The Cultural and Ecological Health of the Tokaanu Stream

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Abstract

Freshwater ecosystems worldwide face increasing threats from human activities like land development and altered flow regimes. These pressures, along with climate change, jeopardize water quality and quantity. Despite these challenges, effective management can improve water quality and habitat, thus sustaining biodiversity and ecosystem services.

Lake Taupō, Aotearoa New Zealand's largest freshwater lake, holds immense significance for the local iwi, Ngāti Tūwharetoa. The Tokaanu Stream is a tributary of Lake Taupō that was once considered a premier fly-fishing spot. However, the stream has been severely impacted by the Tongariro Power Scheme, which required it to be bisected and channelized to accommodate the Tokaanu tailrace. Coupled with land-use changes in the catchment, these alterations have caused the local hapū, Ngāti Kurauia, who have mana whenua over the lower stream, to raise concerns about its ecological and cultural degradation. To address this problem, I developed a cultural monitoring framework (CMF) in collaboration with Ngāti Kurauia, alongside conventional stream monitoring, at six sites in the lower Tokaanu Stream.

The bespoke CMF was developed through kōrero and wānanga (discussions and workshops) with Ngāti Kurauia. This participatory approach resulted in a CMF with 16 attributes covering vegetation, birdlife, water quality, pollution, engineering, and substrate. Regular assessments revealed a longitudinal decline in stream condition from the most upstream site (Site 1) to the most downstream (Site 6). The state of Site 3 was identified as the most desirable, whilst Site 5 was the most degraded.

Alongside the CMF, I assessed stream health using conventional scientific measures. This monitoring also showed a longitudinal decline in stream ecosystem health moving

downstream. Water quality worsened, with indicator bacteria increasing from 45 to 190 CFU/100 ml and total ammoniacal nitrogen from 0.029 to 0.125 g/m^3 over the 4 km segment. Deposited fine sediment cover was high, increasing from 69% cover at Site 1 to 83% at Site 6. Cellulose degradation rates (a functional indicator) were diminished at Sites 5 and 6 in both years, even with warming from geothermal springs. Macroinvertebrate communities, monitored in 2023 and 2024, initially showed a linear decline moving downstream in 2023. However, in-stream remediation in early 2024, undertaken by a private contractor, significantly improved macroinvertebrate indicators at impacted sites (Sites 4-6).

The challenges facing the Tokaanu Stream are complex, stemming from geothermal inputs, urbanisation, upstream agriculture, and channelization. Declining water quality may be linked to faulty sewage infrastructure in Tokaanu Village. The stream's diversion includes a tailrace spillway that prevents larger downstream flows, potentially reducing scouring events crucial for natural sediment dynamics. These changes have significant ecological and cultural ramifications for Ngāti Kurauia.

To better understand and address these issues, I argue for an additional downstream State of the Environment (SOE) monitoring site. The current site, near the upstream spring, fails to capture the full impact of catchment inputs, including diffuse pollution from Tokaanu Village and altered sediment dynamics from the diversion. An additional SOE site, coupled with the findings of my thesis, would provide crucial knowledge to support efforts in restoring the Tokaanu Stream's ecological health and the mana of Ngāti Kurauia.

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Nāu te rourou, nāku te rourou, ka ora ai te iwi

With my basket, and your basket, the people will thrive

Personal Statement

Since Aotearoa was inhabited by voyaging Māori communities between 1250 and 1300 AD (Smith, 2008), New Zealand has witnessed a multitude of migrations.

Māori were eventually colonised by European nations who aside from exploiting Aotearoa for her rich and valuable resources, also sought to 'convert and save the unwashed masses' for institutions such as the Church of England and the Crown as it was and remains today. This is something that my whānau understands more than many as my own great-great-great-grandfather Julius Eastwood, an indigenous Jamaican Reverend who travelled to Aotearoa to 'save' the inhabitants of our nation shortly after Te Tiriti o Waitangi, Aotearoa New Zealand's founding document was signed.

Settling in Whakaoriori (Masterton) his whānau later struck out to the west coast of the North Island and travelled up-river to Ōhura on a paddle steamer where they lived for approximately another 100 years before moving to the Waikato. It was in Ōhura during what would become a relatively sordid period of history that the whakapapa becomes somewhat blurry. Arguments remain about where my Māori whakapapa enters the line. However, my belated mother strenuously asserted before passing away that we have Māori whakapapa.

Moving forward to the birth of my own tamariki. I have married a beautiful wāhine who has whakapapa to Ngāti Tūwharetoa and Ngāti Maniapoto among others. Our tamariki and mokopuna are proud and staunchly assert that they are descendants of these iwi. While this is fabulous, it saddens me that, like the other 15 percent of the Māori population (Lloyd Carpenter, pers communication, 2024), I am not able to add to the richness of Māori whakapapa with any confirmed lineage.

Having a blended culture adds a richness and complexity to any mahi we undertake, especially in terms of our Jamaican and European heritage. While many see this blended whakapapa as a strength many others do not agree. Too far removed from either Europe or Jamaica, as well as an absence of confirmed Māori whakapapa has left me feeling like an imposter in Māoridom. I am continually accused of being a 'plastic-Māori', disconnected from Europe, and my skin-tone has been too watered down to be obvious as Jamaican at a glance.

As a relatively late bloomer in formal education settings, I went to university when I was 30. After attaining a couple of 'pieces of paper', I went on to work as a project manager, ecologist, and advisor for the next 15 years until an opportunity to finish my Master of Science (Research) presented itself and we felt heavy the hand of our tūpuna guiding us.

Like Sara Belcher in her 2021 thesis, I carry my blended culture with me, and I see this study as an opportunity to grow within myself and my culture (Belcher, 2021), while also being able to work with Ngāti Kurauia, a hapū of Ngāti Tūwharetoa, whom I admire and respect. I want to change the stereotype and preconceived negative imagery of both scientists and Māori alike. Scientists are no longer just white, middle aged (or older) men with coke-bottle glasses, pocket protectors, sandals, and walking socks. On the flip side of the coin, Māori are not uneducated, unemployed, untrustworthy, vagrants which our society need to tolerate, when in fact the opposite is true. Māori are tangata whenua maintaining mana whenua who allowed the 'other' to come to Aotearoa New Zealand and settle in relative peace, tranquillity, and prosperity (Smith, 2008). Both examples, while extreme stereotypes, are examples I have encountered many times over the years and find myself accustomed to defending and addressing as it serves no one to perpetuate such candidly racist perspectives.

My desire is to blend both perspectives together. In doing so, I want to prove to all and sundry that scientific advancement is attainable for anyone who strives to excel, regardless of ethnicity.

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Glossary

Term	Description
Andesitic	A volcanic rock type that has intermediate levels of silica in its composition
Aotearoa	Māori name for New Zealand
ASPM	Average Score Per Metric
Awa	Flowing body of water. Can be a creek, stream, river, etc.
BCE	Before Current Era
CHI	Cultural Health Index
DMS	Degrees, Minutes, Seconds
DNA	Deoxyribose Nucleic Acid
E. coli	*Escherichia coli*, a bacterium typically found in the intestines of animals including humans
eDNA	Environmental DNA
Ephemeral	Fleeting or short lived
Haerenga	Journey, trip
Haka	Posture dance/performance
Hapū	Subtribe
Harakeke	Flax
Hegemonic	The dominance of a group, or idea, over another
Hīkoi	Trip as in journey
Hui	Congregation, gathering, meeting
Hui taurima	Annual hui
Hypothesis	A statement that attempts to explain a phenomenon
Ika	Fish
Io	Supreme being
Iwi	Tribe
Kai	Food, sustenance
Kainga	Settlement
Kaitiakitanga	Stewardship
Kaumātua	Elder. Person of respect within the community
Kererū	New Zealand Pigeon / Wood Pigeon

Kete	Woven basket traditionally made of flax. Typically referred to in pūrākau as holding knowledge
Kīngitanga	Māori King movement origination in the 1850s
Koroneihana	Celebration of Māori kīngitanga movements coronation
Koura	New Zealand freshwater crayfish
Kōwhaiwhai	Māori motifs that tell a story
Lake Taupō	A popular tourist spot situated at the centre of the North Island of New Zealand
Lotic System	Stream system containing flowing water
Magellan Clouds	Dwarf galaxies
Māhinga kai	Food gathering place
Māori	Indigenous person of Aotearoa
Māoridom	Customs, beliefs, and practices of the Māori people
Mātauranga	Knowledge
Mātauranga Māori	Māori knowledge that can be contemporary or taonga tuku iho
Mahi rangahau	Research
Manākitanga	Hospitality, generosity, or support
Mana Motuhake	Autonomy, self-determination or self-government and authority
Mana Whakahaere	See Mana Motuhake
Mana Whenua	Authority over land associated with the possession and occupation of tribal land
Māuiui	Sick, unwell, fatigued
Mauri	Life force or essence
MCI	Macroinvertebrate Community Index
Mokopuna	Grandchild/Grandchildren
Ngāti Kurauia	Hapū of Ngāti Tūwharetoa
Ngāti Maniapoto	Tribal group of the King Country area
Ngāti Tūwharetoa	Tribal group of the Lake Taupō area
NPS FM	National Policy Statement Freshwater Management
Ōhura	Village to the west of Lake Taupō
Pākeha	A person who has the appearance (fair skin) of European descent
Palisade	A wall made of stakes
Paru	Rubbish, Pollution

Progeny	Offspring
Puia	Hot pool(s)
Puku	Stomach
Pūrākau	Story passed down through the generations
QMCI	Quantitative Macroinvertebrate Community Index
Rārahu	Bracken fern
Rāranga	To weave
Raupō	Bullrush
Rohe	Home territory of an iwi or hapū
Rongoā Māori	Traditional healing
Rotopounamu	A lake of the southern slopes of Mount Pihanga
Rūnanga	Māori tribal council or Iwi authority
Tamariki	Child/children - Mainly used as a plural
Taniwha	A supernatural being that can be linked to either good or bad happenings
Tangata Whenua	Local people of the tribe belonging to the area
Taonga	Treasure
Taonga Tuku Iho	Heirloom, something passed down through the generations. Can be a physical object or knowledge
Tau kōura	Bracken fern bundle(s) traditionally used by Māori to capture kōura for customary purposes
Te ika a Maui	North Island of New Zealand
Te Kore	The void
Te Pō	The perpetual night
Te Tiriti o Waitangi	Aotearoa/New Zealand founding document. AKA The Treaty of Waitangi
Te Waipounamu	South Island of New Zealand
Tī kōuka	Cabbage tree
Tītī	Mutton bird / Shearwater
Tino Rangatiratanga	Self-determination
Tokaanu	Village at the southern end of Lake Taupō
Tuahu	Sacred place where rituals were/are performed
Tūpuna/Tupuna/Tipuna	Ancestors
Urupā	Cemetery
Wāhine/Wahine	Woman
Wai Māori	Freshwater

Waiata	Song(s)
Wairua	Spirit, spiritual connection
Waitangi Tribunal	A commission of inquiry who assesses breaches of Te Tiriti o Waitangi
Wānanga	Conference, forum, educational seminar
Whaikōrero	Oration or formal speech
Whakairo	Traditional carving in wood, stone, or bone
Whānau	Family group. Can be nuclear or extended family
Whakaoriori	Masterton, a town on the east coast of New Zealand's north island
Whakapapa	Genealogy which is central to all Māori institutions
Whakatauaki	Proverb highlighting the intrinsic intelligence of the Māori culture
Whenua	Land

1 Introduction

1.1 Global threats to freshwaters

Globally, freshwater resources are facing threats that impact their quantity and quality. According to the United Nations, more than 98% of the worlds freshwater reserves are being drawn upon for agriculture, municipal and industrial use (Food and Agriculture Organisation of the United Nations, 2021). Consequently, the freshwater remaining is often insufficient for the environment, and in particular the organisms living in running waters which rely on natural flow regimes for survival (Hara, 2006; Poff *et al.*, 1997). The exploitation of water resources is complicated further as the water returning to aquatic ecosystems is often degraded through pollution by fine sediment, nutrients, chemicals, and more recently, microplastics (Burdon *et al.*, 2020; de Guzman *et al.*, 2022). These contaminants vary in their effects but often have the common feature that once present, they will continue to accumulate throughout catchments with adverse impacts on biota (Orr *et al.*, 2024; Raju *et al.*, 2023). The origins of these anthropogenic pollutants can be numerous, though common sources include urban stormwater flows and runoff from agricultural land uses.

The natural flow regime of streams and rivers includes periods of low ebbs and high flows, which are characterised by events such as droughts and floods (Poff *et al.*, 1997). A natural flow regime is not only essential for providing habitat for fluvial biota, but it also transports sediment from areas of high energy to areas of low energy (Wohl *et al.*, 2015), leading to the related ‘natural sediment regime’ concept. Natural flow and sediment regimes drive complexity within lotic environments and provides the spatio-temporal habitat structure for the communities inhabiting streams and rivers (Poff & Ward, 1989). More than ever, the natural flow regimes of the world's waterways are being placed at risk due to anthropogenic activities such as increased channelisation, dam building, or modification for other uses (Awatere *et al.*, 2021; Poff *et al.*, 1997). While pressures may be inevitable as the demands for freshwater resources grow, there is a strong need to understand how aquatic ecosystems and the species that inhabit them are responding, with the goal of finding better ways to conserve them. Sensitive species may be the most vulnerable as stream and river habitats are homogenised, leading to less biodiverse assemblages dominated by generalist species (Hicks & Jowett, 1992; Lytle & Poff, 2004; Poff & Ward, 1989)

1.2 Human societies and rivers

Rivers and streams provide a wide range of ecosystem services that support human wellbeing. Rivers offer desirable functions that enable provisioning, regulating, supporting and cultural services. These services bring people together for a variety of reasons spanning from resource provision (freshwater, food), to regulating (nutrient removal, drainage) and recreational services (Bataille *et al.*, 2021; Collins *et al.*, 2020; Hein *et al.*, 2019; Ministry for the Environment & Stats NZ, 2020). Human activities and land use practices at the landscape scale disrupt the natural geomorphic processes that sustain riverscapes and their associated biological communities, often leading to degraded stream habitats (Allan, 2004). While there is a direct relationship between contemporary rainfall and river flows, groundwater inputs operating on different timescales also add significant amounts of freshwater (Xie *et al.*, 2024). Nutrients and other contaminants applied to the landscape historically can often take decades to reach receiving surface waters due to lags in groundwater inputs (Ministry for the Environment & Stats NZ, 2019, 2020; Vero *et al.*, 2018). As such, the continued decline in ecosystem health and subsequent sensitive species can be the result (Hara, 2006; Ministry for the Environment & Stats NZ, 2020; Vero *et al.*, 2018).

The Danube River

The Danube River is the second largest river in Europe with a catchment area of 807,827 km^2. It flows through 19 countries, thus requiring transboundary water management strategies (Hein *et al.*, 2019). Despite the vast catchment, Hein *et al.* (2019) recognised that there are three key factors which have significant impacts on the river's health. These are the long-term impacts of floods and associated consequences or point and non-points pollution sources, the impact of engineering upon the river, and the different legal frameworks acting over the river and its large geographical scale. Considering that many human societies have harnessed the multitude of ecosystem services offered by the river leading to large population centres on its banks, adverse impacts on river quality and quantity have had severe impacts on the populous as well as the environment.

