

# **Working with river process in managing sediment flux from the Kourawhero Catchment into Kaipara Harbour, Aotearoa New Zealand**

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## **Key Points**

- Three geomorphic assessment methodologies, the River Styles Framework, Geomorphically Effective Management Solutions (GEMS) and Rapid Geomorphic Assessments, provide a suite of information to guide the management of Kourawhero catchment at catchment, reach and site-specific scales.
- Catchment understandings ensure that management works with and respects river diversity. Management applications are unlikely to be successful unless they work with the river's geomorphic structure, function and evolutionary trajectory.
- Reach scale assessment provides understanding of the processes driving change (e.g. critical shear stress and bank stability) Modelling analyses identify key areas of geomorphic adjustment, the potential for sediment generation and geomorphically effective management solutions that work with river processes. Headcut propagation and protection of undercutting banks are key components of management in the Kourawhero catchment.

## **Abstract**

A major catchment-scale rehabilitation initiative addresses sediment flux in river systems that drain into Kaipara Harbour, northwest Auckland, Aotearoa New Zealand. Our study area, the Kourawhero Stream, drains approximately 13% of the catchment but has been identified as a key sediment hotspot.

This is an unusual river system in New Zealand, behaving as a fine-grained cut-and-fill river system. Geologically-induced accommodation space, alongside long-term tectonic uplift has influenced the base level of the river and long-term patterns of sediment storage. Subsequent incision and ongoing headcut erosion has released large volumes of sediment which are efficiently conveyed through to the harbour.

Collaborative investigations by researchers at the University of Auckland and river managers/practitioners at Auckland Council uses the River Styles Framework, combined with field investigations and modelling analyses to assess river processes to inform management practices. An approach for 'Geomorphologically Effective Management Solutions' (GEMS) developed by Auckland Council works with river processes to address sedimentation issues from rivers into Kaipara Harbour. The River Styles Framework presents opportunities for geomorphic analyses to support the upscaling of such applications.

## **Keywords**

Cut-and-fill river system

River Styles

River management

River diversity

Fine grained

## **Introduction**

Various forms of geomorphic insight are being used to inform management of the Kourawhero catchment, where high rates of sediment flux are causing problems in the ecologically important Kaipara Harbour, north of Auckland. While the Kourawhero subcatchment makes up only 13% of the Hōteio Catchment, it contributes an average load of 15,100 tonnes of sediment per year, more than all other reaches on the Hōteio and its tributaries combined (Cardno, 2016). This is an unusual river system in New Zealand, behaving as a fine-grained cut-and-fill river system. Respecting the distinctive properties of the river is critical to successful management.

Here we reflect upon the alignment of three initiatives to support geomorphologically-informed management of this important, charismatic river system. The River Styles Framework provides systematic baseline information of the catchment, establishing a platform for comparability/transferability between catchments and assessment of the evolutionary trajectory of the river so that management can work with the river.

Auckland Council has developed the Geomorphically Effective Management Solutions (GEMS) framework to address accelerated erosion across the region. Standard approaches to erosion management have typically focused on hydrology management in urban stormwater systems to reduce peak flows in stream channels during storm events, with little regard to the physical nature of the conveyance channel itself. The GEMS framework applies a more physical geomorphic approach to stream management incorporating qualitative and quantitative assessment to better address the driving and resisting forces associated with erosion processes.

In the Kourawhero Stream, these analyses are framed alongside a combination of qualitative Rapid Geomorphic Assessments (Simon and Hupp, 1986; Simon, 1989; Simon and Downs, 1995) and quantitative assessments of geotechnical and hydraulic resistance parameters which use critical soil shear stress and modelled peak flows to determine areas of potentially higher erosion and inform locations for additional investigation and analysis (Cardno, 2016). Management of a headcut that is propagating upstream, causing incision and bank instability, informs the development of iwi and community led process-based restoration strategies.

Watercourse Assessment Report (WAR) is a further tool used by Auckland Council. This provides a reach scale condition assessment of streams, including the state of erosion, built and natural asset condition and ecological health. To date, the WAR programme has mostly focused on urban streams. It provides the most comprehensive database of natural asset condition which informs catchment management planning and monitoring. It summarises information on the condition of both natural assets (streams, wetlands) and also the built infrastructure associated with conveyance, such as channel linings, inlets and outlets.

