Bedload Transport and Gravel Supply in the Waiapu Catchment

Steps toward a framework for managing gravel extraction

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Executive Summary

REPORT OBJECTIVES

- This report identifies issues regarding gravel extraction on the Waiapu River, and proposes some steps towards developing a sustainable management framework. The report further aims to inform best practices for gravel extraction, with a view to enhancing community engagement with decision making, managing water quality issues, and nurturing the development of river habitat.

- The report is framed using five interconnected elements that must be considered prior to establishing a programme of extraction: ***Community Values***, ***Environment & Ecosystem***, ***River Morphology***, ***Protective Works*** and ***Cumulative Impacts.***

- Under the 2015 Joint Management Agreement (JMA), an agreement between Ngāti Porou and Gisborne District Council, the extraction consenting and resource allocation process will engage hapū and landowners more closely and will be a guided, overarching management programme for the river. River management and Te Mana o Te Wai require all decision-makers and users to appreciate relationships to - and values held of - the river. This report reviews criteria to be visited by the consenting authority when considering applications for gravel extraction.

- The report provides an overview of river geomorphology and its links to ecology, river connectivity relationships within the drainage network, and an approach to assessing sensitive sites along river corridors and sustainability of the proposed activity. Some perspective on adaptation in a changing climate is outlined: gravel supply is ultimately determined by storm climate, and therefore extraction regime should reflect this variation.

- We review some of the options for flood control and managing aggradation within the river system. It can be challenging to remove gravel in the places where this is needed (downstream from gully complexes, mainly), in a sustainable manner that is also economically feasible.

- Monitoring of the river system has become faster, more detailed, and less expensive with LiDAR and drone survey technology. In addition to bed topography, ecological and bed texture monitoring should be implemented as part of annual site review. We highlight this with two case studies from the study catchment: the Tapuaeroa, and the Waiapu. Topographic differencing over a one year interval shows typical rates of sediment transfer, and determines the sustainability of the extraction rate. These results can also be used to provide validation for 1D and 2D numerical models of sediment yield, which in turn can help with longer-term catchment planning.

ISSUES IDENTIFIED

Hapū Values/Community Values

- Activity must be guided by ***initial engagement and ongoing interaction***, particularly with Hapū and Iwi and also the wider community. Custodial linkages with the river are expressed through kaitiakitanga (guardianship), mana whenua and with an acknowledgement of ancestral linkages that position people as part of landscapes and ecosystems (Marsden, 2003). The term 'community' here is defined as all those living in, having a cultural relationship with, or holding significant interest in, the Waiapu catchment. In light of the ambitions for the JMA, gravel extraction or any other proposed modification of the river must be addressed through broad consensus.

- ***Economic opportunity*** needs to be balanced with the vision for river restoration. Assessment of employment and economic gains from aggregate industry, and cascading effects for construction and forestry should be carried out.

- ***A catchment management plan*** that is both scientifically informed and driven by Hapū aspirations and community consensus is needed to clearly define targets for managing both site-specific and catchment-wide issues, including impacts from river aggradation. Different tributaries will have different considerations, from a community or Hapū values perspective. Plans for each takiwa (hapū collective) should be developed.

Environment and Ecosystem

- ***The ecology of the Waiapu River and its tributaries***, and the potential for recovery to pre-forest-clearance levels, is not very well characterised. In order to manage the risks of habitat degradation in a gravel extraction operation, it is important to understand spawning/nesting, rearing and feeding requirements of existing (and potential) bird, fish, and macroinvertebrate species, as well as linkages in the riverine/riparian food web.

- Best practices for ***monitoring impacts*** from gravel extraction should include consideration of bed substrate conditions (invertebrate populations, median grain size, abundance of fines) and the diversity and relative abundance of hydraulic environments (riffles, pools).

- ***Riparian zones*** are important buffer areas between the river and floodplain ecosystems; these are sites of exceptional species diversity (e.g. Gray and Harding, 2007). Terrestrial macroinvertebrates and organic detritus from these zones serve as a food source and moderate the aquatic food web. There is no clear policy for protecting, rehabilitating and/or enhancing these sites in the design of gravel extraction schemes.

- ***The parafluvial zone*** is the area adjacent to active channels with subsurface flow. The area represents important connectivity for nutrients and longer-term storage of river base flow. Protecting underground water pathways has been highlighted as an important priority in traditional management of the river (Scion, 2012).

- ***Air quality*** has been reported to be an issue, as dried silt particles from the river bed are easily entrained by strong winds in the valley. The issue is exacerbated by gravel extraction operations, with heavy trucks moving long distances over the floodplains.

ISSUES IDENTIFIED (CONT.)

Cumulative Effects

- ***Multiple operations over time***: current rates of extraction consents within the catchment have reached nearly 450 000 m^3 per year (roughly 150 000 m^3 in the mainstem river) as of February 2020. This is in significant excess of the estimated minimum rates of net bedload transfer for the mainstem - which vary widely - but were assessed to be about 35-45 000 $m^3 \cdot yr^{-1}$, based on repeat photogrammetric river bed surveys in 2019-2020. If drawing down bed levels is the management aim, then a sediment budget and a practical assessment of extraction rates should be developed.

- ***Multiple operations in space***: potential locations for extraction operations are constrained by transport distances, quality of the gravel, access to the river, land ownership, available terrain for stocks, screening and loading, and other factors. A majority (~81%) of the gravel extraction efforts have been focused on the Mata (41%) and Waiapu (40%) rivers. Since there has been no aggradation on the Mata since 1997 (Peacock, 2016), there seems little justification for continuing to remove sediment at high rates here. Most of the riverbed aggradation in the catchment is occurring within the Tapuaeroa Valley. Only about 8% and 12% of abstractions are currently sourced from operations within the Tapuaeroa and Mangaoparo, respectively.

River Morphology and Sustainable Sediment Supply

- The lower river and the many tributaries that feed into it all have a distinctive transport regime and character, and extraction conditions should reflect this. Different river morphologies (e.g. confined headwaters, meandering, braided) will have different disturbance histories, ecology, and susceptibility to disturbance. Response to gravel extraction will vary according to factors such as channel slope, sediment supply, floodplain storage dynamics, substrate quality and texture. ***Criteria for selecting extraction sites, and operational procedures for the extraction work should reflect the river character.***

- A river with a sediment deficit will begin to reduce its active width, entrench its bed and simplify its morphology. A river deprived of sediment has excess energy and typically erodes its bed and banks to regain that sediment load (Kondolf, 1994). An example from the Aorongiwai River (tributary to the Mata) shows significant vertical bed erosion, where extraction rates from a short-lived operation there were in significant excess of the annual yield.

Protective River Works

- In the right circumstances, extraction works can be used to improve flood conveyance, protect bridge infrastructure, and to coax a river channel away from an eroding river bank. In 2010, gravel extraction was employed as part of an effort to move the river away from an eroding bluff near Ruatoria, for instance. While this can be very useful, the timeframe and location of the works may make it difficult to build an affordable or profitable enterprise from this.

- A review of potential sites that might benefit from rehabilitative gravel removal should be developed, in consultation with the community.

CONCLUSIONS AND RECOMMENDATIONS

- With the implementation of a Joint Management Agreement, extractive activities should be designed in a collaborative way with the affected community, moderated via the local consenting collective.

- A catchment ***Gravel Management Strategy*** should be developed, assimilating the available information on bedload transport rate, cross-section change, and community concern for the river's health and mauri. A map of sensitive riverine environments should be developed to proactively manage the gravel resource.

- Surveys of stream fauna and flora, as well as terrestrial and bird life are limited, but show some of the abundance and diversity that is expected of this unique braided river habitat (Wilson, 2001; Gray and Harding, 2007; Roil and Death, 2018). Guidelines for protecting riverine habitat are based on current conditions, but given aspirations for ***moving the Waiapu toward a more desired environmental state*** (*cf.* Scion, 2012) consideration should be taken of the potential conditions, as the deleterious effects of erosion and landuse are progressively mitigated.

- The effects of natural variation in annual gravel yield has not been accounted for in gravel extraction plans: consents should be tied to flood intensity and duration (thus bedload yield) for a given year. Recharge rates for 2019-2020 were shown to be very low, relative to ongoing extraction rates.

- Extraction may be promoted as a useful means for mitigating the deleterious effects of river aggradation. Extraction sites should be located within aggrading reaches, with clearly identified sediment influx rates and source areas, with clear criteria for allocating extraction volumes.

- Most of the currently aggrading reaches are found within the Tapuaeroa, Mangaoparo and some parts of the Waiapu mainstem (*cf.* Peacock 2017). Given the goal of countering the effects of sediment over-supply, a detailed management plan should address how best to leverage extraction efforts in the affected locations.

- Monitoring should include site surveys, grain-size surveys, and ongoing census of riverine biota. Adaptive management is required to assess the trajectory of any river reach under extraction. Operation should cease or relocate, if the local gravel deficit is impacting the channel in ways that were not foreseen.

- Where in-stream extraction is seen as a means to managing sediment surplus, extraction should proceed with fine sediment management and protection of riparian riverbank environments in mind. Operations that source gravel from older deposits, out of the range of base flows to flood flows, will have lower impacts on riverine habitat.

- An expanded programme of monitoring and research is needed in order to better understand effects of gravel extraction on the ecology of Waiapu rivers. Further studies of channel change in response to abstraction works would also be highly beneficial; researchers collaborating with extractors to refine extraction techniques will be particularly effective.

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Steps toward a framework for managing gravel extraction

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Sofia Minson from newzealandartwork.com has very kindly given permission to reproduce her original artwork on pages 8-9.

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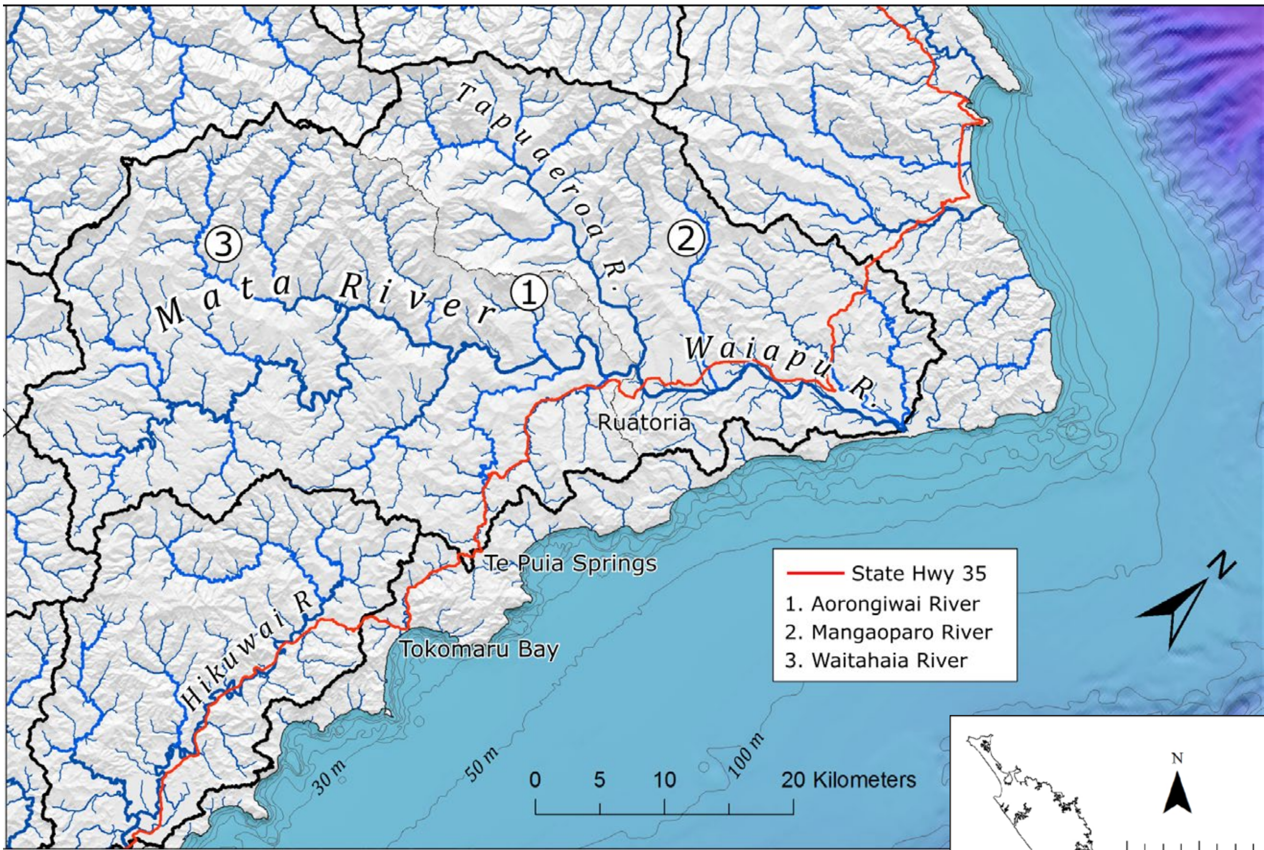
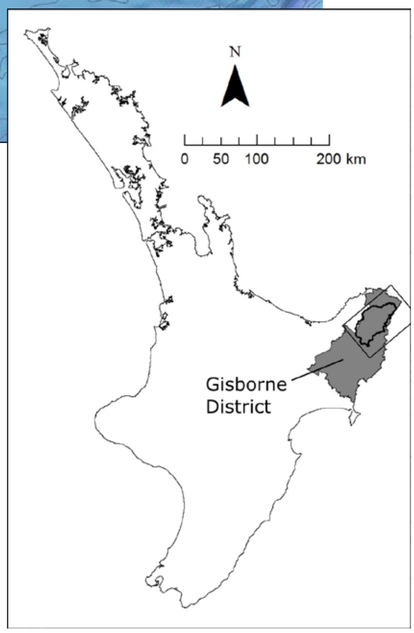
Catchment Map



The Waiapu Catchment, with a few sites referenced in the text highlighted.



1. Waiapu Koka Huhua: Waiapu Of Many Mothers

Ko Hikurangi te maunga
Ko Waiapu te awa
Ko Ngāti Porou te iwi.

The Waiapu River is a symbol of Ngāti Porou identity, as expressed in the above pepeha. The river is an important self-identifying feature of the Iwi and of individuals. The river is situated at the heart of the rohe of Ngāti Porou, and is of great cultural significance to its people. The community within the valley have long been responsible for protecting the mauri of the river. The term 'community' here is defined as all those living in, having a cultural relationship with, or holding significant interest in, the Waiapu catchment (Harmsworth *et al*., 2002).

A common prefix in river and stream names in the valley is 'manga-', reflecting the branched connectivity of the system; this report emphasises the diverse character of many of these branches. The Māori place names of the many streams and rivers reflect the identity of each system, and should be considered as more than merely superficial impressions of river characteristics. The name Waiapu means 'to gobble up, to consume': the remarkable power of the river to devour floodplains, and to transfer large quantities of material, is a defining characteristic. Starving the river would seem antithetical to its nature. Tapuaeroa means 'the long sacred footstep'. This river gathers a remarkable sediment load from rivers draining the Raukumara range front and carries it 20 km along the valley, where it joins with the Mata River to form the Waiapu.

“The Garden of Waiapu“ Artwork by Sofia Minson, oil on canvas, ©2007
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More importantly, these many branches are connected, and removal of a resource from any of the upper branches will eventually affect the lower trunk, and so management and planning must proceed on this basis. The river is considered to be an interconnected, living being that cannot simply be understood as a collection of measurable or definable parts. Rivers are a complex and emergent network of plants, animals, land, water and people in a dynamic process of coevolution (Salmond, 2018).

Every branch of the river has a history. The signature of past changes and disturbance can be discerned in abandoned channels, broad sediment storage zones, high terraces, sediments of variable provenance, and other remnant evidence. Recovery and rebalancing is still in play at many locations. Ecological assemblages and channel morphology have organised according to the magnitude and frequency of such disturbances. Any branch’s predisposition to change will be determined by this regime. This also must be considered when contemplating resource extraction.

As well as having a history, the river is also an ancestor. It has its own life force, authority and prestige, and sacredness (Brierley et al., 2018). This ancestral linkage positions people as part of the landscapes and ecosystems (Marsden, 2003). There is a strong sense of the importance of passing this resource on, undiminished, to the next generation. Therefore the importance of sustainable management: the fluxes and flows of riverbed substrate should be well understood before consenting to remove material.

Finally, rivers are taonga of whānau, hapū and iwi both from a physical and spiritual perspective. The river has long been “a valuable food resource to those who possess it, which carries its own separate mauri (life force) and is guarded by the taniwha that inhabit it. The physical cannot be divorced from the metaphysical; the two are inseparable.” (*Te Ika Whenua Rivers Report*, Waitangi Tribunal 1998).

2. The Interwoven Effects of Extraction Activity on Rivers

Rivers are naturally adjusting systems that adapt over years to decades to changes in sediment supply; there are many well-documented examples of the ways in which river morphology will respond to a surplus or deficit of material provided from the headwaters of the catchment. Historic cycles of climate change, for instance, can lead to gradual metamorphosis from braided to meandering river morphology. Systematic removal of sediment supply, if not carefully managed, may also lead to changes in river morphology, in turn leading to changes in river habitat, ecological relationships, and human interactions with the river. Erosion issues, and impacts on property and infrastructure may be further unintended consequences of gravel extraction.

The communities within the greater Waiapu catchment have a strong interest in protecting the river and fostering the well-being of freshwater ecosystem. The river and its tributaries are inextricably tied to the identity of Iwi and Hapū. People have deep linkages to the river and its ecosystem through long-held customs of kaitiakitanga (guardianship). The Waiapu provides rare habitat, one of the few large and wild braided-to-wandering gravel bed systems on the North Island. It has not been as severely impacted by gravel and water extraction as others in New Zealand. While there are economic opportunities to be had in gravel extraction, there are many important linkages to be considered.

When planning extraction activities on a river system, it is important to take into consideration these numerous, complex linkages (Figure 2.1). Each category in the figure consists of multiple sub-components: ***Community Values***, for instance, includes the initiative for self-determination, economic opportunity, fishing and other harvesting opportunities, scenic value, and nurturing the mauri of the river. Interactions amongst components can be constructive or in tension (or potentially both): in the following sections we follow some of the major strands that could be problematic in the course of gravel extraction from the river.

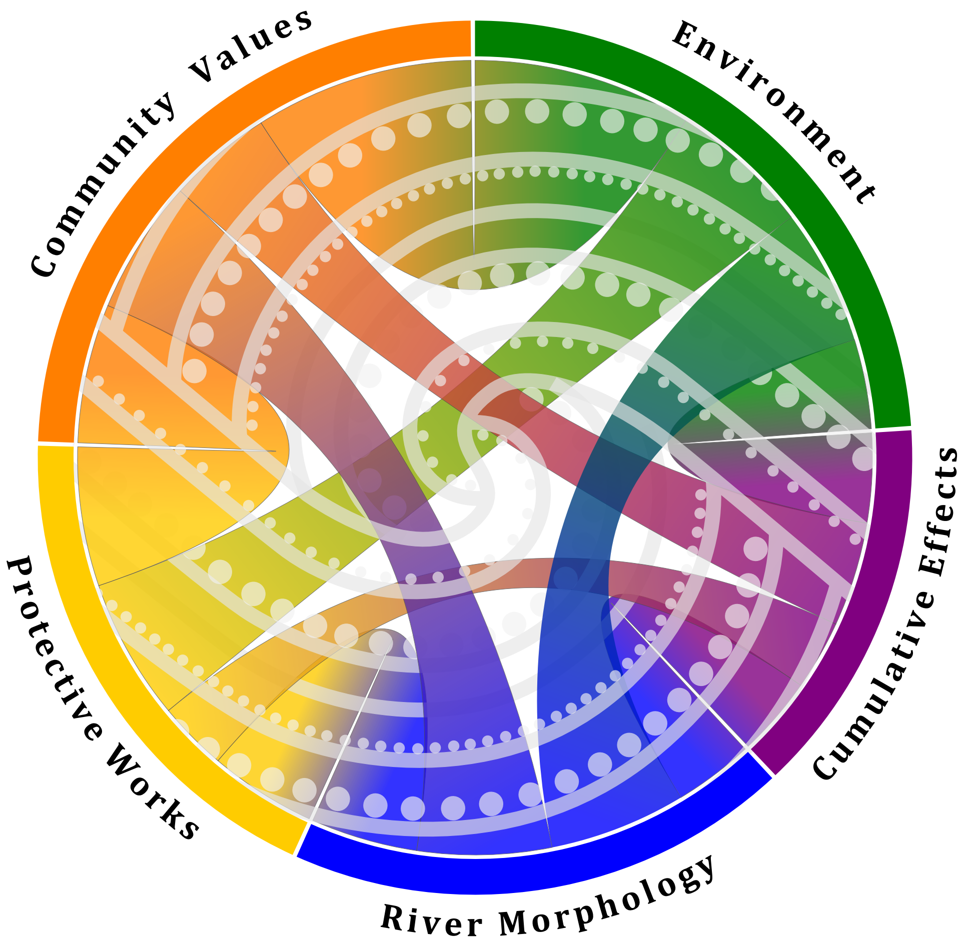
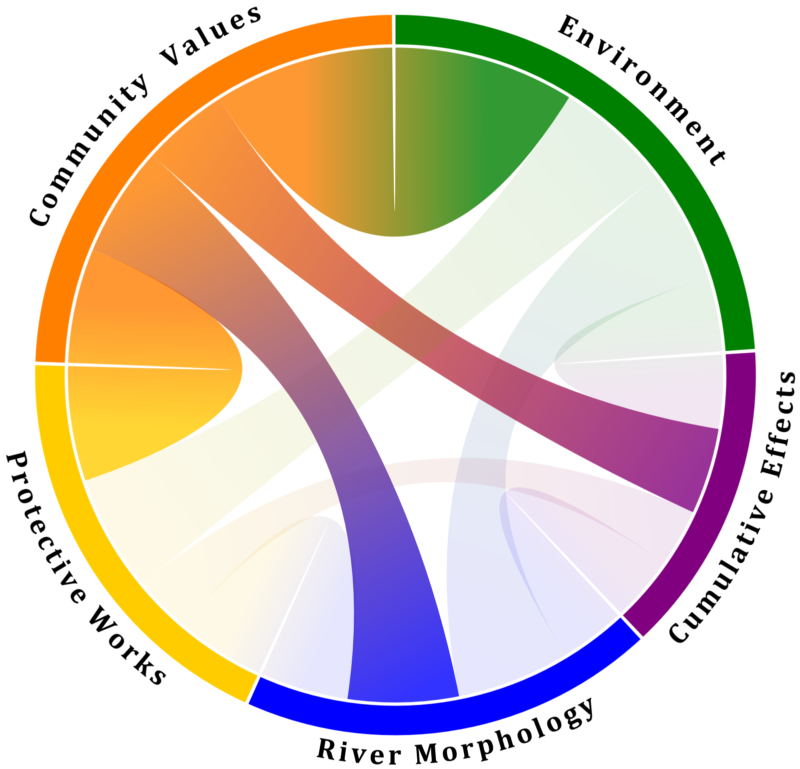


Figure 2-1 - *Framework of interacting effects of gravel extraction on Community Values, Environment, and River Morphology, with consideration of suitably aligned Protective Works and possible Cumulative Effects from multiple operations over time and across space. The strands consist of many subcomponents (not pictured) that will interact across the various categories in various ways: both tensions and practical synergies. Matauranga permeates across all these relationships, as represented by the interwoven "Maui" motif (modified from Tamati Ngakaho, decorator of Ropata Wahawaha's famous house "Waiomatatini", on the Waiapu River. National Library, Tiaki IRN: 233561). This is the fundamental basis for management of the river.*

The ***Environment*** category includes air and water quality, ecosystem health, species abundance and diversity, and nutrient availability. ***Cumulative effects*** are particularly important, as extraction activity can impact other system components through repeated takes by different operators over time, along the same river reaches. A deficit of material can migrate quickly through the network, interacting with natural erosion processes and exacerbating the effects of shortages in other parts of the catchment over time. ***River morphology*** is responsive to sediment supply conditions; a river may narrow and simplify its character with a sediment deficit, leading to changes in habitat diversity and availability. Finally, gravel extraction has also been used as a management tool, in order to coax the river away from property or key infrastructure, or to reduce the likelihood of flooding in a particular site. ***Protective works*** must also be managed in the context of a broader management plan, since such extractions must be adaptive (responding to fluctuations in river conditions), coordinated, and dedicated over time. Lastly, all strands are interwoven with principles of kaitiakitanga, mātauranga, sustainability, respectful dialogue and strategic economic vision.



2.1 Community Connections to the River

Just as there is a diversity of river morphologies along the numerous tributaries of the Waiapu, there is a diversity of values and viewpoints on how best to conserve and manage the system; the community has been contributing to a long-running process of developing a common vision for the Waiapu and integrating tikanga (indigenous laws and values) into river governance and management.

Proponents contemplating extraction works on the river must engage in meaningful dialogue with local Hapū, and look to align the work with the broader management vision for the river. This process cannot be bypassed in implementing extraction works on the river. Concerns over extractive practises on the river have long been expressed by community members, and there is a strong collective sense that management of the river has not adequately taken consideration of the holistic health of the river and its people (see Porou *et al.*, 2012, p.229). These concerns have not been allayed or addressed, to date.

As an outcome of lengthy and extensive consultation with the community, Porou *et al.* (2012) provide a summary of the consensus on a desired state for the Waiapu River, which is worth citing here:

"Ngāti Porou have identified that they desire a river that is clean, has drinkable water, and flows freely — a river where Ngāti Porou can swim, play, and enjoy the waters safely to contribute to the re-invigoration of the relationship between the people and the environment. They envisage a future in which they have control over the river and its catchment as kaitiaki and have the ability to decide and influence the protection and sustainable use of the Waiapu, and through this influence they could reduce the sources of pollution to the awa and use matauranga that was honoured, respected, and relevant to restore the catchment.

Ngāti Porou want a river that is again a kapata kai, bountiful with flora and fauna to sustain Ngāti Porou and, in turn, for Ngāti Porou to sustain the river. They desire a future in which Ngāti Porou again understand the intimate relationship that the people once had with the River and, through this improved understanding, take greater responsibility for their land use choices and how they affect the Waiapu, and create economic opportunity through innovation and sustainability to improve the lives and incomes of Ngāti Porou people...

Finally, Ngāti Porou want to ensure that they do not pass the River onto future generations in a state worse than its current state — to at the very least, do no further harm to the River and its catchment."

Figure 2-2 *Cooling off in the Mata River. Photo Credit: M. Caddie.*

The Joint Management Agreement (JMA)

The Resource Management Act (RMA) was amended in 2005 to strengthen the role for Māori, by creating an obligation to consult with tangata whenua in the preparation of a proposed policy statement or plan if they may be affected by the policy or plan. A further amendment provided for public authorities and Iwi to enter into "joint management agreements" under which decisions taken have the legal effect of a decision of the local authority. In 2015, as a response to a long-held desire for greater voice in resource decision-making and better self-determination, Te Runanganui o Ngati Porou and Gisborne District Council entered into a Joint Management Agreement for the Waiapu Catchment. This enables the two agencies to jointly carry out the functions and duties under Section 36B of the RMA, and other legislation relating to all land and water resources within or affecting the Waiapu Catchment. The agreement builds on the work of the existing Waiapu Kōkā Hūhua partnership between the Council, Te Runanganui o Ngati Porou and the Ministry of Primary Industries to restore the Waiapu Catchment.