Ecosystems are rarely impacted by a single environmental stressor. Instead, multiple stressors usually occur together, both geographically and over time. These combined effects are often complex and difficult to predict (Townsend *et al.*, 2008). This is known as the multiple stressor paradigm in ecology. Multiple stressors affecting ecosystems are often detrimental and may lead to tipping points being reached (Ataria *et al.*, 2018). The threats posed by multiple stressors mean that it is imperative to have robust management policies, plans and practices in place that are both rigorous and achievable (Hein *et al.*, 2019). It is also important to take a whole catchment perspective. In the case of the Danube River, there is a whole basin management plan (International Commision for the Protection of the Danube River, 2024). However, there are many catchments which do not have such plans that are also suffering from biodiversity declines and ecosystem degradation (Bataille *et al.*, 2021; Ruru *et al.*, 2017). An absence of coordinated management strategies at the catchment scale is a major problem for river ecosystems internationally and in Aotearoa New Zealand.

The Waikato River

The Waikato River is Aotearoa New Zealand's longest river holding immense cultural value for Māori as a tupuna (ancestor) and a taonga (treasure) imbued with mauri (life force), historically providing sustenance and a vital transport network. In the modern age, the river is crucial for hydroelectric power, municipal drinking water, and tourism. Despite its importance, the river faces significant environmental challenges from pollution and habitat degradation, leading to ongoing large-scale restoration efforts.

The outflow from Lake Taupō is the main source of the Waikato River, carrying high quality fresh water away from the northern mouth of the lake, at the Taupō township (Stewart, 2018). Lake Taupō is Aotearoa New Zealand's largest lake with a catchment of 2,800 km^2 (Vant, 2013). A major part of the catchment has been modified for hydroelectrical power generation. Due to the Tokaanu power scheme, water is diverted from across the North Island's central plateau (Chapman, 1996), used to generate energy for the national electrical grid, and stored in Lake Taupō before flowing down the Waikato River (and additional hydroelectrical dams) before eventually reaching the Tasman Sea at Port Waikato.

To quote David 'Topia' Rameka, former CEO of the Tūwharetoa Māori Trust Board, Lake Taupō "is the source of freshwater for a third of the countries freshwater needs and it is [Tūwharetoa's] responsibility to ensure it remains healthy for everyone to use" (Topia Rameka, pers. comm., 2018). Whilst the exact number may be debatable, it is clearly apparent that the Waikato River is a river of national importance, given its prominent role in provisioning services that include hydroelectrical power generation and municipal drinking water for centres such as Kirikiriroa Hamilton. In addition to Hamilton, Tāmaki Makaurau Auckland, New Zealand's largest city, draws water from the Waikato River to meet the city's water requirements (Morgan & Te Aho, 2013).

Although the Waikato River is smaller than the Danube, it shares many of the same management concerns. This includes flood management during sustained periods of rain, point and non-point source pollution (>1,600 identified point source inputs), the impacts of engineering for New Zealand's growing energy demand (Chapman, 1996; Hicks & Jowett, 1992; Pingram *et al.*, 2021), and nutrient and sediment enrichment through land use change (Morgan & Te Aho, 2013). In addition, while the Waikato River only flows within the bounds of one country, it does flow through the rohe of four iwi (Ngāti Tūwharetoa, Te Arawa River Iwi, Ngāti Raukawa and Waikato–Tainui) (Waikato River Authority, 2011). This can make engagement for stakeholders, and management of the river itself, complicated at times.

To assist in the management of the Waikato River, *Te Ture Whaimana o Te Awa o Waikato* - Vison and Strategy for the Waikato River (hereafter Te Ture Whaimana) was developed by the Waikato River Authority (WRA). Te Ture Whaimana is a foundational document for the Waikato and Waipā Rivers. It has significant legal standing in New Zealand, particularly regarding resource management and environmental protection in the Waikato region. Te Ture Whaimana is considered the overarching document for the restoration and protection of the Waikato and Waipā Rivers and all activities within their catchments that affect the rivers. It effectively "trumps" other inconsistent provisions in national policy statements or national environmental standards in certain circumstances. Many of the stated goals contained within Te Ture Whaimana are managed by the WRA. The WRA is a legislated entity, and sole trustee to the Waikato River Clean Up Trust, tasked with managing the restoration and protection of the Waikato River. Furthermore, the WRA works to provide integrated and best management through collaboration with iwi, community, and formal partnerships (Harcourt *et al.*, 2022; Waikato River Authority, 2011).

1.3 Catchment management

There is need for information about water quality in catchments throughout many countries. However, any new information can lead to misplaced interpretations without historic data to baseline changes upon. Furthermore, knowing the best indicators to measure temporal changes remain uncertain. For example, in the United Kingdom, Jackson (2024) describes how the number of waterways previously categorised as 'good' have decreased from 24% in 2009 to 15% in 2024. While this may be considered alarming, English stream biodiversity has simultaneously increased, despite the declines in 'good' ecosystem status. Notably, this includes the sensitive EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa consisting of mayflies, stoneflies, and caddisflies, generally recognised as the most sensitive of macroinvertebrates, which appeared to have increased by 300%. Whilst the increased use of municipal wastewater treatment has improved river ecosystem health in England (Vaughan & Ormerod, 2012), there remain widespread challenges leading to static or declining ecological status (Vaughan & Gotelli, 2019). The nationwide catchment-based approach to water management in England introduced by the Department for Environment, Food, and Rural Affairs in 2013 has helped decision-makers (Collins *et al.*, 2020), further highlighting how monitoring should consider the entire watershed.

Freshwater is unevenly distributed globally and many areas of the world experience scarcity of this essential resource. Even where freshwater is relatively abundant, such as in Aotearoa

New Zealand, anthropogenic pressures threaten the ecosystem service provided by this finite resource (Burritt & Christ, 2017; Jackson, 2024; Smith *et al.*, 2015). The threats to freshwater may be more acute in drier climates, and the United Nations Department of Economic and Social Affairs asserted that in 2020 there were 2.4 billion people who living in water-stressed countries (UN DESASD, 2024). Managing the threats to freshwater resources can benefit from the involvement of community groups and 'citizen scientists' combined with catchment-based holistic approaches to biomonitoring (Peters *et al.*, 2015; Sinner *et al.*, 2016). Catchment management groups are increasingly involved in management activities traditionally undertaken by regional and central government agencies (Cradock-Henry *et al.*, 2017; Sinner *et al.*, 2016). This increased agency empowers each community group to make decisions based on monitoring at different scales, including at the whole of catchment level. This involvement of stakeholders with strong linkages to the ecosystems of interest encourage decision-making and management actions that are 'bottom-up' (Collins *et al.*, 2020).

1.4 Managing rivers in Aotearoa New Zealand

Aotearoa New Zealand is a mountainous island nation in the South Pacific. It sits upon a tectonic plate boundary that arises from the collision of the Pacific plate and the Australian plate (Wallace *et al.*, 2012). The bottom part of Te Waipounamu (South Island) sees the Australian plate subducted under the Pacific plate, while the upper half of the Te Ika-a-Maui (North Island) has the reverse, with both tectonic processes creating vast mountain ranges. The areas in between are located on top of a strike-slip fault (Wallace *et al.*, 2012). Aside from numerous earthquakes per annum, the mountainous terrain resulting from plate tectonics forces water vapor from the surrounding oceans to rapidly gain elevation and cool, thus leading to ample precipitation across large parts of the country (Krishna *et al.*, 2024). Rain shadows occur in some regions because of the mountainous terrain and general westerly direction of weather systems (Hamilton *et al.*, 2013; Krishna *et al.*, 2024). In Aotearoa, this phenomenon is best observed along western parts of both islands, with noticeably lower rainfall in eastern regions.

Whilst rainfall is abundant in Aotearoa New Zealand, the topography can drive differences in precipitation that can couple with land-use pressures, particularly in the summer months. These differences are recognised in the River Environment Classification (REC) database of catchment spatial attributes, summarised for every segment in Aotearoa's network of rivers (Snelder and Biggs 2002). The REC database is important for freshwater management, as is the Te Mana o Te Wai principle. Freshwater resources have a level of protection that recognises the fundamental live-sustaining properties of these ecosystems, espoused in the Te Mana o Te Wai principle that is a key tenet of the National Policy Statement for Freshwater Management (NPS-FM; New Zealand Government 2020). This means that freshwater values not only consider its uses for industry, agriculture, municipal, or recreational and cultural applications (New Zealand Government, 2020). Whilst the abundant rainfall and sizeable water yields in Aotearoa may lead some to consider freshwater management issues less pressing, there are considerable impacts on freshwater quality and quantity that require active management. In many catchments, there are noticeable declines in water quality and ecosystem health moving from upland to lowland sites (Larned *et al.*, 2016). Often the deterioration of freshwater resources begins as soon as it contacts the whenua (land), leading to significant concerns for mana whenua as the mauri of streams, rivers and their receiving environments are impacted (Harmsworth *et al.*, 2016).

Many freshwater ecosystems in Aotearoa have been negatively impacted by anthropogenic pressures such as pastoral agriculture (Ruru *et al.*, 2017). The degradation of freshwater ecosystems have contributed to impacts on endemic lotic species (Ministry for the Environment & Stats NZ, 2020), and approximately 68% of our freshwater fish are listed as threatened (Joy & Death, 2013). Barriers remain for active participation by tangata whenua in freshwater management. Whilst Ruru *et al.* (2017) suggests that Crown policies interfere with tangata whenua being able to engage with Te Taiao (the environment) they also argue that conservation reforms encourage Māori to get actively involved in conservation. There are key policies in Aotearoa (e.g., the Te Mana o Te Wai principle in the NPS-FM 2020) formulated in recent years that protect freshwater resources and the wider environment whilst also recognising Te Ao Māori. Moreover, these policies have placed importance on working alongside tangata whenua to increase iwi and community involvement in decision making and management (Kusabs *et al.*, 2018). Further examples of such policies include *Te Ture Whaimana o Te Awa o Waikato* as a vision and strategy document for managing the Waikato River and its catchment, and the recognition of the Whanganui River as a legal entity (*Te Awa Tupua* – the river which is an ancestral being) with associated rights (Hikuroa *et al.*, 2021).

The importance of the Te Mana o te Wai principle in the NPS-FM 2020 represented a shift to a bicultural understanding of our freshwater resources and their essential role in ecosystems. By protecting and rehabilitating streams and rivers, multiple positive benefits are met including the restoration of mauri, the wider environment, and communities at large (Ministry for the Environment & Stats NZ, 2020; New Zealand Government, 2020).

The Te Mana o te Wai framework was designed to help protect the environment via a hierarchy of needs alongside six overarching principles which are unique for Aotearoa. This was because the well-being of water, and the ecosystems contained within it, were prioritised over other aspects including drinking water and other uses (New Zealand Government, 2020), Although the new government has reformed and weakened this tenet, it retains its mana through recognition in regional plans (MfE, 2024). Whilst the hierarchy of obligations to freshwater posed challenges for planners, practitioners, and businesses (Larned *et al.*, 2022) other researchers including Harmsworth *et al.* (2016) lauded the new approach and see it as an opportunity to further incorporate Mātauranga Māori into decision making.

Though not explicitly Mātauranga Māori practices, the six overarching principles take cues from Te Ao Māori with their relation to tangata whenua: Mana Whakahaere, Kaitiakitanga, Manākitanga, Governance, Stewardship and Care and Respect (New Zealand Government, 2020). While these principles have been set in place to impower Māori communities it remains unclear why these specific principles have been used since Mana Whakahaere, Kaitiakitanga, and Manākitanga are, depending on the source, loosely translated to be the same as governance, stewardships, and care and respect, only in different languages. This duplication of meaning may have been intentional, so that nothing was lost in translation.

The first iteration of the National Policy Statement for Freshwater Management (NPS-FM) was introduced in 2011 (Larned *et al.*, 2022). Subsequent amendments to the original publication have most recently produced the NPS-FM 2020 (Larned *et al.*, 2022; New Zealand Government, 2020). Harmsworth *et al.* (2016) discusses that while there were once 13 attributes to monitor in freshwaters, there are now 21 water quality and ecological attributes that require quantification (Larned *et al.*, 2022; New Zealand Government, 2020).

The attributes in the NPS-FM are designed to target key indicators of anthropogenic stress. These include deposited fine sediment, which is a pervasive stressor of stream and rivers associated with upstream human land uses. Fine sediment negatively impacts stream communities when it settles on the streambed by filling in the interstitial voids that fish and macroinvertebrates use for refuge, degrading food resources, and increasing environmental stresses through saltating particles and increased turbidity (Burdon *et al.*, 2013; Ministry for the Environment & Stats NZ, 2020). Impacts of fine sediment due to erosion may be less pronounced in the early stages of catchment development. However, Burdon *et al.* (2013) and Clapcott *et al.* (2011) both discuss that potential for sediment tipping points where adverse impacts disproportionately increase as sediment cover in naturally gravel-bottomed streams exceeds 20%. The NPS-FM recognises this threshold whilst accounting for different stream types underpinned by the River Environment Classification schema. As such, this example highlights how the NPS-FM 2020 uses up-to-date scientific information to help preserve the health of the environment (Larned *et al.*, 2022; New Zealand Government, 2020).

Freshwater biodiversity

Aotearoa's endemic freshwater species are increasingly under pressure from multiple threats. Since 68% our native freshwater fish species are listed as threatened, these provide a prime example of species at risk of extinction (Awatere *et al.*, 2021). These declines are despite the central importance of these taonga species to tangata whenua. For example, Bataille *et al.* (2021) discusses that the use of māhinga kai (traditional value of food resources and their ecosystems) is a key aspect to the maintenance of Mātauranga Māori and cultural practices. However, the loss of Mātauranga may have contributed to the decline in kōura (freshwater crayfish) populations since the arrival of Europeans (Kusabs, 2015).

In Aotearoa, kōura are considered a taonga species (Kusabs *et al.*, 2018; Kusabs, 2015) in decline (Clearwater *et al.*, 2014). Kōura rely on healthy ecosystems to thrive. Pollution leading to eutrophication and anoxia are major challenges to kōura populations, particularly in lakes. They also require habitat heterogeneity and complexity. When shedding their exoskeleton during moults they require shaded areas and a cobbly substrate to avoid predation (Kusabs, 2015). Macrophyte beds and inputs of large wood may provide kōura protection from predators and a nursery for juveniles (Kusabs *et al.*, 2018). Evidence to support this assumption can be found in several of Dr Ian Kusab's mahi rangahau (research) where the incorporation of a traditional collection method used by Te Arawa and Ngāti Tūwharetoa can improve our understanding of kōura demographics. The 'tau kōura' (bracken fern bundles) method has been successfully used in monitoring kōura populations instead of standardised electrofishing or trapping methods because it helps prevent undue stress and statistical biases (Kusabs *et al.*, 2018; Kusabs, 2015; Kusabs & Quinn, 2009).