Here we look at how a coordinated and coherent geomorphic insight of a catchment is informing management practices in the Kourawhero catchment as a case study to show how we go about this in the Auckland region. As large volumes of suspended sediment are delivered to a sensitive coastal receiving environment during storm events, most of which is sourced from stream erosion processes, enhanced water quality and sedimentation issues are the key drivers of improved stream erosion management in this system.

## **Regional Setting**

The Kourawhero catchment drains an area of 78 km<sup>2</sup> (Figure 1). The main stream flows westward into the Hoteio River and then down to the Kaipara Harbour. It is 14.9km long and has a number of tributaries that branch off the Kourawhero stream to the north and south, the most significant of which is the Onehunga Stream. The receiving environment of the Hōteio River is the Kaipara Harbour, the largest estuary in New Zealand. The harbour has a high tide surface area of approximately 950 km<sup>2</sup>, of which 43% is intertidal, with a reporting catchment land area of around 6,000 km<sup>2</sup>. Current annual average sediment loads delivered to the harbour are estimated to be around 700,000 tonnes per year, significantly higher than the approximately 120,000 tonnes per year estimated in pre-human times (Green and Daigneault, 2018). The stream has a

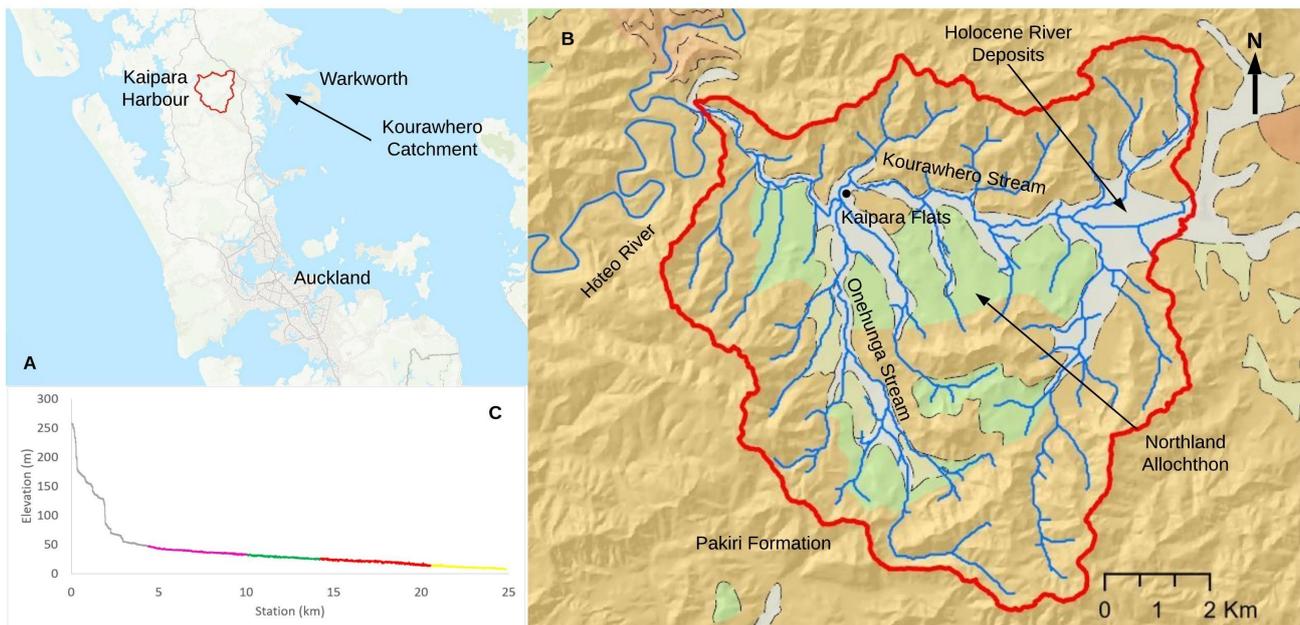
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median annual flow of less than  $1\text{m}^3\text{s}^{-1}$ . At overbank stage, flows extend for hundreds of meters from the channel because of the subdued topography of low-lying swamplands that make up the Kaipara Flats.

