extraction over a 10 year period. In general the majority of the change occurred between 1 and 5 years after extraction. The rate at which an extraction affects the adjacent reaches upstream and downstream was found to be highly dependent on the amount of transport taking place which in turn depends on flow conditions at the time. Note that in the Gravel Resource Report for the Tutaekuri River the mean bed level is increasing with supply exceeding demand overall.

4. General River / Fluvial Matters

a) *The proposal would be greatly strengthened with a presentation of the modelled results (including validation of historic river trajectories) for all rivers under consideration, and therefore some objective and transparent criteria for managing consent conditions. Results should be presented as a suite of outcomes, reflecting uncertainty in the input parameters and governing conditions. Despite the many uncertainties and approximations involved, a mass balance model should emerge that can be used to generate more robust determination of extraction thresholds. A plot showing mean bed elevation trends and gravel transport rates over time (past 50 years, and going forward 25 years) should provide a good demonstration of how well we understand these systems, and will provide a strong basis for managing this resource.*
Reply*:* This suggestion is seen as a desirable study and management tool that is in part in the process of being developed as explained in the reply to Comment 2.f. There are a number of questions and uncertainties to be resolved in reaching a sound conclusion from what would be a complex research study. There is a practical difficulty to go back 50 years when the data is sporadic and accuracy unable to be verified. There is also a question around whether the past 50 years provides a good representation of the next 25 years given the significant changes in the catchment and river corridor over the time. We do not believe that what has been suggested is necessary at this time for this consent application but are prepared to commit to carrying out a study to achieve a mass balance model for determining extraction thresholds using the modelling work we are already committed to. This would be completed within the next 5 years subject to funding.

b) *The key component of the 'proposed activity' is the extraction of gravel material. The rationale (Part A; Form 9) for the volume to be extracted is dependent upon (a) calculation and comparison of mean bed levels and reach volumes with bed level design grade lines; (b) comparison of the mean bed levels and reach volumes with bed level design grade lines; and (c) based on (a) and (b), an assessment of the sustainable extraction for the current year.*
Mean bed level has a 'design grade line' for comparison, but it is not clear how volumes are used in the decision-making process. Mean bed level changes may not reflect lateral adjustments and changes to reach sediment stores. Cross-sections must be considered and analysed as a longitudinal pattern to determine any trends of system accumulation or deficit. Haschenburger and Cowie (2009), for instance, show the swings from positive to negative volumetric balance within different survey epochs in the Ngaruroro River (their Figure 7), emphasising the variation in capacities for storage and transfer within these reaches and possible bedrock controls. This may also reflect the role of tributaries and major sediment source areas.
Reply: To determine allocation volumes a comparison is made between the grade-line and mean bed level for the survey period. Mean bed level calculations do reflect lateral

changes to the reach by comparison with both survey and aerial photography to identify plan changes in channel width. The active channel width, which may vary, is used for mean bed level determination. For gravel management purposes, only the active channel is analysed as reach storage outside this area (berm area) consists of silts and fine sands particularly in the lower managed reaches, and historical deposition bound with vegetation. The work by Haschenburger and Cowie was in an unmanaged braided reach of the Ngaruroro River with wide fluctuations in active width. This is not the case for HB rivers within managed flood protection schemes, i.e. where the majority of extraction takes place. Further analysis including trends in active channel width and volumes is presented in the Gravel Resource Report.

Changes in channel storage are not fully reflected in mean bed level measurements. This '1dimensional' view of channel behaviour does not account for important changes in active lateral width, channel/floodplain configuration, and planform morphology, which could be signalling local sediment surplus or deficits without accompanying vertical changes. Some further criteria for evaluating reach condition should be included in the Annual Gravel Status Assessments.

Reply: Yes, but the method of assessing mean bed levels and volume changes is the primary tool used by regional councils, supplemented by photo analysis and site inspections between cross sections. (Ref. *Monitoring of riverbed stability and morphology by regional councils in New Zealand: application to gravel extraction management. Landcare Research, 0206/138*). For gravel management purposes, active channel surveys are carried out 3 yearly and total fairway surveys at 6 yearly intervals. The fairway is the total width of the floodway and thus any change in active lateral width and planform morphology is included in the survey. Flood capacity is checked with the 6 yearly surveys and an increase in the flood level would be an indication of reduced capacity. If this signalled a sediment surplus this would be dealt with either by extraction (e.g. silt is extracted off the berms currently) or trigger the need for a scheme review.