Other examples of taonga species in decline include all *Galaxias* spp. which make up the lightly regulated 'whitebait' fishery. Goodman (2018) lists the five traditional galaxiid species that constitute the whitebait fishery: *Galaxias maculatus* (īnanga), *G. brevipinnis* (kōaro), *G. faciatus* (banded kōkopu), *G. argenteus* (giant kōkopu) and *G. postvectis* (shortjaw kōkopu). Goodman (2018) describes how the populations of all whitebait species, excluding banded kōkopu, have been in decline for decades, though most notably since 2009.

In light of a notable decline in many taonga species (Clearwater *et al.*, 2014; Ministry for the Environment & Stats NZ, 2019; Ruru *et al.*, 2017), as well as the direction set in place by Te Mana o te Wai through the NPS-FM 2020, many communities are actively insisting on increased involvement in research, education, and other workstreams. Furthermore, funding agencies actively require effective partnerships with Māori communities (Ministry for Research & Technology, 2005) so that they can become increasingly involved in opportunities where they hold mana whenua (Kusabs, 2015), therefore activating kaitiakitanga. The challenge however is that, while cross-collaborations are becoming increasingly prominent, Māori communities find there is a lack of genuine engagement between them and outsiders who want to undertake mahi within their rohe. While this may be a perception, this misalignment could benefit from more attention (Ataria *et al.*, 2018).

Aotearoa's endemic flora and fauna are vital to the wider identity of the country (Ministry for the Environment & Stats NZ, 2019) and successfully conserving them requires 'buy-in' from all stakeholders. These stakeholders include tangata whenua who whakapapa to important freshwater ecosystems and their biota, thus having intimate connections to the environment. As such, multiple frameworks have been developed across Aotearoa and adopted throughout the regions to enable Māori communities to become more involved in monitoring. These frameworks incorporate site-specific Mātauranga Māori and bring agency to local iwi as they track declines in ecosystem health and biodiversity reflected by more conventional scientific indicators (Department of Conservation, 2020).

Cultural frameworks that reflect the values of mana whenua are essential to their participation in conservation and environmental management. One example of these frameworks in Aotearoa is the Cultural Health Index (CHI). The CHI has three focus areas which include the cultural significance of the site being monitored, a māhinga kai measure, and a stream health measure (Harmsworth *et al.*, 2008; Ministry for the Environment & Stats NZ, 2020; Tipa & Teirney, 2006a; Tipa & Tierney, 2003; Townsend *et al.*, 2004). The CHI is significant as it attempts to include values which mana whenua place importance on to measure freshwater ecosystem health (Harmsworth *et al.*, 2008; Ministry for the Environment & Stats NZ, 2019; Townsend *et al.*, 2004). This approach contrasts from more conventional indicators which often underpin values but are more abstract in their direct relevance (e.g., dissolved oxygen concentrations). While the CHI is arguably the most notable Māori-focussed framework, it is important to acknowledge other cultural monitoring frameworks used across Aotearoa (Ataria *et al.*, 2018; Morgan, 2018; Rainforth & Harmsworth, 2019).

Regional management concerns

The Resource Management Act (RMA) 1991 (RMA, 1991) instructs all regional council entities to liaise with the Māori communities within their boundaries (Harmsworth *et al.*, 2016; Luketina & Dickie, 2006). Not only does this meet council obligations to mana whenua, but it also recognises the unique connection that these communities have with wai māori (freshwater) through whakapapa, traditions, and culture (Harmsworth *et al.*, 2016).

This instruction is also supported by the Ministry for the Environment, as every regional council must engage with all communities, not just tangata whenua, to determine how Te Mana o te Wai is applied to wai māori through the implementation of the NPS-FM 2020 within each rohe (Larned *et al.*, 2022; New Zealand Government, 2020). Coupled with the provision of adequate resourcing Harmsworth *et al.* (2016) found that establishing enduring relationships and trust between communities and regional council can lead to greater success in outcomes.

Throughout Aotearoa there are numerous examples of effective partnerships between iwi and regional/local council bodies. However, two specific examples have been observed in recent years in the Waikato region where the Waikato Regional Council (WRC) is working alongside iwi. The first example is the incorporation of Māori in the review of the regional councils Freshwater Policy, while another example is the successful transfer of duties in terms of the RMA 1991.

In 2022, the WRC began a collaborative approach, working with mana whenua from across the region, to review its freshwater policy (Gray, 2023). Multiple publicly held hui with iwi and hapū were undertaken to ascertain the thoughts and feelings of tangata whenua, specifically with the incorporation and use of Mātauranga Māori (MM) within policy development. Although the WRC is required to engage with mana whenua due to the NPS-FM 2020 and RMA 1991, I was able to witness the process as an attendee and found it to be genuine and authentic with over 270 individuals being engaged with and able to provide guidance to the WRC.

Another example of localised iwi engagement involves the Tūwharetoa Māori Trust Board (TMTB) and the WRC. According to Iorns Magallanes (2021), under section 33 of the RMA 1991, any iwi entity may apply to the Minister for the Environment for a transfer of functions from a regional council. If successful, the regional body is not only required to transfer duties but is also required to provide resourcing. On this occasion, the TMTB was successful in their application to take over the monitoring of the freshwater resources in the Lake Taupō catchment. This was the first case where an iwi entity has been successful in a Section 33 application in the 30 years that the RMA 1991 has been in force (Iorns Magallanes, 2021)

Management concerns in the Lake Taupō catchment

Lake Taupō is Aotearoa's largest lake covering an area of 616 km^2 and has an average depth of approximately 100 m (Kusabs, 1989; Stewart, 2018). As an oligotrophic lake, it is well regarded for its excellent water quality and clarity. Furthermore, it is valued for its ecosystem services that include kai, recreation, aesthetics, and cultural connections (Stewart, 2018).

While the various forms of nitrogen (N) and phosphorus (P) are essential for plant growth, excessive growth poses the largest threat to Lake Taupō and the surrounding catchment in the absence of checks and balances. Adding to this threat, climatic conditions make the soil more readily susceptible to erosion, potentially mobilizing more P bound to sediment (Spicer *et al.*, 2021). During the 1990's, concerns were raised about the increasing levels of nutrients, primarily N, entering the lake through land conversion to pastoral agriculture (Vant, 2013). With Lake Taupō being N-limited (Stewart, 2018), the Environment Court confirmed the regional plan variation 5 (RPV5) in 2011 placing a cap on total nitrogen loads entering Lake Taupō (Vant, 2013), implementing the Lake Taupō Nitrogen Trading Programme in 2011 (Spicer *et al.*, 2021). However, the threats posed by increasing nutrient levels, while important, are not the only threats to Lake Taupō, the surrounding catchment, or its many tributaries.

Pollution also often comes from urban areas caused by a variety of human activities. The "Urban Stream Syndrome" describes the consistent ecological degradation observed in streams that drain urbanized areas (Walsh *et al.*, 2005). Untreated urban run-off often includes nutrients, heavy metals, suspended solids, hydrocarbons, and pathogens such as *Escherichia coli* from sewage overflow (Chakravarthy *et al.*, 2019). Other changes include altered flow regimes, decreased habitat diversity, and an increased prevalence of exotic species.

Sewage discharges from untreated wastewater, and the subsequent contamination of groundwater may also carry pharmaceuticals which can bioaccumulate within the food web (Chakravarthy *et al.*, 2019; Pang *et al.*, 2004). Aside from presenting a public health risk, activities such as tourism, recreation, and food collection are often impacted. As such, Pang *et al.* (2004) has identified in many cases an arbitrary set back distances from surface water and groundwater sources have been set. Arbitrary in the sense that, around Lake Taupō, septic tanks can contribute up to 76% of P and 90% of N to local water bodies depending on how much pressure is on the system and how modern the septic system is (Rutherford, 1984).

Impacts from climate change also leads to increased disturbance in New Zealand's freshwaters (Hamilton *et al.*, 2013). Elevated water temperatures and altered nutrient cycles from climate change and geothermal inputs in 'Taupō waters' are tolerated well by invasive species such as the brown bullhead catfish (*Ameiurus nebulosus*) and goldfish (*Carassius auratus*), while less tolerant species diminish in diversity and abundance (Hamilton *et al.*, 2013)

As with other lakes, Lake Taupō faces numerous pressures from human activities. One of these pressures is the introduction of exotic aquatic species. In Lake Taupō this includes brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), common smelt (*Retropinna retropinna*), goldfish (*Carassius auratus*), and catfish (*Ameriurus nebulosus*) among others (Hicks & Jowett, 1992; Kusabs, 2017; Stewart, 2018). While Kusabs (1989) is correct in his assertion that the effects of trout on native fish species are contentious, one cannot deny the impacts that these predators can have on native fish populations (Townsend & Crowl, 1991). The reasons for the demise of the New Zealand grayling (*Prototroctes oxyrhynchus*) remain controversial, but it seems likely that trout introductions contributed to its extinction (Kusabs & Swale, 1991; Ministry for the Environment & Stats NZ, 2020; NIWA., 2024).

Lake levels have also been raised in recent decades due to the introduction and implementation of hydro-electric dams along the Waikato River and the Tongariro power scheme (Hochstein & Prebble, 2006). This had resulted in multiple concerns by hapū residing alongside Lake Taupō with worries primarily focussed on sedimentation, erosion, and invasive species replacing desired species (Gray, 2023). Water is collected from a 2,600 km^2 area around the Central Plateau region, including the headwaters of the Whanganui River (Genesis

Energy, N.D.; Waitangi Tribunal, 1995), and diverted through a series of canals and tunnels where is it stored in a series of hydro lakes before passing through the Tokaanu power station, generating ~361.8MW of electricity, and feeding the national grid (Genesis Energy, N.D.).

While renewable energy is required to feed the growing electricity demand (Irvine *et al.*, 1987), this has not come without controversy (Ngāti Kurauia, 2017). Hochstein and Prebble (2006) explain how, during the construction of the Tokaanu tailrace, the extent of the geothermal field was poorly known. Yet, despite not understanding the extent of the field, the whenua which was to be the tailrace was dewatered resulting in the geothermal properties being minimised and subsequently buried. Furthermore, Hochstein and Prebble (2006) go on to describe that no mapping of the geothermal field was undertaken even after the construction was finished.

Another source of controversy resulting from the implementation of the Tokaanu Power Scheme saw the Tokaanu Stream, the awa tūpuna of Ngāti Kurauia, bisected to allow for the passage of the Tokaanu tailrace (Waitangi Tribunal, 1995). Furthermore, according to the Waitangi Tribunal (1995), the Tokaanu was connected to allow for downstream flow solely to allow for the "minimum disturbance to trout during the spawning season from June to November" (pg. 134.). Regardless of the actual reason, the Tokaanu Stream has been redirected and now is carried over the Tokaanu tailrace via an aqueduct, which is attached underneath State Highway 41 before it is returned to the stream (OPUS, 2012; McConchie 2018).

In wānanga, Ngāti Kurauia stated that the realignment of the channel has had significant cultural impacts upon the stream as it has been redirected through areas it has never flowed before, decreased opportunities to gather kai (food) (Ngāti Kurauia Marae Committee, pers.

comm. 2023; Waitangi Tribunal, 1995), and may have significantly increased sedimentation in the Tokaanu Stream with anecdotal evidence of infilling of recreational and cultural bathing areas (Ngāti Kurauia Marae Committee, pers. comm. 2023; Waitangi Tribunal, 1995). While these changes are more apparent to mana whenua who live beside the stream, it is in opposition to the statements made from OPUS (2012) in their report to the Taupō District Council.

1.5 Mātauranga Māori

As a body of knowledge, the use of Mātauranga Māori is unique and has been intentionally incorporated into this study as a knowledge system, it incorporates both traditional Māori and Polynesian concepts, perspectives and practices which are fixed within their identity (Clapcott *et al.*, 2018). Furthermore, as an evolving knowledge system, Mātauranga Māori also incorporates contemporary aspects. Mātauranga Māori has vast applications and is gaining traction in what is an ever-increasing community of awareness and open-mindedness including culturally appropriate restoration, research, and policy development within Aotearoa's resource management space (Clapcott *et al.*, 2018).

Mātauranga Māori encompasses learnings and perspectives that are part of broader knowledge systems collectively known as Traditional Environmental Knowledge (TEK) in a Te Ao Māori context (Belcher, 2021; McAllister *et al.*, 2023). Mātauranga Māori has been passed down through the generations via whakapapa and wānanga. The continuation of these traditions are particularly important so younger indigenous people can make sense of observations without the help of their elders to develop, recognise, or even articulate TEK which may be locally relevant (Berkes, 2009).

Society and the paradigms that operate within it can place knowledge into silos; however, there is a growing recognition that melding the two knowledge systems (Mātauranga Māori and Western Science) in an Aotearoa New Zealand context generates unique structures of knowledge seeking, creation, and understanding (Jones *et al.*, 2020; Mercier, 2018). While there is a recognition that different knowledge systems (TEK and Western Science) are often polarising, finding a middle ground for the contrasting perspectives held in Table 1 (see below) would surely add value to our global knowledge base in time of rapid environmental change.

Table 1: Comparison of values and perspectives between Mātauranga Māori and Western Science. Modified from (Fenemor et al., 2011; Hikuroa, 2017; Jones et al., 2020; Joseph et al., 2018; Rauika Māngai, 2020).

Mātauranga Māori	**Western Science**
Knowledge Holding	Knowledge Seeking
Considered an add-on	Dominant Mainstream Paradigm
Holistic	Analytical
Based on Accepted Truths	Sceptical
Uses Environmental Encounters	Measurable and Replicable
Centrifugal Thinking	Centripetal Thinking
Illuminates Similarities	Highlights Differences
Practitioners Typically Older	Younger Practitioners
Time Enhances Knowledge	Time Diminishes Science
Steadily Evolving	Knowledge Advances
Classed as Myth and Legend	Considered Fact
Malleable	Rigid
Participation in Systems	Observes Systems
Intrinsic Values	Instrumental Values

Knowledge as Belonging	Knowledge as Control
Intuition Valued	Intuition Rarely Acknowledged
Includes Facts and Values	Separates Facts from Values

Globally, indigenous people who have lived for generations in the same place, or series of places, notice both macro- and micro-level changes within the environment because of the intimate connections they hold to the ecology of these areas. In Aotearoa New Zealand this is relevant as iwi, hapū and rūnanga have occupied lands for generations. Events have been observed, information gathered and honed to form an understanding of the rohe (Belcher, 2021; Tipa & Tierney, 2003). Therefore, Mātauranga Māori has increasingly been recognised as a valid way of knowing the environment and has become much more accepted in mainstream environmental science and management.

As potential conflict can occur between the researcher and the researched, Belcher (2021) suggests that Kaupapa Māori research should only occur within wānanga (formal hui within a walled environment) and not in Te Ao, the natural world. This is a perspective that is also supported by Smith (2012) who goes further by suggesting that only Māori should work with Māori. However, by placing limits on how indigenous knowledge is shared and applied, alienation and fragmentation can occur, therefore marginalising the voice of indigenous people. By legitimising Mātauranga Māori, power imbalances can be challenged and addressed in a manner that is relevant, at the same time fostering wider community involvement (Belcher, 2021). This creates a synergy and adds value by linking cultural and community values, environmental knowledge, tino rangatiratanga (self-determination) and strengthens traditional practices (Mercier, 2018).