Council and Te Runanganui will make the following decisions jointly in accordance with this JMA:

- decisions on notified resource consent applications under section 104 of the RMA within the Waiapu catchment
- decisions on RMA planning documents under clause 10(1) of Schedule 1 of the RMA that affect the Waiapu catchment, including the Waiapu Catchment Plan
- decisions on private plan changes within, or affecting, the Waiapu Catchment

The Ngati Porou, Gisborne District Council JMA differs from other JMAs, in that it applies to all the freshwater, air and land within the Waiapu Catchment. This JMA will provide a model for the recognition of Iwi rights and interests in freshwater, as well as provide a practical 'collaboration vehicle' to enable effective, inclusive and robust management of freshwater and land resources, within the Waiapu Catchment.

Te Mana o te Wai

Te Mana o te Wai is a framework to guide freshwater management, including allocation. The NPS-FM 2020 provides strong direction to local authorities to give effect to Te Mana O Te Wai Freshwater Plan. Resources must be managed in a way that gives effect to Te Mana o te Wai through:

- involving tangata whenua
- working with tangata whenua and communities to set out long-term visions in the regional policy statement, and
- prioritising the health and wellbeing of water bodies firstly, then the essential needs of people, followed by other uses.

Involving tangata whenua and engaging communities and kaitiaki to be more proactively involved in the governance and management of the wai is central.

The framework has been initiated in response to the different freshwater values and demands to be managed within the Ngati Porou rohe. It will be a Regional Plan under the Resource Management Act 1991 (RMA), and will provide key resource management direction for the management of freshwater and natural resources in the Waiapu.

Embodying a full partnership approach means the plan will be co-designed and co-written by Ngati Porou and the Gisborne District Council. Sharing decision-making powers and responsibilities with Ngati Porou over natural resources in the Waiapu Catchment provides more opportunities to utilise and sustainably manage resources for the benefit of all the people living in the Waiapu Catchment area (National Nati News, 2019).

This report is designed to provide some input on the issues related to extraction of gravel, which has so far not had much technical attention.

Economic Benefits

The positive benefits of gravel extraction should be considered alongside any adverse effects. Positive effects include:

- the provision of direct and indirect employment opportunities
- contribution to economic and social development through the provision of materials to maintain and enhance roads, particularly within the forestry sector.
- diversification of the local economy and support of ancillary services such as engineering, road works and construction businesses
- the reduced social and economic costs of having aggregate resources closer to demand
- enhanced flood and erosion protection through the removal of excess aggregate from the riverbed
- other flow-on regional benefits, including complementary businesses or services.

Substantial capital investment is usually required for excavation, sorting, screening and transport equipment. Firms in the industry require trucks, excavating equipment, washing and screening facilities and conveyor belts. Demand for aggregate is rising, and the economic model is becoming increasingly favourable for extractors (Leask, 2018; Zaki, RNZ, 2018).

Community Values: The Mauri of the River

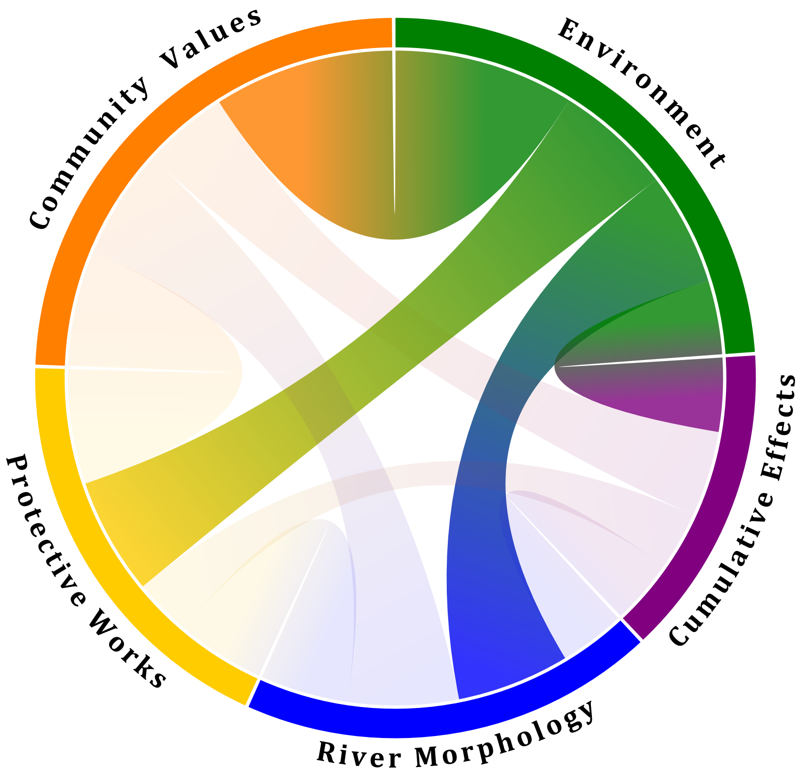
The study by Scion (2012) indicated that deforestation and land development over the last 120+ years have had an enormous impact on cultural values and Maori well-being through spiritual loss, degradation and reduction in the area of natural resources, decreased access to traditional resources, increased flooding risk, loss and deterioration of culturally significant flora and fauna habitats, loss and modification of cultural sites and tikanga (practices associated with those sites and resources), and the continuing decline in the mauri (life force or health) of the river and the quality of its resources through the deposition of enormous quantities of sediment.

The concept of mauri encompasses multiple aspects, beyond the river itself: the larger catchment system, the associated cliffs, hills, river flats, lakes, swamps, tributaries, and all other things that serve to show its character and form. It is reflected in its people, as well. It is important tangata whenua are involved in environmental decision making and planning. As kaitiaki of the Waiapu River (or the specific tributary therein), the community follows an obligation to maintain the mauri of the river.

Figure 2-3 *Looking downstream on the Waiapu River, close to Tutara Hill. Photo Credit: M. Caddie.*

Key Messages

- Self-determination on questions of river management has been a long-held aspiration for local Hapū and Iwi, and the wider community. The Joint Management Agreement provides a mechanism for consultation and consensus on extractive activities on the river.
- Te Mana O Te Wai is a management framework under development that will encourage tangata whenua, community and kaitiaki to become more involved in governance and management of the wai.
- Economic benefits may be realised from gravel extraction, and market conditions are favourable for development of the resource, but an improved consultation and decision-making process is needed to target appropriate river deposits.
- Insights from matauranga can be brought to the decision-making process, as well as an expanded and accessible scientific information base.



2.2 River Ecosystems and Environment

Braided rivers are notable for their biodiversity values; they naturally support highly specialised and diverse assemblages of flora and fauna (Wiser *et al*., 2013). A key concern in managing the Waiapu and its tributaries is maintaining the integrity of riverine habitat and thus the ecosystem. While East Coast fish and invertebrate populations have been determined to be lower than elsewhere in New Zealand (Rowe *et al*., 1999), there is good potential for rejuvenating aquatic populations as land use practices change and afforestation takes hold within the catchment. The low-gradient reaches closest to the coast have particularly good prospects for recovery.

Varied and complex hydraulic environments such as riffles, pools and backwater refugia are vital habitat areas for fish and macroinverterates (e.g. insects, crustaceans, molluscs, worms and leeches). Hughey *et al* (2011) identified the lower Waiapu as a site of Regional Significance (the highest rating among Gisborne District Rivers). They noted abundant, good quality habitat, and sightings of stilt, dotterel and Caspian tern. The Waiapu has several fish species such as longfin eel, torrentfish, giant kokopu, koaro, inanga, short jaw kokopu and redfin bully. Duncan and Sykes (2015) note that while there is an abundance of good physical habitat and ideal hydraulic environments in the Waiapu and its tributaries, fish populations are limited by food availability, due to turbid waters and drapes of sediment on the riverbed. Richardson and Jowett (2002) offer the further observation that fish abundance is most strongly linked to stable stream morphologies with low bedload transport rates, providing some indication that managing surplus sediment may have some directly beneficial effects on fish populations.

In their survey of invertebrate communities within braided river systems, Gray and Harding (2010) have shown that, in surveys of 11 braided rivers, from the southernmost South Island to the Waiapu, the Waiapu had the lowest overall taxonomic richness for macroinvertebrates, roughly half the abundance of the highest scoring Wairau River.

Anecdotal accounts summarised by Harmsworth *et al.* (2002) relate that the Waiapu River and its major tributaries were able to support a healthy population of fish and eel around the turn of the century, and up until about the 1950s. The Waiapu River was considered a major source of kai to Ngāti Porou, and eel (tuna) was a dietary staple. Kokopu and inanga (whitebait) were present up till the 1960's in the Waiapu, Makarika, Tapuaeroa and Mareahara Rivers. In pre-European days, the Raparapaririki Stream (and other tributaries to the Waiapu) supported a population of eels (Harmsworth *et al*., 2002; Peacock & Marden, 2004), and the literal translation of the name means "small eels hung out to dry".

Prior to Cyclone Bola in 1988, tributaries to the Waiapu (specifically the Tapuaeroa River and Raparapaririki Stream) were typically "steep bouldery mountain torrents" (Peacock & Marden, 2004), and in the 1970's and 1980's were known to support a population of trout. Kokopu, inanga and eels are still present in some upper river reaches that are not laden with silt, such as the Maraehara. However, the populations are much reduced, and have disappeared completely from some tributaries (e.g. Tapuaeroa). Brown trout populations are present in the Waitahaia River, where the water quality is suitable.

River Substrate

Coarse substrate is very important for native species that inhabit New Zealand rivers. Richardson and Jowett (2002) showed that fish abundance and diversity in East Cape rivers tended to drop off as sediment load increased, remarking that it is deposited sediment, rather than sediment in suspension, that may most strongly limit habitat availability for fish. Fine gravel, sand, and silt-sized bed material filling spaces between the larger rocks tends to limit the ability of fish to feed. Diatoms cannot flourish in these silt-laden environments, further limiting resources for macroinvertebrates. Spawning opportunities are reduced for some species. Thus the importance of managing extraction operations such that concentrated inputs of fine material do not accumulate in key riverbed habitats.

Natural river gravel deposits tend to have a coarser surface layer that has been worked ('winnowed') by flood flows, and thus has little matrix material. Skimming removes this surface layer of sediment, which may favour bed erosion and increasing local bedload transport (Figure 2-4; Collins and Dunne, 1990; Rinaldi et al., 2005). Once this surface layer is removed, either by high discharge or by mechanical excavation, the matrix material stored below easily becomes

Figure 2-4 *Extraction works near the Rotokautuku Bridge (SH35) are carried out using a combination of skimming the bar surface, as well as deeper elongate trenches, parallel with the flow.*

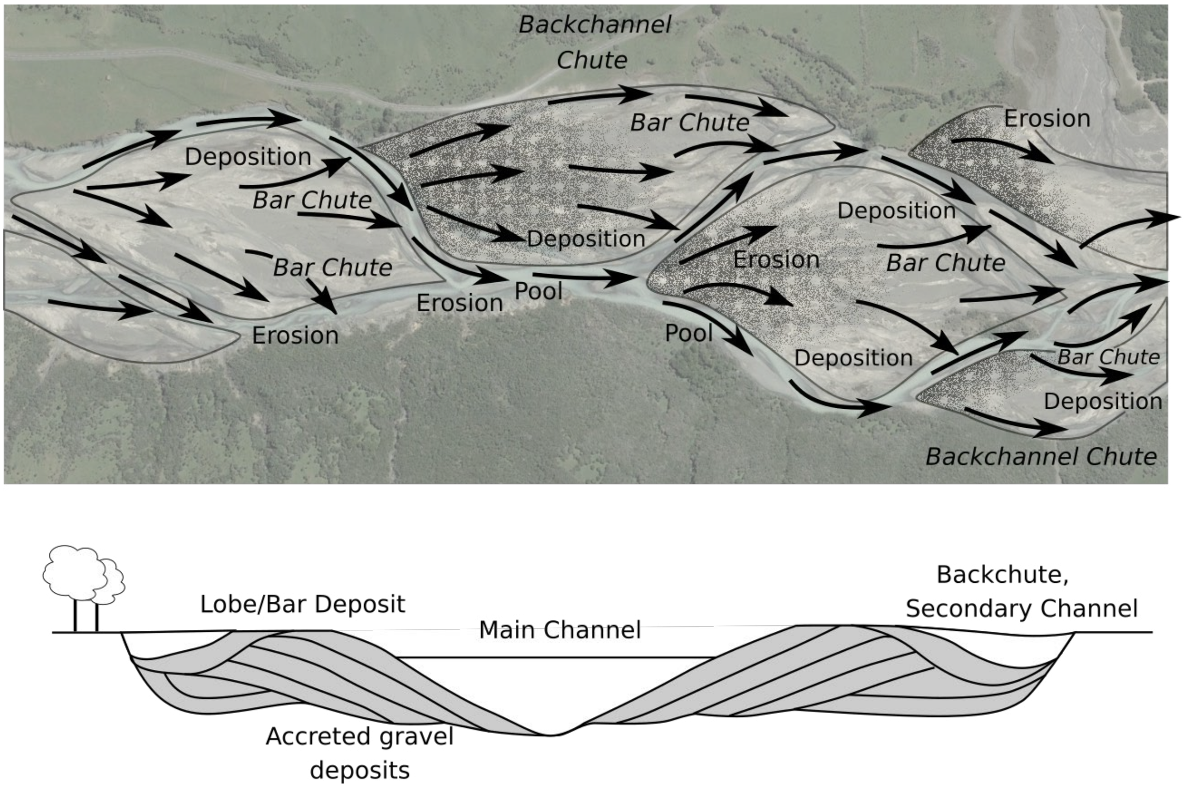


Figure 2-5 *An example of sediment pathways in a braided river system. The system is more active than the meandering case, with multiple, low-relief lobes steering the flow through a sequence of chutes and pools. Darker stippled shading reflects coarser gravels. (Background image ©Digital Globe, Google Earth)*

liberated to the river again. Thus, bar skimming has been associated with greater release of fine material in flood flows. A structured surface layer is also associated with higher quality fish habitat, which is of particular concern in rivers with spawning salmonid populations. Skimming operations have largely fallen out of favour in the Pacific Northwest of the US and western Canada (Rosenau and Angelo, 2000) for this reason.

One of the inherent risks of skimming river bars involves promoting the development of a relatively wide, flat cross section which can reduce the effectiveness of the main channel to transport bed material. Cross sections should have a channel that is deep enough to maintain competent flows to transfer coarse bed material downstream. Other studies (*cf*. Weatherley *et al*., 2007) have identified the high points on these bars (upper third) as important shallow water refugia for some fish species and macroinvertebrates during periods of high flow. While some aquatic species can thrive under a regime of natural riverbed disturbance, stable surfaces are quite important for others (Gray and Harding, 2007).

Hydraulic Environments

Rivers tend to meander by eroding material from the outer bank, downstream from bends, and depositing that material on the inner bank of the next bend (Figure 2-5). Gravel deposits develop through deposition along the edges of bars, such that they grow laterally into the channel, often acting to induce erosion on the opposite bank. The gravelly floodplain builds up as successive sheets of bed material are deposited on the flanks of the bars. Finer material (sand and silt) may be deposited from suspension during overbank flooding, capping bars and riparian areas (Rhoads and Welford, 1991) with drapes of this material. Reworking of the floodplain occurs as the main flow thread migrates or avulses, often reactivating abandoned back chute channels (Figure 2-5) in the process.

In braided rivers, there is a suite of processes acting to evolve the channel and transfer sediment downstream. Braiding can be initiated by local deposition in midstream topographic lows or by erosional dissection of topographic highs (Bridge, 1993; Ferguson, 1993). Deposition of bar material initiates scour upstream, causing flow to diverge, and carrying bedload material to the next braid bar downstream.

Channels shift across the floodplain, resulting in bar incision, bank erosion, as well as the stabilisation of previously active areas. Incision of bar deposits during particularly high flows leaves locally elevated bar surfaces that remain above regular flood events and are further stabilised by vegetation colonisation and growth. These processes result in a mosaic of different deposit types and sedimentary environments along the length of the floodplain (Figure 2-5).

The active riverbed is that portion of the river cross-sectional profile that experiences high flows over the course of one or more floods in a given year. Aggrading, braided rivers are distinct from other river types in that they tend to have quite wide courses with relatively low relief, and the main flow thread can change frequently. The active channel is demarcated by an absence of vegetation, mobile alluvium, signs of erosion and deposition (Figure 2-6).

The broader alluvial surface includes older abandoned bars and back channels, and floodplain surfaces that are perched at higher elevations above the modern riverbed. As sediment supply diminishes, a braided system will begin to cut into the alluvial surface, further isolating the active riverbed from older deposits.

From a habitat perspective, the islands and back channels provide varied flow environments and sites of diverse texture, topography and vegetation. These are important refugia, nesting sites, and shaded environments that satisfy habitat requirements for a variety of riverine species (Arscott *et al*., 2005; Corenblit *et al*., 2007; Gray and Harding, 2007, 2010; O'Donnell *et al*., 2016) and promote the development of a rich and complex food web.

Parafluvial and Floodplain Environments

Because the sediment surrounding alluvial rivers is porous, there is a less obvious but equally important coupling of the river with (1) the subsurface groundwater system, (2) off-channel water bodies (lakes, ponds, and abandoned side channels), and (3) floodplain soils and vegetation. Deep groundwater may represent the greatest aquatic volume of the river, and is a vital reservoir in times of water stress.

The hyporheic zone is defined by the extent of surface-subsurface mixing (hyporheic exchange) through the porous sediment surrounding a river, and is characterised by circulation cells that move surface water into the surrounding alluvium and back to the river again. Hyporheic exchange is

Figure 2-6 *Wide, active alluvial surfaces distinguish braided and wandering rivers from more confined/stable meandering ones. A riparian buffer (at right) on a large river (Tapuaeroa) can moderate and filter inputs from adjacent farmland.*

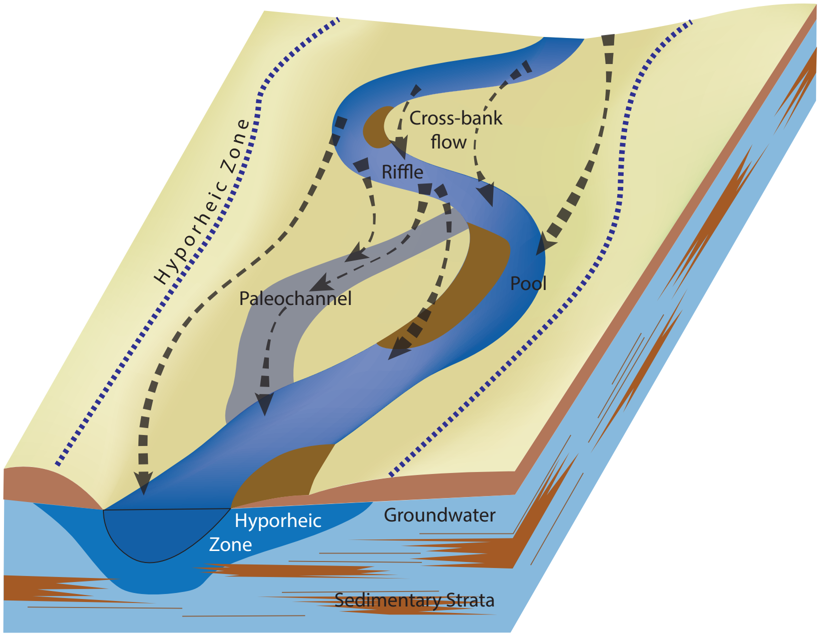


Figure 2-7 *Water pathways through the hyporheic zone in gravel bed rivers provide linkages for oxygen and nutrient flux, which are important for stream biota forming the basis of the riverine food web. Preferential flow may occur in abandoned paleochannels. Alteration of these pathways can impact the potential for ecological recovery of the river. After Tonina and Buffington (2009).*

distinct from far-field inflow of groundwater and from one-way outflow of river water (i.e. flow paths that do not circulate water from the river and back again).

The Riparian Zone

The riparian zone is land adjacent to the active channel. This boundary, a few metres to hundreds of metres wide, forms a key interface between river and land that moderates all hydrological, geomorphological, and biological processes associated with this interconnected fluvial corridor (Gregory *et al.*, 1991). In undisturbed environments, it is a zone of high species diversity, with a succession of vegetation from pioneer willows to mature forest.

Riparian areas provide a buffer that will
- protect banks from erosion and localised changes in morphology
- moderate the input of nutrients, silt, microbes and pesticides from overland flow
- decrease the flow velocity of overbank flood flows, thus limiting erosive energy.
- maintain stream temperature and microclimate

The influence of riparian zones on the adjacent watercourse increases as the width of the river course decreases (Collier et al., 1995), thus smaller streams derive proportionally greater benefits from healthy riparian areas. That said, for even the widest alluvial sections of the Waiapu, riparian areas play key ecological, hydrological and geomorphic roles, and therefore should be protected and maintained. Gravel stocks, and screening and loading operations should be kept at a distance from the active alluvial surface, with a good buffer of vegetation around the site.

Quarry Traffic

Hauling many hundreds of thousands of cubic metres of gravel from the river involves many tens of thousands of truck trips, increasing traffic on local roads and adding wear to transport infrastructure. Effects of quarry traffic include vibration, congestion, safety and noise. Given the relatively quiet setting of Ruatoria and surrounding communities, there is potential for these impacts to be significant.

Air Quality

An emerging complaint for residents near the river is the entrainment by the wind of dried silt that has been layered on the floodplains. During dry spells in late summer, the dust is carried great distances by strong convective winds originating mainly from the Raukuara Ranges to the northwest (Figure 2-8a). This effect is strongly exacerbated by heavy vehicle traffic over the floodplains, excavation of new material, and dumping of excavated material in stockpiles. (Figure 2-8b,c). Dust can also arise from dumping, sorting and screening processes at the gravel landings next to the river.

Key Messages:

- The Waiapu River's benthic (river bed) environment, and fish/eel populations, have changed markedly in the last fifty years. Broader ecological recovery in the catchment depends on rehabilitation of functional river habitat.
- River substrate is important to river biota. Coarse cobble/gravel fractions are important, yet these are also an attractive target for extraction operations. A balance must be struck, preserving longitudinal and lateral connectivity of river habitat, rearing grounds and refugia.
- Connectivity includes subsurface pathways: the integrity of 'undergrounds rivers' and the hyporheic zone within floodplains should be evaluated when mapping out the footprint of proposed extraction activities.
- Riparian zones are a vital interface between terrestrial and riverine habitat and nutrients, and buffer the river system from erosion. These should be protected and revitalised, where possible.
- Impacts from extraction include traffic, noise and exacerbation of air quality issues. These should be addressed in consenting conditions.

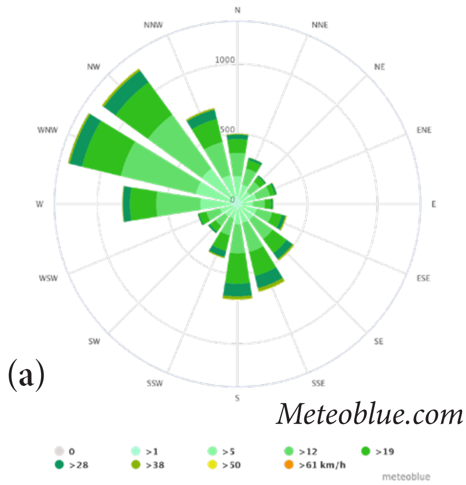
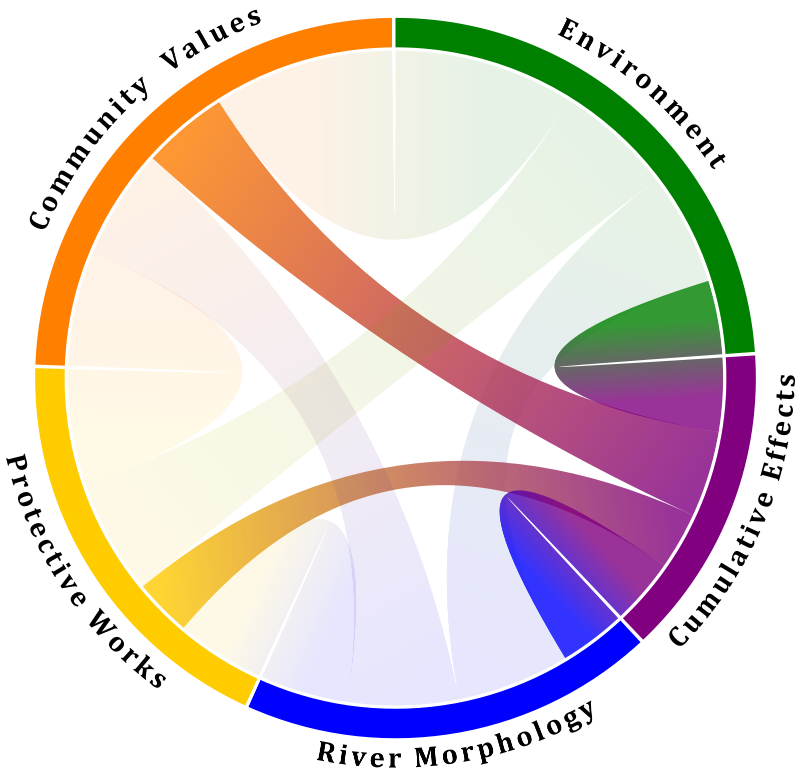


Figure 2-8 - *A wind rose diagram (top) shows the predominant wind direction from the NW. Dust clouds billow over the Waiomatatini Road site in the wake of haulage trucks disturbing dry silty river sediments draped over the bar. Middle: truck hauling gravel upstream of the SH35 bridge; Bottom: Looking SE from Te Araroa Road (SH35).*



2.3 Cumulative Effects

Consenting and allocation of gravel extraction should take careful consideration of recent and/or ongoing operations both upstream and downstream. A local deficit of material, for instance, may form a knickpoint or discontinuity in the river long profile, and this can travel upstream, steepening the bed and enhancing local erosion of material. Alternately, local shortfalls in gravel supply can cascade downstream, moving as a kinematic 'wave' and enhancing erosion effects downstream (James, 2010). Because of the way river networks are organised, effects can interact, potentially amplifying the nature of many smaller perturbations. The impacts of reduced sediment supply may not be evident for many flood cycles, and indeed, may affect the river long after gravel extraction operations have ceased (see Martín-Vide *et al.*, 2010). The transit of material is a function of the channel geometry and the recurrence interval of large floods: in a large catchment with many tens of kilometres of active channel, it will take some time for any surplus or shortfall to work through the system.

In this section we consider (1) cumulative temporal effects that can occur from persistent extraction from one point in the river, with consideration of lags and transit times, and (2) cumulative spatial effects that occur from extracting a multitude of points upstream of the river's main stem (in this case the Waiapu). We first review the types of extraction operation currently active in the Waiapu.

Gravel Extraction Methods

Extraction within the Waiapu occurs mainly via one, or some combination, of the following techniques, ordered here by the degree of encroachment upon the active channel:

(1) ***In-channel works***. Extraction, screening, stockpiling all occur within the active channel.

(2) ***Excavation within the alluvial floodplain*** (though not within active channel). Stripping (skimming, scalping) of the active surface (generally <0.5 m, or bucket depth). This is by far the simplest and most common approach. The volumes removed are typically smaller than those removed for pit excavation (cf. Kondolf, 1994).

(3) ***Trench or deep pit excavation*** (>=0.7 m), mining of substrate in the active floodplain or low terraces. This may occur adjacent to the active channel, or closer to the middle of the bar.

(4) ***Excavation of the floodplain near the active channel but confined within a gravel berm***, designed to keep flowing water out at baseflow, and provide a spillway for high flows.