The catchment comprises three distinct geological units (Figure 1B). Alternating beds of sandstone and mudstone that make up the Pakiri Formation form the steep terrain that borders the catchment. The sheared mudstone of the Northland Allochthon is located centrally within the catchment. Emplacement of a series of thrust sheets created an asymmetrical drainage basin with the Kourawhero Stream located towards the northern margin. An expansive valley floor has infilled with river deposits (Edbrooke, 2001; Haywood, 2017).

Following European settlement in the area in the 1830's, the kauri forests were cleared and the land opened up for agriculture (Waitangi Tribunal, 2006). Today, an estimated 10% of the original forest cover remains (Richards, 2007).



**Figure 1: A) Regional setting of the Kourawhero catchment, B) Key features of the Kourawhero catchment, with underlying geology, C) Longitudinal profile of the Kourawhero Stream.**

## Geomorphic Assessment of the Kourawhero

Three different toolkits have been used by Auckland Council to assess river systems that feed into the Kaipara Harbour. Together, this generates better understanding of the system to inform management from the catchment scale down to reach scale processes.

### River Styles Assessment

To understand the catchment scale processes that are influencing erosion in the Kourawhero, the catchment has been assessed using the River Styles Framework (Brierley and Fryirs, 2005; Fryirs and Brierley, 2018). The assessment included site visits and GIS analysis based on the digital elevation model (DEM) with a 1 m vertical resolution. The River Styles Framework assesses the contemporary river and applies a hierarchy of principles to differentiate reaches and interpret their process based behaviour (Fryirs & Brierley, 2018).

**The River Styles assessment separated the Kourawhero into 11 distinct styles based on the geomorphic characteristics of the contemporary stream (**

Figure 2). The suite of river diversity has been shaped by the underlying geology, valley confinement and impacts from anthropogenic changes in the catchment. Short, confined, headwaters are located on the steeper topography to the north and south of the catchment. These transition downstream through a

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laterally unconfined valley setting to a partly confined, terrace controlled, incised channel at Kaipara Flats. This is followed by a partly confined bedrock controlled incised channel which extends to the confluence with the Hōteō River. The downstream pattern of River Styles longitudinally indicates expected post incisional responses to channel geometry within fine grained systems (Simon, 1989). Bank failures along downstream reaches reflect exceedance of critical bank height, widening the channel. Upstream reaches are yet to be affected by increases in stream power due to headcut propagation processes.

The tributaries on the southern side of the catchment are a combination of laterally unconfined and partly confined, passively meandering channels. Vast sediment stored and available for reworking in this area. The tributaries are significantly longer on the southern side of the catchment than to the north. The long profiles for the Kourawhero Stream and tributaries on the northern and southern sides of the catchment highlight the difference in tributary length on either side of the catchment as well as showing how far incision has propagated upstream.

### ***Geomorphically Effective Management Solutions***

Auckland Council has developed a method of assessing areas vulnerable to geomorphic work. This approach takes into account geotechnical and hydraulic resistance parameters including critical shear stress of bed and bank material and critical bank height. Analysed in relation to peak flow velocities, these factors determine erosion hot spots for further assessment. The Kourawhero was identified as a hotspot where erosion was generating significant volumes of fine-grained sediment relative to the rest of the Hōteō River catchment. A reach based assessment undertaken by Cardno US (2016) identified processes leading to degradation in the catchment. The Bank Stability and Toe Erosion Model (BSTEM) quantitatively determined the amount of sediment generated by erosion processes and the effectiveness of different management solutions to address issues at a “hotspot” reach level (Simon, Pollen-Bankhead and Thomas, 2011).