As Mātauranga Māori in many instances may go back as far as the Polynesian voyages - some 700+ years ago - there have been tens of generations who have passed Mātauranga down through whakapapa (Clapcott *et al.*, 2018; Hall *et al.*, 2021; Harmsworth & Awatere, 2013; Smith, 2008). Since this form of knowledge transmission was utilised well before the written word arrived in Aotearoa New Zealand, there is a vast amount of Mātauranga expressed and communicated through other forms, such as Toi Māori (Māori arts and crafts) which can include Raranga (weaving), Kōwhaiwhai (Māori art work), Whakairo (carvings), Waiata (songs), Haka (performance), Whaikōrero (speech), and Whakatauākī (proverbs). This knowledge is a symbolic representation that links with people's identities, and may also contain historical evidence (Lyver *et al.*, 2017; Mercier, 2018) should hapū and iwi need to refer to this repository of knowledge to help them in the future.

Over the generations, Mātauranga has morphed into an increasingly specific knowledge system, currently referred to as Mātauranga Māori. The evidence retained and obtained through employing Mātauranga Māori techniques can keep cultural practices alive through partnership, reciprocity, and empowerment (Clapcott *et al.*, 2018; Mercier, 2018). Whakapapa and kaitiaki practices have often been called upon as taonga tuku iho, incorporating local dialect, to manage environmental services, and overall environmental decline. This is a large responsibility considering many Māori communities have been colonised, urbanised, and diminished by urban drift (Clapcott *et al.*, 2018; Hall *et al.*, 2021; McAllister *et al.*, 2023).

There is little doubt that localised Māori communities around Aotearoa New Zealand have a unique relationship with their environment and the natural resources that these ecosystems support. As such, many Māori who live in these communities in particular, see the declining state of the environment as significant (Harmsworth & Awatere, 2013). This is particularly important when considering māhinga kai and mauri, as when mauri is high, ecosystem services are usually high (Lyver *et al.*, 2017). Conversely, when mauri is diminished, ecosystem services are more homogenous, thus reducing māhinga kai resources and potentially causing irreversible damage to taonga species (Harmsworth & Awatere, 2013; Lyver *et al.*, 2017; McAllister *et al.*, 2019). Many Māori communities are frustrated by the Western Science approach and its ability to identify water quality concerns and desire a greater incorporation of Mātauranga Māori in monitoring. This can be observed in the National Policy Statement – freshwater management and National Objectives Framework, by the absence of cultural monitoring as a tool to monitor the environment. Many Māori organisations strive to incorporate TEK into the decision-making processes which aims to return a healthy mauri to the environment due to the holistic approach of Mātauranga Māori.

Harvesting Māhinga kai from healthy environments is imperative. In a changing political environment, Māori and Māori communities are making the natural environment a priority for management, rather than only reminiscing over times gone by (Stewart *et al.*, 2011; Zygadlo, 2016). Interestingly, research that incorporates Mātauranga Māori remains relatively uncommon in Aotearoa New Zealand (McAllister *et al.*, 2019). Requirements are placed on researchers by many funding agencies to include Vision Mātauranga statements, including how they intend to meet their obligations to Te Tiriti o Waitangi and the WAI262 Waitangi Tribunal outcome (Clapcott *et al.*, 2018; McAllister *et al.*, 2023).

1.6 Cultural Monitoring Frameworks

Over the centuries, tangata whenua and their tūpuna have observed the environment and grown their Mātauranga Māori. Often this was via observation and discussion. However, more recently this has included more 'scientific' measures. As both have grown, a wider base of understanding has grown and can be used to report on the state of the environment.

Within the last 30 years several frameworks have been created by notable Māori researchers to increase tangata whenua engagement and participation within the stewardship and research space. This included the development and socialisation of frameworks such as Gail Tipa and Laurel Teirney's Cultural Health Index (Tipa & Teirney, 2006a; Tipa & Tierney, 2003), Kepa Morgan's Mauri Model (Wilkinson *et al.*, 2020), Richard Jefferies and Nathan Kennedy's Kaupapa Māori Outcomes and Indicators Kete (Jefferies & Kennedy, 2009), and Ian Ruru's Mauri Compass (mauricompass.com, N.D.). These are but a few of the ever-increasing number of tools that whānau, hapū, iwi, and other organisations, can use to help them be meet regulatory requirements and uphold tino rangatiratanga.

1.7 Why develop a new framework?

I have had discussions with multiple iwi and hapū over the years surrounding the topic of cultural monitoring. Time and time again I have identified that they simply want the 'right tool for the right place' rather than a generic tool that does not reflect local conditions and aspirations. One such hapū was Ngāti Kurauia (Ngāti Tūwharetoa), who sought to measure the ecological health of the Tokaanu Stream (a tributary of Lake Taupō) and to create a culturally appropriate framework for their awa tūpuna. After looking into what frameworks were available, it was agreed that no existing frameworks were suitable for Ngāti Kurauia.

By creating a bespoke and site-specific framework, the overall goal of my thesis is to describe the current state of the environment of the (lower) Tokaanu Stream in both cultural and ecological terms. Once complete, the cultural monitoring framework will be gifted to Ngāti Kurauia. This gift is intended to give them greater agency around environmental matters and so that they feel more comfortable in meeting their aspirations. Just as Harmsworth (2002) predicted, once complete, this mahi rangahau shall flip the current narrative away from westernisation and toward the richness of indigenous knowledge systems.

However, developing this framework is not without peril. Warnings have been sounded by authors such as Memon and Kirk (2012) who signal that researchers may seek to claim the views of Ngāti Kurauia, or any other indigenous community, for themselves. However, while this has undoubtedly happened in the past, it will not occur with this mahi. The cultural monitoring framework has been developed to reflect the values of Ngāti Kurauia. The creation of this bespoke approach will enhance their credibility amongst the neighbouring communities in the Lake Taupō catchment. Their cultural monitoring framework empowers Ngāti Kurauia to meet their aspirations for the environment.

1.8 Objectives

The overall objective of this study was to work collaboratively with Ngāti Kurauia, a hapū of Ngāti Tūwharetoa, to measure the ecological health of the Tokaanu Stream and to create a culturally appropriate framework for the Tokaanu Stream. Specifically, this relates to the downstream portion of the Tokaanu Stream from State Highway 47 to the Tokaanu Stream delta as it enters Lake Taupō where Ngāti Kurauia uphold mana whenua.

This is the first time that a study of this kind has been attempted along the lower reaches of the Tokaanu Stream with Ngāti Kurauia. The research is unique as it 'flips' the hegemonic narrative and has traditional scientific measures in support of Mātauranga Māori, as opposed to Mātauranga Māori playing a supporting role. Moreover, the research is doubly unique as this project was requested by multiple kaumātua of Ngāti Kurauia who aspired to see this mahi completed in their lifetime.

There are multiple objectives that this study seeks to meet. These are:

1. To engage mana whenua, specifically Ngāti Kurauia, in this project and add to their kete of knowledge using quantifiable attributes that hold value to them.
2. Increase the amount of involvement that hapū members and neighbouring residents have with their immediate environment and create a means to continue this reconnection with the environment.
3. Create several data sets which can be used for multiple purposes. This includes for the formation and completion of this thesis as well as for purposes that Ngāti Kurauia deem appropriate in the future.
4. To identify what structure(s) are causing negative downstream impacts for Ngāti Kurauia and the Tokaanu Stream.

1.9 Hypotheses

There is a perception that the Tokaanu Stream has been negatively affected by the Tokaanu hydro scheme and challenges with the sewerage infrastructure, in addition to the naturally-occurring geothermal inputs. By weaving Kaupapa Māori, Mātauranga Māori, and conventional biomonitoring approaches, I aimed to investigate three putative hypotheses about the ecological and cultural health of the Tokaanu Stream:

1. The diversion above the Tokaanu Tailrace Canal is an impediment to a natural flow regime in the Tokaanu Stream resulting in altered hydrology leading to changes in thermal dynamics and benthic substrate downstream.
2. The urban dwellings in the Tokaanu Village are contributing to reduced water quality due to stormwater inputs and potential leakage from septic tanks and/or faulty sewage infrastructure.

3. The combined impacts of the diversion and urbanisation are degrading the ecological and cultural health of the Tokaanu Stream with potential negative impacts on the receiving environment of Lake Taupō.

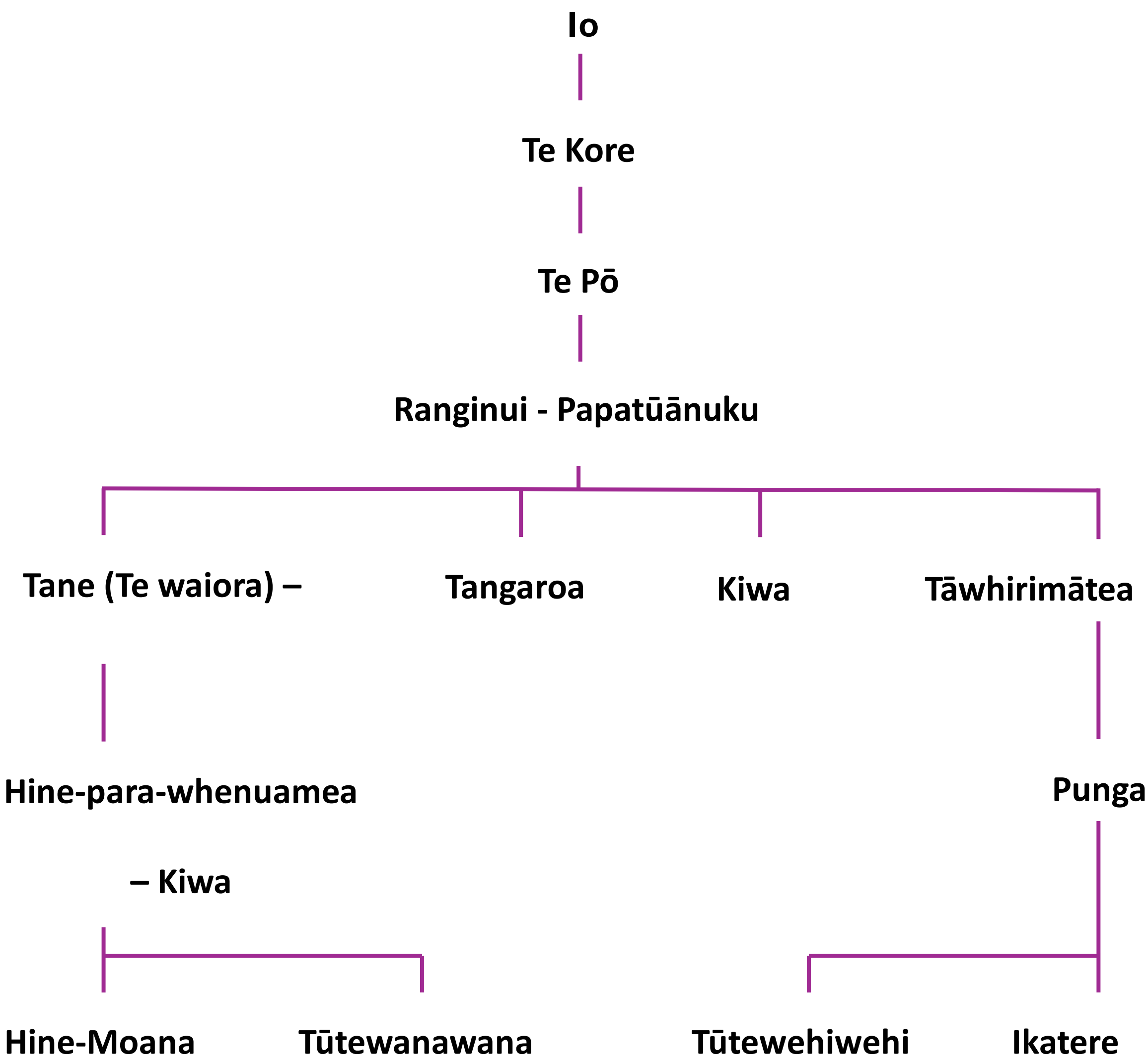
Selected freshwater attributes described in the National Policy Statement for Freshwater Management (NPS-FM) were recorded to support the cultural health assessments guided by Mātauranga Māori.

2 Site Information

2.1 Whakapapa

This section contains privileged information provided by Ngāti Kurauia. The whakapapa descends in hierarchy from Io to Taupō Moana.

The information in this section was provided to the Waitangi Tribunal (1995, pp. 130-132) by the late Te Rangihouhiri William (Bill) Asher (1925 – 2004). A special thankyou is extended to Mātua George Asher, and his whānau, for providing the information for this section.

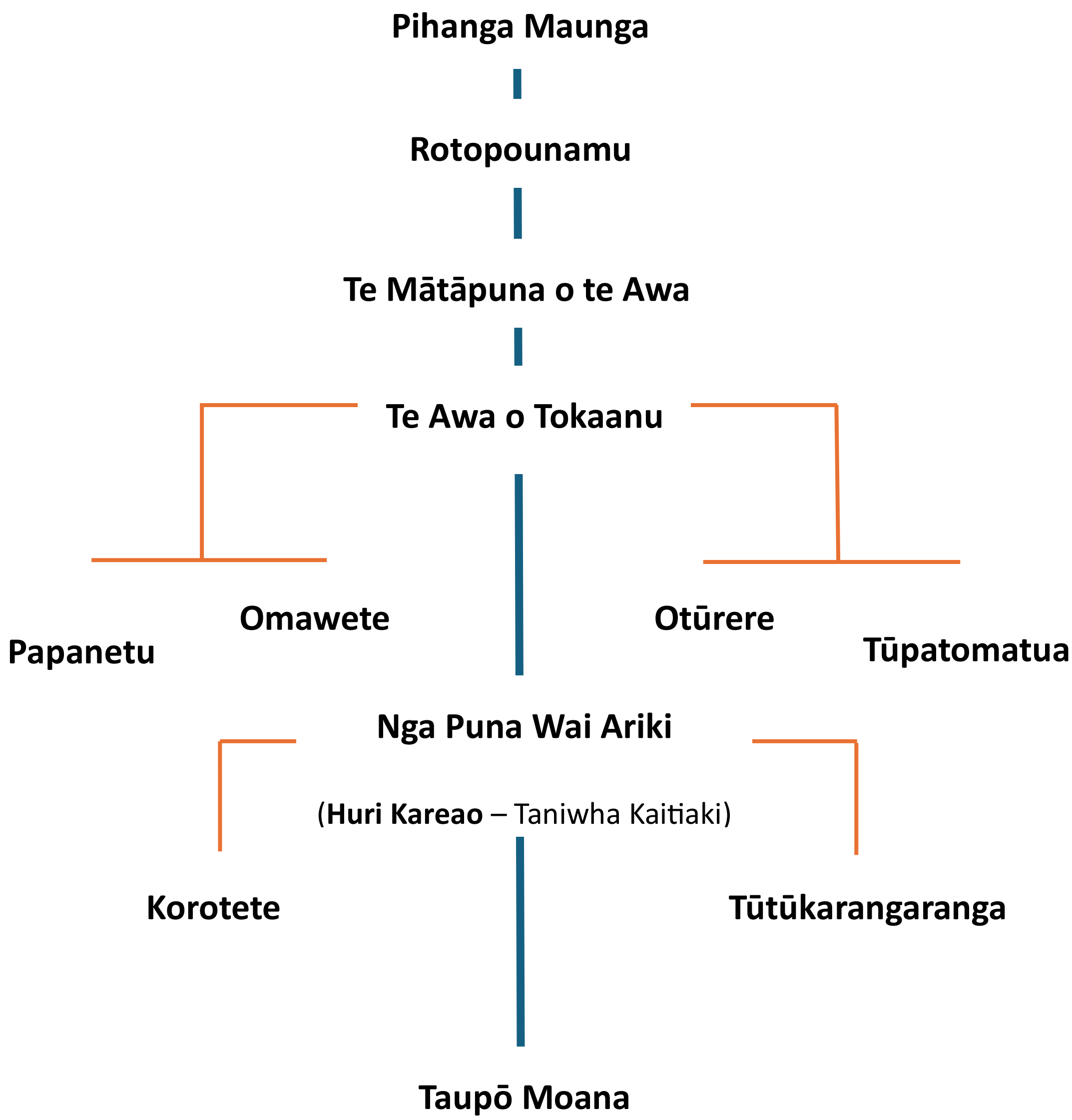


Hinewai and Hine-Ihorangi [both][1] produce [freshwater in the form of] rainwater, the tears of Ranginui. [These] abide with Hine-Kapua producer of clouds. The progeny of Hine-pūkohurangi create the mists that represent the tears of Papatūānuku[2] (George Asher, pers communication, 2024).