(5) ***Off-channel excavation of relict floodplains, terraces, fans and other deposits***. Older alluvial deposits adjacent to the channel hold large quantities of river gravel that can be accessed without entering the river system.

Work is generally carried out using excavators, graders and bulldozers. Material is carried away in dump trucks. Excavations are typically designed to ensure no silt laden material escapes into the active river channel. (Stevens and Larsen, 2015). Disturbance can be either relatively wide and shallow (Technique 1 and 5), or less extensive and deep (Technique 2-4).

Figure 2-9 *The Aorongiwai Stream (right) has experienced bed degradation (leading to undermining of bridge support), through a combination of gravel extraction and reduced sediment delivery from the upper catchment.*

Multiple Operations over Time

Persistent over-extraction from a site can impact river morphology, longitudinal profile, and texture (grain-size) of the river. Figure 2-9 shows the impacts of gravel extraction on the Aorongiwai Bridge, a few years after cessation of operations on the river, roughly 800 m upstream. In-channel excavation and stockpiling (Technique 1) occurred around the same time as forestry operations in the catchment (ca. 2008-2009). The forestry work, and the confined setting resulted in traffic of machinery and sediment recruitment to the channel. The channel course has narrowed, straightened and cut down in the years following this work (Figure 2-10). This could be attributable, in part, to the shutdown of a large gully system 1.4 km upstream. The Aorongiwai bridge abutments were subsequently undermined, and the pilings have been exposed (photo was taken in 2016). Tenders for repair of the bridge were sent out in 2019. A large landslide in the headwaters that occurred in mid-2020 may change the trajectory again. The sequence provides a good example of the response time (6-7 years), and the impacts of sediment deficit in a relatively small system (~23 km^2) where rates of replenishment are quite variable, and the river may reconfigure itself fairly rapidly in response to supply changes. Similar cases of extraction within smaller catchments have been reported in Liébault and Piégay (2001) and Marston *et al.* (2003).

Figure 2-10 *Aorongiwai River, upstream of the Matahaia Bridge (see Figure 2-9). Flow is left to right. Gravel operations were carried out in-stream, gravel was stockpiled on the river bed, and note the absence of barriers between flowing water and active excavation. The example emphasises the capacity for relatively rapid change in sediment supply, even following cessation of gravel extraction (©Digital Globe, Google Earth).*

Figure 2-12 *A bar surface is reconfigured by stripping operations (Technique 2) at a bar head in the Mata River, near Te Koau. Flow is left to right. ©Digital Globe, Google Earth, 2019.*

Figure 2-12 shows a bar surface reconfigured by stripping operations (**Technique 2**) at a bar head in the Mata River, near Te Koau. The depth of disturbance is shallower than deep pit mining, though the disturbance extends across a much broader portion of the riverbed for a given volume of yield. The upstream 'head' of the bar has been targeted for the relatively coarser gravels that can be found there (*cf.* Section 2.4). This is an area of high flow attack and thus it is usually relatively 'armoured' with coarse gravels and cobbles (Collins and Dunne, 1990; Rinaldi *et al.*, 2005). Given the confined setting on the Mata River, most of this site will be inundated and the bar surface reworked in the next large flood. The biased removal of coarser and more durable material (thereby enriching fine material) can lead to morphological changes in the reach over time.

The technique of bar-edge scalping, downstream from the bar head (lower two-thirds of the bar) along the margin of the active channel has been recommended as a better (if experimental, thus far) approach (Church *et al.*, 2001), as it maintains channel conveyance and minimises impacts to channel stability and morphology. Excavation work plans should take care to document the prevailing morphology pre-excavation and consider how best to work *with* the river to maintain a functional morphology, grain size distribution and sediment transport regime.

The depth of pit excavations also requires some consideration. Once a deep pit is excavated within the channel, the profile of the streambed is no longer in equilibrium with the sediment load from upstream. The channel form must re-grade itself to maintain a continuous gradient; the steep slope at the upstream end of the pit accelerates erosion there, resulting in knickpoint retreat (Figure 2-11). The pit fills with the eroded sediment, and material is eroded from the bed downstream. This effect can extend for hundreds of metres, to kilometres upstream, depending on the volume excavated from the bed and rates of bedload replenishment from upstream (see Kondolf, 1997).

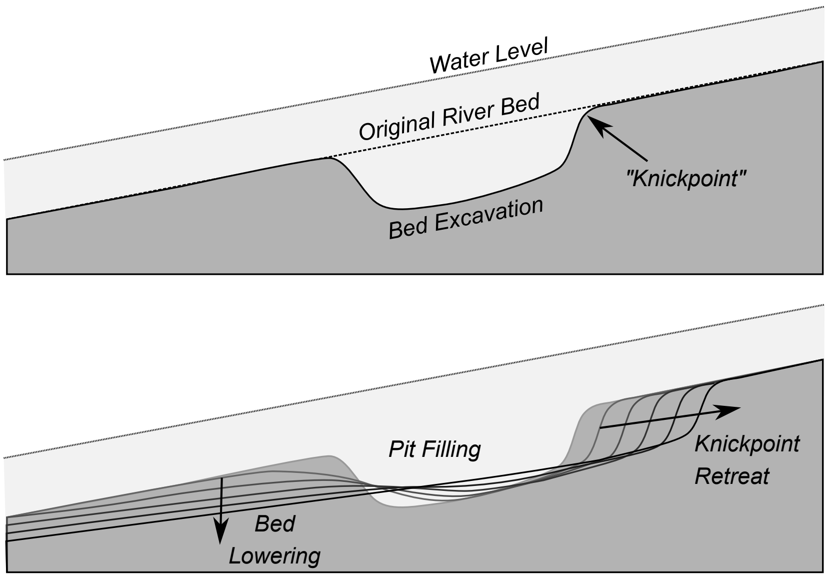


Figure 2-11 *Conceptual diagram showing the effects of deep pit excavation within a riverbed (diagram adapted from Kondolf (1994)). The scale and proportions of these erosional effects will vary, depending on river scale, sediment supply, and other hydraulic and sedimentary factors.*

Multiple Operations in Space

Gravel supply conditions will vary throughout the catchment, and it is therefore important to take into consideration how the system may respond to surplus or deficit within the many network linkages of the system. Over-extraction at any given point in the network can lead to knickpoint development (Kondolf, 1994; Wishart *et al*., 2008), and may also induces shortages downstream that can lead to enhanced erosion, for instance, via lateral bank erosion (Liébault and Piégay, 2001). A river flowing at a given discharge and slope needs to satisfy its equilibrium sediment concentration; a river starved of supply from upstream will adopt a “hungry water” disposition (Kondolf, 1997), satisfying the shortage through lateral erosion of the floodplains and/or the river bed.

At the time of writing, least four contracting operations are currently working in the catchment (Figure 2-13). Consenting agreements are set for about 8 years, on average, allowing for some measure of economic certainty on returns for the contractor, although the Council reserves the right to modify operations if there are signs of riverbed degradation. Current levels of extraction would allow a maximum of 450 000 m^3 (~720 000 t) to be removed from rivers in the catchment every year. Consented operations have grown significantly since the early 2000s when commercial operations on the Waiapu and Mata first got underway (Figure 2-13b).

By way of comparison, the Ngaruroro River in Hawkes Bay (2 010 km^2), the most heavily extracted system on the North Island’s East Coast, has reduced extraction rates from an average of 300 000 $m^3 \cdot yr^{-1}$, since 2013 (Clode and Beya, 2018). Gravel takes from the Waimakariri (3 110 km^2) from 1993-2003 are variable, but on the order of 320 000 $m^3 \cdot yr^{-1,}$ according to Hudson (2005). Current rates in the Waiapu are thus high, for a river catchment of its size, and the accelerating rate over time is notable.

Transport costs figure significantly into the profitability of gravel extraction. Sites that are

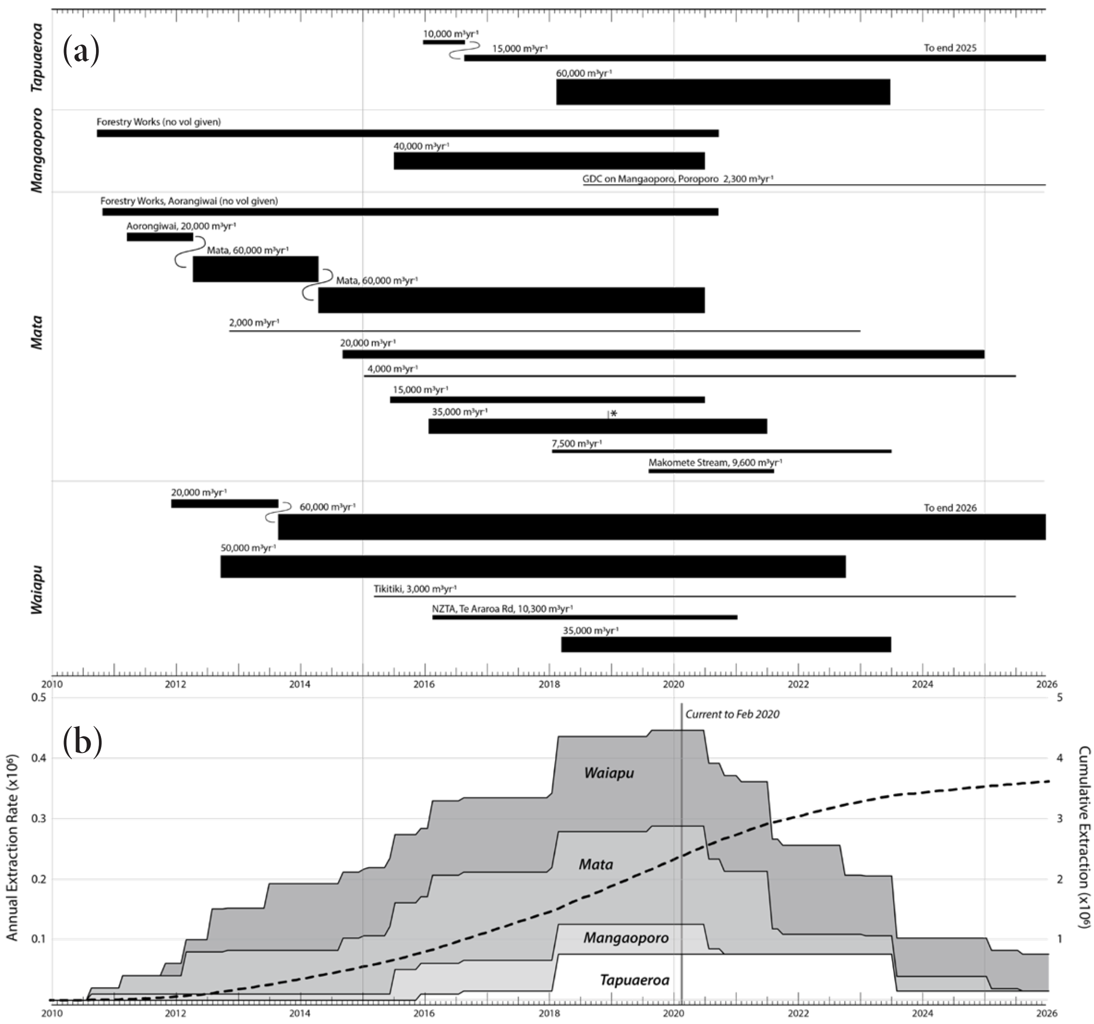


Figure 2-13 *Extraction timeline for the Tapuaeroa, Mangaoporo, Mata and Waiapu Rivers. Conditions and agreements in place as of February 2020.*

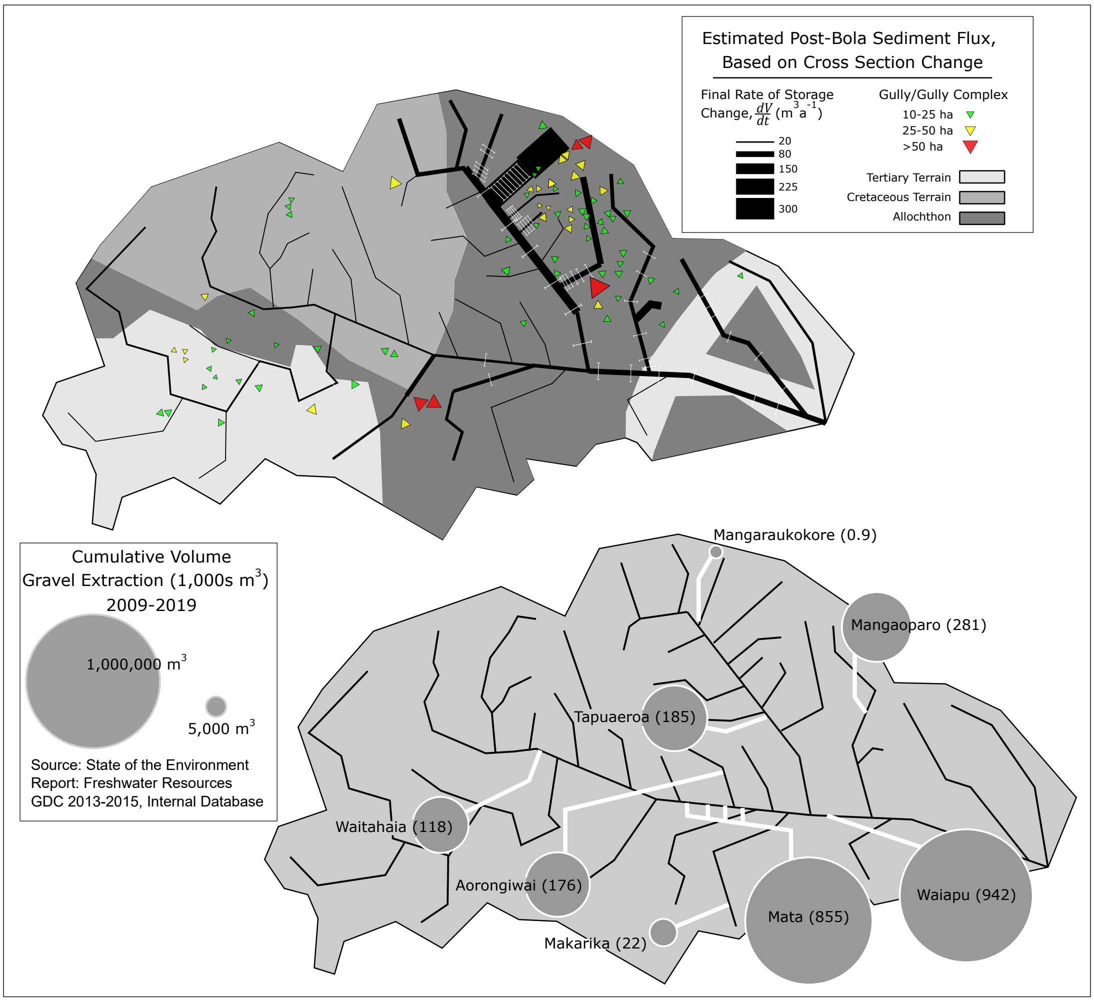


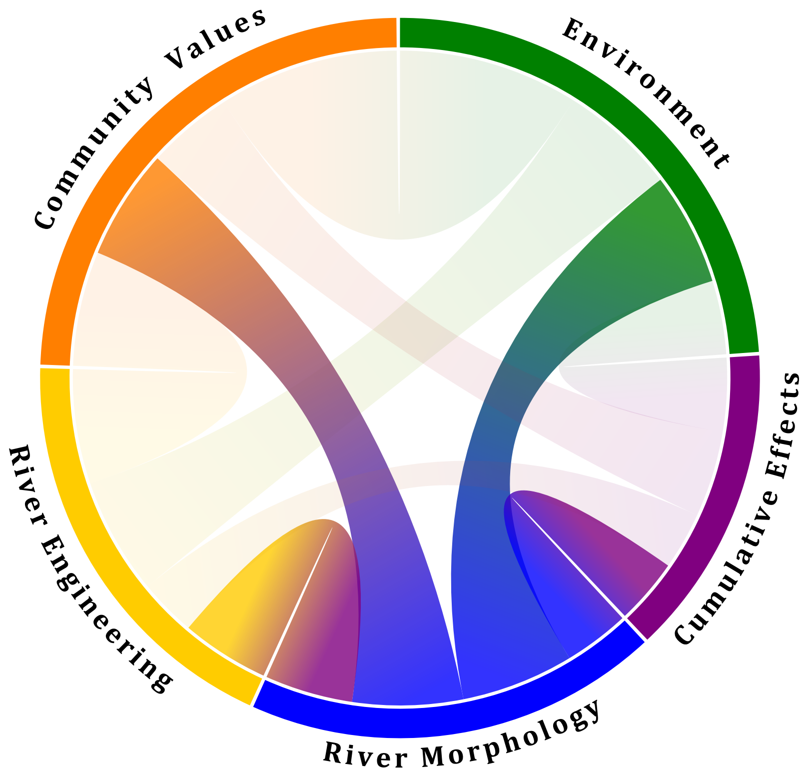
Figure 2-14 ***(Top) Schematic of the catchment, showing the river network and cross-section monitoring sites. The thickness of the lines reflects the relative rates of sediment flux, based on changes observed in cross-section measurements since 1988 (see Tunnicliffe et al., 2018). (Bottom) Sites of gravel extraction within the Waiapu catchment active and reporting between 2009 and 2019. Volumes were consented, but not necessarily extracted.***

located near major transport routes are able to keep costs down and remain competitive. For each tonne of aggregate produced, the first 30 kilometres it has to travel doubles the overall cost (Christie *et al*., 2001). Most of the current gravel operations are within roughly 5 km of the state highway. Some gravel supplies may have a destination within forestry operation sites or elsewhere off the state highway corridor, so this model does not apply everywhere.

Road access to the riverbed is not evenly distributed along the river corridor, and the most easily accessed sites are not necessarily those that would benefit from extraction. These sites are therefore prone to overuse and cumulative effects, and thus it is important to first assess where intervention by extraction can be beneficial, and then secondly consider how access can be best arranged. Extractors could be incentivised to work in sites that may otherwise be considered to have sub-optimal conditions or access.

The areas known to be aggrading within the Waiapu system are the ones draining the northern bounding Raukumara range front. Tributaries to the Tapuaeroa such as the Raparapapririki and Waiorongomai are subject to extreme rates of landsliding and debris flow from gully mass wasting complexes (Marden *et al*. 2012). The Mata River has not been impacted to a similar extent, although there are two major gully mass wasting complexes impacting the Ihungia and Makarika Rivers. The current spatial pattern of gravel extraction, however, is not consistent with the observed sites of surplus within the system.

Figure 2-14 shows a schematised summary of the cross-section database. Most of the aggradation and high flux rates are occurring in the Tapuaeroa catchment. The lower figure shows the historical distribution of gravel extraction sites within the Waiapu (2009-2015). This pattern is driven by the factors described above: proximity to the state highway, access to the river, and quality of gravel available. A few small remote operations are attributable to construction and maintenance of forestry roads.



2.4 River Morphology and Sustainable Sediment Supply

River morphology is very closely linked to sediment supply; changes to the rate of incoming material will change the nature of the channel morphology. The frequency of islands and bars and the natural dynamism of the river system is related to the rate of supply from upstream. The morphology of the river, in turn, will govern the availability of habitat, hydraulic environments for the life cycle of various freshwater fauna, and vegetation that can flourish within the floodplain and riparian environment (Figure 2-16).

The Waiapu Sedimentary System consists of the train of material from hillslope deposition to the coastal tract, to the offshore shelf (Page *et al.*, 2001; Carter *et al.*, 2010; Litchfield *et al.*, 2008; Kuehl *et al.*, 2016). The system is remarkably dynamic, by global standards, and is continually adjusting through time, as material builds up in some areas, and evacuates from others. Marden *et al.* have (2018) emphasised that adjustments related to forest clearance and storm climate in the last century are superimposed upon very long term (post-glacial) adjustments that are still very much in play. A sediment budget framework is essential to developing management objectives such as flood protection or restoring ecological processes. As one component of a larger toolset for river management, sustained gravel extraction can be used to influence the trajectory of the system over time; gravel removal and redistribution is an expensive undertaking, otherwise.

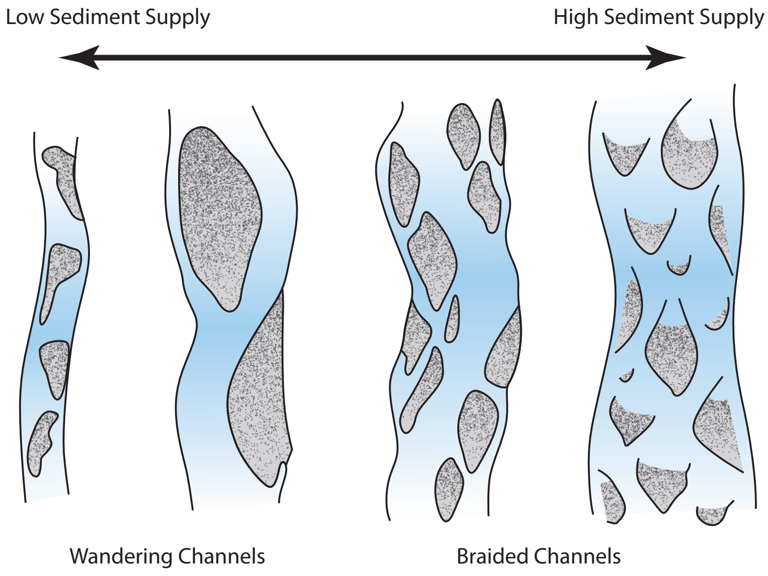


Figure 2-16 ***The influence of sediment supply on river morphology. System complexity and habitat diversity increase with higher rates of sediment transfer, though optimum ecological conditions are thought to be in the mid- to high range of this spectrum (see Piegay et al., 2006 for further details).***

Substrate Texture & Quality

The composition of the riverbed is of critical importance both for ecological processes and for the viability of the gravel extraction operation. A coarse-grained bed, with minimal sand and silt provides excellent habitat for stream-dwelling fish and macroinvertebrates (Richardson and Jowett, 2002; Parkyn *et al*., 2010; Roil and Death, 2018); these are also desirable qualities for gravel extraction. In contrast to rivers draining 'hard rock' greywacke or volcanic terrain in NZ, many rivers of the Waiapu catchment have relatively high concentrations of sand, silt and clay (>30% by deposit volume), which comes from the breakdown of the highly weathered clasts, sourced from 'soft-rock' silt- and mudstone parent material in sediment source areas. The spatial distribution of grain size varies across the bar environment, and as outlined in Section 2.2, coarser material tends to reside at bar heads, on the surface of the deposit.

Figure 2-15 provides an example of surface grain size characteristics for river systems in the Mata and Tapuaeroa catchments. The aggraded sections of the rivers tend to be relatively fine-grained deposits, while some of the alluvial surfaces that have undergone strong winnowing, followed by degradation, tend to be quite coarse-grained (the Raparapaririki being a notable case in point). A braided system such as the Tapuaeroa is an intermediate case, with some strong variation in surface sedimentary facies types, depending on the hydraulic environment (e.g. pools, riffles, surface drapes, backwater channels).

From a commercial aggregate perspective, materials greater than about 32 mm are of principal interest, though this varies depending on the intended market. Crushed river gravels must produce chips with enough broken faces to meet specifications, making larger clasts a more highly valued resource. Thus, when evaluating potential sites, it is important to assess the hardness of the stone, sorting of the deposit, and the relative proportion of fines. Estimates from Hawkes Bay contractors suggest that of the total material extracted from the river, less than 60% (approximately) is saleable product; there is likely an even lower proportion for Waiapu rivers. The ultimate yield may also vary depending on the outcome of the crushing and screening processes (Stevens and Larsen, 2015).

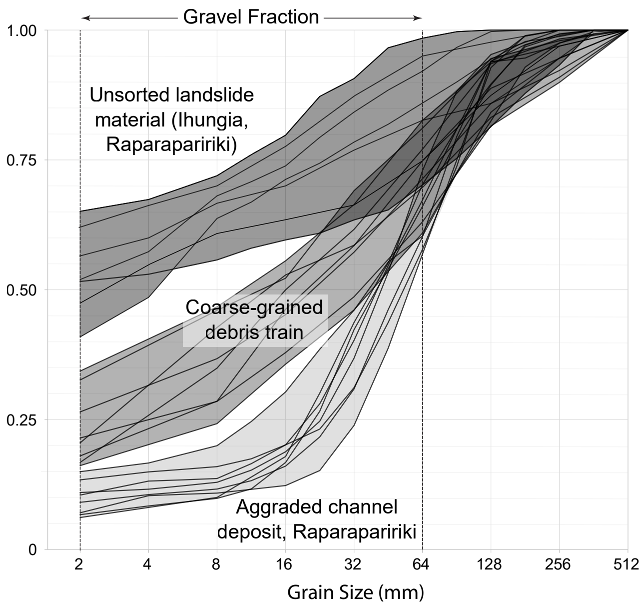


Figure 2-15 ***Surface grain size characteristics, sample by point counts of surface gravels. The subsurface material (not shown here) tends to be more enriched in sand and silt fractions.***

Sediment Supply and River Form

A continuum of river types may be observed throughout the Waiapu catchment, from steep mountain channels to lowland coastal reaches (Figure 2-17). The relative stability of the channel can be assessed from the lateral extent of river deposits along the river course, and the nature of changes exhibited over time. As channel slope diminishes to less than about 2% gradient, gravel bars become more prominent, and floodplains may develop adjacent to the river channel. In assessing catchment trends of aggradation and transport-limited conditions in rivers, a channel typology can be developed to map out where sediment is building up within the fluvial system (e.g. Brierley and Fryirs, 2005).

Figure 2-18 provides an example of a narrow, confined river system (Waingakia Stream), characteristic of many steepland rivers in Waiapu catchment. It has limited opportunity for deposition. There is little evidence of year-to-year variation in channel course. The system has a reservoir of material upstream, but only limited storage of material through the narrow gorge. Steep and confined river systems such as this one tend to be quite closely coupled with tributaries, landslips and other sediment sources. These sites are not good targets for extraction.

The Aorongiwai (Figure 2-19), roughly 4.5 km upstream from its confluence with the Mata River, shows signs of meander movement and exchange between channel and floodplain, with development of lateral and point bars, channel bifurcations and overbank deposition. Vegetation growth has stabilised older alluvial deposits, and provides enhanced resistance to erosion on the banks. Some small, targeted extraction of short duration may be possible.

The Mangapaoro River (Figure 2-20), downstream of a confined section, shows exceptionally active planform dynamics, and a very broad reworked floodplain surface. The notable patterns of change in the Mangapaoro have recently been reported by (Kasai *et al.*, 2019). This particular reach, (EC 542) has been aggrading at a modest rate (17.8 mm·a^{-1}) since monitoring began in 1958 (Peacock, 2017b). Extraction within a suitably delimited floodplain section may be sustainable, subject to other considerations (Figure 2-1).

The Waiorongomai (Figure 2-21) is perhaps an extreme end member, with very high rates of erosion from gully mass-wasting complexes upstream leading to some remarkable river sedimentation and resultant braid morphology near the tributary outlet. The Mean Bed Level has risen 1.5 m over the monitoring record, and there has been considerable widening of the floodplain.