For the analysis of volumetric change between surveys if the channel widens over the period between surveys then the gravel change before the change and after the change are calculated using the new wider width, thus the analysis correctly identifies that erosion has occurred in the inter survey period. When carrying out the analysis small changes of width (often survey interpretation) are of little consequence and are ignored.

A key consideration when setting grade lines is to avoid bank undercutting (i.e. width increases, often related to excess energy in locally over steep reaches). If bank undercutting and active width expansion became apparent then this would be a clear indication the grade line may need adjustment.

The shortcomings are well recognised and managed as noted already through photographic analysis and site inspections. That being said, we are also working towards improving the studies and management tools as already discussed.

Please provide:

1. *A more robust prediction system of sustainable extractable gravel volumes across the full width and length of the channel instead of just mean bed levels – e.g. can the applicant have a more robust prediction system of volumes instead of mean bed levels?*

Reply: We have provided with the Gravel Resource Report analysis that looks at five parameters (mean bed level, mean bed level slopes, active channel widths, relative maximum depths, and volumes). We have examined:

- Active channel mean bed level
- Mean bed level relative to the grade line over time
- Rate of change of mean bed level relative to the grade line along the river
- The change in time of the mean bed level relative to the grade line with error limits
- The active channel mean bed level slopes
- The change in time of the average mean bed level slope with error limits
- The active channel width with river distance over time
- The rate of change of active channel width with river distance with error limits
- The change over time of the active channel widths and error limits
- Relative maximum depth (Mean bed level – minimum bed level) with distance
- Relative maximum depth rate of change with error limits
- The change in time of the average relative maximum depth with error limits
- Gravel volume availability
- Historical change in measured gravel availability
- Cumulative volumes
- Net supply rates

We are carrying out what is standard practice for the purpose of gravel extraction management. It is through LIDAR techniques that a more robust prediction system of sustainable gravel volumes can be achieved and the shortcoming of cross sectional analysis will be improved. Thus provided the cost and reliability are acceptable, Council will commit to the more robust technique. The Gravel Resource Report can be referred to for further information on predicted volumes.

2. *An electronic copy of: Stevens, M., Larsen, B., (2015): Gravel Management Plan - Gravel Demand Forecast (Issue 5), March 2015.*
   Reply: Copy of report included
3. *An electronic copy of: Stevens, M., Larsen, B., (2015): Gravel Management Plan Gravel Resource Inventory (Issue 3).*
   Reply: Copy of report included

c) *With a cross-section database that dates to the 1940s, it should be feasible for the applicant to demonstrate the typical range of reach storage volume variability and, crucially, the rates of change in both natural and managed regimes.*
Reaches that could be susceptible to rapid change can then be identified – some reaches are bound to be more resilient to disturbance than others, based on storage characteristics (e.g., Lisle and Church, 2002). By presenting this information, it can be made clear what sensible thresholds could be proposed as an acceptable quantum of change within a given interval before extraction operations cease. These data would also provide some idea of recourse for ceasing extraction operations before bed degradation sets in (recalling the precautionary motive). In the current application, the reader is provided no insights into the potential magnitude or characteristic timescales of storage changes.

Longitudinal bed level (ideally storage volume) trends should be considered in more detail. Longitudinal trends may signal a translating wave of surplus or deficit, and may show a cumulative response developing from multiple extraction sites. By the time mean *bed level drops below design levels in the 3-yearly surveys, it may be too late to intervene and prevent erosional response. A historic summary would be helpful, to show the range of natural, as well as extraction-induced variability, and to demonstrate how realistic decision-making thresholds could be developed.*

*As part of the presentation of model results in (a), a plot of historic bed levels and volume changes from 1960s to present should be provided. A few cumulative plots (volume vs. time, summing the net volume change year-to-year) from representative survey reaches will show the running surplus or deficit, and should demonstrate the sustainability of this resource under the managed supply regime**. Please provide** plots/graphs.*

Reply: Although a few cross sections date back to the 1940's on some river reaches, it is not a continuous record and the accuracy is unable to be verified. The early cross sections don't relate well to the current managed river channel. As noted previously it is also questionable how well the longer term data will reliably reflect future sustainable volumes given the changes in the catchment and the river corridor. Further analysis is presented in the Gravel Resource Report.