[1] The [and] have been incorporated in this instance to add the occasional word from the Author for clarity.

[2] As conveyed by Chris Winitana in 1998 (G. Asher, pers. comm.)

2.2 Source of Tokaanu Awa



The Tokaanu Stream was described as 'he taonga tapu, he awa tapu' by Bill Asher in his submission to the Waitangi Tribunal. The Tokaanu is a sacred waterbody, a highly valued resource, and a taonga in the perception of local people.

Te Mātāpuna is the source of the Tokaanu from the springs below the headland. The headland is known as Kohatu Kaioraora. There are also other puna feeding the Tokaanu in the vicinity of Te Reporepo. It is believed the ultimate source of the river is Rotopounamu, a lake high on the southern flanks of Pihanga Maunga. The water flows underground through the heavily broken and faulted andesitic rocks and lava flows and reappears throughout the forementioned puna.

Te Mātāpuna is the abode of two taniwha (Tikatakata and Tihorehore [Tioreore]) who sometimes travelled to the springs downstream at Te Reporepo. These taniwha are protective beings and are associated with healing and the tapu quality of the water upwelling from these springs. Tikatakata and Tihorehore are also the names of stars which Pākeha call the Magellan Clouds. As stars, they also have a protective role whereas, based on their relative position in the sky, they were used to predict the wind and bad weather.

The Tokaanu Stream once flowed to the east of Maunganamu, past Te Waiariki, and into the lagoon in the swamp known as Te Awa o Taringa. The river was turned from its course by another taniwha, Kohuru Kareao, later known as Huri Kareao, who now dwells in the hot springs near the Tokaanu Village. This taniwha caused an earth movement which diverted the river.

The Tongariro River was also diverted by a taniwha. It once flowed westward into the Tokaanu Stream but was turned to its present course by Huruhurumahina, a name which is still used by the people from the area south of Maunganamu where the two bodies of water once joined. Once settled in its present course, the Tokaanu Stream became the main highway for canoe traffic between many kainga along its banks.

The volcanic origin of the mountains south of Lake Taupō meant that periodic earthquakes and subsequent earth movements occurred. These were recorded in traditional accounts and usually ascribed to taniwha. Huruhurumahina was responsible for the uplift that created the waterfall, or Wairere, on the Hangarito Stream. Other earth movements also caused some former settlements to be submerged under the waters of Lake Taupō.

There are two old kainga beneath the lake waters near where the water from the Tokaanu Power Station Tailrace flows into the lake. Their submergence is also ascribed to a Taniwha.

A woman tohunga, named Aratukutuku, had been disturbed at her tuahu by a man, who had thereby broken the tapu tikanga. He had been on his way to the lake to go fishing, but he did not return. Aratukutuku was beaten to death by his relatives for allegedly causing his death. However, before she died, she was able to call on her taniwha to submerge the land and engulf the two kainga along with their inhabitants, into the lake. In the 1930's, local elders stated the palisades of the old kainga were still visible on the lakebed.

2.3 General Location

Lake Taupō is located at the southern end of the Taupō Volcanic Zone (TVZ) which extends from Whakaari/White Island and beyond in the north to the southern end of Mount Ruapehu (Robinson, 1994; Robinson *et al.*, 1995). Formed by successive volcanic eruptions (Barker *et al.*, 2021), the latest and arguably most notable during the recorded timescale, carved the existing caldera to what exists today along with the iconic shape.

Multiple Iwi are scattered around the TVZ from successive arrivals circa 700 ago with the most predominant in Taupō, Ngāti Tūwharetoa, holding legal ownership of the lakebed today. With 29 hapū spread across 30 Marae (Tuwharetoa Māori Trust Board, N.D.), the geographical range they cover is vast from Mōkai Marae in the north to Tokorangi Marae in the south.

Ngāti Kurauia (Tokaanu Marae), is one of the 29 Ngāti Tūwharetoa hapū whom uphold mana whenua in their rohe. Situated adjacent to the Tokaanu Stream, Ngāti Kurauia have noticed a change in the Tokaanu Stream and its multiple unique features along its relatively short path. They have voiced their eagerness to have a bespoke cultural monitoring framework generated for their use to help inform their opinions. As such, they supported the application from this researcher to enhance their mana, exercise tino rangatiratanga, and activate kaitiakitanga. Included in the subsequent cultural framework I also incorporated traditional scientific measures to ascertain the health of the Tokaanu Stream while supporting Mātauranga Māori.

The cultural framework was developed after engaging with members of the Ngāti Kurauia hapū through hui, wānanga, and kōrero. The traditional scientific measures which were incorporated are in line with Aotearoa New Zealand's National Policy Statement for Freshwater Management. However, extra measures were also included to help 'paint the picture' of the state of the environment.

2.4 Site Description

The Tokaanu Stream flows from the northern slopes of Mt Pihanga into Lake Taupō along a north-northwest trajectory. There are two predominant hapū of the iwi Ngāti Tūwharetoa, who have significant connections to the Tokaanu Stream, Ngāti Tūrangitukua and Ngāti Kurauia.

Originating from Mt Pihanga, Ngāti Tūrangitukua maintain mana whenua at the spring-fed origin of the stream, whereas Ngāti Kurauia assert their mana whenua from State Highway 47 downstream as the Tokaanu Stream flows into Lake Taupō.

2.5 Site Selection

Six sites were selected for sampling by the local hapū, Ngāti Kurauia. All sites are downstream of State Highway 47 and were selected due to them being sites of interest for Ngāti Kurauia, safe accessibility as hapū members of all ages would join in on sampling, as well as the sites being representative of the stream (Figure 1).

Site 1 is the most upstream site while Site 6 was the most downstream site. This naming protocol was selected as the cultural monitoring would begin at the uppermost permitted reach of the Tokaanu Stream and gradually work downstream to the lowermost site. More traditional scientific monitoring was undertaken in reverse order, moving from downstream to upstream to ensure no downstream contamination by nutrient or sediment plumes. This

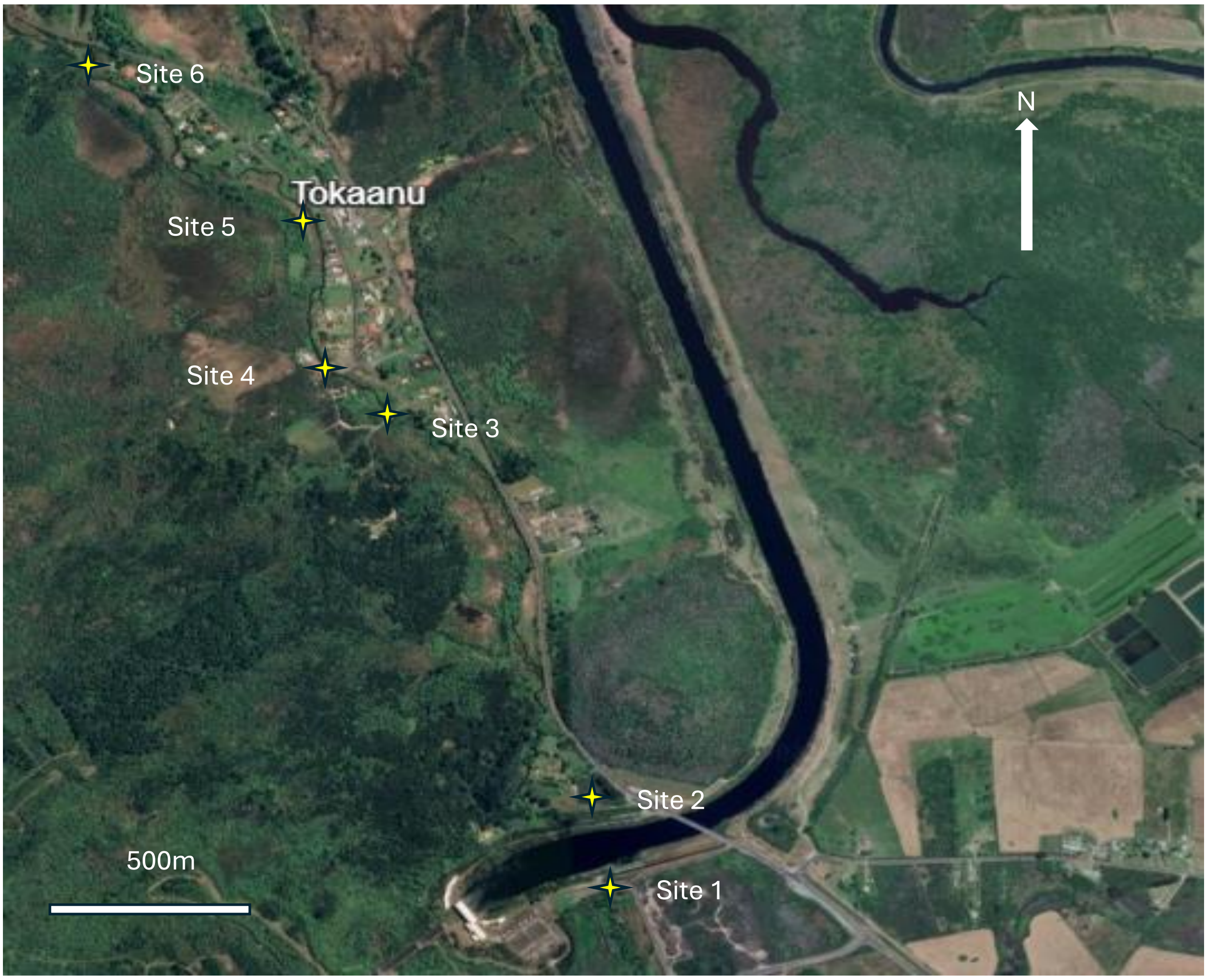


Figure 1: The Tokaanu Stream as it flows along an approximate North-North-West direction from SH47 in the south to the Tokaanu Stream delta in the north. The large right-angled body of water curving to the northward around the eastern flank of Mount Maunganamu is the Tokaanu Power Station Diversion. SH41 crosses the Tokaanu tailrace. Image retrieved from GOOGLE Earth 21 January 2024.

was imperative for sites that were relatively close to one another such as Sites 1 and 2, as well as Sites 3 and 4.

Site 1

Site 1 is located directly upstream of the Tokaanu Stream diversion at the Tokaanu Power Station tailrace. This diversion was engineered to provide an amount of continuity of the Tokaanu Stream to the downstream reaches of the catchment and to manage the impacts of flooding events (OPUS, 2012) once the Tokaanu Power Station was operational. Without this diversion it is likely that the Tokaanu Stream's world-renowned trout spawning habitat may have been at risk along with the Tokaanu Village water supply.

Access to Site 1 was gained along the true-left bank which is owned by Genesis Energy. In-stream water chemistry sampling was conducted along the interface between the natural streambed and the engineered bed at the beginning of the artificial concrete culvert which is located directly underneath the Tokaanu Power Station's bridge.

The land-use immediately adjacent to Site 1 is a mixture of power generation, pasture, roading, and land which appears to have been left to revert to scrub.

Site 2

Site 2 is located immediately downstream of the Tokaanu Stream diversion where the aqueduct discharges water into what is now the Tokaanu Stream. Access to the stream was made from the true left stream bank that has been artificially engineered to prevent scouring of the streambed while also allowing fish passage into the aqueduct.

Nearby land-use is mixed with State Highway 41, the Tokaanu Power Station's tailrace, and private residences. Other adjacent land-use includes a nature reserve on Mount Maunganamu dominated by endemic species with exotic species interspersed including *Salix* spp. as well as *Pinus* spp.

Site 3

Site 3 is located on Marama Street, Tokaanu, and is significant to Ngāti Kurauia as it is the only bridge along the Tokaanu Stream providing public vehicular access to the true left of the stream, and the urupā beyond. Multiple nearby streams provide a constant sediment load to the Tokaanu Stream which Ngāti Kurauia have voiced concern about. Access to the stream was made alongside the bridge abutment (Figure 2) on the true right of the stream.

Land-use at Site 3 is a mixture of Urban dwellings and Shrubland (Figure 2). Blackberry and Broome appear to be the dominant species which line the stream alongside five-finger (*Pseudopanax* spp.) and Willow (*Salix* spp.).

Site 4

Site 4 is located at the Tokaanu hot pools, a popular tourist destination. As this site is geothermally active, discussions were had with the site manager who advised the safest access was on the true right of the stream at the footbridge (Figure 3).

Nearby land-use includes both urban dwellings and commercial tourism properties alongside active puia.

Site 5

Site 5 is located at the intersection of Kōpū and Matariki Streets. Although the site did not contain puia, a point-source geothermal water input from a neighbouring motel was discovered which occasionally generated a strong localised thermocline within the stream.

Figure 2: Image A identifies the access point for Site 3 on the true right-hand side of the Tokaanu Stream, indicated by the yellow arrow. Image B provides an indicative overview of the upstream landuse and state of the Tokaanu Stream.

Figure 3: Tokaanu hot pools foot bridge with car park behind. The arrow indicates where stream habitat was accessed safely to avoid geothermal risk within the stream at the point.

Figure 4: Access point as Site 5 looking downstream. Raupō wetlands are on the true left bank.

Access to the stream was made from the true right stream bank (Figure 4). Nearby land use is a mixture of urban on the true right and endemic Raupō wetlands on the true left.

Site 6

Site 6 was the most downstream site of the sampling reach. Site 6 was marginally upstream of the SH41 bridge (Figure 5) that crosses the Tokaanu Stream before the stream becomes too compromised to sample due to lacustrine interference from Lake Taupō.

Site 6 had an amount of geothermal input into the Tokaanu Stream at this location. Access to the stream was made along the true left bank of the stream and multiple wildlife species were observed including large 'river rats' (*Rattus* spp.) and Dabchicks.