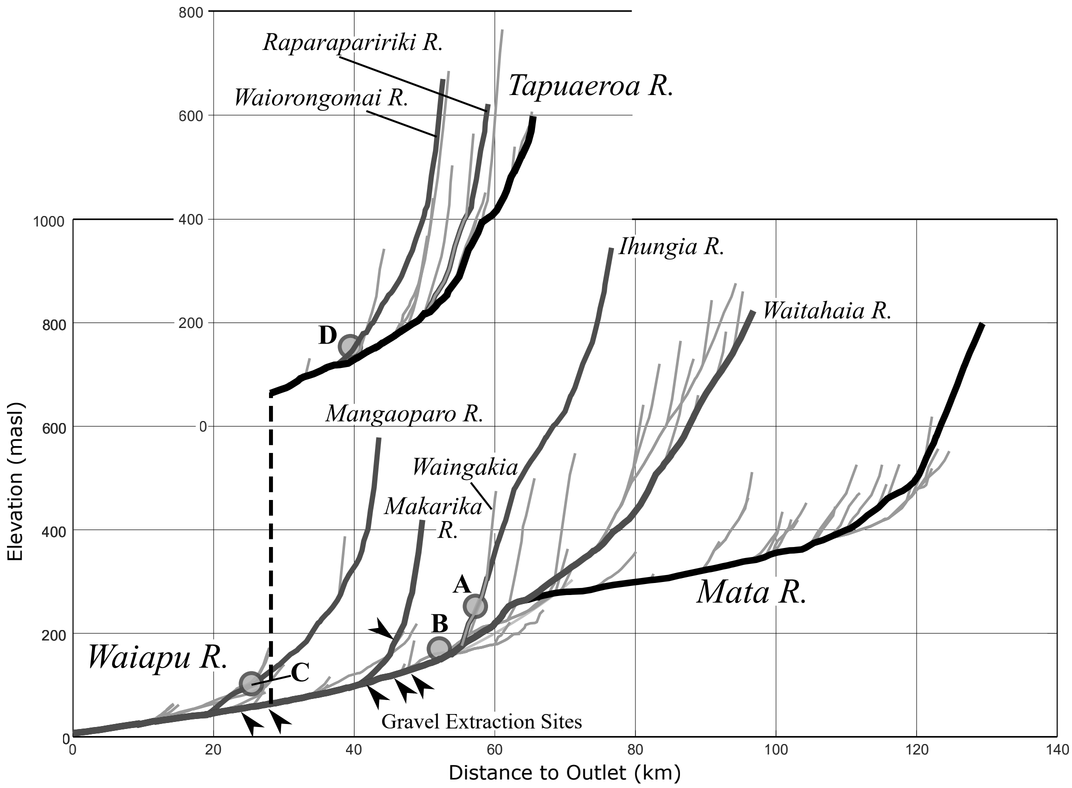


Figure 2-17 *Longitudinal profile of Waiapu River and it's tributaries. Letters with circle symbol indicate location of sample reaches discussed in the text, and pictured in subsequent figures.*

Figure 2-18 *Waingakia Stream (A). Flow is left to right. Steep and confined, with bedrock boundaries.*

Figure 2-19 *Aorongiwai Stream (B). Flow is left to right. Floodplain storage, within terrace-confined margins.*

Figure 2-20 *Mangaoporo Stream (C). Flow is left to right. Multiple active channels rework a broad alluvial surface.*

Figure 2-21 *Waiorongomai Stream (D). Flow is left to right. Upstream of the confluence with the Tapuaeroa. Significant sediment delivery upstream has led to an extensively braided morphology.*

River Morphology and Metamorphosis

A river's morphology reflects the sediment storage capacity of the river, and thus it's capacity to dynamically adjust to variations in sediment supply (surplus or deficit). When storage is reduced in the river, disturbances are able to cascade more rapidly through the system.

The morphologies of the Tapuaeroa and Waiapu River (proper) are dominated by large lobes of labile gravelly materials that grow within the confined channel sections and splay out to form diagonal and point bars (Section 2.2; Figure 2-22, 2-24). These deposits are an attractive source for aggregate recovery, but over-extraction will eventually affect the mechanisms by which they develop and propagate within the river.

Greater storage is also linked to more abundant and diverse habitat types. Gray and Harding (2007) underline the importance of floodplain habitat, which tends to be substantially more complex and diverse than the main channel. Aquatic invertebrate communities that evolve within alluvial springs and ponds on the floodplain, as well as within shallow groundwater or hyporheic zones, form the basis of the riverine food web. Removal of gravels in the river can either directly (near the point of excavation) or indirectly (through headcut or knickpoint development) lower the water table, and thus impact the ecological communities there. A 0.5 m drop in the bed of the lower Motueka River was predicted to reduce summer aquifer recharge by 24%, for instance. This may be an important consideration for Waiapu Rivers that become particularly dry at the height of summer.

Figure 2-22 *Recent emplacement of a gravel lobe upstream of the Walker Rd gravel extraction site, sourced mainly from erosion at a bend 200 m upstream. Viewpoint is looking upstream; extraction site is at lower left. The hillshade model comes from a photogrammetric survey in Feb 2020 (cf. Section 3.2).*

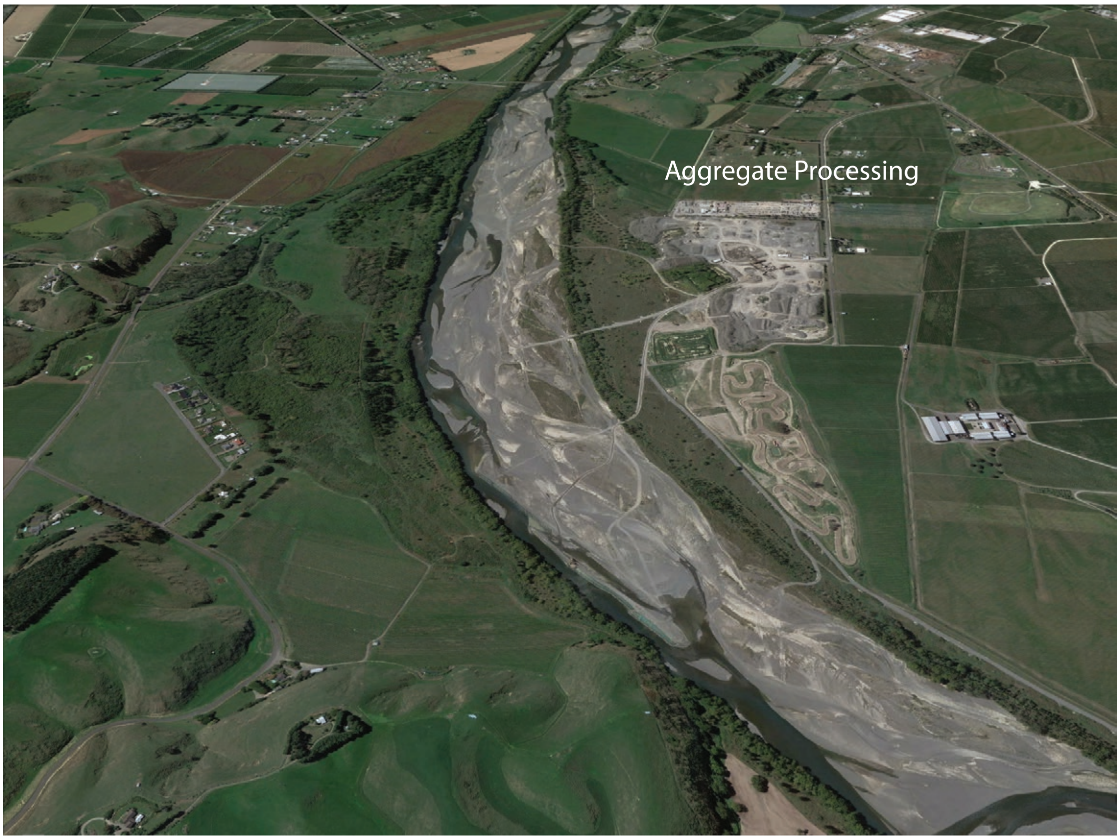


Figure 2-23 *(Facing page and above) Historical trajectory of the Ngaruroro River, Hawkes Bay, 1950 (left) - 2020 (right). Gravels from the Ngaruroro have provided aggregate to supply road building and construction since the 1960s. Extraction rates have been variable, but have averaged roughly 300 000 m^3/year since the 1980s. A major spike in extraction in the early 1990's (up to 700 000 m^3/yr) coincided with the construction of the Napier Expressway. The contrast between these photos highlights the morphological response of the river to gravel extraction: the morphology is greatly simplified, and the active corridor has narrowed to roughly 1/3 of its former extent.*

Finally, the development of braids, floodplain vegetation, and a dynamic river environment reflect the continued renewal of the mauri of the river: while its form is dynamic, the river is in balance with sediment supply, and has adjusted to optimise replenishment of hydrological and ecological requirements of the surrounding environment.

Many years of gravel extraction on the Ngaruroro River (Figure 2-23) have evidently reduced the heterogeneity of hydraulic units (e.g. pools, riffles, back channels) and the diversity of available aquatic, floodplain and riparian habitat. In order to understand the vulnerabilities of the Waiapu to such alteration of the valley floor 'mosaic' of potential habitat and changes to ecological connectivity within the system, an inventory of riverine biota will be of considerable importance.

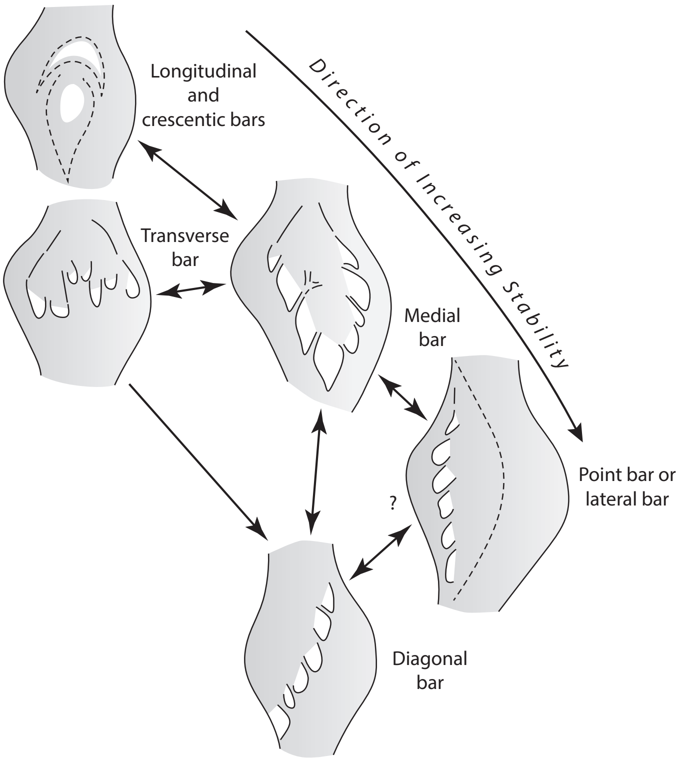
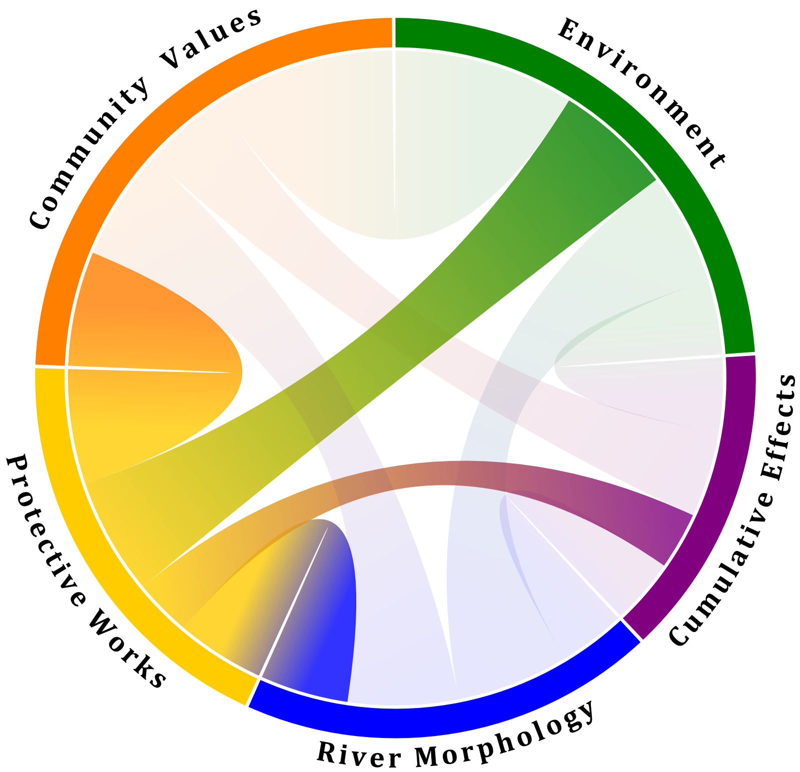


Figure 2-24 *The relative stability of bar types within braided to wandering gravel bed rivers, according to Kellerhals et al. (1976). The Waiapu tends to exhibit the more stable medial, lateral and diagonal bars, indicative of relatively high rates of sediment transport, though perhaps not as high as a more intensively braided system.*



2.5 River Engineering and Protective Works

Gravel extraction can be used to manage help erosion issues and flood conveyance, if there is a clear trajectory evident, and extraction can be suitably balanced with the intended goals. Interventions will tend to be targeted, both in time and space, and may not be conducive to longer term, industrial-scale extraction. Gisborne Council carries out small-scale extraction to protect culvert and bridge infrastructure, for instance, but this is carried out on an *ad hoc* basis. Sustained remedial extraction work requires careful planning, monitoring, and adaptive response. Additional expense may be incurred for associated engineering works, as well.

Larger-scale extraction for the purpose of channel realignment can be a difficult issue, since any subsequent bank erosion or unfavourable deposition downstream from the re-aligned channel is apt to be linked to the work and could undermine community support for the work. Realignment proposals require careful study and should be entertained only in serious need. (Church, 2000)

Proposals for bank protection must be dealt with in a holistic manner; the transfer of gravel downstream depends heavily on bank erosion for recruitment of gravel. Reinforcing river banks will inhibit this process, leading to compensating erosion of unprotected channel islands and the edges of bars along the river. In combination with gravel extraction, the sediment deficit will very strongly impact the erosional regime. As outlined in the previous section, this systematic manipulation of the sediment supply will lead to a change in river character along the length of the system.

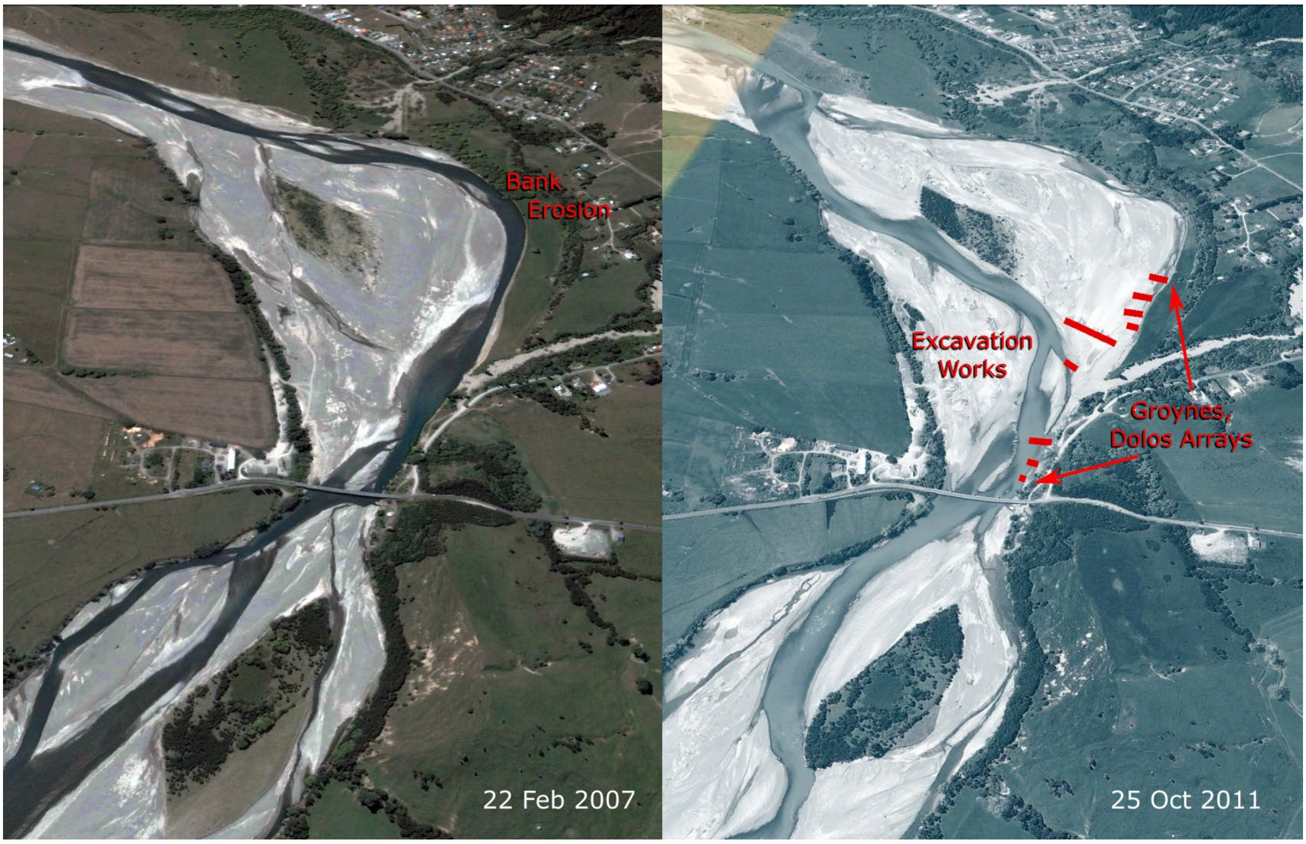


Figure 2-25 *The realignment of the Waiapu River was carried out through a combination of gravel extraction on the left bank and emplacement of dolos structure as groynes on the right bank. This combination of strategies has successfully moved the river over to the left bank. Deposition around the groynes has ensured that the channel is not likely to avulse back toward the right bank.*

Channel Alignment

Gravel extraction can be used to coax the river from one side of the valley to another, by generating a lower elevation pocket through which water will preferentially move. Groynes are used to deflect the channel, and to dissipate flow energy and encourage deposition. The technique proved useful in protecting Ruatoria from erosion in 2010 (Figure 2-25). Such operations are costly undertakings, however; roughly $1.8M went toward groynes and other infrastructure which, in conjunction with gravel removal, acted to divert the Waiapu (GDC Operations Committee, 2009).

Current extraction patterns (2019-2021) at the extraction site upstream of Rotokautuku Bridge (SH35) involve long trenches, parallel to the flow, that may help to divert the river to the southern margin (right bank) of the floodplain, in hopes of maintaining a thalweg course that continues to move the river away from the bank at Ruatoria (Tim Kennedy, *pers. comm*).

The Waiapu River is advancing by downstream translation and extension of its meander pattern (Figure 2-26, 2-27). There are a few bedrock exposures and narrowing of valley topography that limit this movement, but the overall pattern of evolution of the system is clear from historic aerial imagery. This is a characteristic behaviour of wandering gravel bed rivers moving within its ancestral plain, driven by the interplay of flow and sediment supply, and may be considered the unhindered expression of the mauri of this river system (*cf*. Brierley et al., 2018).

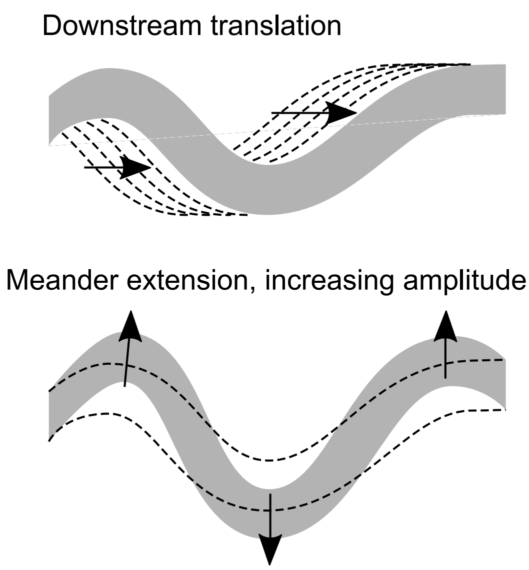


Figure 2-26 *Mechanisms of meander belt evolution on the Waiapu.*

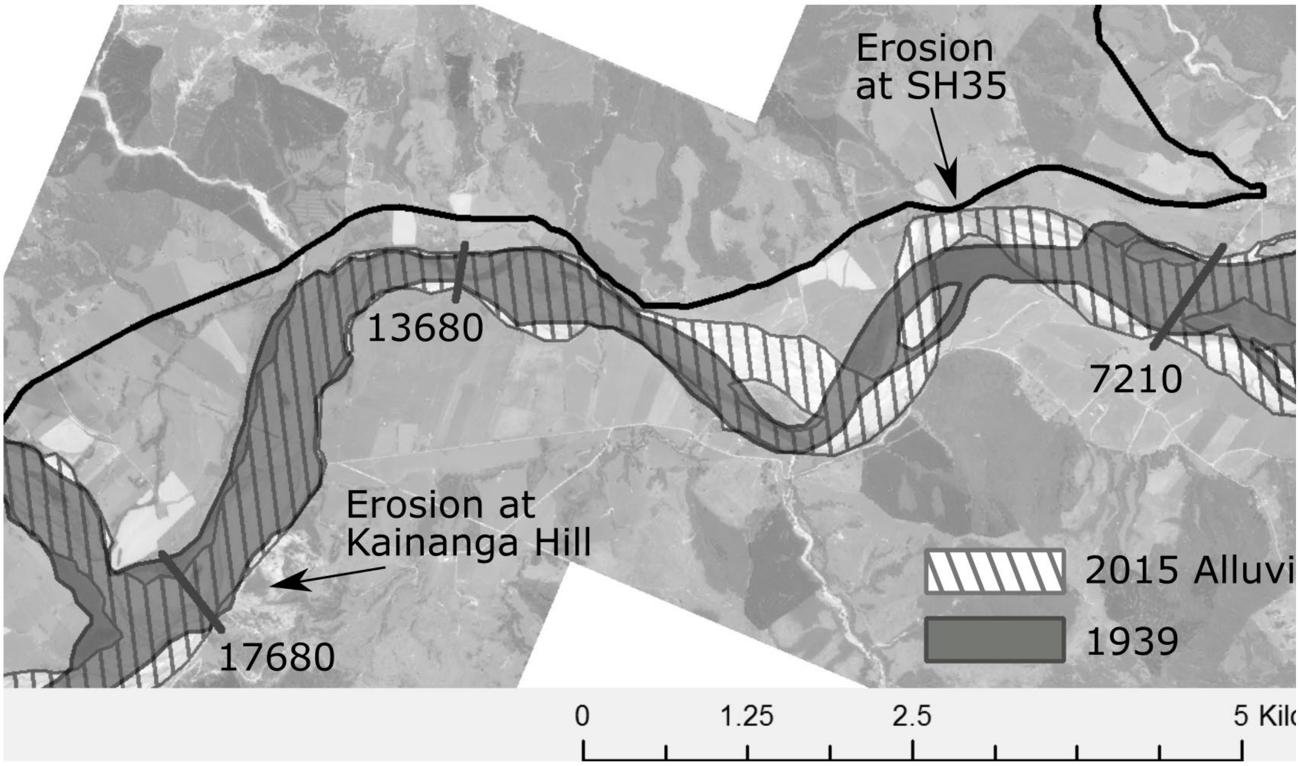


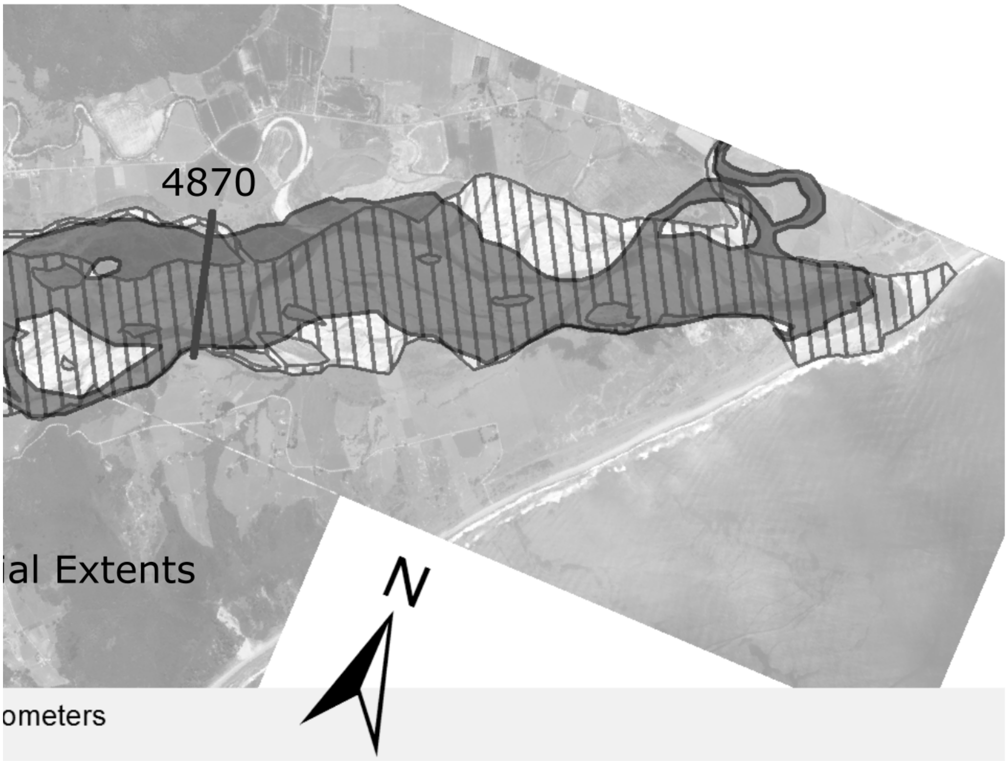
Figure 2-27 *Transitions in the Waiapu River's extent, from 1936 to 2015. The river has evolved through a combination of downstream translation, and extension of its meander bends. On average, the active width of the modern floodplain in the lower 15 km has increased by about 20% since 1939.*

There are few sites on the lower river where gravel extraction could be implemented with clear long-term management benefits. Peacock (2017a) has show that bed levels are stable or declining at sites on the Waiapu downstream from the Mangaoparo River confluence. From SH35 to the Mangaoparo, bed levels are stable or may have had a modest buildup between 2010-2017; this is where gravel extraction works are currently underway, and aggradation here is unlikely to continue.

A case could potentially be made for removal of gravel on the fan of the Mangaoparo River, which is currently acting to divert the Waiapu River against the toe of the Kainanga (Kai-Inanga) Hill earthflow complex (Figure 2-28a). The Waiapu has been eroding bank material on the southern valley side and steepening the base of the slope, enhancing the progression of the earthflow. This in turn has persistently de-stabilised road infrastructure further upslope. With careful and coordinated planning, and consideration of the broader Waipu River gravel budget, flows could potentially be diverted away from the base of the earthflow.

The other candidate site for extraction work is on the Tapuaeroa River between the confluence points of Raparapaririki and Mangapoi streams (Figure 2-28b). A vigorous trend of aggradation has tailed off in the last decade, but having now aggraded by more than 3-4 metres across the ~300 m valley width since 1988 the river bed has drawn level with Tapuaeroa Valley Road, which was once safely situated a few metres above it (Monitoring Site EC531; Peacock, 2016).

There remains significant questions of access and transport infrastructure in both of these cases. There are also the many interwoven strands of potential effects to consider (Section 2.1) in such undertakings, but if managed with the wider river condition in mind, management of these sites could present a coherent rationale that could draw broader support from the community.