d) *While HBRC's statutory flood hazard management responsibilities provide an important mandate for gravel extraction, the reviewers felt that the sections on flood protection (Section 2.2) lacked much detail on particular areas that were subject to aggradation-induced exacerbation of flood risk, relative to gravel surplus or deficit. There is mention of hydrodynamic models (Section 2.2; p. 8, 2.3.1; p.9), but the results from these studies do not appear to be brought to bear in this application.* ***Please provide*** *figures showing longitudinal trends in river bed build-up relative to infrastructure and residences at risk, with accompanying annotations of the maps in Appendix A.*

Reply: We consider the request to be outside the scope of this application. Schemes exist for flood hazard management reasons and their value and purpose have been well documented. They exist due to the community desire for flood protection and the reasons for flood protection were well known and the flooding effects and at risk areas well known. Refer also to the Gravel Resource Report.

e) ***Please clarify*** *which volumes of which fractions typically apply to contractor consents, and whether consented volumes pertain to gross or net extraction. For instance, if 75% of material is finer than the desired fractions, four times the volume of raw material must be excavated, and considerably more fine-grained, mobile material is left behind.*

Reply: Extraction is for 100%, no sorting is allowed on the riverbed and all material removed from the river bed is counted against a contractor's allocation, even if some fractions are then stockpiled.

f) *The description of proposed activity states that they would like to extract the gravel more efficiently (Section 3.1; p.21), although there is no qualification of this. Please clarify this point.*

Reply: Meaning that we would like the ability to direct extraction from specific areas e.g. requiring a contractor to take a percentage of their allocation from southern Hawke's Bay prior to using their Heretaunga Plains allocation.

g) *The application provides little consideration of alternative mitigation measures for dealing with the principal problems: flood risk and land protection. We suggest there is scope for broadly considering other alternatives to solving the aggradation problem, including the creation of 'room to move' for the river (e.g. Biron et al., 2014; Buffin-*

Bélanger et al., 2015). By widening the river corridor at sites of notable aggradation, there is increased conveyance for flood flows, and the river has room to erode and modify the accumulated deposits. This point in the river's long profile is, after all, the former site of unconfined fans and braid plains, which dealt with aggradation by frequent switching and reworking of the deposit. This also creates more braided riverbed habitat, which is mentioned as being uncommon and important (Sec 2.6). Some further investigation into the feasibility of this would seem warranted. This is one example – and there are likely good reasons for not accepting this model - but a considered review of alternative river management strategies would strengthen the justification for the proposed gravel extraction regime. ***Please provide*** *an alternatives assessment for the proposal.*

Reply: We consider this to be outside the scope of this application. This application is not for flood risk and land protection although gravel management is included as part of it. This suggestion has more to do with how our rivers are managed and although the concept may have some validity it is not the path Council and scheme ratepayers have considered and chosen to take for its river management. This suggestion may well be something to consider for a levels of service review, but alternative flood mitigation measures are not in our view part of this consent which is to extract gravel. There is also an economic consideration, which although not a primary concern for HBRC is a primary concern for the construction industry and a consideration required under the RMA. Being able to extract excess gravel at little or no cost to the scheme is economically beneficial to both the construction industry and scheme ratepayers. Any other models than that which exist now would be an additional burden to ratepayers with no guarantee of being any more value.

h) Linked to question 4 (a) and (c) above, we believe the proposal could be significantly strengthened with a more quantitative framework, and a completion of the analyses that are said to be in progress (Part B, Section 4.2 of the application). While the historic and forecast extraction volumes are quite precise, the reviewers could find no estimates for rates of natural gravel supply and transfer. In order to declare the management scheme to be a sustainable venture, it must be made clear what proportion of this resource is being captured, what margin of safety is required in order to maintain equilibrium, and in the case of over-extraction, what the pathway and timeline to recovery will be. The Ngaruroro River modelling looks like a promising step towards this. ***Please provide*** *further details on these matters.*

Reply: Refer to the Gravel Resource Report.

6. General Coastal Matters

a) *Section 4.7 of the applications does not provide a strong treatment of the question of coastal sediment budget; however, Appendix H at least provides some further context. Numbers are offered in 4.7, showing a deficit of material transferred across the coastal tract at the mouth of the Tukituki River, with little commentary. It is difficult to resolve the different numbers in Section 4.7 and Appendix H, as only a few of the quantities would seem to agree. The earliest reference we could find for numbers in Appendix H is Tonkin and Taylor (2005). The Komar (2015) text is cited extensively, but it does not appear in any references, nor does it appear to be accessible from the HBRC website. Please provide 'up to date' numbers and the Komar (2015) report and highlight the research provenance of the original estimates.*