Nearby land-use is a mixture of pasture, state highway 41, a small amount of Raupō wetlands along the true right bank, and pest plant species.

Figure 5. Access to Site 6 was achieved along the true left bank, upstream of the State Highway 41 bridge as it crosses the Tokaanu Stream below it empties into Lake Taupō.

3 Methods

This section intentionally separates the development of a cultural health monitoring framework from the methods used for conventional environmental monitoring that come from a more Western science perspective. It is intended that both knowledge systems have the equal amounts of mana without one dominating the other in their application to the Tokaanu Stream.

3.1 Cultural Health Framework

The development of a bespoke cultural monitoring framework was integral to this project. In doing so, Ngāti Kurauia contributed to this project and thus maintained their agency and mana throughout the project development and subsequent field monitoring. Two initial wānanga at Tokaanu Marae were organised to develop and ratify the bespoke cultural health framework for the Tokaanu Stream designed by Ngāti Kurauia.

Wānanga Tuatahi

The first development wānanga (Wānanga Tuatahi) was hosted by Ngāti Kurauia at Tokaanu Marae on the 30th September 2023. The wānanga observed the tikanga and kawa of Ngāti Kurauia. Thirteen people attended including kaumatua and tamariki.

Wānanga tuatahi began with the background of how this mahi rangahau came to be initiated through engagement with Ngāti Kurauia. Hapū were presented with a conceptual diagram (Figure 6) providing an overview of the steps that could be taken through this project.

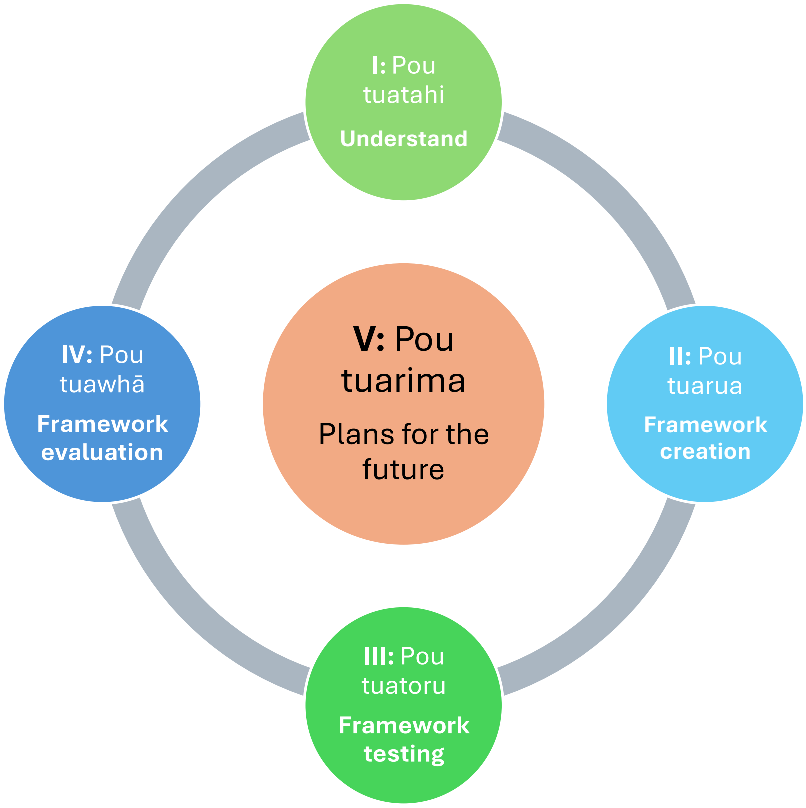


Figure 6. Representation of the four main pou involved with this mahi rangahau on te Awa ō Tokaanu me te taiao (Tokaanu Stream and surrounding environs), and how each pou contributes to the overall plans (pou 5) for Ngāti Kurauia's future.

Pou Tuatahi

Pou tuatahi began during Wānanga Tuatahi and continued until the end of the formal research period (Figure 6). This first step was crucial to understand the Mātauranga that Ngāti Kurauia hold in relation to te Awa ō Tokaanu me te taiao (the Tokaanu Stream and neighbouring environment) and provided context for the planned work. Our increased understanding helped inform the next steps in pou tuarua, tuatoru, tuawhā, and tuarima.

Pou Tuarua

Pou tuarua was initially called the "cultural framework creation" stage. This name was changed to 'general framework creation' after discussion with hapū members during Wānanga Tuatahi. Ngāti Kurauia wanted pou tuarua to also include the Western science attributes consistent with the National Policy Statement for Freshwater Management (NPS-FM) 2020. While the name was changed, our discussions recognised the mana of Mātauranga Māori and how it is important. A consensus was developed that my research would seek to weave both knowledge systems together when monitoring the Tokaanu Stream.

Pou tuarua was informed by our discussions that identified multiple attributes. These attributes were intended to generate rigorous, defensible data that would inform my thesis research. Although conventional monitoring remains firmly rooted in the Western science knowledge system, there is a growing recognition that environmental monitoring needs to be more participatory to help involve citizen scientists and recognise traditional ecological knowledge (TEK) (Tengö *et al.*, 2021). As a reflection of this desire, my final field protocol incorporated mātauranga Ngāti Kurauia and was developed so that it could be used by citizen scientists regardless of their previous experience (Appendix A).

Pou tuarua was developed during Wānanga Tuatahi and the following Wānanga Tuarua, along with hui and kōrero during field monitoring. While the framework was settled upon to complete my thesis research, it is intended to be a living framework that is informed by practice. Thus, it may be altered by Ngāti Kurauia to suit their needs in the future should they so desire.

Pou Tuatoru

Pou Tuatoru (Figure 6) was about implementing and testing the framework. This did not occur until later and is described in the Wānanga Tuarua section.

Pou Tuawhā

Pou Tuawhā (Figure 6) was about evaluating the framework and describing these finding in my thesis. Like Pou Tuatoru, it was not directly relevant to Wānanga Tuatahi and thus only discussed briefly. However, the University of Waikato ethics requirements were discussed with those attending the wānanga. This was to ensure Ngāti Kurauia gave informed consent. The study information sheet and participant consent form were sent to the marae secretary for further consideration by the Ngāti Kurauia committee. It was also shared among the hapū mailing list for their reference.

Pou Tuarima

Pou Tuarima focused on future outcomes resulting from monitoring the Tokaanu Stream. Like Pou Tuawhā, Pou Tuarima was not addressed in depth at the first wānanga. Rather, discussions with Ngāti Kurauia focused on Pou Tuatahi to Tuawhā, alongside other aspirations Ngāti Kurauia have for the future.

Cultural Framework Attributes

During Wānanga Tuatahi it was decided that twelve attributes would be subjectively assessed per site using a Likert scale. In no particular order, these are as follows:

1. Smell of the water
2. Clarity of the water
3. Taste of the water[3]
4. Māhinga kai observed

[3] Due to health and safety concerns, it was stressed that this attribute would not to be tested. Rather, a question was included in the field book asking if the participants would drink the water, and if not, then why not.

5. Affliction/Engineering both in the water and immediately adjacent
6. Pollution
7. Sound – Water flow
8. Sound – Bird song
9. Bird diversity
10. Vegetation – In-stream
11. Vegetation – Trees/shrubs adjacent to the stream
12. Vegetation – Percentage vegetation cover immediately adjacent to the stream

In line with the kaupapa of Wānanga Tuatahi, attendees contributed to the design of the field protocol. Following our group discussions, we decided that the above attributes were to be assessed using a Likert scale (0-5) to subjectively quantify the state of each attribute.

Other questions were included to assist in building a descriptive knowledge set about the Tokaanu Stream. Two questions required either a Yes or No answer with the remain six questions requiring scores ranging from -2 to 2 (Appendix A). A notes section was also provided for Ngāti Kurauia whānau who wanted to expand further. The questions included:

1. Would you drink the water as it is? If not, why not?
2. Would you swim in the water as it is? If not, why not?
3. Is the awa wider or narrower at this location than in the past?
4. Is the awa deeper or shallower at this location than in the past?
5. Has the awa's potential to flood increased or decreased over time?
6. Are there differences in the in-stream habitat (sediment, macrophytes)?
7. Are there differences in the riparian habitat (composition, cover)?

8. What biological changes have occurred (loss/gain of Koura, Taonga species, kōaro, birds etc)?

Site selection

Figure 7. Members of Ngāti Kurauia discuss possible sites to sample along the lower reach of the Tokaanu Stream from Genesis Energy's Tokaanu Power Station's tailrace.

Selecting appropriate sites for sampling was an important topic as there were a range of issues to consider. Firstly, the sites in question needed to be suitable for sampling using contemporary methods as well as a Kaupapa Māori framework. Secondly, we wanted a good spatial distribution to help identify potential sources of stream impairment. Thirdly, the sites also had to be safe for people of all ages and abilities to access. When sampling near puia, participant health and safety was paramount. Finally, due to the rohe boundaries of Ngāti Kurauia, the mahi rangahau was bound to the Tokaanu Stream downstream from where the Saddle Road (SH 47) meets SH 41.

A large aerial photograph was used to determine the sites that met the above conditions and were deemed appropriate by Ngāti Kurauia (Figure 7). Participants at the wānanga discussed where potential sites could be located to meet our goals and then placed post-it notes with an arrow indicating the stretch to be sampled. Once these sites were identified, the stream channel (indicated in Figure 7 by the light blue line) on the aerial photograph was marked. We selected six sites based on these criteria. Each site was visited before the end of 2023 to record the exact position using GPS (Table 2).

Table 2. Site coordinates and names for the six sampling locations on the Tokaanu Stream. These were selected based on engagement with Ngāti Kurauia during Wānanga Tuatahi. All six sites (1-6) have a unique name to help better describe each.

Site	Name	Site coordinates
1	Upstream diversion canal	-38° 58' 49.3026"S 175° 46' 20.5212"E
2	Downstream diversion canal	-38° 58' 6.9054"S, 175° 46' 22.065"E
3	Urupā bridge	-38° 58' 6.9054"S, 175° 45' 58.7334"E
4	Tokaanu Hotpools	-38° 58' 1.9806"S, 175° 45' 53.3268"E
5	Intersection of Kaiwaka and Matariki Street	-38° 57' 48.6462"S, 175° 45' 52.0914"E
6	Last bridge over Tokaanu Stream before it enters Lake Taupō	-38° 57' 33.3894"S, 175° 45' 27.8352"E

Wānanga Tuarua

The second wānanga (Wānanga Tuarua) was hosted by Ngāti Kurauia at Tokaanu Marae on 28 October 2023. Eight hapū members including kaumatua, tamariki and mokopuna attended.

Cultural Framework Amendments

During Wānanga Tuatahi, hapū members identified 12 attributes they thought were important in the development of the cultural framework. At Wānanga Tuarua, hapū members added 5 more attributes to the framework. All attributes then had descriptors for each increment of the Likert scale added except for wairua. Wairua[4] only had the extreme points of 0 and 5 applied as this attribute is of spiritual significance to Ngāti Kurauia and it would be inappropriate to grade it in general terms using the Likert scale. The additional attributes included at Wānanga Tuarua were (in no particular order):

1. Feel of the water
2. Wairua
3. Stream-bed composition
4. Colour of the substrate
5. Colour of the water

During Wānanga Tuarua we visited the stream to confirm the sites along the length of the stream segment. This hikoi meant that there was not sufficient time to articulate each attribute during the wānanga. To decide upon the final descriptors for the Likert values an additional hui took place with a select group of hapū members. Once the attributes and the

[4] Mauri was considered instead of wairua but was declined by the hapū.

way they were to be quantified was fully discussed, the final recommendations were then passed onto the Chair of Tokaanu Marae's Environmental Committee for ratification (Table 3).

Table 3. The seventeen attributes chosen to assess the health of the Tokaanu Stream.

Attribute	0 (0%)	1 (20%)	2 (40%)	3 (60%)	4 (80%)	5 (100%)
Smell of Water	Bad, offensive smells	Marginal offensive smells	Light offensive smells	No smell	Mild pleasant smell	Abundant pleasant smells
Clarity of the Water	All mud or thick sludge	Muddy, no sludge	Heavily cloudy water	Light cloudy water	Can see things floating but no clouds	Completely clear
Stream-bed make-up	Mud	Silty	Silty/Sand	Sandy	Pebbles/Gravel	Rocks
Taste of Water	There were health and safety concerns with consuming water as part of this study. Therefore, participants were asked a follow up question instead of drinking the stream water. "Would you drink the water as it is? If not, why not?" This was also accompanied by a 0 – 5 Likert scale.					
Māhinga kai observed	No Māhinga kai	1 Māhinga kai species	2 Māhinga kai species	3 Māhinga kai species	4 Māhinga kai species	5 + Māhinga kai species seen
Development in and next to water	Structures dominate the streambed within 50m	Structures dominate the stream side within 50m	More structures within 50 m than not	Less structure dominating within 50m	Occasional structures within 50m	No structures present within 50m reach
Pollution	Lots of paru/rubbish, cars, dead animals etc	Lots of paru and difficult to collect	Mixture of paru and difficult to collect	Mixture of paru, needs dedication to collect	Occasional paru, easy to collect	No pollution/paru

Sound – Water flow	No sound	Little to no sound	Mixture of little to no sound and flushing	Flushing sound	Constant sound of normal flowing water	Continuous sound of fast flowing water
Sound – Bird Song	No Bird Song	Little bird song, mainly from introduced species	Lots of bird song, only from introduced species	Mixture of native and exotic bird song	Mainly native song, within 30 minutes	Mainly native song, within 10 minutes
Bird Diversity	No Birdlife	Relatively few, only introduced birds	Abundant numbers, introduced only	Mixture of native and introduced, more introduced	Mixture of native and introduced, more native	Abundant native birds
In-stream vegetation	No plants in the stream	Only non-beneficial plants in the stream	More non-beneficial plants than beneficial	Even mixture of beneficial and non-beneficial plants	More beneficial plants than non-beneficial	Only beneficial plants in the stream
Vegetation adjacent to the stream	No trees/shrubs at all. Concrete or compacted dirt	All exotic trees and maybe some weeds	Mostly exotic trees/shrubs with some natives	Mixture of native and exotic trees/shrubs	Mostly native trees/shrubs with some exotics	Lush native trees/shrubs only
Percentage vegetation cover adjacent to stream	0%	20%	40%	60%	80%	100%
Feel of the Water	Slimy	Less slimy, very gritty	Very gritty	Gritty	Clean, light, but occasionally gritty	Clean, light, fresh

Colour of the Water	Black	Dark brown	Looks dirty	Heavily clouded	Lightly clouded	Clear
Colour of the Substrate	Black	Dark grey	Light grey	Green	Green-Brown	Light brown/ yellow/ orange
Wairua	Heavy – Sick - Burdened	These spaces were intentionally left blank and participants can decide where they feel the wairua sits on the scale				Light and rejuvenating

Upon completion, I asked Ngāti Kurauia if they could rank the variables in order of importance. This was opposed as Ngāti Kurauia view the environment holistically and not in isolation. As a result, I decided that the variables for the cultural monitoring framework would not be placed in a hierarchical order.