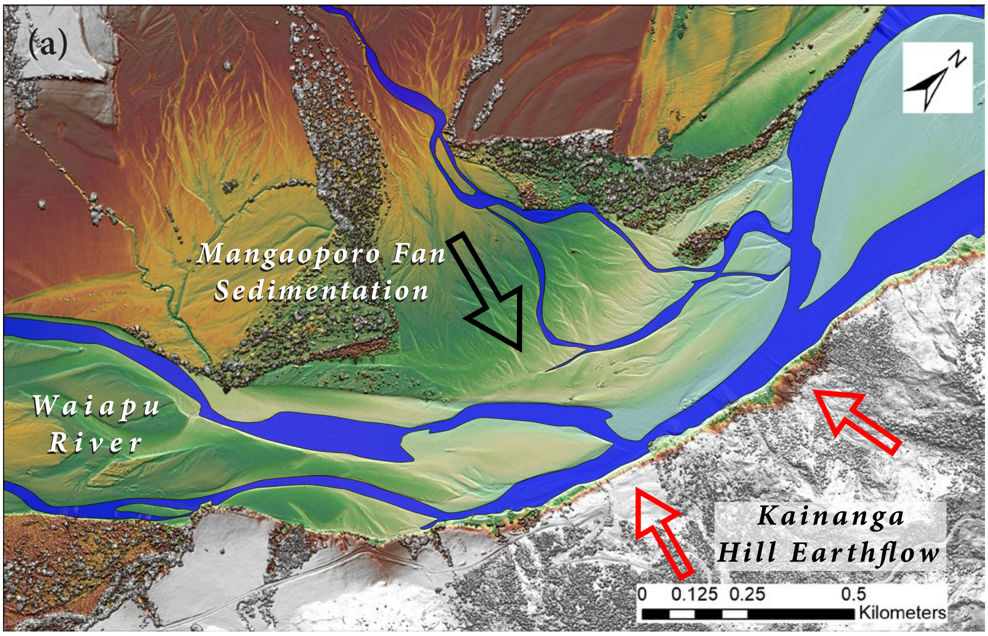


Figure 2-28 *Prospective sites of gravel extraction, pending further study. (a) The Mangaoporo Fan (b) Upper Tapuaeroa River between Mangapoi and Mangawhairiki streams. Arrow indicates where alluvium is closely impinging on Tapuaeroa Valley Road. See text for discussion.*

3. Managing and Monitoring Gravel Extraction in the Waiapu

Managing the gravel resource must take consideration of the interlinked nature of many river components described in Section 2. In this section we consider key elements for establishing the gravel extraction regime, with a view to developing a programme that takes holistic consideration of requirements for a broader river management plan. Five key questions are addressed:

1) Community Consultation
2) How Much Material?
3) Assessing Change: Cross-Sections and Difference Models
4) Adaptive Approach, and Modelling Forward
5) Monitoring Change

Community Consultation

With the implementation of ***Te Mana o te Wai*** framework (Section 2.1), a forum is available through which gravel extraction operators may engage in dialogue with Hapū, tangata whenua and the catchment communities, as well as Ngati Porou and the Gisborne District Council. Through this process all parties can develop an improved understanding of the proposed works, site sensitivities, ecological connectivity, matauranga understandings, available baseline data, ongoing rehabilitation efforts, monitoring requirements, and potential common benefits. The process must be viewed as a continuing engagement rather than a single consultation.

How Much Material?

The principal cause of impacts from in-stream mining is the modification of system sediment supply, with the removal of more material than the system can naturally replenish. While there has been very good cross-section monitoring of Waiapu rivers since the late 1950s, there has been little systematic appraisal of bedload transport rates, particularly as extraction rates ramp up in recent years. In order to assess the renewable nature of this resource for a given reach, some rational basis for evaluating gravel volumes is needed. It is important to be able to assess future extraction impacts on the resource further downstream, as well. The key question becomes "***how much gravel can be sustainably removed from a river reach, as a proportion of the annual resupply rates?***" This is referred to as the bed material extraction ratio.

Guidance on this question varies, and naturally it depends on the natural dynamism and sensitivity of the system. Most management approaches in NZ involve regular *post hoc* assessment of mean bed levels relative to the established river grade line (Basher, 2006; Environment Canterbury, 2006; Clode and Beya, 2018). As long as the river has not degraded below the pre-determined grade line (Section 3.2), then extraction can continue. Given the goal of countering the effects of aggradation in some parts of the Waiapu, the argument could be made for more permissive extraction rates, to deliberately draw down sediment storage. There will be other potential changes to the system that must be considered as part of this, including altered channel morphology and changing habitat structure, for instance (Section 2.1).

Sutek and Kellerhals (1989) provide some guidelines for extraction volumes in Table 3-1. Given the very high error bounds in transport estimates, and quite high variation in annual rates, they recommend employing the most conservation estimate ('***lower bound***') when working to develop targets for annual extraction. Refinement of this lower bound can be greatly refined and validated by use of annual topographic floodplain surveys and modelling (more on this below) in order to assess rates of change within the active alluvial zone under extraction.

Annual Removal	Gravel supply comes mainly from upstream of the site; no additional sources	25% of lower bound gravel supply
Annual Removal	Major tributaries downstream supplying coarse sediments.	50% of lower bound gravel supply.
Annual Removal	Gravel accumulation zone. No downstream transport	Up to 100% of lower bound gravel supply
One time removal	No further removal for 5 years.	Up to 100% of lower bound gravel supply

Table 3-1 ***Sutek and Kellerhals (1989) provide some guidelines for extraction rates, based on some lower bound estimate of gravel supply to a given reach. Having a framework that links extraction rates to supply assessment is an important part of planning the extraction regime.***

A vertical reference datum is commonly used to assess the status of the river and track storage within a given cross-section or river reach in NZ (e.g., Environment Canterbury, 2006; Stevens and Larsen, 2015). Clode and Beya (2018) define grade lines in relation to the 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 over flowing onto the floodplain. While this is well-suited to the meandering-to-wandering morphologies of managed rivers within a flood protection scheme, the concept does not apply readily to more laterally active, wandering-to-braided rivers encountered in the Waiapu system. For our purposes, the grade line relates to the Mean Bed Level that was first measured at a cross-section. Subsequent departures in stored volume from this point reflect the relative change to the system.

Gravel extraction management schemes in New Zealand have long relied on a regime of regular cross-section measurements (typically irregularly, 2-6 year intervals) to determine long-term behaviour of the river system. Changes in channel cross section reflect the magnitude of exchanges within the river system. Changes are reported as rise or fall in the Mean Bed Level, which is the integrated average of vertical change at all points across the active alluvial width at a given cross-section.

Significant changes can occur over the course of a flood, or a sequence of floods, between surveys. Thus, there may be a great deal of compensating erosion and deposition between surveys, leading to negative bias in the estimates of net volume change between surveys (*cf.* Lane *et al.*, 1994; Ashmore and Church, 1998; Lindsay and Ashmore, 2002; Brasington *et al.*, 2003). Bedload transport estimates derived from such cross-sections (Figure 3-29) are therefore necessarily a minimum, but they do provide a good indication of dynamism within the reach.

The presence of bedrock controls can limit vertical and lateral adjustment of the bed (Figure 3-33). When interpreting the temporal trajectory of surveyed cross-sections, it is important to look for any structural controls that may limit the vertical or lateral response in the river. Shortfalls in sediment supply may otherwise manifest as a narrowing of the active river corridor or simplification of morphology, rather than lowering of the Mean Bed Level (see Section 2.4). With more detailed monitoring of river reaches using high-resolution topographic surveys (see below), it becomes possible to assess natural rates of erosion from bank failure, channel switching or floodplain stripping, for instance.

Transport Path Length

An important consideration for computing bedload transport rates is the mean travel distance of grains during a flood event, commonly known as the path length, <*L*> (Neill, 1969; McLean and Church, 1999; Pyrce and Ashmore, 2003; Kasprak *et al.*, 2015; Vericat et al, 2017). The spatial scale tends to conform closely with the distance between successive meander forms (Figure 3-30), or the distance between loci of erosion and deposition within the river system. If the transfer occurs in time *t*, then bedload moves with at a 'virtual velocity' of $v_b = L/t$.

Typical transfer distances may be influenced by the intensity and duration of the flood, as well as by the bed topography. Laboratory and field studies have found that bar forms will influence the transport distance: most grains tend to travel to the next bar downstream, however, the distribution of path lengths has a long tail, as some grains will move beyond this. This gives rise to the 'bimodal' or 'symmetrical' distributions observed by Pyrce and Ashmore (2003). Habersack (2000) used radio-traced particles in the Waimakariri River to characterise transport distances, showing movement of up to 176 m (Figure 3-31) in intermittent hops of 6.7 m, on average.

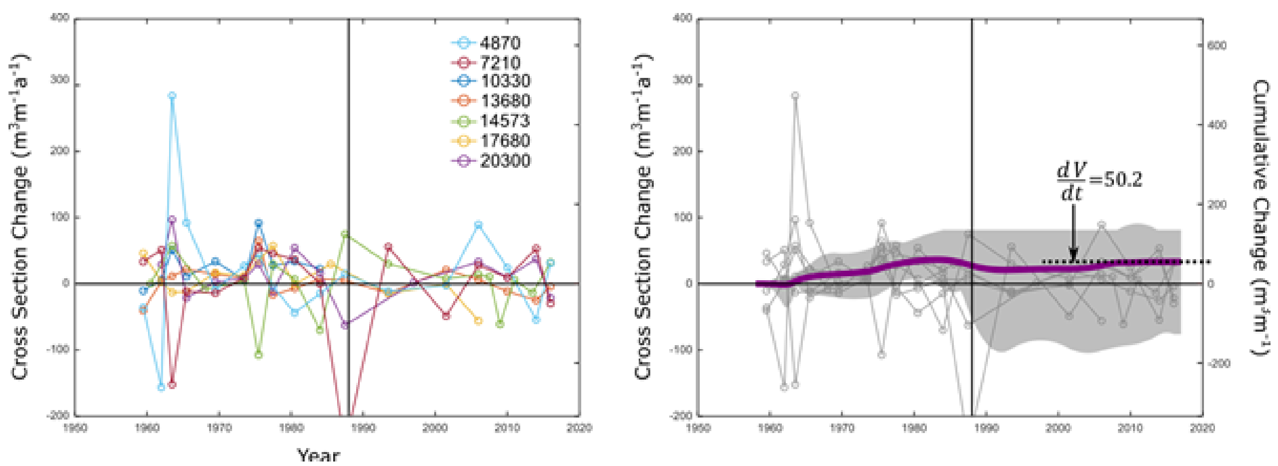


Figure 3-29 *Summary of cross-section change in the Waiapu River. At right, mean bed level change is plotted for each cross-section, since the first differencing epoch (1958-1961). On the left, the cumulative departure from the initial bed configuration is shown (thick purple line). Variation at all positions in the cross-section within the active width (not just mean bed level) is shown as a gray envelope. Stable, compensating erosion and deposition from year to year has resulted in a steady positive trend over time; the mean flux rate (discharge at the cross-section) is 50.2 m³ per linear m of river length, per year (m³·m⁻¹·a⁻¹)*

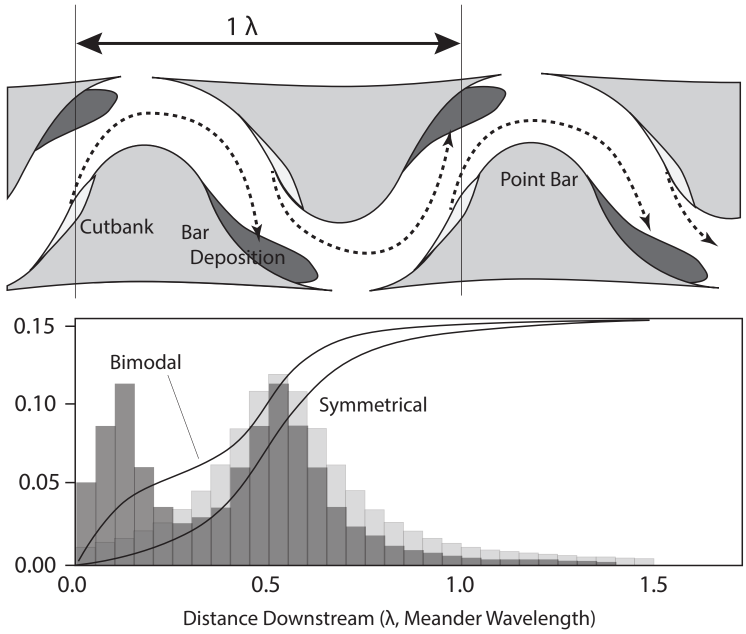


Figure 3-30 *The transport path length of a given bedload particle is thought to extend about one half of a meander wavelength: from erosion at a scour zone or outside bend, to deposition downstream of the next point bar, for instance. In laboratory experiments, Pyrce and Ashmore (2003) observed cases where most deposition occurred either close to source (leading to a bimodal distribution), or around 0.5 λ, near the next point bar downstream (symmetrical). Thus, the dominant wavelength should provide a good first-order estimate of <L> for long-term average transport rate estimates.*

When computing the bedload transport rate through observations of erosion and deposition in the channel, we assume most material has moved about one half wavelength, on average. Naturally, the absolute distance will vary with the meander scale of the river system. The long-term velocity of particles is therefore equal to the downstream migration rate of bars or bends. It should be noted, though, that wash load and suspended load (sand and silt) comprise a significant proportion of the floodplain deposit (~10-20%) and should be accounted for accordingly. The magnitude of change observed from successive surveys of the alluvial surface (see below) are typically discretised into cells or subreaches along the river course that are larger than the expected path length, such that material eroded near the upstream boundary of one subreach is not passing through the next downstream subreach (Vericat, 2017).

Assessment of gravel transport rates, and thus the sustainability of gravel extraction, requires explicit consideration of transport path length. Bedload transport rates are reported either as a function of distance downstream (e.g. $m^3 \cdot m^{-1} \cdot a^{-1}$, as in Figure 3-29) or yield per unit transport path length, and thus if the extraction site extends further than the transport path length, the expected yield for than reach should be adjusted accordingly. Unlike water extraction, where upstream supply may be immediately replenished, the fluvial sedimentary system behaves more like a chain of connected reservoirs that may take some time to replenish, and a given reach will have varying capacity for storage and recharge.

Peacock (2016, 2017a) has summarised trends in Mean Bed Level (MBL) change for 11 rivers and streams in the catchment. Such datasets provide a long-term (60 year+) picture of how the river systems have changed over time. In the course of developing a catchment management programme, it is important to consider how trends from the upper catchment will translate to the lower catchment, and where gravel extraction might be of most practical utility.

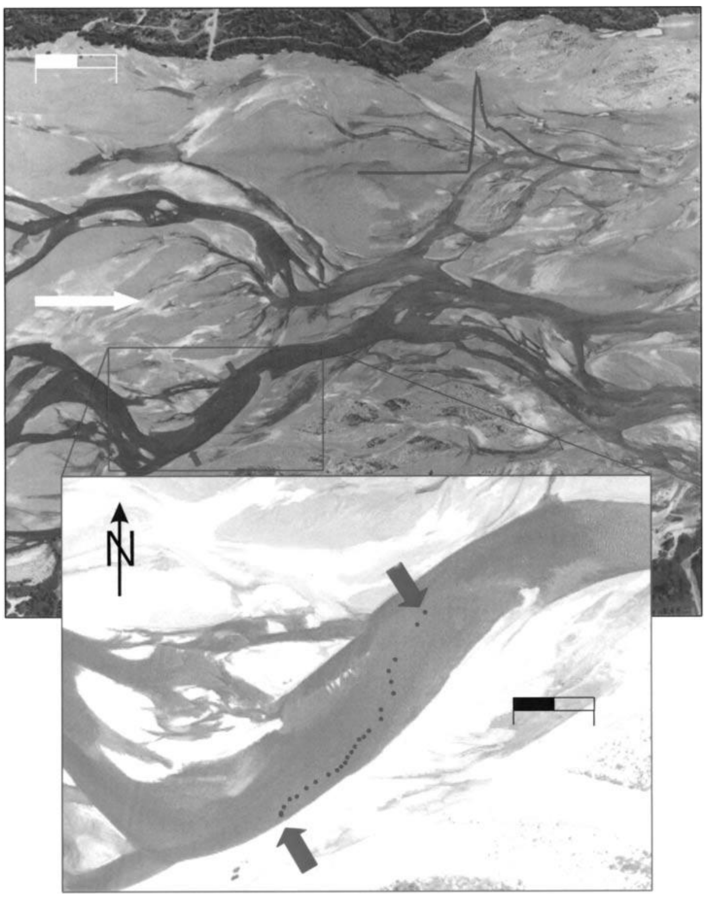


Figure 3-31 *Habersack (2000) used radio-tagged particles to trace the transport path of grains on the bed of the Waimakariri River at Crossbank. The lower figure shows the resting positions of the grain as it moves from erosion site to deposition site on the rising and falling limb of a flood hydrograph.*

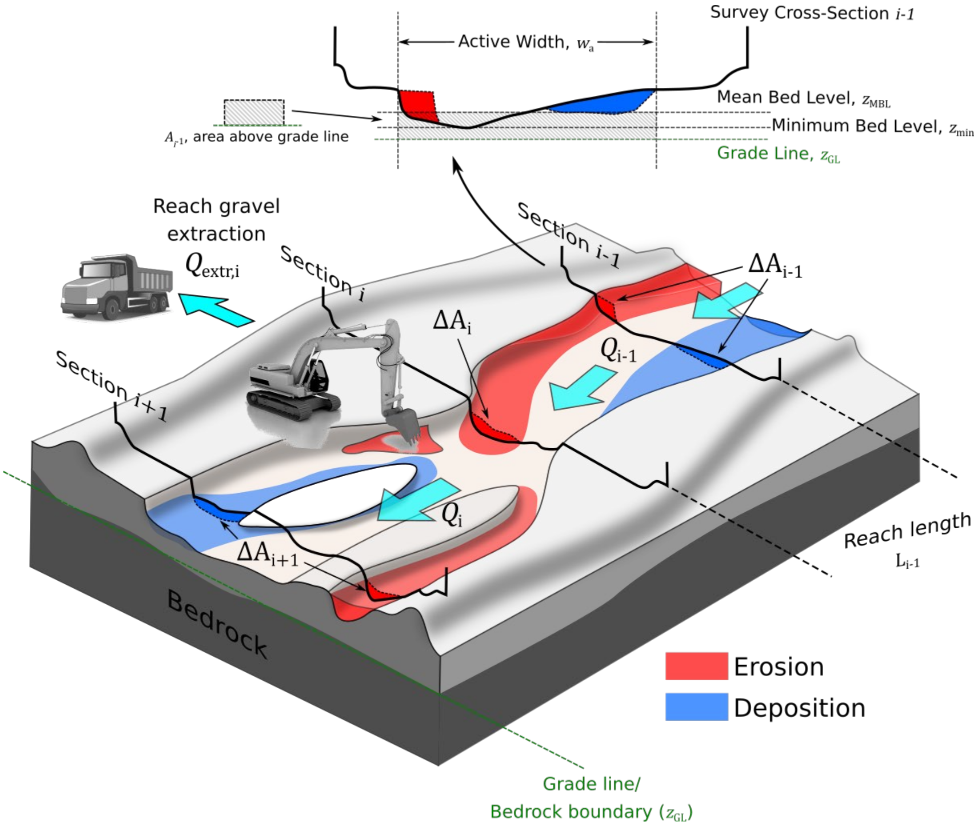


Figure 3-32 *A schematic showing typical gains and losses within a reach. Note that reaches are set to roughly the transport path length. The gains and losses are weighed up for each reach (..i-1, i, i+1..), and the balance is routed downstream as sediment discharge (Q). If the downstream cumulative balance remains close to zero (gains and losses cancel out), then the system is considered to be in equilibrium. If there are more gains than losses along the reaches, the system aggrades, building up the bed; and vice-versa, with systematic losses, the system degrades.*

Figure 3-33 *Bedrock exposure on the Mata River hints at the presence of controls on the vertical adjustment of the riverbed. Cross-section surveys will accurately reflect any aggradation (surplus material) here, but the river will be hindered in its capacity to degrade, owing to this structural limit. Thus, a stable mean bed level may not necessarily be indicative of equilibrium conditions in the long term: monitoring for changes in erosion and deposition of the alluvial substrate provides the most reliable picture of sediment flux within the channel.*

In Figure 3-32, the area of erosion and deposition (ΔA, m^2) within each cross-section is averaged between survey lines (i-1, i, i+1), to come up with estimates of change over the course of many surveys.

'Q' or 'Q_b' is commonly used to denote a volume transfer, e.g. bedload [m^3·a^{-1}]
'A' is used for cross-section area [m^2]
'V' is for reach storage volume [m^3]
'z' or 'η' is used for bed elevation [m]
'w' is used for bed width [m]
'x' is the downstream coordinate of the upstream and downstream boundaries of the reach [m]
't' is the time interval between surveys
'γ' is the deposit porosity (typically ~0.6)

Using this mass balance framework, one can assess the average rates of transfer, and determine whether more material is leaving a given reach than is being supplied by sources upstream. The transfer of material in (Q_{IN}) and out (Q_{OUT}) of the reach is related to changing reach storage (ΔV) as:

$$Q_{IN} = Q_{OUT} - \frac{\Delta V}{t}(1-\gamma) \quad (1)$$

For the case of gravel extraction, we include an additional transport term, Q_{ext} [m^3·a^{-1}], representing removal of material from the reach. Looking at a length of river divided into reaches by the cross-sections, the 'IN' term is denoted i-1 (arriving from the upstream node) and the outgoing material is represented as 'i' (transferred downstream to node i+1).

$$Q_{i-1} = Q_i - Q_{EXT,i} - \frac{\Delta V}{t}(1-\gamma) \quad (2)$$

Volumetric transport (Q, m^3) and changes in storage volumes (ΔV, m^3) are related via a deposit porosity term (γ). Porosity is typically ~0.4 for fluvial gravels. Moving from the upper end of the river to the lower, the balance of gains (blue zones, deposition) and losses (red zones, erosion) can be summed, and the net change is routed downstream. We can assume the suspended and washload materials move through the system during the flood without significantly altering the morphology or contributing to the reach budget, and are therefore not considered in detail at this level of analysis.

In the next section we consider the case of topographic surveys (rather than cross-sections) and overlaying a surface from one epoch with another to determine volumetric change over time.

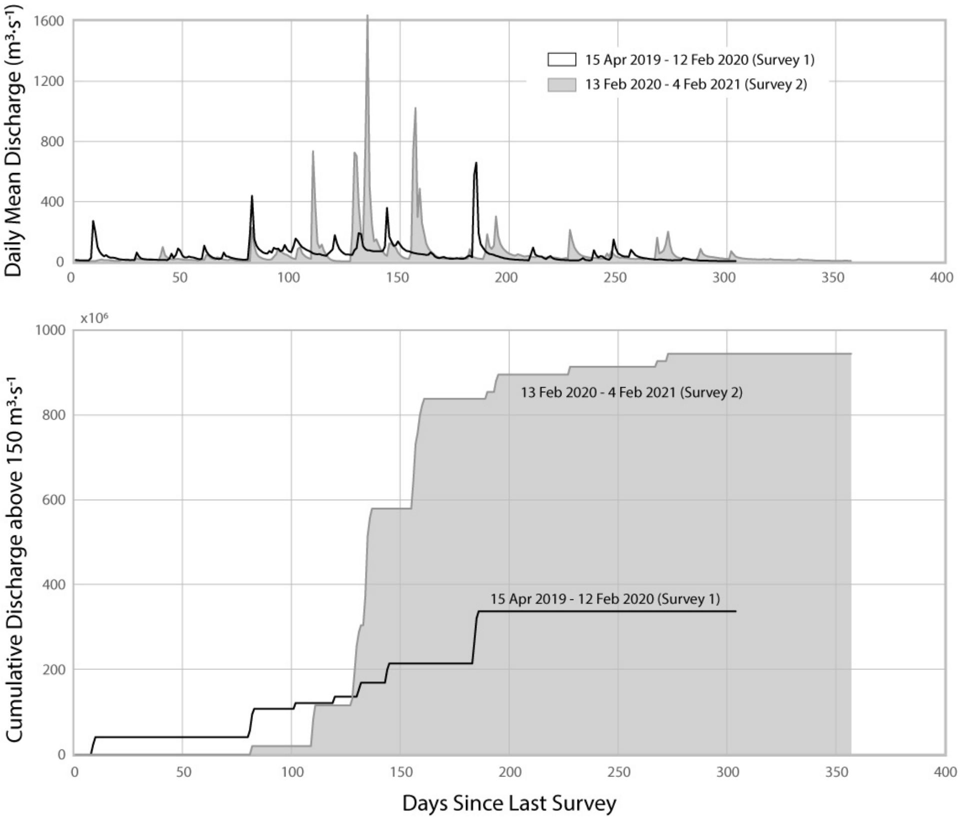


Figure 3-34 *Hydrograph record at Rotokautuku Bridge (SH35) for the periods between three surveys undertaken on the lower Waiapu River between 15 April 2019 and 4 February 2020 (next page). Winter flood conditions were more intense in the second interval, leading to higher magnitude bedload movement.*

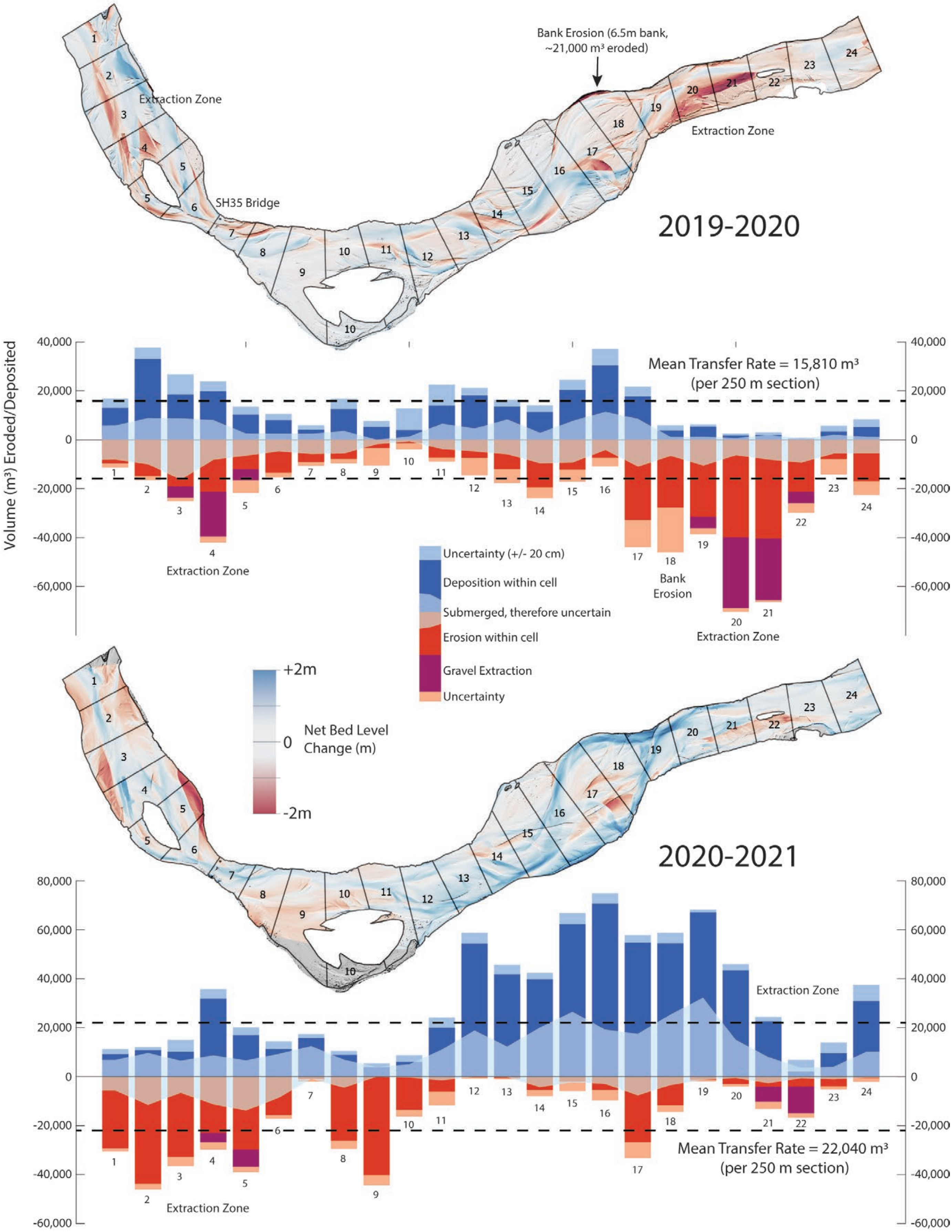


Figure 3-35 *Digital Elevation Model (DEM) of Difference, for the Waiapu River, extending 6 km from the Tapuaeroa-Mata confluence to (roughly) Walker Road. Shading on the map shows the magnitude of erosion (red) and deposition (blue) from three successive surveys between April 2019 and February 2021. See text for further details.*