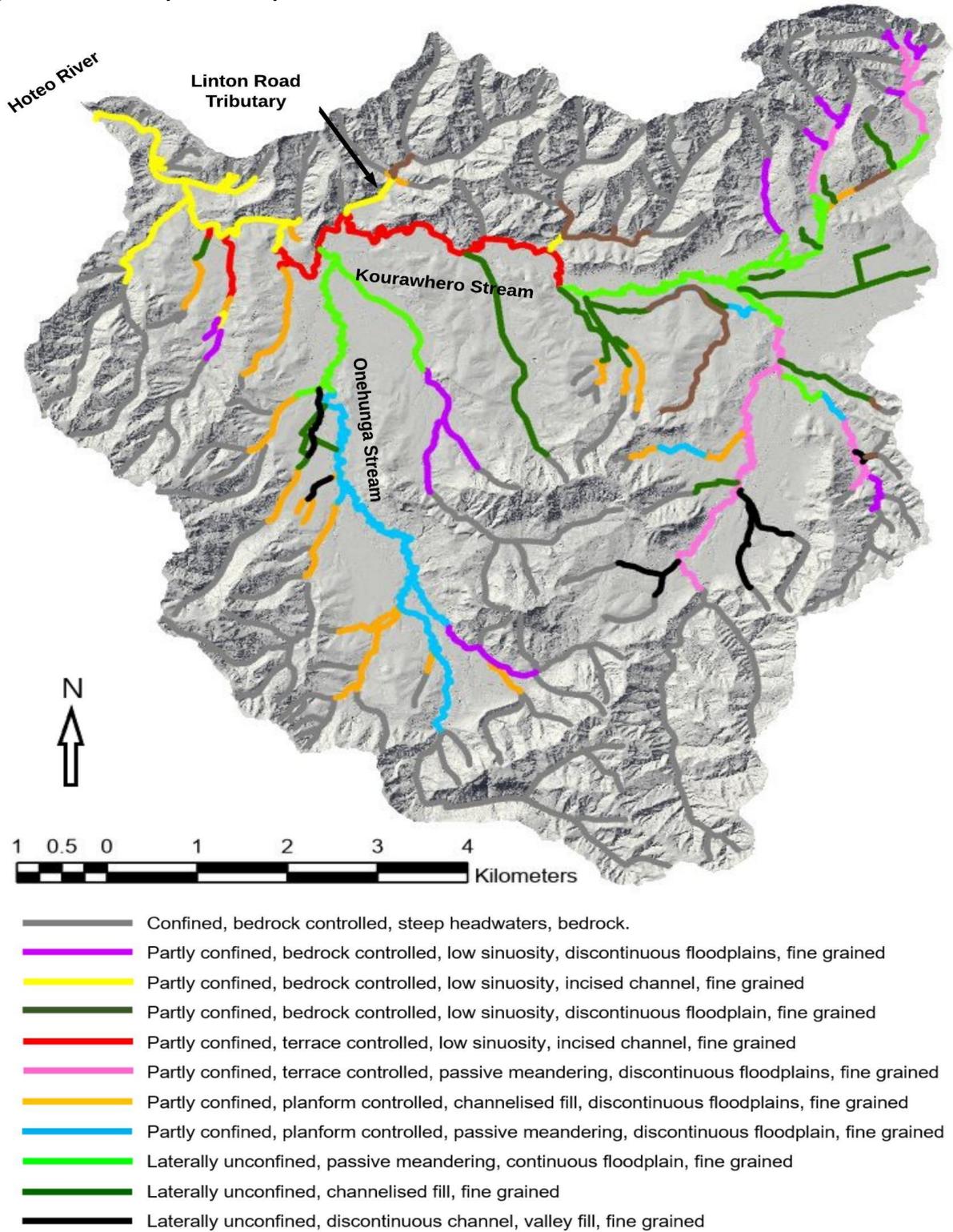
Building on applications of BSTEM assessment, different management solutions were compared. This led to the development of Geomorphically Effective Management Solutions (GEMS) framework that aims to apply a more physical geomorphic approach to stream management. This approach incorporates qualitative and quantitative assessment of natural conveyance channels to better address the driving and resisting forces associated with erosion processes (especially hotspots). Erosion remediation strategies focused on working with iwi and local communities to identify cost effective, environmentally sensitive engineering solutions such as bank battering, flow deflectors, rock rip rap, toe protection, riparian planting and stock exclusion to help reduce sediment loads caused by erosion. Furthermore, grade structures were proposed to stop upstream propagation of a headcut (Cardno, 2016). Due to the GEMS being proposed on private land, a key part of this work has been working with landowners to ensure these mitigations are practical for the day-to-day running of their property.