Consideration was given to how the field protocol would be designed. The mahi rangahau by Tipa and Tierney (2003) provided a semi-quantitative approach for hapū, iwi, and other organisations to assess attributes on a similar scale (i.e., between 1 and 5). In this mahi with Ngāti Kurauia however we decided on a scale from 0 to 5. This approach provides for increments of 20% as opposed to the coarser 25% increments.

3.2 Conventional Sampling Framework

Environmental Indicators

This sub-section will describe the methods involved with the scientific sampling regime undertaken on the Tokaanu Stream. Included within this sub-section is macroinvertebrate community sampling, cotton strip assays, riparian habitat assessment, stream profiling and velocity metrics, environmental DNA, water sampling including both basic and advanced analysis, total suspended fine sediment and deposited fine sediment.

Physicochemical

Water quality parameters, including temperature (°C), dissolved oxygen (mg/L and % saturation), and conductivity (ambient and specific conductivity, µS/cm), were measured at each site using a YSI Pro2030 Dissolved Oxygen and Conductivity Meter (YSI Inc., Yellow Springs, OH, USA). This meter was calibrated on-site before sampling. pH was recorded using an EC-PCTestr35 handheld probe (Eutech Instruments Pte Ltd, Paisley, UK). All measurements were taken between 9 a.m. and 4 p.m., and the mean values for each site were used in data analyses.

Water clarity (cm) was measured with a 1 m clear acrylic tube (50 mm diameter) equipped with a magnetic black slider. The target (i.e., black slider) allows for visual assessment of water clarity. The target is slid away from the viewer until it disappears, with greater distances indicating clearer water. This method is effective for turbid water (clarity less than 1 m) but unsuitable for clearer waters due to the tube's length limitation, meaning that it was only able to detect impaired water clarity during or just after rain events.

Physicochemical sampling was undertaken every six weeks, two days after every planned cultural monitoring effort. Hapū members were invited to attend, though their presence wasn't required for this component. Sampling was undertaken nine times throughout the 2023/24 period. Physicochemical variables were measured on 14 December 2023, 22 January 2024, 4 March 2024, 22 April 2024, 27 May 2024, 8 July 2024, 20 August 2024, 23 September 2024, and 31 October 2024.

Water Quality

I collected water samples at each site for laboratory analysis, adhering to the National Environmental Monitoring Standards (NEMS) for surface water. Stream water was sampled just below the surface at the channel thalweg. Two samples were collected. The first was a 500 ml sample for microbial analysis (*Escherichia coli* counts), Total Nitrogen (TN) and Dissolved Reactive Phosphorus (DRP). A separate 100 ml sample, preserved with sulphuric acid, was taken for Total Ammoniacal-N, Nitrate-N and Nitrite-N, Total Kjeldahl Nitrogen (TKN), and Total Phosphorus (TP). Water samples from my six sites were collected on the same day and sent to Hill Laboratories in Hamilton for analysis. Water quality parameters were analyzed using standard methods (APHA 1995). Samples were collected 3 times to reflect variable water quality conditions over time. The dates sampled were 14 December 2023, 3 May 2024, and 15 July 2024.

Suspended Fine Sediment

Water samples for estimation of suspended fine sediment (SFS) were also collected. Fine sediment (< 2mm) is widely recognised as an important pollutant of aquatic habitats that is often associated with human impacts on streams and rivers (Hughes, 2016). A 1 L sample was collected from each site every six weeks alongside the stream physicochemical monitoring. I processed the SFS samples in the laboratory. Firstly, I pre-ashed the filters (Whatman GF/C, 47 mm diameter) prior to filtering the water samples. Each filter was heated to 550° C in a Nabertherm furnace for 4 hours to remove any organic matter that may have been present. Once ashed, each filter was weighed, recorded, and placed in a numbered tray ready to filter the water samples.

In the laboratory, each water sample was separated into a 500 ml subsample and filtered through a pre-ashed GF/C filter. Each filter was dried for 24 hours in a Contherm Digital Series Oven preheated to 60° C prior to weighing and ashing. Samples were weighed to determine the total dry weight of the total suspended sediment (TSS). Following this, each filter was ashed to remove the total organic sediment (TOS), leaving only the total inorganic sediment (TIS) load and then reweighed when cool. TSS, TOS, and TIS were expressed as mg/L.

Deposited Fine Sediment

Deposited fine sediment (DFS) and general substrate composition were determined on 31 October 2024 using the stream assessment method 2 (SAM2) and outlined in Clapcott *et al.* (2011). Deposited fine sediment is a major stressor in stony-bottomed streams and rivers due to its ability to smother benthic habitat, degrade food resources, cause physical harm through abrasion and gill-clogging and contribute to increased turbidity (reducing light attenuation), thus negatively impacting stream health (Burdon *et al.*, 2013).

The SAM2 method visually assesses DFS on the streambed. This involves selecting five random transects across the stream channel within the study reach. Along each transect, I observed the streambed at four random points using a bathyscope (underwater viewer). The visible percentage of DFS cover within four quadrants in the bathyscope was estimated and recorded. This process was repeated for all five transects, yielding a total of 20 independent observations, as per Clapcott *et al.* (2011). Mean values were expressed as % DFS.

Discharge and Stream Profile

Discharge and the stream profile was measured at all six sites on 31 October 2024 under base flow conditions. Channel widths, depths, and flow velocities were measured on a single transect at each site following Harding *et al.* (2009). Flow velocity was measured using a Marsh-McBirney Flo-Mate 2000 (HACH Company, Frederick, MD, USA). At Site 6 only the true left side was sampled due to the depth of the stream on the day of sampling. This means that my estimates of discharge at this site are less certain than that at Sites 1-5.

Riparian Habitat Assessment

Rapid riparian habitat assessment is a common component of stream sampling. It is a critical tool for understanding the health of a stream or river by evaluating the condition of the land immediately bordering it—the riparian zone. Some researchers seek to assess the ecological state of a stream environment by examining its riparian habitat (Abboud *et al.*, 2012). Other researchers use riparian habitat assessments in stream studies to better explain the overall impacts on these ecosystems (Lukman & Lukman, 2023).

The P2d Stream Habitat Assessment Protocols (SHAP) described in Harding *et al.* (2009) was used to provide a descriptive summary of the riparian habitat along the Tokaanu Stream at each study site. Thirteen riparian attributes were assessed at each of the six sites along the Tokaanu Stream with the assistance of a hapū member on 18 January 2024. The P2d protocol involves scoring 13 riparian attributes 1-5 on each bank and summing the average score for each attribute to derive a Riparian Condition Index, where higher scores indicate more intact and high-quality riparian habitat.

Structural Indicators

Macroinvertebrates

Macroinvertebrate samples were collected following the National Environmental Monitoring Standards (NEMS) protocol recommended for kicknet sampling in wadable streams (NEMS, 2022). I used a kicknet (mesh size 0.5 mm, frame width ~30 cm) for macroinvertebrate sampling. The reach sampled at each stream site contained habitat representative of the entire stream segment, and sampling targeted the most commonly available wadable mesohabitats (e.g., riffles, runs) within the reach. A single composite sample was comprised of 4–8 sampling units, with effort split based on the proportional contribution of each mesohabitat in the sampling reach. Each sampling unit was approximately 0.1–0.15 m^2 in area, and the total sampled area sampled was 0.6–0.9 m^2. Samples were preserved in 70% ethanol, labelled and stored for further processing (NEMS, 2022). Stream macroinvertebrates were sampled from all sites on two dates (14 December 2023, 31 October 2024). Sampling was conducted in summer after a period (one week) of settled weather without rain (NEMS, 2022).

Macroinvertebrate samples were processed according to the Fixed Count (200) and Scan for Rare Taxa protocol (NEMS 2020) (Death & Collier, 2010). Ethanol from samples was drained under a fume hood, and samples washed using a 500µm mesh sieve remove any fine sediment (clays and silt) and residual alcohol. Samples that contained a lot of sand were also first rinsed through a 1 mm sieve to remove the larger fine particles from the sample. Washed samples were subsampled at 25% increments. Subsamples were placed into flat bottom white trays for sorting. Trays were partially filled with water until the sample was completely immersed to prevent sample desiccation and aid sorting.

The first subsample was processed by removing individuals, identifying and enumerating them to MCI-level taxonomy under a stereo microscope using standard guides (Winterbourn *et al.*, 2006). If the first subsample did not contain 200 individuals, the second subsample (i.e., 25% of the sample) was sorted in its entirety until an excess of 200 individuals were identified and enumerated. Empty caddisfly cases, pupae, terrestrial invertebrates, and moulted exuviae were excluded from final counts. The final scan of remaining subsamples identified any rare taxa not recorded during the fixed count. The rare taxa were identified and enumerated in a separate column on my datasheet. Individual kōura (*Paranephrops planifrons*) released when the samples were collected were also recorded as rare taxa for the relevant site. Picked specimens and sample residuals were stored separately in 70% ethanol for quality control/quality assurance (QC/QA). My supervisor (Dr Frank Burdon) provided QC/QA to ensure that specimens were accurately identified. Upon processing completion, count data from each site was entered into Excel. This data was shared with Dr Frank Burdon for final QC/QA. The final data was provided to hapū kaumatua (Mr George Asher) as a key deliverable of my project.

Environmental DNA

I collected environmental DNA (eDNA) sampled from the Tokaanu Stream on two dates. On the first sampling date (14 December 2023), I sampled the most upstream site (Site 1) and the most downstream site (Site 6). On the second sampling date (8 July 2024), I only sampled Site 6. On both occasions, eDNA sampling used the six-replicate method recommended by Smith *et al.* (2024) for the detection of freshwater fish. Water samples were collected from just below the water surface of the channel thalweg using a standard 50 ml syringe and then passed through a 1.2 µm cellulose acetate syringe filter until 1 L of stream water was filtered. At the end of filtering, samples were preserved with 350 µl DNA/RNA Shield preservation buffer (Zymo Research, Irvine, CA, USA) and placed in a sealed bag. Samples from each site were collected using independent 50 ml syringes and gloves were changes between sites to reduce contamination.

Filters were sent to WilderLab (Wellington, NZ) for DNA metabarcoding. This process involved DNA extraction, PCR amplification, sequencing, and bioinformatic processing following the methods outlined in (Wilkinson *et al.*, 2024). DNA metabarcoding allows for the simultaneous identification of numerous Operational Taxonomic Units (OTUs) or Amplicon Specific Variants (ASVs) in eDNA samples by generating millions of sequences using high-throughput sequencing (HTS) techniques after PCR amplification. The eDNA results have not been made publicly available online via the WilderLab website out of respect for Ngāti Kurauia.

Functional Indicators

Cotton Strip Assay

The Cotton Strip Assay (CSA) is a simple, inexpensive, and standardized method used to assess the rate of organic matter decomposition, particularly cellulose breakdown, in various environments like soil and aquatic ecosystems (Tiegs *et al.*, 2013). The CSA has been extensively used in stream ecosystems (Tiegs *et al.*, 2024) and is increasingly used in non-wadeable streams and rivers (Pingram *et al.*, 2020; Wood *et al.*, 2021) to determine ecosystem health. I used the CSA as a functional indicator to help monitor the ecosystem health of the Tokaanu Stream. The CSA uses the rate of cellulose decomposition as an integrative measure of microbial activity and the overall health and functioning of an ecosystem's decomposition processes. The CSA is sensitive to various environmental factors, including temperature, nutrient availability, and the presence of pollutants (Burdon *et al.*, 2020).

Preparation: Cotton strips were prepared using Artist’s canvas fabric (Fredrix, Style #548) to the standard described in Tiegs *et al.* (2013). Cotton strips were 80 mm in length and 25 mm width with a 3 mm frayed fringe. A hole was pushed into one end of each cotton strip to allow for easy insertion of a plastic cable binder (11.5 cm x 3mm).

Deployment*:* Cotton strips were deployed on two occasions during the sampling period. The first CSA was from 14 December 2023 to 28 December 2023, while the second CSA was from 31 October 2024 until 13 November 2024. On both occasions, a light chain was used so the cotton strips would quickly sink yet be easily retrieved. Each chain included a two-meter length of paracord attached to the upstream end of the chain and fixed to the stream bank (either a tree trunk or a wooden stake hammered into the bank). Wooden stakes were avoided where possible to prevent disturbance to the stream bank and to make the CSA less conspicuous. Cable binders inserted into the cotton strips were used to secure individual cotton strips equidistant along the length of chain. The chain was deployed on the stream bed parallel with current flow.

During the first sampling period, four cotton strips were attached to each length of chain, two at each site for a total of eight strips at each sampling site within the sample reach. Included with the cotton strips at each site was a HOBO MX2202 water temperature/light level logger (Onset Computer Corp., Bourne, MA, USA). I was particularly interested in the effect of temperature due to the Tokaanu Stream having areas of geothermal activity.

The second round of the CSA tested two different deployment methods. The first method was the same as the first sampling round using eight cotton strips. The second method attached each of eight cotton strips to short lengths of black 4 mm polypropylene rope. The polypropylene rope was buoyant and intended to lift the cotton strips off the streambed. Burial in fine sediment can impact microbial activity and reduce cellulose degradation rates (Mack *et al.*, 2024). Thus, this second method was intended to reduce the influence of fine sediment burial on the CSA.

Retrieval: The cotton strips were retrieved from the Tokaanu Stream after 14 days consistent with the recommendations in Tiegs *et al.* (2013) for New Zealand streams. When retrieving the cotton strips, they were carefully removed to prevent damage. Cable binders were cut, and each cotton strip was placed into 96% Ethanol for 10 seconds before being placed into an individually labelled zip-lock bag. The bags were placed on ice in a cooler bin for transport and stored in -20 °C freezer until they were processed.

Laboratory Processing*:* The frozen cotton strips were thawed for three hours before being processed. Each cotton strip was soaked in tap water and gently rubbed to remove biofilms and particulate matter. Once washed, each cotton strip was again immersed in 96% Ethanol for at least 10 seconds, then placed into aluminium trays for drying. Once all strips had been processed, they were dried in a Contherm Digital Series Oven preheated to 60 ° C for 48 hours. Tensile strength (N) was measured for each strip using a Mark-10 Model MG100 tensiometer (Copiague, NY, USA) mounted on a motorized test stand, with strips pulled at 2 cm/min. To establish a baseline, control strips were wetted in tap water, gently rubbed, sterilized with 96% ethanol, and then processed alongside the treatment strips. Tensile loss was calculated as the percent of the initial tensile strength lost per day of incubation (Eq.1) following Tiegs et al. (2013) and as the breakdown coefficient *k* per day of incubation (Eq.2) following Burdon et al. (2020). The percent of the initial tensile strength lost per day of incubation (*TSL*) was calculated as (Eq.1):

$$TSL = \frac{\left(1 - \frac{TS_t}{TS_0}\right) \times 100}{t} \qquad (1)$$

where TS_t is the maximum tensile strength recorded for each of the strips incubated in the field, TS_0 is the mean tensile strength of the control strips that were not incubated in the field, and t is the incubation period (days).

The breakdown coefficient k per day of incubation (Eq.2) was calculated as:

$$k = \frac{-ln\left(\frac{TS_t}{TS_0}\right)}{t} \tag{2}$$

where TS_t is the maximum tensile strength recorded for each of the strips incubated in the field, TS_0 is the mean tensile strength of the control strips that were not incubated in the field, and t is the incubation period (days).