Reply: Refer to the Gravel Resource Report. The reference to Komar (2015) is an error and it should be Komar (2014). The full title is "*Hawke's Bay-New Zealand: Global Climate Change and Barrier-Beach Responses, Komar and Harris, March 2014. (https://www.hbrc.govt.nz/assets/Document-Library/Reports/Coastal-Hazards/4600-AM-14-02-HB0.-Hawkes-Bay-Climate-and-Hazards-Report-BINDER-1.pdf).* The other report is Komar (2005), full title "*Hawke's Bay: Environmental Change, Shoreline Erosion and Management Issues: Komar November 2005."*
(https://www.napier.govt.nz/assets/Documents/westshore-erosion-full-07-1.pdf
https://www.napier.govt.nz/assets/Documents/westshore-erosion-full-07-2.pdf
https://www.napier.govt.nz/assets/Documents/westshore-erosion-full-07-3.pdf
https://www.napier.govt.nz/assets/Documents/westshore-erosion-full-07-4.pdf)

b) *Coastal hazard issues are a major concern in Hawke's Bay. The Clifton to Tangoio Coastal Hazards Strategy 2120 (2016) maps out the critical importance of managing the regional coastal sediment supply. The Coastal Hazards and Climate Change (2017) further emphasizes regional exposure to coastal risks. While the New Zealand Coastal Policy Statement (2010) is deemed irrelevant in Section 5.2.2, we feel that it would be well to invoke Policy 3 from this document:*

Adopt a precautionary approach towards proposed activities whose effects on the coastal environment are uncertain, unknown, or little understood, but potentially significantly adverse.

Gravel yield from the lower Tukituki River is assessed at 28,000 m3·yr-1, though extractions from this lower part of the river have averaged roughly 50,000 m3·yr-1 since 2000. Please provide a more detailed study in order to justify continued removals from this portion of the Tukituki River, given the timescales for recovery of gravel stores. The study must include, as a minimum, indication of uncertainty and natural variability in estimated transport rates (both fluvial and coastal), and an assessment of the threshold transport rates in the Tukituki River required to maintain gravel nourishment of the coastal sedimentary system.

Reply: Refer to the Gravel Resource Report. HBRC is taking a precautionary approach through continual monitoring and adjustment of allocation requirements. Gravel extraction in the period 2000 to 2012 has averaged 49,000 m3/year. In the period 2013 to 2015 it has averaged 21,000 m3/year and for 2016 to 2017 it has averaged 10,500 m3/year and currently commercial extraction has ceased. This reducing and eventual ceasing of extraction is an example of how the minimum mean bed level approach to calculating available volumes is applied to prevent over extraction. Extraction will only recommence in the Lower Tukituki if or when natural aggradation raises mean bed levels.

The gravel supply (yield) depends on the time period considered and reach considered. The relationship between gravel supply volume in the Lower Tukituki and the volume that ends up on the beach is not known. From the sediment balance equations the average supply volume from 1978 to 2015 is 41,400 m3/year with large variations between survey periods. Note that due to the nature of the gravel balance approach this is a minimum rate, as it is not possible to quantify any “throughput” occurring within the interval between surveys.

c) *Related questions that arise is what is the effect on beach protection from coastal swells and tsunami arising from the reduction of gravel supplies to the coast from the Tukituki River? Given that a reduction in gravel supply from the Tukituki River will render the coast more susceptible to erosion, what mitigation measures should be considered to protect the coast from storm swells, tsunami and rising sea levels?*
Reply: This is outside the scope of this application. Mitigation strategies are part of a much larger body of work being carried out by the 3 local councils and it is not appropriate to introduce this here. Some further work on supply volumes is presented in the Gravel Resource Report. Komar in his 2014 report (Section 1.3 Beach Sediment Budgets) noted that the most significant factor for the negative balance in the southern cell (-45,000 m3/year) was the commercial mining of gravel and sand from the beach at Awatoto (-47,800 m3/year) and the elimination of the commercial mining would essentially balance the budget. All extraction from the beach has now ceased.