### ***Watercourse Assessments and Rapid Geomorphic Assessments***

Watercourse Assessment Reports (WAR) provide baseline information on the existing condition of waterways, including both infrastructure and stream state (Lowe, Ingleby and Young, 2016). WARs inform management of waterways for ecological health, stormwater infrastructure, erosion hotspots, stormwater conveyance and land-use planning.

The Rapid Geomorphic Assessment (RGA) provides a standardised approach to determine erosion risk on a reach scale based on a qualitative assessment of stream morphology and condition (Simon and Hupp, 1986; Simon, 1989; Simon and Downs, 1995). Application by Cardno US in the Kourawhero helps to determine areas of higher risk based on existing conditions as well as long term condition monitoring. RGA data can be combined with physical data from the bed and banks of watercourses to estimate annual erosion rates and sediment loads within a catchment (Cardno 2016).

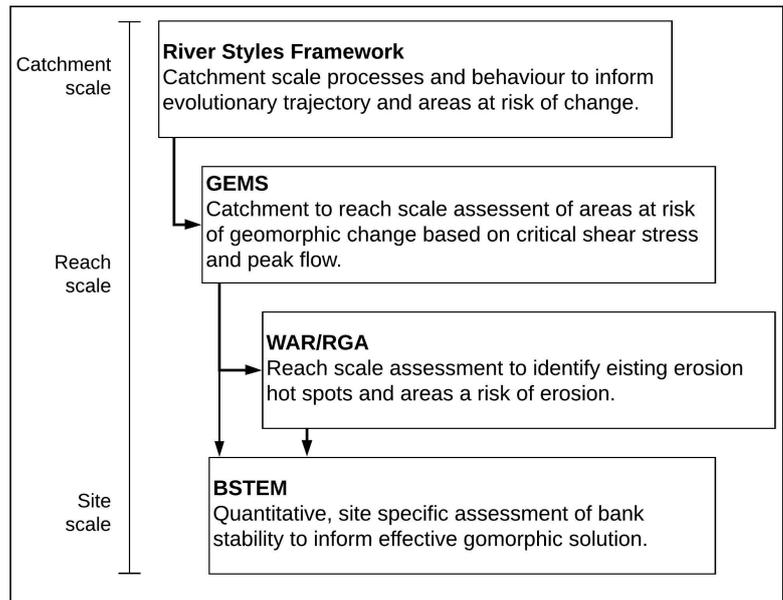
Figure 2: The diversity of River Styles in the Kourawhero Catchment.



### Linking of the Three Systems of Assessment

The River Styles assessment provides for the strategic, big picture understanding of a catchment in its contemporary setting. It assesses the imposed boundary conditions that shape the catchment and the processes and behaviour that are occurring within the river. Through this lens, systematic mapping of patterns of geomorphic processes inform interpretations of the evolutionary trajectory of the river. The River Styles, GEMS and RGA frameworks assessments all identified similar high risk areas, with the River Styles framework providing the catchment scale process understanding, GEMS providing a reach scale qualitative and quantitative assessment of driving

forces of erosion and the RGA providing a qualitative risk and condition assessment. Together, these assessments provide a coherent platform for targeted remediation strategies that apply appropriately contextualized process based solutions (Figure 3).



**Figure 3: The river management strategy to provide geomorphic insight of a river system from the catchment down to a site specific scale and inform geomorphically informed management solutions.**

### Implications for Management

The Kourawhero stream sits within a fine grained cut-and-fill landscape that is currently going through a period of incision and reworking of the sediment stored within the valley floor. Cut-and-fill river systems are not common in New Zealand and it is therefore important to understand the mechanisms driving change to ensure remediation measures are successful. The River Styles assessment identified considerable diversity within the catchment related to incision propagating upstream and resulting in a catchment at different stages of channel evolution. It also identified areas of significant sediment storage and tributary-trunk relationships which has been used to inform where proactive management can be undertaken to address future change.

It is easy to direct river management to areas which are currently showing sediment generation through bank erosion. However, the pattern of River Styles identifies what processes are driving change in the catchment, what we should expect to see and the areas that are most at risk of adverse change. It allows for a systematic region-wide appraisal of geomorphic character, behaviour and evolution of river catchments and supports the transfer of understanding from one reach/catchment to another (Fryirs et al., 2021). New and emerging technologies can assist with remote assessment of catchments, reducing time on the ground and focusing in on areas that should be targeted for more systematic assessment (Fryirs et al., 2019).