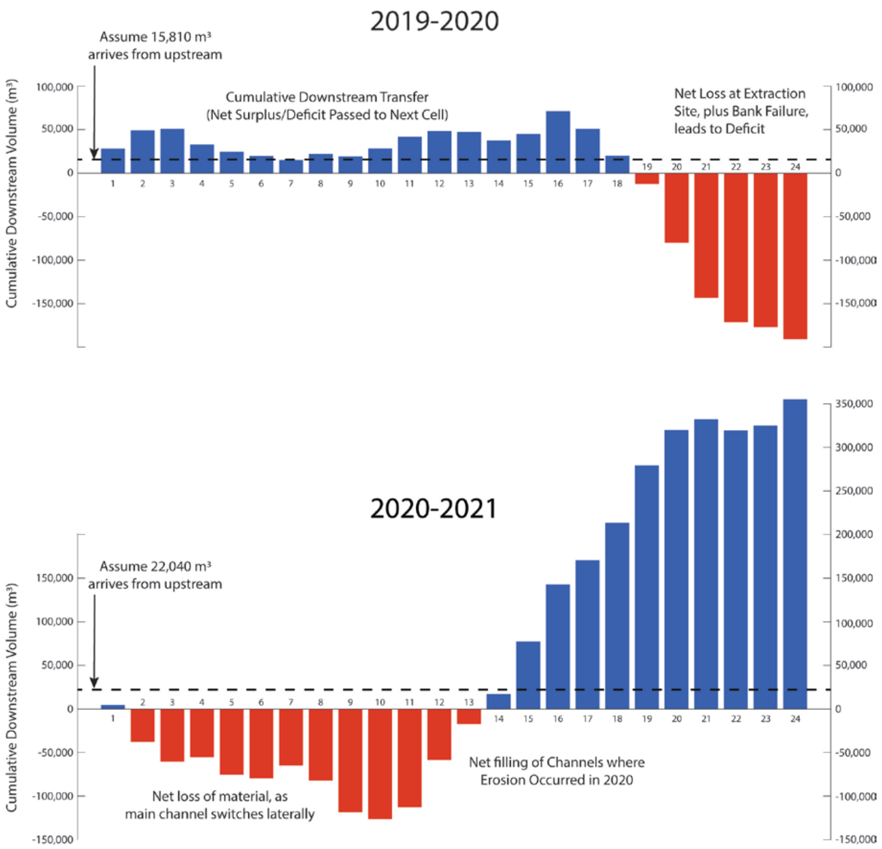


Figure 3-36 *Longitudinal charts showing cumulative downstream sediment transfer, based on the gains and losses within each cell of the survey (charts in Figure 3-35). The balance of cut and fill in a cell is routed to the next cell downstream: a series of cells with net losses will lead to progressive lowering of the trend into the red (negative values); likewise serial gains will lead to a rise in the trend. Perfectly balanced gains and losses in series will produce a horizontal line.*

Difference Models

The foregoing mass balance principles can be applied to a time series of topographic surveys. Figure 3-35 shows two Digital Elevation Models (DEMs) of Difference (DoD), for the Waiapu River near Rotokautuku Bridge (SH35) for the interval between 15th February, 2019 and 13th February 2020 (upper map), followed by a second differencing epoch, completed on February 3rd, 2021 (lower). The surveys encompass two extraction operations: one upstream of Rotokautuku Bridge (cells 2-4), and another near Walker Road (cells 19-22).

The first survey was carried out with airborne LiDAR (GDC Regional Survey), and the second and third were carried out using drone-based photogrammetry (Structure-from-Motion). By evaluating elevation differences across the exposed alluvial surfaces (subtracting the 2019 surface from that of 2020, then 2021 minus 2020), we can see the changes in storage that occurred along the reach over the course of two years (charts beneath each map: lighter tones reflect survey error, semi-transparent middle band indicates submerged topography, which has greater uncertainty, purple colour shows losses most likely attributable to gravel extraction).

There were six flood events with daily mean flows over 400 $m^3{\cdot}s^{-1}$ in the study period (Figure 3-34), four of them in the latter study period, and two of those were over 1 000 $m^3{\cdot}s^{-1}$ (June 26 and July 18, 2020). Thus the transporting capacity in the second survey epoch was much greater than in the first. The overall average magnitude of erosion/deposition within each survey cell ranged from 15 810 m^3 in the first survey (dashed line) to 22,040 m^3 in the second. Given the average distance from loci of erosion to deposition was about 500 m, this equates to an average gravel volume flux rate of 37 850 $m^3{\cdot}yr^{-1}$ ±6 400.

The bar charts in Figure 3-36 shows a simple downstream routing scheme, where the net balance of erosion and deposition within each cell is transferred to the next cell downstream. We make an assumption that the average cell erosion volume arrives from upstream to the survey area. For the first differencing epoch, an equilibrium evolves along most of the cells until a site of major bank erosion (cell 19) draws down the positive downstream-moving balance. Once in the lower gravel extraction domain (cells 20-22), the balance is brought further into the negatives, meaning that there is substantially more material leaving these cells than is being replenished from upstream.

By contrast, in the 2020-2021 interval, there is net erosion in the reaches above the bridge, owing mainly to lateral migration of the main channel. Filling of the elongate excavation pits in this reach is evident. Downstream from the bridge, a strong positive-trending balance can be seen in the chart. Sheets of material from the upper reach evidently moved downstream during the relatively higher flood activity, to fill in the channel between reaches 12 and 20.

The contrasting behaviour between the two years provides a good illustration of the high variability in bedload transport rates, and the moving loci of relative surplus and deficit in the river. A six kilometre reach, monitored over two years, is a small window into the much larger-scale adjustments occurring within the system, but it does provide some important perspective on the magnitude of these fluctuations, and emphasises the importance of considering supply changes in wet versus dry years. Gravel extraction rates appeared to be lower in the second survey interval, though until there is a more regular regime of surveying, it will be difficult to draw more definitive relationships between specific sites of extraction and consequent river adjustments.

Modelling Forward

Both 1D and 2D hydraulics-based sediment transport models can be used to simulate bedload transport conditions on the Waiapu, using a combination of LiDAR, Structure-from-Motion (drone-based) surveys and acoustic doppler surveys of the submerged channel. For example, using the domain from our DEM of Difference studies (above), we used open-source Delft3D (www.deltares.nl) to model floods of varying magnitude with a multi-fraction sediment transport formula (Wilcock and Crowe, 2003; Figure 3-37). Results can be used to assess river response to extraction, or trajectory of channel form.

Numerical estimates of bedload transport under Feb 2019-Feb 2000 conditions align reasonably well with our survey results, and the model reveals changing sediment supply conditions as channel sections of varying width adjust to the onset of flood conditions. Numerical results show migrating lobes of bedload material moving along the channel (Figure 3-39), consistent with our field observations of lobe emplacement along the length of the river (Figure 2-22).

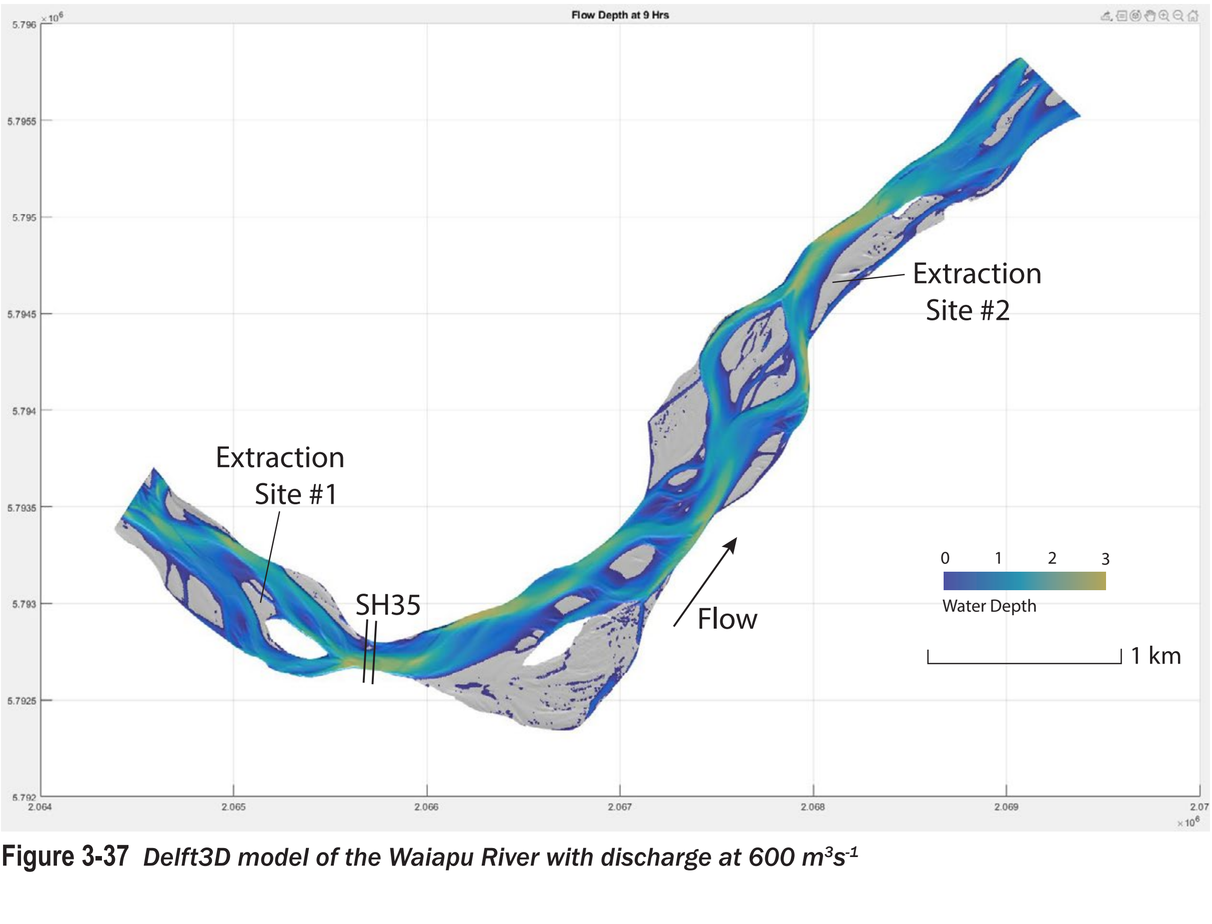


Figure 3-37 *Delft3D model of the Waiapu River with discharge at 600 m^3s^{-1}*

This also accounts for the unsteady nature of sediment transport, and possibly the hysteresis relationships (response lag) observed in the transport rates (Figure 3-38). Modelling is still in early stages, but could provide some insights into the influence of extraction on bedload processes.

Different reaches show varying capacity to transfer bedload along the channel. We used a number of '1-D', cross-section-based calculations to assess transport rates, and these showed some wide variation. Estimates also tended to be fairly high, emphasising that such calculations tend to assume unlimited supply conditions upstream, which is not always the case. We therefore bracket our rating relationship (Figure 3-38a) with a 'Transport Limited' (optimistic) line and a 'Supply Limited' case, which aligned better with 2D simulations and our field surveys.

Another interesting insight from cross-section-based modelling (en.bedloadweb.com) was that annual yields are likely to vary substantially from year to year. Computing yield rates for annual flow duration curves (Figure 3-40) reveals variations from -80% (nearly halving) to over 100% (more than doubling) of the long-term average transport rate. This helps to further set our survey results (above) in context: 2019 was a relatively dry year, and there was little resupply of material relative to 2020. This raises the issue of setting consent levels to a rate that is suitably conservative and precautionary, given the forecast trend towards drier conditions in the region.

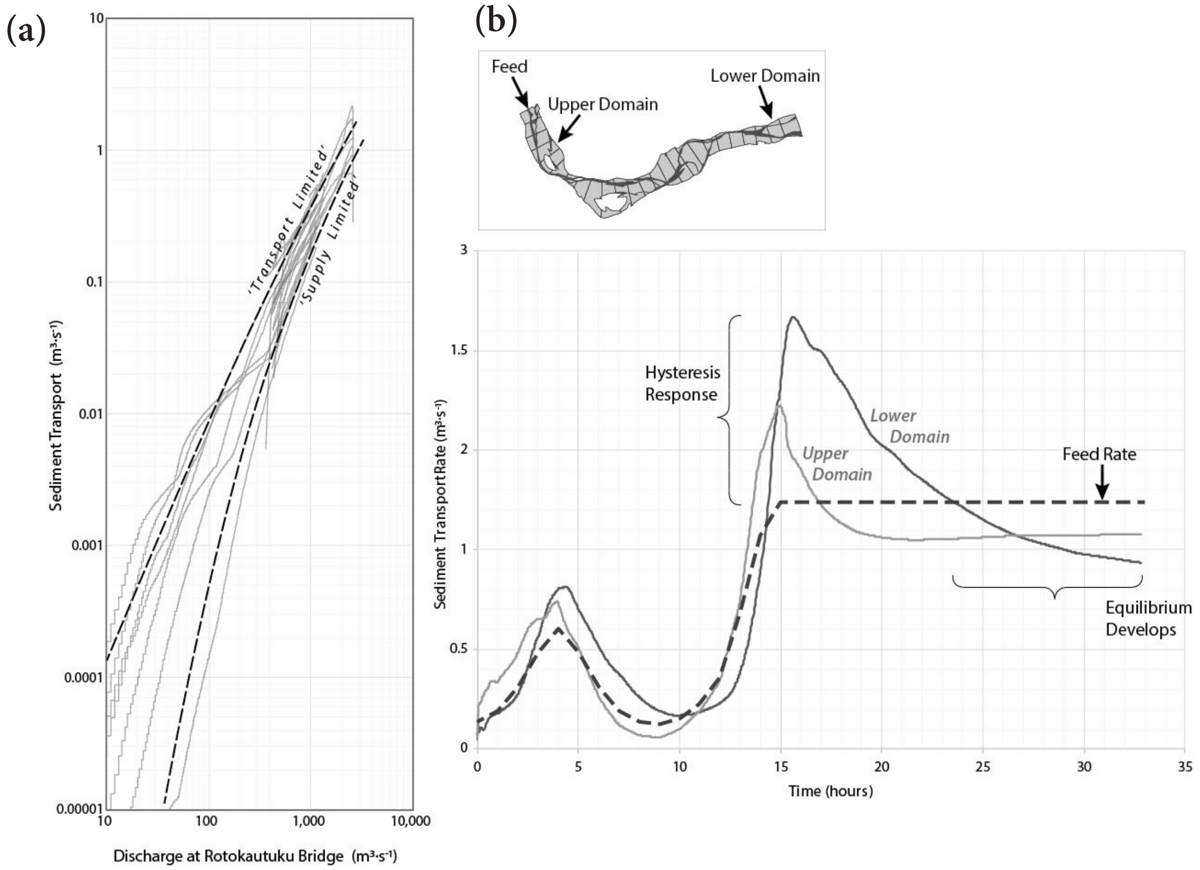


Figure 3-38 *Transport rates observed in 1D and 2D, live-bed Delft3D morphodynamic model. (a) Transport rating relationships, based on 1D and 2D simulations of bedload transport along the study reach. (b) Time series from a model run, showing the highest feed rate that could be maintained without substantial riverbed aggradation. The river hydrograph was ramped up to 3 000 m^3s^{-1} with a maximum feed rate of 1.5 m^3s^{-1} (making the assumption 1 m^3 = 1 600 kg) The results show that in the early stage of model 'spin-up' the river can deliver material above the feed rate, as material is eroded from within the reach. Eventually, the model establishes an equilibrium and rates adjust to more effectively transfer the rate fed from upstream. We refer to these initial conditions as being 'transport limited', where the river has an effectively unlimited supply of bedload from upstream, and 'supply limited', where within-reach supply has been exhausted, and the upstream supply becomes limited by the variable conveyance capacity along the river, and delivery of material falls more or less into line with the supplied rate from upstream.*

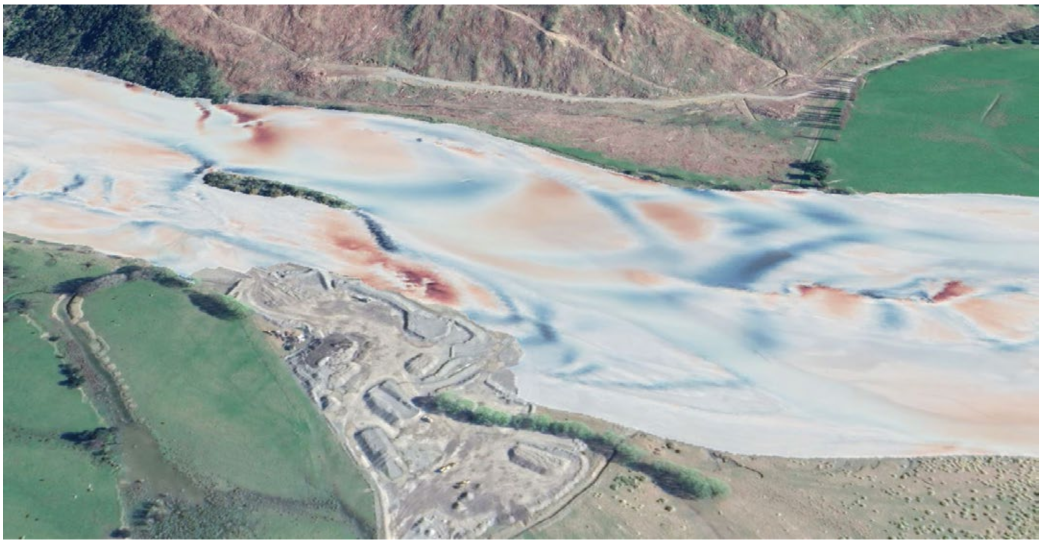


Figure 3-39 *Waiapu River near the Walker Road extraction site. Bedload transport within the Delft3D model consists of migrating lobes of gravel moving along the river bed, shaping (and being shaped by) river flows. The transit of these bedforms is another reason for the highly non-linear transport rates observed in the model, and the lagged response to changing sediment feed rate at different cross-sections over time. Red denotes erosion (troughs) and blue is deposition (peaks) of the migrating bedforms.*

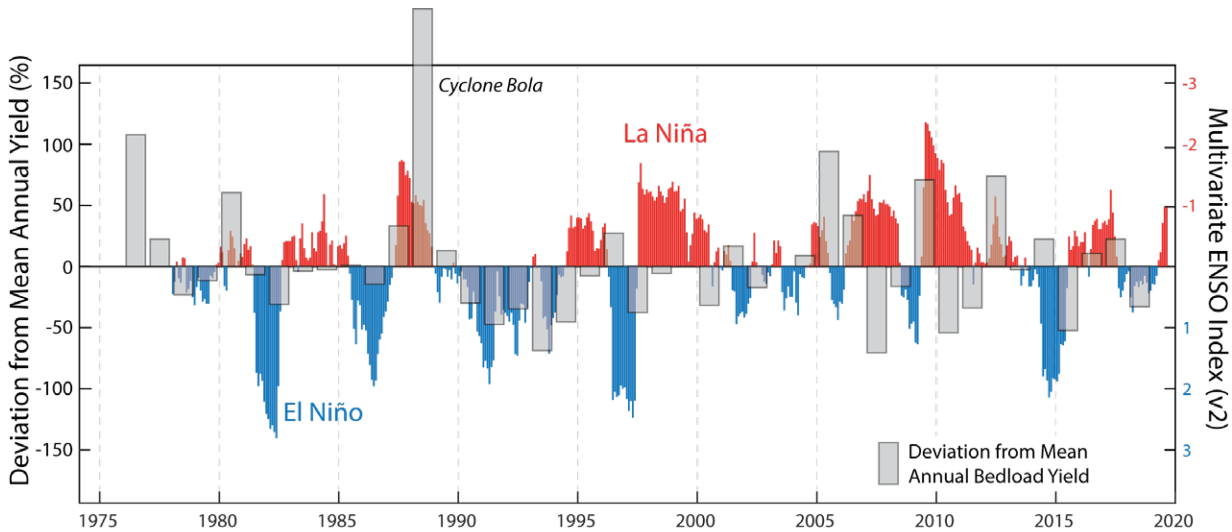


Figure 3-40 *Cross-section-based modelling of bedload transport, based on the annual flow duration curves for flows from 1976 to 2019. We used the Wilcock-Crowe (2003) equation, basing calculations on sediments and hydraulic conditions within the study site near Rotokautuku Bridge. The bar chart shows yield as a percentage deviation from the long term mean ('0'). Wet years may have twice as much bedload (+100%) relative to the long term mean; dry years will have less (-80%). The Multivariate El Niño/Southern Oscillation (ENSO) Index refers to the variation in sea surface temperatures across the equatorial Pacific Ocean and surface atmospheric pressure in the tropical Pacific (cf. Mullan, 1995; Mosley, 2000). This trend can strongly influence New Zealand storm climate, and the setup of weather systems. While it is not a perfect relationship, it does provide some insight into the longer-term controls on gravel yield, and the significant decadal-scale variability.*

Monitoring Change

Results from the above studies show that high-resolution LiDAR and/or photogrammetric monitoring provides a means of relatively rapid and accurate assessment of morphologic change, providing perspective on the trajectory of a reach-scale sediment budget, and therefore the relative sustainability of a given extraction regime. Once survey controls are established for a reach, the acquisition of drone imagery can be repeated every year, in order to assess change.

Low-level (drone) aerial imagery can also be used to assess changing bed roughness, and variation in proportions of sedimentary assemblages on bars and the bed. The models record changes to stockpile volumes (Figure 3-41), vegetation, and the relative abundance of productive river habitat; the latter elements are helpful for assessing changes to ecosystem structure. Ideally, this information could be held in a GIS database that could be accessed by community members.

An additional form of monitoring would be routine annual assessments of grain size characteristics at the site, as well as upstream and downstream, using well-established sampling techniques (e.g. Pebble Count, Quorer Survey; *see* Bunte & Abt, 2001; Clapcott *et al*., 2011).

Key Messages:

- Assessment of gravel extraction take necessarily begins, and progresses, with community consultation.
- The bounds of sustainable extraction can be assessed through annual surveys of the river, either using drone-based photogrammetry or airborne LiDAR surveys. While cross-section surveys provide a reliable, and very long term picture of channel change, the reach-scale sediment budget can be most accurately assessed using a time-series of high-resolution surveys.
- There is a characteristic length scale between sites of erosion and deposition, typically linked to meander wavelength, that is used for segmenting the sediment budget along the river course. Extraction works should clearly indicate (and enforce) the footprint of their operation relative to this scale, in order to model the supply accurately. Annual surveys of extraction sites should extend a wavelength or more (Figure 3-30) upstream and downstream of the active operation.
- Gravel yield is closely coupled to storm climate. Years with fewer, and/or smaller floods will move less gravel through the system, with at least four-fold variation in yield rates. Consented extraction quantities should be based on forecast 'low-year' scenarios, with added extraction quantities awarded in years of proven surplus.
- Drone-based photogrammetry presents a relatively inexpensive option for rapid (a few hours for a site with established ground control) surveys of extraction sites. Ongoing surveys of surface grain size distribution and total suspendible solids would provide a valuable characterisation of the extraction resource, habitat quality, as well as an index of change.

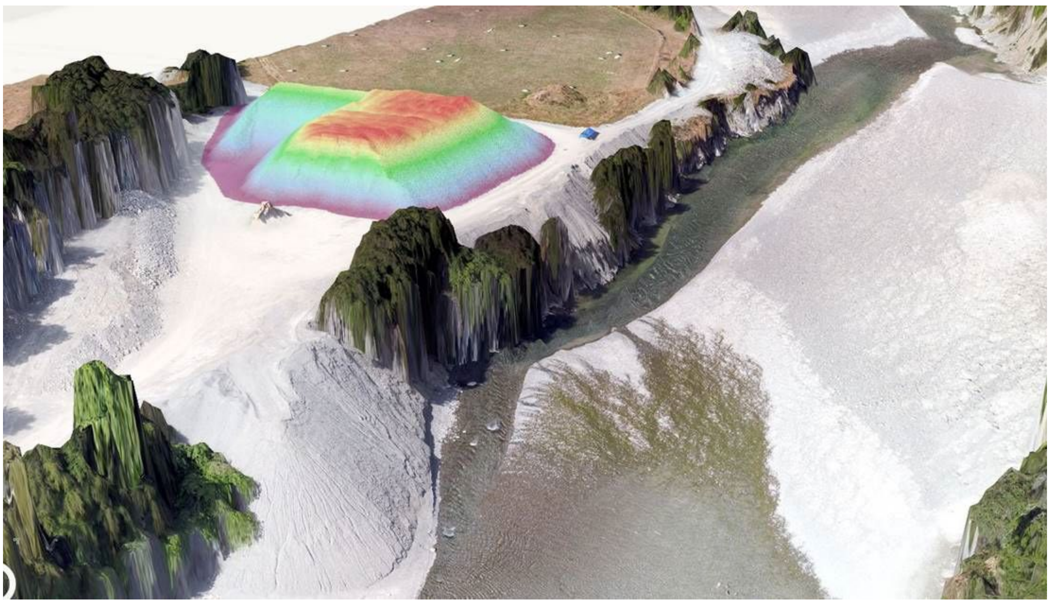


Figure 3-41 *Oblique view of a digital SfM model (2cm resolution). A stockpile of gravel taken from the Mata River, off of Horehore Road is highlighted, with colours representing the relative height of the pile (up to 10 m). With Structure-from-Motion and point cloud processing software, discrete volumes of cut and fill quantities can be quickly assessed with relative precision on the order of 1-2%.*

4. Implications for an Integrated Catchment Management Plan

Throughout the report, it is emphasised that an integrated catchment plan should0 be developed to guide extraction efforts and to minimise a number of potential impacts, including cumulative effects from multiple operators working at varying intensity in space and time. A framework for consenting extraction operations (Figure 4-40) should continually and consistently maximise benefits such as mitigating the effects of gravel surplus and/or enhancing habitat potential. Once the management aims are established, a sustainable extraction programme can be developed to support these aims. An annual review, based on ongoing collection of site data will help to determine the sustainability of the removals, and identify impacts or beneficial effects of the work.