7. Climate Change

We note that the application states ‘a 5% reduction in flow, as expected with future climate change, causes a 6-10% reduction in gravel supply into the extraction reaches’. Climate and river hydrology, including the potential effects of climate change, require further consideration. Hydrologic and in-channel hydraulic drivers are principal concerns for forecasting sediment supply. Thus, please provide assessment of variation and changing trends warranted for any long-term endeavour (e.g. 10-year extraction consent or 25-year management horizon) along with further consideration of climate change effects. Linking the historic presentation of bed-level and volume trends in 5(c) to prevailing climatic conditions should be effective in elucidating this relationship.
Reply: Refer to the Gravel Resource Report for analysis of bed-level and volume trends. To date the modelling carried out for the Ngaruroro River (NIWA, Measures 2012) is as stated above. What has yet to be modelled is the effects of more intense rainfall and more frequent larger events which could result in an increase in gravel supply to the extraction reaches. The work to link bed-level and volume trends to prevailing climatic conditions as suggested has not been done at present. We do not consider it necessary for this consent as there are checks and balances in the allocation process and regular monitoring to ensure sustainable extraction, even if it is at a lower rate at the end of a 10 year authorisation than at the start. Extractors understand that their allocation is based on supply and that rivers are managed to a design grade (minimum mean bed level) with no guarantees given on long term availability. As signalled already, there are plenty of areas requiring further investigation and we can implement them as a continuing part of gravel management.

However, it is considered that gravel extraction can be managed in a sustainable way in the interim without needing further information on climate change effects, and until our modelling (which is complex) can be completed and better verified.

8. Ecology

a) *P22 S3.6.2 of the AEE: How has the value of '1m' buffer distance between gravel extraction area and active channel been determined? It seems quite close for a highly porous river bed material. Does the applicant have observations that this has prevented muddy water in the extraction pits from seeping through and into the flowing river? Please provide some evidence (e.g. anecdotal and/or photos) that a buffer of 1m is enough to prevent an increase in suspended sediment downstream of the gravel activity.*
Reply: The 1 metre buffer is the width at the surface of the gravel area (above the river water level) and it is wider by another metre or so at the water level due to the angle of repose of the gravel. Also in order for there to be suspended sediment leaching through the gravels there needs to be a difference in head (water level) between the river and the excavation area in order to generate seepage pressure. The river water level is either higher than or at the same level as the water in the extraction area and hence seepage won't occur under these conditions. The photograph below illustrates the effectiveness of the bund, with the river on the left adjacent to the willow trees.

How would gravel extractor sub-contractors be held accountable for any deviation they make away from the approved practice / consent conditions by the applicant/consent holder (i.e. not the regulator)?
Reply: Contractors that do not comply with the authorisation conditions imposed by HBRC Asset Management as consent holder will be barred from the river for either a period of time or permanently and their allocation given to others. We have managed the extraction operation for many years now and extractors know what is required of them and they have performed well in the past with any infringements dealt with promptly.

b) *We note the Environmental Code of Practice and the Ecological Management and Enhancement Plans provide commentary on a range of enhancement initiatives. In particular Section 5.7 of the code discusses the potential for artificial pool creation:*

"The maintenance of permanent deep pools in rivers is important for providing habitat for fisheries, particularly as refugia during low flows. Pools and riffles naturally migrate

over time within a river system. However, there is potential for some river work activities, such as beach raking and edge retreat, to contribute to or exacerbate the natural instability of pool and riffle systems. Consequently, the creation of artificial deep pools can be highly beneficial. These can also have the added advantage of being able to be used as swimming holes by the public and as water supply sources by the Rural Fire Control authorities."

The Tutaekuri and Ngaruroro River Ecological Management and Enhancement Plans recommend further studies on the effects of gravel extraction and raking and investigating the artificial creation of pools for ecological habitat enhancement.

The allowance for there to be some "ecological enhancement" gravel extraction, which may include extraction from the wetted channel, as part of this consent, could be of benefit. The purpose would be for deeper pools to be dug out of the rivers to provide better habitat for salmonids if the river systems appear to be losing their deeper pools. Or, for gravel pits to be dug deeper than they would normally be such that when they are reconnected they form a deeper pool. This addition could be considered part of an offset mitigation for the river management activity overall, if the applicant would consider incorporating this as part of the proposal as a consent condition that specifies general triggers for when pool creation (and studies) will be undertaken and monitored?
Reply: Note the Gravel Resource Report has some details relating to relative mean bed levels (mean bed level minus the minimum bed level). There is no conclusive evidence either way that gravel extraction is having an effect on pool depths. As part of the ecological enhancement we support the creation of deeper pools as part of the extraction process where appropriate. There would need to be recognition that this cannot be done without disturbing and releasing some sediment in the flow. Pool creation is likely to be short lived as deposition will continue. A recent example of pool creation at Waiohiki in summer was short lived.

Ir Gary Clode

Regional Asset Manager

Hawke's Bay Regional Council

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