Process based insights from a River Styles assessment are fundamental in providing a deeper understanding of the mechanics at work within the catchment, including hydraulics and flood history, and connecting this with the variability of behavioral regimes and evolutionary trajectories. This then links with the GEMS framework which provides information on stream power and anthropogenic changes to hydrology that inform areas susceptible to geomorphic work. These areas can then be targeted proactively. Currently, a lack of catchment-wide case studies of geomorphic responses to human disturbance in Aotearoa New Zealand limits our capacity to support broader-based (regional scale) comparative analyses.

Advances in geospatial data collection and analysis allow these approaches to be applied at much larger whole of catchment and regional scales to identify areas most at risk of erosion processes and sediment

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generation. This capacity will be of critical importance for addressing future water quality management requirements associated with the new national policies under development in New Zealand including the National Policy for Freshwater Management (MfE, 2020), the Natural and Built Environments Act (replacing the current Resource Management Act) and will help to uphold the overarching principles of Te Mana o te Wai Essential Freshwater (MfE, 2019).

It is increasingly recognized that principles of river science that integrate concerns for water quality, ecology, hydrology, aquatic geochemistry and geomorphology aligns with Mātauranga Māori principles (Hikuroa, 2017). Changes to the geomorphic character and behaviour of rivers influence habitat type and availability, water quality and their combined effects on biotic and chemical interactions, along with cultural, social and amenity values of freshwater and coastal habitats. Geomorphology can therefore be used to address concerns for the key drivers of process relationships in a given system, informing management initiatives that maintain and enhance ecosystems based on the characteristics of that system. Links between geomorphic insights and hydrology, ecology and water quality studies and community/iwi expectations can inform future scenario setting, striving to ensure that river management strategies work with geomorphic processes to ensure beneficial outcomes for all.

The community often play a fundamental role in restoration programmes, through both participation and governance. They often have the best intentions but may unwittingly undertake strategies that do not lead to advantageous outcomes. Sharing of best available understandings is a fundamental premise of co-management. Communicating the science of river management to the community is important so that they are brought along on the journey and are actively engaged with the river that they are protecting. In turn, local knowledge provides fundamental insight into the history of the river, the changes that have been observed and insights into how the river operates during high flows.

Partnerships with local iwi are fundamental components of river restoration in Aotearoa. Geomorphology and Mātauranga Māori have been highlighted as the clearest example of alignment in the Te Ao Māori and Western Science paradigms (e.g. Brierley et al., 2019). Hence, engaging and partnering with the local iwi allows for a more holistic approach to be applied to river restoration. This support kaitiakitanga (guardianship) of the waterway by the historic owners of the area. In turn, this enhances collective capacity to develop a deeper understanding of the river system to inform restoration mitigations. This partnership has been displayed in the Kourawhero, with Auckland Council and the local iwi showing the mutual benefits and meaningful outcomes.

## **Conclusions**

The Kourawhero Catchment has the potential to continue to generate vast amounts of sediment to Kaipara Harbour through incision and subsequent channel widening. Successful management is vital to protect this sensitive receiving environment from detrimental sedimentation. By using a suite of geomorphic assessment methodologies that provide both catchment and reach scale understanding, Auckland Council has been able to develop a geomorphically informed management programme that works with the unique nature of the Kourawhero and respects river diversity.

The River Styles Framework provides an understanding of the catchment scale dynamics driving the processes and behaviour of the Kourawhero stream and the baseline information that other river systems can be compared against. It also highlights the high risk areas that should be targeted for further assessment and the development of process based solutions which work with the river for Geomorphically Effective Management Solutions. Reach based condition assessments also provide for detailed capture of stream data and for on-going monitoring programmes. Each tool is valuable when used individually, but when used together, they provide a cross scalar understanding of process relationships at the catchment scale. The application of a coherent scientific lens and the incorporation of the relationships to Mātauranga Māori creates a basis for informed remediation methods that respect the individuality of a river.

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