A long-term average gravel extraction rate that is modest relative to the overall transport volume should not unduly impact the processes that produce a particular river morphology. It should furthermore maintain water quality and maintain functionally connected habitat for native species of riverine birds, fish and aquatic invertebrates. The programme should minimise impacts to community and cultural values, recreation opportunities, and the Waiapu's scenic riverscapes. It should include a suitable monitoring framework, ongoing system analysis, feedback via reporting, and an adaptive approach to managing the resource. Deliberative engagement with tangata whenua, community and kaitiaki at the outset, and in review, will improve the outcomes for the proponent and for the river.

Figure 4-42 *Raparapariviki Stream, in the headwaters of the Tapuaeroa catchment, has exhibited some of the highest sedimentation rates in New Zealand. The riverbed has built up by more than 30 m in some locations, over the course of 25 years.*

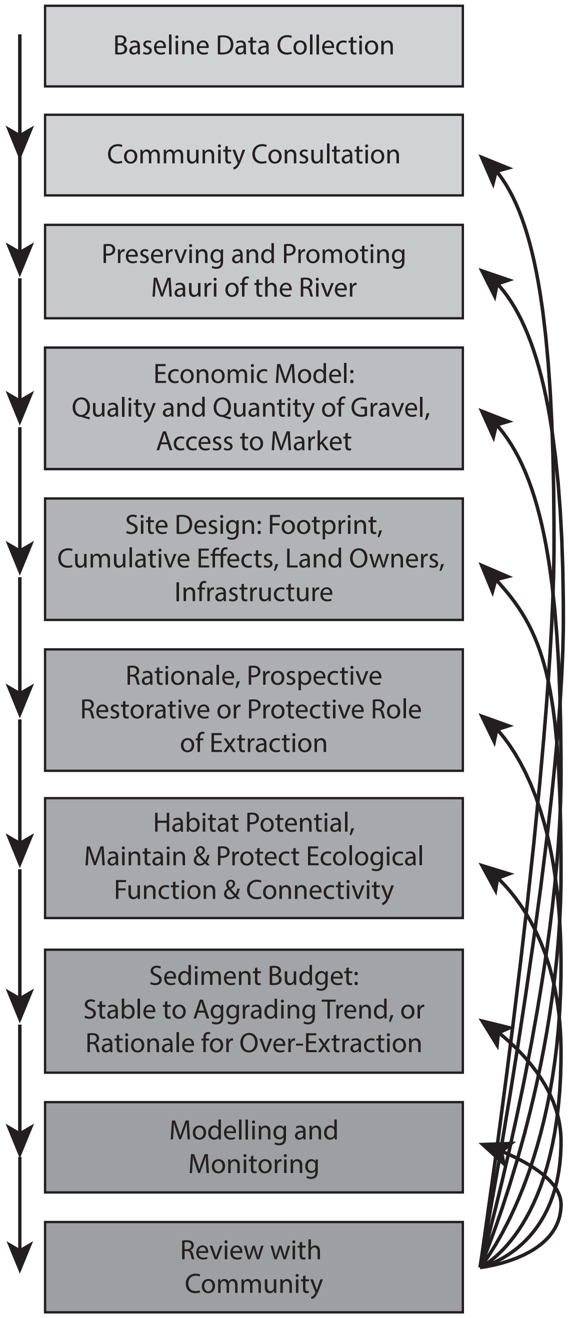


Figure 4-43 *Steps to managing gravel resources, with annual review that includes community input. Steps are revisited, as required, and the programme is adapted to any changing conditions.*

Baseline Data Collection
The information base required to assess the sustainability of a gravel extraction operation includes (1) an assessment of topographic (and bathymetric) change over the course of at least one year prior to work, (2) quantitative information on the grain size composition of surface and subsurface material, in order to assess impacts of fractional removal rates on habitat and bedload transport, and (3) a survey of local riverine species composition and abundance. With this information, it is possible to evaluate consent conditions, determine impacts in the future, and link change to a particular operation.

Community Consultation
Preliminary consultation is required to ensure that community aspirations for river recovery are being achieved, and that the aims of the *Te Mana o te Wai* framework are being met, through involving tangata whenua and appropriate prioritisation of the health and wellbeing of the wai. Consultation is ongoing, with at least an annual review of the gravel removal regime, as well exchanges with other operators on the river, technical staff from council and researchers to assess river trajectory over time.

Preserving and promoting mauri, special sites on the river
Places of cultural or spiritual significance should be taken into consideration. Every tributary has unique characteristics and values to be protected. Planting and protection of riparian zones, floodplain habitat, and restoration of landings, quarried river sites should be ongoing. Management of dust emissions should be reviewed.

Economic Model
The proponent must review the abundance of material relative to consented quantities as well as the quality of gravels: the relative hardness, splitting characteristics, and grain size distribution of the deposit. Transport costs, acquisition of specialised equipment, and ongoing infrastructure requirements are reviewed to determine ongoing feasibility.

Site Design
The extraction plan should be assessed with land owners and community groups to review potential impacts to recreation, fishing, swimming, among other usages of the river. Individual with interests along the river should bear in mind that the effects of gravel deficit can propagate both upstream and downstream from the work site. Operating guidelines should be set up such that impacts to water quality, air quality, stream biota and geomorphic function of the reach are minimised (Figure 4-41). The possibility of cumulative effects arising from too many operations in the catchment should be reviewed, as well as any legacy effects from past operations at the site. The overall footprint of the extraction site should be well-defined, to avoid extensive spatial impacts from roaming operations that preferentially target particular sedimentary assemblages, thus systematically impoverishing the river of certain grains-size fractions. The operation should be confined to one side of the river, such that an undisturbed corridor is available for passage of fish and other stream dwellers.

Rationale, Prospects for Remediation
Ideally, extraction operations can be established such that work is aligned with efforts to mitigate surplus sediment, improve flood conveyance, create habitat, or divert the channel from eroding boundaries (Section 2.5). This underlying rationale should be reviewed on an ongoing basis, comparing new survey and monitoring data to baseline conditions.

Ecological Function and Connectivity
Changes to channel configuration as a result of extraction should be analysed with a view to maintaining functional habitat: a combination of stable and dynamic benthic environments for aquatic invertebrates, minimal accumulation of coarse drapes of fine material downstream from extraction works, connected patches of suitable spawning and rearing grounds, and good diversity of hydraulic environments for riverine species. The checklist of requirements will vary with river setting, but this can be established at the outset of operations and modified with any ongoing evolution of the reach under the extraction regime.

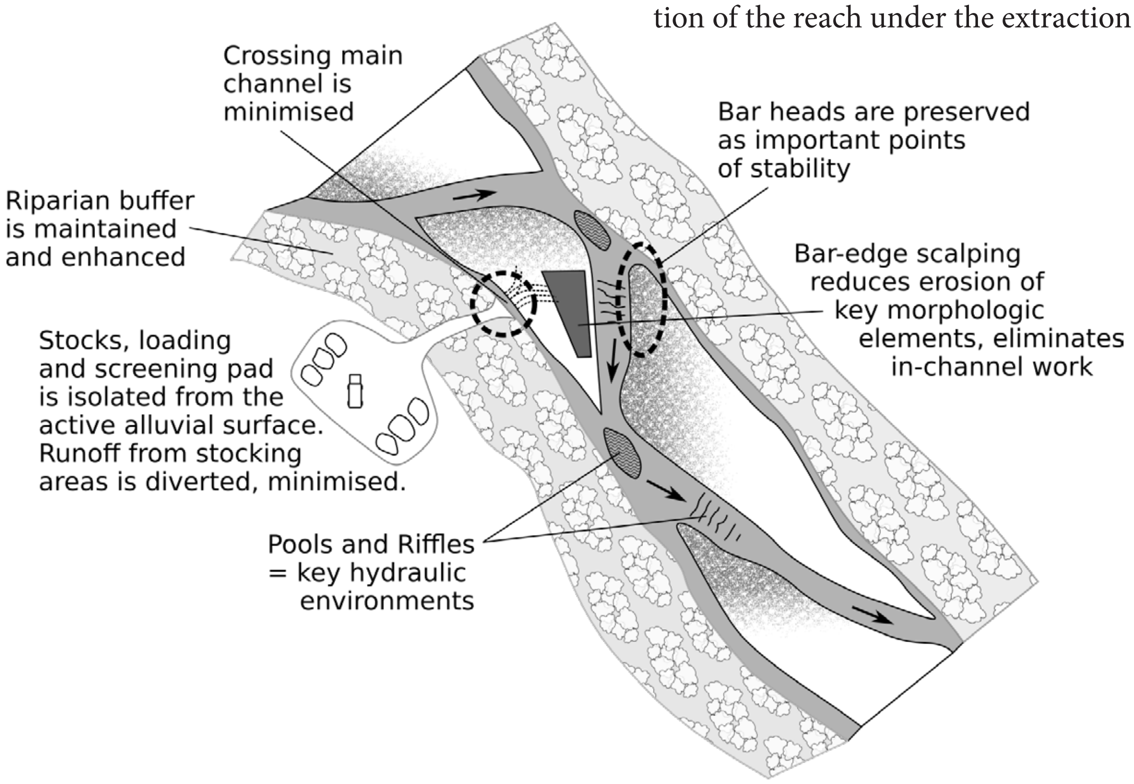


Figure 4-44 *Site design to minimise impacts on ecological and geomorphic processes within the extraction reach. Operations should stay out of flowing water where possible, minimise impact on channel morphology and prevailing grain size distribution in the river, and maintain and protect the riparian zone between the channel and surrounding environment.*

Sediment Budget

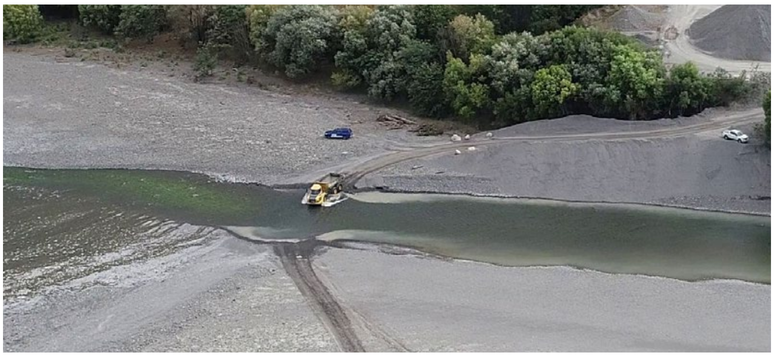
Annual surveys of the river reach provide a picture of inflows, transfers, and outflows, as well as capturing concomitant changes to river morphology. Cross-sections and topographic surveys extending several meander wavelengths upstream and downstream of the work will reveal any surplus or deficit of material working its way through the reach (Section 3). Evaluation of changing grain-size composition and proportion of suspendible solids on the bed will reveal any systematic deficit of coarser materials, or surplus of fines entering the system.

Modelling and Monitoring

The overall sustainability of the gravel extraction operation, or progress toward underlying management aims, can only be evaluated with ongoing analysis of reach conditions, relative to the baseline dataset, or conditions from the previous year. Modelling efforts will provide additional insights, and will help the consenting authority to explore scenarios related to changing climatic conditions, cumulative effects, and strategies for maximising economic return with minimal impacts to the river ecosystems and mauri status.

Review with Community

A summary of this analysis should be shared with stakeholders and catchment community on an ongoing basis. Any ongoing concerns can then be addressed, and the aims, rationale and sustainability of the work reviewed. This deliberative engagement with tangata whenua, community and kaitiaki will improve the outcomes for the proponent and for the river. Feedback from the group can be incorporated into future operations, monitoring and analysis.



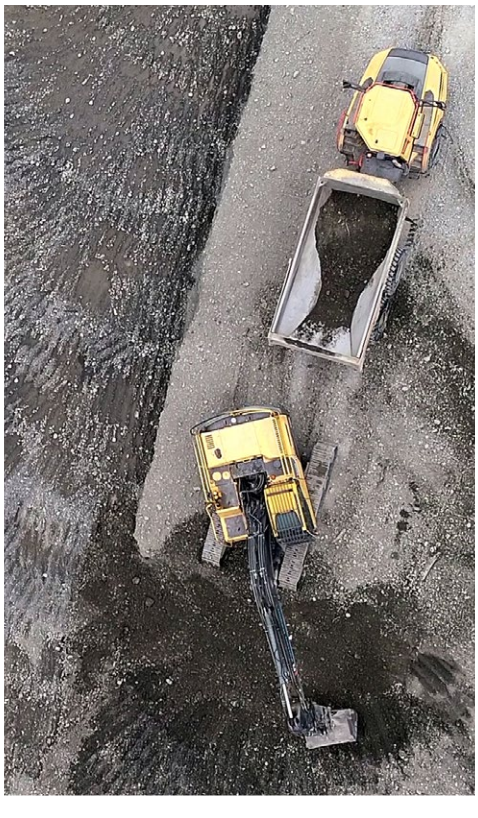


Figure 4-45 *Gravel extraction on the Waiapu, 600 m upstream of SH35 bridge ©Digital Globe, Google Earth, 2019. Stockpile landing pad should be well above riverbed elevation, and water-crossings should be minimised. Here, long trenches are excavated, eventually filled and modified by the river in flood.*

5. Conclusions and Some General Recommendations

This report has focused on the many interacting strands involved in gravel extraction from the Waiapu River: if the river is managed as an integrated, whole and dynamically adjusting system, the community is better positioned to manage impacts and leverage economic benefits from river resources. Ongoing community consultation is essential. The process of gravel removal, by necessity, will have some impact on the river; it is up to the community and kaitiaki to consider how best to manage potential effects on water quality, habitat quality, and/or biodiversity for greater overall gains for the catchment and community, including reduced flooding, a connected network of riverine habitat, channel stability, and economic returns from aggregate mining. Problems of cumulative impacts may be particularly severe; a clear catchment-scale management strategy will help to alleviate some of these issues.

The Waiapu River and its tributaries have a complex history of response to exceptional rates of sediment recruitment from mass wasting processes over the last 120 years. There are a number of initiatives underway to restore the ecological vitality of river systems to a point where biodiversity and species richness can recover to pre-deforestation levels. Re-planting of erosion-prone land, diversifying land-use and other measures have been implemented to reduce the sediment load currently reaching the lower Mata, Tapuaeroa and Waiapu rivers.

As part of the restoration process, a long-term gravel management strategy is needed to leverage the potential benefits of gravel abstraction within the Waiapu. The strategy can be used to assess proposed works, evaluate potentially beneficial interventions on the river via extraction, and to direct data gathering and monitoring work related to river issues. The approach is necessarily adaptive, as there are many interlinked components that are mutually adjusting - on different timescales - within the sedimentary system.

5.1 Community

Activity must be guided by initial engagement and ongoing interaction, particularly with Hapū and Iwi and also the wider community. Custodial linkages with the river are expressed through kaitiakitanga (guardianship), mana whenua and with an acknowledgement of ancestral linkages that position people as part of landscapes and ecosystems (Marsden, 2003). The term 'community' here is defined as all those living in, having a cultural relationship with, or holding significant interest in, the Waiapu catchment. In light of the ambitions for the JMA, gravel extraction or any other proposed modification of the river must be addressed through broad consensus.

Economic opportunity needs to be balanced with the vision for river restoration. Assessment of employment and economic gains from aggregate industry, and cascading effects for construction and forestry should be carried out.

A ***catchment management plan*** that is both scientifically informed and driven by Hapū aspirations and community consensus is needed to clearly define targets for managing both site-specific and catchment-wide issues, including impacts from river aggradation. Different tributaries may have different considerations, from a community or Hapū values perspective. Plans for each takiwa (hapū collective) should be developed.

5.2 Environment

The ecology of the Waiapu River and its tributaries, and the potential for recovery to pre-forest-clearance levels, is not very well characterised. In order to manage the risks of habitat degradation in a gravel extraction operation, it is important to understand spawning/nesting, rearing and feeding requirements of existing (and potential) bird, fish, and macroinvertebrate species, as well as linkages in the riverine/riparian food web.

Best practices for monitoring impacts from gravel extraction should include consideration of bed substrate conditions (invertebrate populations, median grain size, abundance of fines) and the diversity and relative abundance of hydraulic environments (riffles, pools).

Riparian zones are important buffer areas between the river and floodplain ecosystems; these are sites of exceptional species diversity (e.g. Gray and Harding, 2007). Terrestrial macroinvertebrates and organic detritus from these zones serve as a food source, and moderate the aquatic food web. There is no clear policy for protecting, rehabilitating and/or enhancing these sites in the design of gravel extraction schemes.

The parafluvial zone is the area adjacent to active channels with subsurface flow. The area represents important connectivity, for nutrients and longer-term storage of river base flow. Protecting underground water pathways has been pointed out as an important priority in traditional management of the river (Scion, 2012).

Air quality has been reported to be an issue, as dried silt particles from the river bed are easily entrained by strong winds in the valley. The issue is exacerbated by gravel extraction operations, with heavy trucks moving long distances over the floodplains.

5.3 Cumulative Effects

Multiple operations over time: current rates of consented extraction within the catchment have reached nearly 450 000 m^3 per year (roughly 150 000 m^3 in the mainstem river) as of February 2020. This is in significant excess of the estimated rates of net bedload transfer for the mainstem - which vary widely - but were assessed to be about 35-45 000 $m^3 \cdot yr^{-1}$, based on repeat photogrammetric river bed surveys in 2019-2020. If drawing down bed levels is the management aim, then a sediment budget and a practical assessment of extraction rates should be developed.

Multiple operations in space: potential locations for extraction operations are constrained by transport distances, quality of the gravel, access to the river, land ownership, available terrain for stocks, screening and loading, and other factors. A majority (~81%) of the gravel extraction efforts have been focused on the Mata (41%) and Waiapu (40%) rivers. Since there has been no aggradation on the Mata since 1997 (Peacock, 2016), there seems little justification for continuing to remove sediment at high rates here. Most of the riverbed aggradation in the catchment is occurring within the Tapuaeroa Valley. Only about 8% and 12% of abstractions are currently sourced from operations within the Tapuaeroa and Mangaoparo, respectively.

5.4 River Morphology and Sustainable Sediment Supply

The lower river and the many tributaries that feed into it all have a distinctive transport regime and character. Different river morphologies (e.g. confined headwaters, meandering, braided) will have different disturbance histories, ecology, and susceptibility to disturbance. Response to gravel extraction will vary according to factors such as channel slope, sediment supply, floodplain storage dynamics, substrate quality and texture. Criteria for selecting extraction sites, and operational procedures for the extraction work should reflect the river character.

A river with a sediment deficit will begin to reduce its active width, entrench its bed and simplify its morphology. A river deprived of sediment has excess energy and typically erodes its bed and banks to regain that sediment load (Kondolf, 1994). An example from the Aorongiwai River (tributary to the Mata) shows significant vertical bed erosion, where extraction rates from a short-lived operation there were in significant excess of the annual yield.

5.5 Protective River Works

Extraction works can be used to improve flood conveyance, protect bridge infrastructure, and to coax a river channel away from an eroding river bank. In 2010, gravel extraction was employed as part of an effort to move the river away from an eroding bluff near Ruatoria, for instance. While this can be very useful, the timeframe and location of the works may make it difficult to build an affordable or profitable enterprise from this.
A review of potential sites that might benefit from rehabilitative gravel removal should be developed, in consultation with the community.

5.6 Recommendations

Catchment Gravel Management Strategy

Sediment removal at a rate that approximates gravel influx has no immediate effect on river sedimentary processes and morphology. Ecological factors will require closer study. The key problem is to ***assess the ambient rates of gravel flux and accumulation*** over the course of a few years. This can be done via:

- Observations of morphology and change over time, particularly the extents of river bars and signs of dynamic river behaviour (Section 2; this is only helpful in a relative sense)
- Modelling approaches, using 1D or 2D techniques to model rates of sediment transport for floods of varying magnitude (better than first technique, but still approximative).
- Repeat surveys of river cross-sections or scans of river topography; these can be matched with previous or subsequent scans to assess gains or losses within a reach (best technique; expensive and time-consuming).

Gravel extraction has been underway for many years in the Mata and Waiapu; it would be helpful to quantitatively link the reported volumes extracted with observed changes in river morphology and/or Mean Bed Level (Section 3.2). This provides a first order estimate of the 'lower bound' transport rate.

A map of sensitive riverine environments: using a framework of mātauranga, local knowledge, cultural values, habitat requirements and ecological connectivity, a 'traffic light' system could be developed to map out sensitive environments along the length of the rivers in the catchment. Every tributary system will be different, and the exercise will require specialist knowledge in a range of fields to generate meaningful, practical and consistent results.

Flood risk and channel instability have been a problem mainly in the lower reaches of the Waiapu. ***These issues should be systematically compiled.*** Managing the sediment sources upstream from SH35 will help to reduce some of these issues, but more targeted solutions could be developed. It is also important to be mindful of impacts on sediment supply to the coast.

Managing for Cumulative Effects

The distribution of past and present extraction operations should be mapped out and compared with goals articulated in the gravel management strategy. Gravel quality, land access and trucking distance will constrain where operations can be deployed, however, operations should be sited to minimise cascading effects downstream, prevent disproportionate extraction within certain river reaches, and to maximise the potential benefits in countering the effects of aggradation.

The program must be adaptive and precautionary, with provision to change any elements of the program as soon as monitoring activities identify unfavourable changes to river morphology and/or the riverine ecosystem, or as soon as it becomes clear that secular changes in flow and sediment influx are affecting the river.

Advice to - and consent requirements for - extraction operators should offer clear guidance on problems of multiple operations over time, or closely located operations in space. The proponent should be able to demonstrate how the timing, methods, mitigation, and remediation strategies counter any potential cumulative effects. Some assessment of changing climate trends should also be provided.

Gravel Operations

Some general advice on extraction operations has been provided by GDC (https://www.gdc.govt.nz/shingle-and-sand-extraction); this could be expanded upon to meet the objectives set out in the gravel management strategy, including identification of areas of special cultural, recreational, scenic or ecological interest, sensitive river or riparian habitat, seasonal times for nesting/spawning, and the extent of the extraction 'footprint' relative to the consented extraction volume.

Appendix 2 provides an initial summary of issues related to gravel extraction; this list should be modified and expanded, as needed, to customise guidance for conditions in the Waiapu. Gravel operations should take place during low flows and from the above the low-flow water level.

In-channel excavation should be avoided. Bunds, berms, and buffer strips should be used to keep silt-laden runoff out of the river. These barriers should not unduly constrain the river's natural belt of adjustment space, and should be built to withstand high flows, to maintain separation between excavation pits and active flows. The final grading of the alluvial surface should not alter the flow characteristics of the river (See Langer, 2003), and should minimise stranding of aquatic species during recesssional flows.

Gravel extraction should not change the overall *character* of the gravel, that is, the mean grain size, fines content and coarsest fractions. By **not** preferentially leaving finer fractions on the active alluvial surface, this will avoid enriching the system downstream with finer material. Fine material is more mobile, and a higher proportion of it tends to reduce the quality of substrate for aquatic organisms downstream.

The morphology of the reach is the product of ongoing feedbacks between sediment transport and flood flows. Any interruptions of this balance can change the conveyance characteristics of the river and break up important hydraulic units such as riffles and pools. This diversity of morphologic environments is important for macroinvertebrate and fish species that have differing requirements for water temperature, depth and flow velocity. Thus, points of stability such as bar heads should be preserved.

Care should be taken to minimise impacts on infrastructure. Excavation should not occur upstream or downstream of bridges. Similar care should be taken with water intakes, culverts, fences, etc.

Finally, riparian zones should be carefully managed and maintained (enhanced, where possible) in the course of operations. A buffer of vegetation between the screening and stockpile areas and the river will help to buffer any runoff, and will also help to maintain this critical ecological boundary zone.

Monitoring and Modelling

The regional cross-section monitoring network should be expanded, as required, to accommodate potential future gravel extraction demands. While the current network is well-established and provides invaluable historic trend information, more survey sites may be helpful for assessing impacts upstream and downstream from large extraction operations.

Extraction operators should endeavour to survey the state of the river annually (or at completion of work) and, ideally, before and after major flood events. Surveys should extend two or more full meander wavelengths upstream and downstream of the active operation. This is particularly important for new extraction sites. For operations within the active floodplain, flooding will erase the contours of recent excavation, so surveys should be carried out promptly following cessation of extraction.

Surveys will ideally, but not necessarily, include assessment of gravel character and bed conditions upstream and downstream of the site, the relative abundance of avian, fish and macroinvertebrate species. The survey requirements will depend on the magnitude of the extraction effort. More generally, qualitative observations from operators provide helpful information for understanding the nature of river response to gravel mining.

While the approximate bounds of the sediment budget have been outlined here (and in the large literature on East Cape sedimentation issues), ***more detailed modelling is desirable for refining predictions of river behaviour into the future.*** The Waiapu River proper (i.e. downstream of Tapuaeroa/Mata confluence), should be the subject of more detailed morphodynamic modelling work in order to determine the response to sediment influx from upstream, and the impacts of surplus or shortfall to the coastal sediment train. This will be helpful in refining the gravel management strategy for the Waiapu. The recent LiDAR surveys of the catchment (summer 2019) will provide an outstanding resource for modelling and validating geomorphic change within the river system.

5.7 Open Avenues for Investigation

While the aquatic ecosystems of the Waiapu do not show the species biodiversity and population abundance of other, less impacted river systems, there is good potential for recovery over time.

Braided river habitat, with islands and back channels form some exceptional habitat for birds, fish and invertebrates. It is important to inventory these relationships between river environments and species abundance, in the context of broader watershed restoration work. More surveys and baseline studies will help to target sites for protection and enhancement.

Surveys of lithological variation (rock types) in the various catchments would be helpful in determining prospective sites for gravel extraction. Compositional studies of river gravel also provide useful data on the provenance of material from various source areas within the catchment, which will enhance the existing sediment budget database.

Developing a common, accessible geospatial data warehouse for the Waiapu will help Hapū to better manage their rivers, floodplains and ecological environments at the periphery. With the increasing availability of open source GIS software and tools for analysis, this will be an important resource for mapping and sharing results from models and analysis. Similarly, a common storehouse of community knowledge that includes sites of cultural significance and other special sites on the river will help to inform the catchment management plan.

Finally, continuing work on the river sediment budget will provide valuable data that feeds into these efforts to manage the gravel resource. The reconstructed histories, and models of future trajectory, all help us to understand the natural range of variability of the rivers within the network, and improve our understanding of thresholds for change and the sustainable limits required for maintaining the mana, mauri and ora of this living river.

References and Resources

Gravel Extraction Guidelines from other NZ Regional Councils:

Canterbury Regional River Gravel Extraction Code of Practice
https://www.ecan.govt.nz/document/download?uri=2329424
https://www.ecan.govt.nz/your-region/your-environment/river-and-drain-management/river-based-gravel-extraction/

Horizons Environmental Code of Practice for River Works
https://www.horizons.govt.nz/HRC/media/Media/One%20Plan/Environmental-Code-of-Practice-for-River-Works-June-2010.pdf?ext=.pdf

Hawke's Bay Riverbed Gravel Management Plan
https://www.hbrc.govt.nz/assets/Document-Library/Reports/Environmental-Science/Gravel-Management-Plan-March2017-Draft-for-consultation.pdf

Gravel Resource Management (Hawke's Bay Asset Management Group Technical Report)
https://www.hbrc.govt.nz/assets/Document-Library/Consents/Notified-Consents/Gravel-Resource-Sept2018-Final.pdf

Gravel Extraction - Taranaki Regional Council
https://www.trc.govt.nz/assets/Documents/Plans-policies/SoilWaterPlanReview/Draft-FLMP-gravel-june2012.pdf

Waikato Regional Council: Sand and Gravel Extraction Advice
https://www.waikatoregion.govt.nz/Council/Policy-and-plans/Rules-and-regulation/Regional-Plan/Waikato-Regional-Plan/4-River-and-Lake-Bed-Module/43-River-and-Lake-Bed-Disturbances/437-Implementation-Methods-Sand-and-Gravel-Extraction/

Wellington: Quarries (Gravel and Shingle Extraction)
http://www.gw.govt.nz/quarries-gravel-and-shingle-extraction/
http://www.gw.govt.nz/rule-38-minor-sand-and-gravel-extraction/

Landcare Database on Gravel Extraction
https://icm.landcareresearch.co.nz/research/research.asp?theme_id=1&research_id=48

New Tairawhiti Resource Management Plan

https://www.gdc.govt.nz/new-tairawhiti-resource-management-plan
http://www.gdc.govt.nz/tairawhiti-plan/

GDC Freshwater Plan - proposed
http://gdc.govt.nz/freshwater-plan-proposed/

Statutory acknowledgements of Ngāti Porou
http://www.gdc.govt.nz/statutory-acknowledgements-of-ngati-porou

Joint Management Agreement to Manage the Waiapu Catchment
https://www.gdc.govt.nz/joint-management-agreement/

Cited References

Antoniazza, G., Bakker, M., & Lane, S. N. 2019. Revisiting the morphological method in two-dimensions to quantify bed-material transport in braided rivers. Earth Surface Processes and Landforms, 44(11), 2251-2267.

Arscott DB, Tockner K, Ward JV. 2005. Lateral organization of aquatic invertebrates along the corridor of a braided floodplain river. Journal of the North American Benthological Society 24 : 934–954. DOI: 10.1899/05-037.1

Ashmore P, Church M. 1998. Sediment transport and river morphology: a paradigm for study. In Gravel-Bed Rivers in the Environment, Water Resources Publications, LLC; 115–148

Basher L. 2006. Monitoring of riverbed stability and morphology by regional councils in New Zealand: application to gravel extraction management . Landcare Research Report. Tasman District Council: Nelson, New Zealand

Black P. 2009. Geologic inventory of North Island aggregate resources: Influences on engineering materials properties . University of Auckland School of Environment [online] Available from: http://aqa.org.nz/resources/North Island Geological Inventory 2009.pdf (Accessed 15 April 2019)

Brasington J, Langham J, Rumsby B. 2003. Methodological sensitivity of morphometric estimates of coarse fluvial sediment transport. Geomorphology 53 : 299–316. DOI: 10.1016/S0169-555X(02)00320-3

Bridge JS. 1993. The interaction between channel geometry, water flow, sediment transport and deposition in braided rivers. Geological Society, London, Special Publications 75 : 13–71. DOI: 10.1144/GSL.SP.1993.075.01.02

Brierley G, Fryirs K. 2005. Geomorphology and River Management: Applications of the River Styles Framework . John Wiley & Sons.

Brierley G, Tadaki M, Hikuroa D, Blue B, Šunde C, Tunnicliffe J, Salmond A. 2019. A geomorphic perspective on the rights of the river in Aotearoa New Zealand. River Research and Applications, 35(10), 1640-1651.

Bunte K, Abt SR. 2001. Sampling Surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring, General Technical Report RMRS-GTR-74 . U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: Fort Collins, CO.

Carter L, Orpin AR, Kuehl SA. 2010. From mountain source to ocean sink – the passage of sediment across an active margin, Waipaoa Sedimentary System, New Zealand. Marine Geology 270 : 1–10. DOI: 10.1016/j.margeo.2009.12.010

Christie T, Thompson B, Brathwaite B. 2001. Mineral Commodity Report 22 - Aggregate. New Zealand Mining: 6–26.

Church M. 2000. River science and Fraser River: Who controls the river? Gravel Bed Rivers V. In Mosley, P. Ed. Gravel Bed Rivers V. New Zealand Hydrological Society. 642pp.

Church M, Ham DG, Weatherly H. 2001. Gravel Management in Lower Fraser River . Report prepared for the City of Chilliwack. Chilliwack, British Columbia [online] Available from: www.geog.ubc.ca/fraserriver/reports (Accessed 15 April 2019)

Clapcott JE. 2012. Review of Rapid Habitat Assessment Protocols. Prepared for Hawke's Bay Regional Council. Cawthron Report No. 2267. 33 p.

Clapcott JE, Young RG, Harding JS, Matthaei CD, Quinn JM, Death RG. 2011. Sediment Assessment Methods: Protocols and guidelines for assessing the effects of deposited fine sediment on in-stream values. Cawthron Institute, Nelson, New Zealand.

Clode G, Beya J. 2018. Gravel Resource Management . Asset Management Group Technical Report. Hawke's Bay Regional Council: Napier [online] Available from: https://www.hbrc.govt.nz/assets/Document-Library/Consents/Notified-Consents/Gravel-Resource-Sept2018-Final.pdf (Accessed April 2019)

Collier KJ, Cooper AB, Davies-Colley RJ, Rutherford JC, Smith CM, Williamson RB. 1995. Managing riparian zones: a contribution to protecting New Zealand's rivers and streams. Volume 2: Guidelines. [online] https://www.doc.govt.nz/documents/science-and-technical/riparianzones2.pdf. Wellington, NZ. Department of Conservation.

Collins B, Dunne T. 1990. Fluvial geomorphology and river-gravel mining: a guide for planners, case studies included . California Department of Conservation, Division of Mines and Geology

Corenblit D, Tabacchi E, Steiger J, Gurnell AM. 2007. Reciprocal interactions and adjustments between fluvial landforms and vegetation dynamics in river corridors: A review of complementary approaches. Earth-Science Reviews 84 : 56–86. DOI: 10.1016/j.earscirev.2007.05.004

Duncan M, Sykes J. 2015. Instream habitat and minimum flow and allocation requirements in the Waiapu River. Environlink Report 1575-GSDC122 to Gisborne Council. [online]: https://envirolink.govt.nz/assets/Envirolink/1575-GSDC122-Instream-habitat-and-minimum-flow-and-allocation-requirements-for-the-Waiapu-River.pdf. Christchurch, NZ. NIWA.

Environment Canterbury. 2006. Regional Gravel Management Report. Report No R06/1. Environment Canterbury: Christchurch. [online] Available from: https://webcat.niwa.co.nz/documents/ECtrR06-16.pdf (Accessed April 2019)

Ferguson RI. 1993. Understanding braiding processes in gravel-bed rivers: progress and unsolved problems. Geological Society, London, Special Publications 75: 73–87. DOI: 10.1144/GSL.SP.1993.075.01.03

Gisborne District Council. 2009 Report to Operations Committee for Decision (Waiapu River Erosion Protection Work December 2009. 09/653 [online] http://www.gdc.govt.nz/assets/CommitteeMeetings/09-653-Report.pdf (Accessed Nov 2020).

Gray D, Harding J. 2007. Braided river ecology: A literature review of physical habitats and aquatic invertebrate communities. Department of Conservation: Wellington

Gray DP, Harding J. 2010. Spatial variation in invertebrate communities in New Zealand braided rivers . Department of Conservation: Wellington

Gregory SV, Swanson FJ, McKee WA, Cummins KW. 1991. An ecosystem perspective of riparian zones. BioScience. 41(8):540-51.

Habersack HM. 2001. Radio-tracking gravel particles in a large braided river in New Zealand: A field test of the stochastic theory of bed load transport proposed by Einstein. Hydrological Processes. 15(3):377-91.

Harding JS, Clapcott JE, Quinn JM, Hayes JW, Joy MK, Storey RG, Greig HS, Hay J, James T, Beech MA, Ozane R, Meredith AS, Boothroyd IKD 2009. Stream habitat assessment protocols for wadeable rivers and streams of New Zealand. University of Canterbury Press.

Harmsworth G, Warmenhoven T, Pohatu P, Page, M. 2002. Waiapu Catchment Report: Maori community goals for enhancing ecosystem health. FRST Contract TWWX0001. 184 p.

Hughey KF, Booth KL. Monitoring the state of New Zealand rivers: how the river values assessment system can help. New Zealand Journal of Marine and Freshwater Research. 2012 Dec 1;46(4):545-56.

James AL. 2010. Secular sediment waves, channel bed waves, and legacy sediment. Geography Compass. 4(6). 576-98.

Kasai M, Aoki D, Peacock D, Marutani T. 2019. Channel evolution controlled by valley configuration during 70 years in a severely erosive catchment: Mangaoporo River, New Zealand. Catena 174 : 324–338. DOI: 10.1016/j.catena.2018.11.032

Kasprak A, Wheaton JM, Ashmore PE, Hensleigh JW, Peirce S. 2015. The relationship between particle travel distance and channel morphology: Results from physical models of braided rivers. Journal of Geophysical Research: Earth Surface, 120(1), 55-74.

Kellerhals R, Church M, Bray DI. Classification and analysis of river processes. ASCE Journal of the Hydraulics Division. 102(7). 813-29.
Kondolf GM. 1994. Geomorphic and environmental effects of instream gravel mining. Landscape and Urban Planning 28: 225–243.

Kondolf GM. 1997. Hungry water: effects of dams and gravel mining on river channels. Environmental Management 21: 533–551.

Kuehl SA et al. 2016. A source-to-sink perspective of the Waipaoa River margin. Earth-Science Reviews 153 : 301–334. DOI: 10.1016/j.earscirev.2015.10.001.

Lane SN, Richards KS, Chandler JH. 1994. Developments in monitoring and modelling small-scale river bed topography. Earth Surface Processes and Landforms 19 : 349–368. DOI: 10.1002/esp.3290190406.

Langer WH. 2003. A general overview of the technology of in-stream mining of sand and gravel resources, associated potential environmental impacts, and methods to control potential impacts. United States Geological Survey Open-File Report 02-153.

Leask B. 2018. Gisborne Roading Aggregate Supplier Assessment . OPUS Contracted Report. Gisborne District Council: Gisborne [online] Available from: www.gdc.govt.nz/assets/Uploads/18-019-State-of-Gravel-Resource-in-the-District.pdf (Accessed 15 April 2019).

Leenman A, Tunnicliffe J. 2018. Genesis of a major gully mass-wasting complex, and implications for valley filling, East Cape, New Zealand. GSA Bulletin 130 : 1121–1130. DOI: 10.1130/B31849.1

Liébault F, Piégay H. 2001. Assessment of channel changes due to long-term bedload supply decrease, Roubion River, France. Geomorphology 36 : 167–186. DOI: 10.1016/S0169-555X(00)00044-1.

Lindsay JB, Ashmore PE. 2002. The effects of survey frequency on estimates of scour and fill in a braided river model. Earth Surface Processes and Landforms 27 : 27–43. DOI: 10.1002/esp.282.

Litchfield N, Berryman K, Brackley H, Carter L, Marden M, Page M, Trustrum N. 2008. The Waipaoa Sedimentary System: research review and future directions. IAHS Publication 325: 408.

Marden M, Arnold G, Seymour A, Hambling R. 2012. History and distribution of steepland gullies in response to land use change, East Coast Region, North Island, New Zealand. Geomorphology 154 : 81–90. DOI: 10.1016/j.geomorph.2012.02.011.

Marden M, Fuller IC, Herzig A, Betts HD. 2018. Badass gullies: Fluvio-mass-movement gully complexes in New Zealand's East Coast region, and potential for remediation. Geomorphology 307 : 12–23. DOI: 10.1016/j.geomorph.2017.11.012.

Marsden M. 2003. Kaitiakitanga: A definitive introduction to the holistic worldview of the Maori. In TAC Royal (Ed.), The woven universe: selected writings of Rev. Māori Marsden (pp 54-72). Ōttaki: Te Wānagan o Raukawa.

Marston RA, Bravard J-P, Green T. 2003. Impacts of reforestation and gravel mining on the Malnant River, Haute-Savoie, French Alps. Geomorphology 55 : 65–74. DOI: 10.1016/S0169-555X(03)00132-6.

Martín-Vide JP, Ferrer-Boix C, Ollero A, 2010. Incision due to gravel mining : Modeling a case study from the Gallego River, Spain. Geomorphology, 117, 261-271.

Murphy P. 2018. State of Gravel Resource in the District . Gisborne District Council: Gisborne [online] Available from: www.gdc.govt.nz/assets/Uploads/18-019-State-of-Gravel-Resource-in-the-District.pdf (Accessed April 2020).

Nati News. 2015. Joint Management Agreement between the Gisborne District Council and Ngati Porou approved [online] Available from: ngatiporou.com/article/joint-management-agreement-between-gisborne-district-council-and-ngati-porou-approved (Accessed April 2020).

Nicholas AP. 2000. Modelling bedload yield in braided gravel bed rivers. Geomorphology 36 : 89–106.

O'Donnell CF, Sanders M, Woolmore C, Maloney RF. 2016. Management and research priorities for conserving biodiversity on New Zealand's braided rivers. Dept of Conservation: Wellington.

Page M, Marden M, Kasai M, Gomez B, Peacock D, Betts H, Parkner T, Marutani T, Trustrum N. 2007. Changes in basin-scale sediment supply and transfer in a rapidly transformed New Zealand landscape. In Gravel-Bed Rivers VI: From Process Understanding to River Restoration, Habersack H, Piégay H, and Rinaldi M (eds). Elsevier; 337–356.

Parkyn S, Collier K, Clapcott J, David B, Davies-Colley R, Matheson F, Quinn J, Shaw W. 2010. The restoration indicator toolkit . NIWA: Hamilton.

Peacock D. 2016. Tapuaeroa River Mean Bed Level Trends; 1958 TO 2016 . Gisborne District Council: Gisborne [online] Available from: http://www.gdc.govt.nz/river-bed-levels (Accessed April 2019).

Peacock D. 2017a. Waiapu River Mean Bed Level Trends; 1958 TO 2017 . Gisborne District Council: Gisborne [online] Available from: http://www.gdc.govt.nz/river-bed-levels (Accessed April 2019).

Peacock D. 2017b. Mangaoporo River Mean Bed Level Trends; 1958 TO 2015 . Gisborne District Council: Gisborne [online] Available from: http://www.gdc.govt.nz/river-bed-levels (Accessed April 2019).

Peacock D, Marden M. 2004. Bed level changes in the Raparapaririki, Mangapoi and Mangawhairiki Streams, Ruatoria. Gisborne District Council Engineering and Works Technical Report 2004/01 (EWTR 2004/01). 19 p + Appendices.

Peacock D, Marden M. 2014. Bed Level Changes in the Raparapaririki, Mangapoi and Mangawhairiki Streams; Ruatoria Volume 2: 2003 to 2013 . Gisborne District Council: Gisborne.

Piégay H, Grant G, Nakamura F, Trustrum N. 2006. Braided river management: from assessment of river behaviour to improved sustainable development. Braided rivers: process, deposits, ecology and management 36 : 257–275.

Porou, T., Barnard, T., Fitzgerald, G., Moore, D., Barry, L., Garrett, L., & Harrison, D. (2012). Benchmarking, scope assessment, & critical evaluation – social, cultural, & economic aspects of erosion for Ngāti Porou & a desired state for the Waiapu catchment. *In* Scion. Waiapu River Catchment Study – Final Report (pp. 192-259). Scion Confidential Client Report No. 15201. Rotorua, New Zealand: Scion.

Pyrce RS, Ashmore PE. 2003. Particle path length distributions in meandering gravel-bed streams: Results from physical models. Earth Surface Processes and Landforms. 28(9), 951-966.

Rhoads BL, Welford MR. 1991. Initiation of river meandering. Progress in Physical Geography: Earth and Environment 15 : 127–156. DOI: 10.1177/030913339101500201

Richardson J, Jowett IG. 2002. Effects of sediment on fish communities in East Cape streams, North Island, New Zealand. New Zealand Journal of Marine and Freshwater Research 36 : 431–442. DOI: 10.1080/00288330.2002.9517098

Rinaldi M, Wyżga B, Surian N. 2005. Sediment mining in alluvial channels: physical effects and management perspectives. River Research and Applications 21 : 805–828.

Roil H, Death RG. 2018. Aquatic Ecosystems in Gisborne: Macroinvertebrate Communities . Gisborne District Council: Gisborne.

Rosenau M, Angelo M. 2000. Sand and Gravel Management and Fish-Habitat Protection in British Columbia Salmon and Steelhead Steams . Pacific Fisheries Resource Conservation Council: Vancouver, BC [online] Available from: www.fish.bc.ca (Accessed 15 April 2019).

Rowe DK, Chisnall BL, Dean TL, Richardson J. 1999. Effects of land use on native fish communities in east coast streams of the North Island of New Zealand. New Zealand Journal of Marine and Freshwater Research 33 : 141–151.

Salmond A. 2018. Rivers as ancestors and other realities: Governance of waterways In Aotearoa/New Zealand. In B Martin, L Te Aho, M Humphries (Eds.), Responsibility, law and governance for living well with the earth. UK: Routledge. Chapter 12

Scion. 2012. Waiapu River Catchment Study – Final Report. Scion Confidential Client Report No. 15201. Rotorua, New Zealand. [online] Available from: www.mpi.govt.nz/dmsdocument/4064/direct (Accessed June 2020).

Stevens M, Larsen B. 2015. Gravel Management Plan: Gravel Resource Inventory (Issue 3) Hawkes Bay Regional Council: Hawkes Bay. [online] Available from: www.hbrc.govt.nz/assets/Document-Library/Consents/Notified-Consents/Gravel-Resource-Inventory-Final-11082015.pdf (Accessed April 2020).

Sutek Services Ltd., Kellerhals Engineering Services, Ltd. 1989. Assessing Gravel Supply and Removal in Fisheries Stream . Department of Fisheries and Oceans, BC Ministry of Environment: Victoria, BC.

Tonina D, Buffington JM. 2009. Hyporheic exchange in mountain rivers I: Mechanics and environmental effects. Geography Compass, 3(3), 1063-1086.

Tunnicliffe J, Brierley G, Fuller IC, Leenman A, Marden M, Peacock D. 2018. Reaction and relaxation in a coarse-grained fluvial system following catchment-wide disturbance. Geomorphology 307 : 50–64. DOI: 10.1016/j.geomorph.2017.11.006.

Tunnicliffe J, Fuller I, Eaton B, Peacock D, Marden M. 2021. Reconstructing the sediment dynamics of an overloaded gravel bed river, East Cape, New Zealand. Earth Surface Processes and Landforms (in review).

Vericat D, Wheaton JM, Brasington J. 2017. Revisiting the morphological approach: opportunities and challenges with repeat high-resolution topography. In Gravel-Bed Rivers: Process and Disasters.

Williams RD, Brasington J, Hicks DM. 2016. Numerical Modelling of Braided River Morphodynamics: Review and Future Challenges. Geography Compass.

Wilson G. 2001. National distribution of braided rivers and the extent of vegetation colonisation. Contract Report. Landcare Research: Hamilton.

Wishart D, Warburton J, Bracken L. 2008. Gravel extraction and planform change in a wandering gravel-bed river: The River Wear, Northern England. Geomorphology, 94 (1-2), 131-152.

Zaki A. 2018. Rivers of gravel are drying up, causing spiralling costs for roadworks. Stuff.co.nz 15th April [online] Available from: https://www.stuff.co.nz/business/102504675/rivers-of-gravel-are-drying-up-causing-spiralling-costs-for-roadworks (Accessed 15 April 2019)

Appendix 1: Summary of River Status

This database of river change has been summarised in a discussion document by Murphy (2018). The table is reproduced here, showing the coherence with the above summary, and documentation provided to council by Peacock (2016, 2017a,b). The Mangaoporo and Tapuaeroa rivers are flagged as good potential sources for extraction, which is consistent with the observed bed trends and gravel quality.

River	Bed Level Trend	Implication
Waiapu River Catchment		
Waiapu River	Upper catchment gradually increasing; however, lower catchment no significant trend.	Not a high priority for a gravel management plan. **Good location to continue gravel extraction activities.**
Mata River	Upper catchment decreasing, lower catchment increasing.	Many of the gravel extraction sites are in the upper catchment – over time these should be moved downstream to where the river is still aggrading. **A gravel management plan is required.**
Makarika Stream	Gradually increasing	Unknown
Makatote and Kopuaroa Stream	Gradually decreasing	Unknown
Paoaruku Stream	Gradually increasing	Unknown
Mangaoporo River	Increasing	Large gravel abstraction resource available.
Tapuaeroa River	Increasing	Large gravel abstraction resource available.
Waiorongomai Stream	Increasing, poor quality bed material.	This is the source of some of the gravel resource heading down into the Tapuaeroa River.
Poroporo River	Increasing, recently rate has slowed.	Despite large resource, unlikely to be suitable quality of material.
Maraehara River	No significant trend	Unknown
Manutahi Stream	Gradually decreasing trend	Unknown
Mangaharei Stream	Gradually decreasing trend	Unknown
East Cape Rivers		
Karakatuwhero River	No significant trend, geology contributes less bed load material	Gravel resource may be fully allocated. A gravel management plan is required.
Waipaoa River Catchment		
Mangatu River	Gradually increasing	Not a high priority for a gravel management plan. **Good location to continue gravel abstraction activities.**

Appendix 2: Condensed Summary of Potential Impacts from Gravel Extraction

The primary impacts from gravel mining (relevant to the Waiapu) are summarised below. Many of these issues are explicitly recognised in existing guidelines for disturbance of the river bed, although advice from councils varies by region.

Impacts may be cumulative in space and time, and may also be superimposed on other disturbances within the catchment. Catchment context should be reviewed, and cumulative effects considered, before assessing potential environmental impacts of new works.

Issue	*Potential Impacts*	*Mitigation*
Excavation of the river bed	Increased siltation, turbidity via digging and heavy equipment. Fine sediments can clog gills, preventing respiration. Gravel pore space can be clogged, limiting spawning potential and macro-invertebrate populations. Fish predation cannot occur in limited visibility. Excess accumulation of fines can dry up and contribute to air quality issues, further downstream.	Active digging in the alluvial plain is should keep at least 5 m from flowing water. Excavations may employ a bund or barrier to minimize interaction with the channel. Hay bales, pontoons and silt screens may also be used to reduce sedimentation.
	Fining of grain size distribution through preferential removal of coarse-grained substrate results in loss of hydraulic roughness, habitat characteristics, altered morphology. Destruction of benthic environment disrupts algal food supply at the base of the food chain. Scalping/skimming of bars may induce channel instability; removes habitat; bird nesting is disrupted.	Avoid preferential removal of coarser fractions. Fine sediment (spoil from excavation) should be cleared from the river channel to avoid a change in prevailing gravel size distribution. Extraction should occur at times when nesting is not in progress.
	Trapping of fish and benthic fauna within excavations during receding flows.	Excavations sites are graded such that organisms can escape at low flows.
	Drop in water table, impacting streambed habitat, affecting riparian vegetation.	Excavations should not extend below water table, particularly in areas of sensitive riparian vegetation.
	Water intakes may be impacted by turbidity or burial.	Consultation with landowners.
	Mauri of the river is affected.	Broad consultation with Iwi and Hapu to establish mana whenua and special considerations for respecting the river.

Issue	Potential Impacts	Mitigation
Reach impacts from over-extraction	Narrowing of the reach, armouring of the riverbed.	The sediment budget for the reach should be carefully assessed; impacts can reach several km upstream or downstream from the excavation site.
	Sediment deficit to downstream areas, most notably the coastal zone; changes in tidal hydrodynamics	The sediment budget for the reach should be carefully assessed. The effects of degradation can cascade up into tributaries that have not been otherwise impacted.
	Impacts to infrastructure by erosion and undermining (bridge footings, culverts, fences, etc.)	The sediment budget for the reach should be carefully assessed. Impacts can reach several km upstream or downstream from the excavation site.
	Reduction in recreation access, filling of swimming holes, reduced fishing opportunities	Gravel removal sites should be allocated with these recreational usages in mind.
	Effects on riverscape scenery.	Appropriate siting of removal operations, relative to bridges, tramping, fishing and other access ways.
	Traditional sites, cultural heritage, culturally significant places, wahi tapu (sacred sites), papa kainga.	Collaborative planning with local iwi, hapu and community groups.
Alteration of river bars, channel morphology, or flow alignment	Changes to bar morphology affects flow velocity, water depth, and substrate composition, all of which influence the distribution and abundance of aquatic organisms.	Mode of excavation (see next section) should take consideration of potential species' sensitivity and requirements through their life-cycle.
	Riffles and pools may be filled or destroyed, wiping out key hydraulic environments.	Critical hydraulic environments, and historic fluctuations in their location, should be assessed before excavation. Changes in morphology should be part of reporting.
	Channel capture by off-channel pit and reactivation of inactive channels.	Appropriate planning of pit location, particularly in response to changing channel alignment upstream and downstream.

Issue	*Potential Impacts*	*Mitigation*
Alteration of river bars, morphology, or flow alignment (cont.)	Systematic excavation of stable sites (bar head) leads to instability of bar form.	Excavation should proceed at more distal sites (downstream from bar head) along river bars.
	Bank collapse, leading to widening of the channel, shallowing of flows, and reduced transport capacity.	Careful siting of excavations to minimise deflecting river over to the opposite bank. Protect riverbanks.
	Loss of habitat structure, variability and complexity: • Quality and availability of food for stream invertebrates and fish • Refugia for birds, fish and other stream fauna • Distribution of native vegetation, biodiversity of aquatic flora. • Direct loss of habitat for nesting and sheltering native birds	No extractions to occur near (within 100m) at-risk native bird nesting sites and outside the breeding season of threatened birds if they are present. Habitat census, review of functional habitat units within the river corridor. Gravel operations consider connectivity of important habitat linkages.
Machinery in the river and on the margins of active alluvial surface	Accidental discharge of fuels and lubricants from machinery.	Machine refuelling and fuel storage well outside of area of active flow and above the anticipated flood level. Machinery leaking fuel, engine oils, hydraulic fluids or solvents shall be removed from the riverbed immediately. Equipment not in use is stored high above flowing water.
	Introduction of weeds and non-native species into riparian habitats. Weeds may grow prolifically and reduce native vegetation.	Machinery is kept clean to avoid weed and pest transfer. Restricted access to the river to protect the riparian zone from these effects.
	Disturbance of riverbanks results in less shade and higher water temperatures and greater water velocities. Destruction of bank integrity results in shallower flows, more inundation.	Use existing access tracks where available. Locate stockpile and screening areas where they will have minimum impact on the riparian zone. Keep stockpiles above flood levels and avoid removal of native vegetation.
Dust	Excess fine material introduced to the channel accumulates on bar tops over the course of one or more floods. As the deposit dries, blowing silt degrades air quality.	Fine grained deposits (mud, clay) should be deposited in off-channel sites, and buried with layers of coarser material.

This report identifies issues regarding gravel extraction on the Waiapu River, and proposes some steps towards developing a sustainable management framework. The report further aims to inform best practices for gravel extraction, with a view to enhancing community engagement with decision making, managing water quality issues, and nurturing the development of river habitat.

The report provides an overview of river geomorphology and its links to ecology, river connectivity relationships within the drainage network, and an approach to assessing sensitive sites along river corridors and sustainability of the proposed activity. Some perspective on adaptation in a changing climate is outlined: gravel supply is ultimately determined by storm climate, and therefore extraction regime should reflect this variation.

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