I summed the average daily water temperatures over each incubation period to calculate temperature-days (i.e., the temperature-days accumulated from Day 1 to the retrieval day) for an approach that accounts for temperature effects (Colas *et al.*, 2019). Temperature-days were used as t in the above equations (Eq.1,2) to calculate temperature-corrected rates of *TSL* and k.

3.3 Data Analysis

Macroinvertebrate indices

Data was analysed and visualised using R statistical software (R Development Core Team, 2022). I used an R script in RStudio (Version 1.4.1717) to calculate the Macroinvertebrate Community Index (MCI), its quantitative equivalent, the Quantitative Macroinvertebrate Index (QMCI), and the Average Score Per Metric (ASPM). These three metrics are used in Aotearoa New Zealand to determine the health of the macroinvertebrate communities health (New

Zealand Government, 2020). The MCI is a metric that uses taxa tolerance scores to determine an overall score of stream health based on taxa presence. The MCI score is calculated using the following formula (Eq.3):

$$\text{MCI} = \frac{\sum_{i=1}^{i=S} a_i}{S} \times 20 \qquad (3)$$

where S = the total number of taxa in the sample, and a_i = the tolerance value for the ith taxon. MCI scores range from 0 (where no scoring taxa are present) to 200. The Quantitative MCI (QMCI) is calculated from count (abundance) data using the following formula (Eq.4):

$$\text{QMCI} = \sum_{i=1}^{i=S} \frac{(n_i \times a_i)}{N} \qquad (4)$$

Where S = the total number of taxa in a sample, n_i = the abundance for the ith scoring taxon, a_i = the tolerance value for the ith taxon and N = the total abundance of the scoring taxa for the entire sample.

I also calculated the ASPM index, a multi-metric index developed by Collier (2008) and detailed in the NPS-FM. This index assesses stream health by averaging the normalized scores of three key metrics: the Macroinvertebrate Community Index (MCI), % EPT abundance, and EPT richness. Ephemeroptera, Plecoptera, and Trichoptera (EPT)—also known as mayflies, stoneflies, and caddisflies—are aquatic insect taxa generally sensitive to environmental degradation. % EPT abundance represents the proportion of EPT individuals in a sample, while EPT richness is simply the number of different EPT taxa present. Higher values for both indicate good stream health, although some naturally occurring factors, like soft-bottomed streams, can influence EPT presence as they typically prefer stony habitats. I also normalized the ASPM index using values from a local reference site (Site 5) to account for conditions in the segment of the Tokaanu Stream sampled.

Statistical tests

I assessed which attributes in the Ngāti Kurauia cultural monitoring framework were associated with different sites using Principal Components Analysis (PCA). The PCA was generated using the *rda* function in the *vegan* R package (Oksanen *et al.*, 2013).

I used linear regression to visualize the influence of stream distance (i.e., distance in km from Site 1) on selected response variables (e.g., invertebrate metrics including the MCI). To test differences in changes moving downstream between years, I used generalised linear models (GLMs) including distance, year, and their interaction as predictors. GLMs were fitted in R using the *glm* function. I also assessed changes in macroinvertebrate community composition using a multivariate approach. Macroinvertebrate data was Hellinger transformed and converted to a Bray-Curtis similarity matrix. The differences in community composition were visualised with a non-metric multidimensional scaling (NMDS) plot using the *metaMDS* function in the *vegan* R package.

Due to the occurrence of instream habitat remediation in 2024, I also used my macroinvertebrate metrics data in a BACI (Before-After, Control-Impact) design. To test the impact of the instream habitat remediation in 2024 I used a GLM comparing impact sites (Sites 4-6) with control sites (Sites 1-3) in 2023 (Before) and 2024 (After) the intervention. Post-hoc comparisons were tested with Tukey's correction for multiplicity using the *lsmeans* package in R (Lenth, 2016).

I also tested for differences in cotton-strip breakdown using GLMs. The first model tested for differences between years, sites, and their interaction. The second model tested for differences between the two deployments methods, sites and their interaction in the second year. Post-hoc comparisons were tested with Tukey's correction for multiplicity using the *lsmeans* package in R (Lenth, 2016).

4 Results

4.1 Cultural Monitoring Framework

This section presents the results of field assessments undertaken using the Ngāti Kurauia, Cultural Monitoring Framework (CMF). Here I will present results from 16 attributes, assessed via a modified Likert scale (0 – 5 representing 0 – 100%). These attributes include the following: vegetation diversity adjacent to the Tokaanu Stream, vegetation cover adjacent to the stream, in-stream vegetation, stream substrate, bird diversity and bird song, sound of water flow, pollution, engineered (man-made) features, Māhinga kai observed, water clarity, odour, feel and colour of the water, streambed colour, and wairua. The full details of these attributes and how they were assessed are provided in the field book found in Appendix A. This document outlines the field protocols used by hapū participants to assess the list of visual indicators.

Vegetation – Diversity adjacent to the stream

This attribute addresses vegetation diversity immediately adjacent to the stream and each sampling site. A score of 0% indicates no vegetation next to the stream whereas 100% indicates that only native vegetation is present (Figure 8). The maximum mean score was achieved at Site 1 with 66.3% (± standard deviation 4.8%). This score indicated that Site 1 has a mixture of native and exotic woody vegetation (Appendix A). Site 4 attained a mean score of

64.6% (± 30.9%). While not the lowest mean value, Site 4 had the largest amount of variation for any of the six sites assessed. Site 5 was the site with the lowest mean score for vegetation diversity adjacent to the stream, but this score was still 54.17% (± 9.4%).

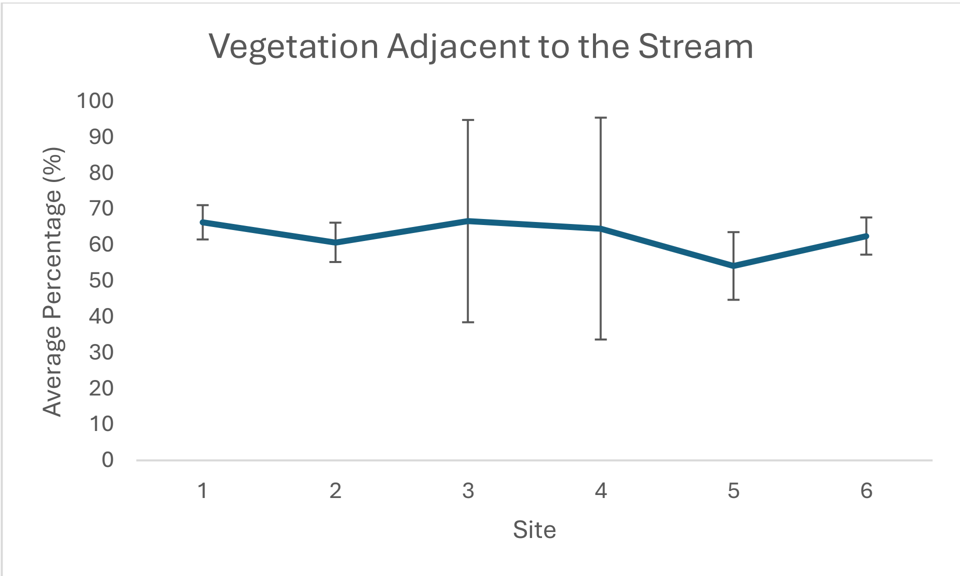


Figure 8. Mean scores (± standard deviation) for the proportion of native versus exotic riparian vegetation assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Vegetation – Cover adjacent to the stream

This attribute estimates the riparian vegetative cover at each site. A score of 0% describes that no vegetation is present adjacent to the stream, whereas 100% indicates complete cover by vegetation along the riparian margin at the site (Appendix A). Site 3 had the maximum mean score of 78.8% (± 32.1%; Figure 9), although this score was highly variable. Site 1 had the lowest variability, but it also had the second lowest mean score with 66.5% (± 5.0%). Site 4 again had the greatest variability with a mean score of 70.6% percent (± 36.6%).

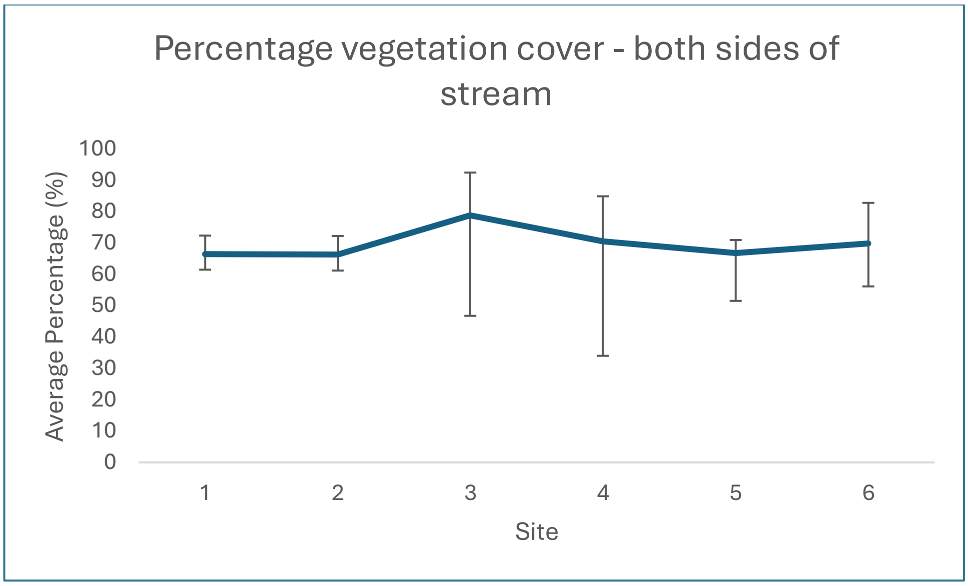


Figure 9. Mean scores (± standard deviation) for the proportional vegetation cover (%) assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Vegetation – In-stream diversity

This attribute addresses the diversity of in-stream vegetation based on whether the species present were deemed beneficial or not. A score of 0% indicates no in-stream vegetation present, whereas 100% indicates that only beneficial vegetation is present at the site (Appendix A). The minimum mean score was at Site 1 with 38.8% (± 4.5%). This score (greater than zero but less than 50%) indicates that Site 1 has in-stream vegetation that Ngāti Kurauia deem as non-beneficial (Figure 10). Site 4 had a mean score of 44.9% (± 21.8%), again showing high variability over the five sampling haerenga (assessment dates).

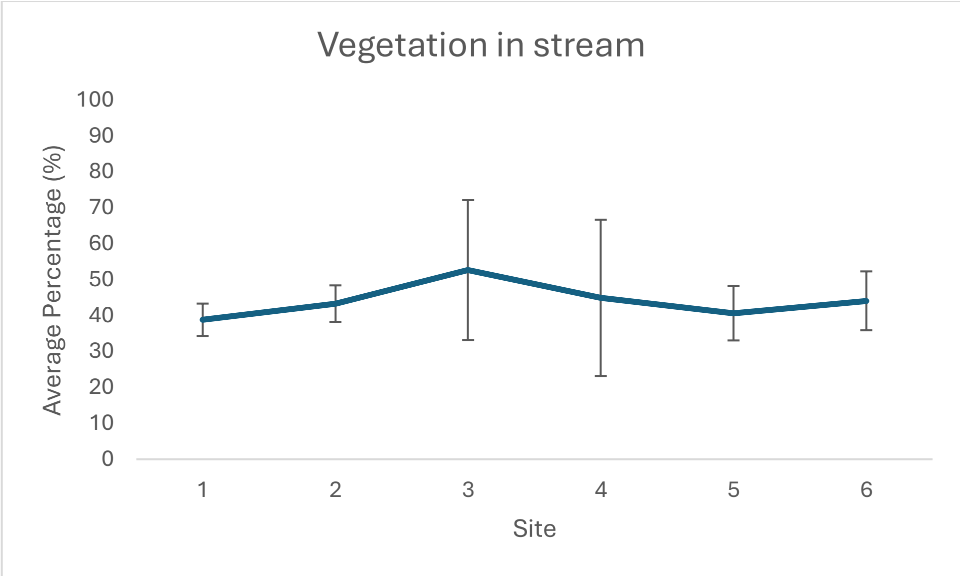


Figure 10. Mean scores (± standard deviation) for the proportion of beneficial vs non-beneficial in-stream vegetation assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Stream substrate

This attribute involved a visual assessment of the stream substrate composition at each site (i.e., ranging from mud and silt to cobbles and boulders). A score of 0% reflects a substrate dominated by mud and/or silt, whereas 100% indicates stream substrate dominated by cobbles and/or boulders (Appendix A). The maximum mean score was found at Site 3 (74.3% ± 25.1%), whereas the lowest mean score was recorded at Site 5 (42.4% ± 10.7%) (Figure 11). Site 5 was notable in that it had the lowest variability, indicating strong agreement across the five haerenga.

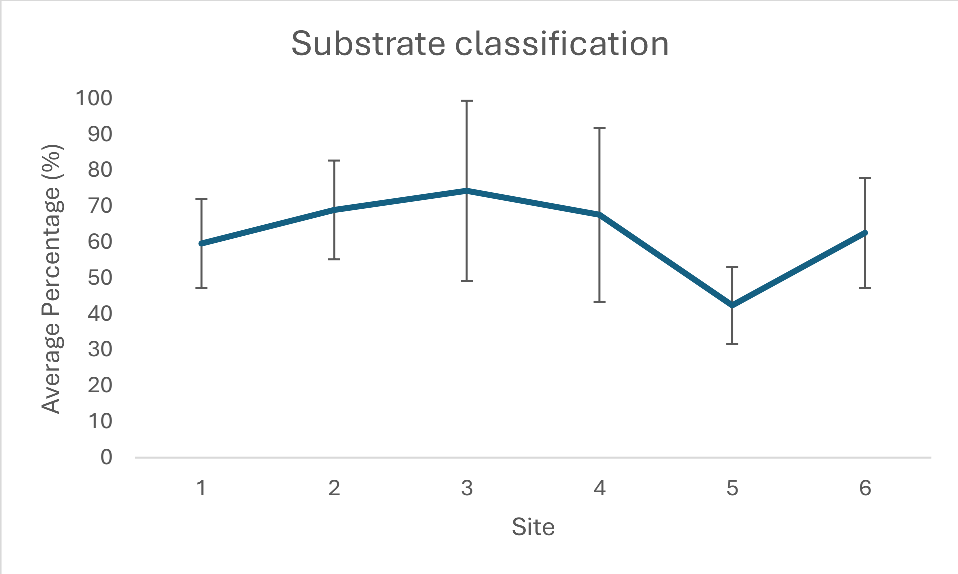


Figure 11. Mean scores (± standard deviation) for in-stream substrate composition assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute. A score of 0 describes a streambed covered in silt whereas a score of 100 indicates a rocky streambed dominated by cobbles and/or boulders.

Bird diversity

This attribute assesses the bird community at each site and whether the birds seen were native or exotic. A score of 0% indicates no birds were observed on the day of cultural monitoring, whereas 100% indicates only native species were observed (Appendix A). Site 1 recorded the maximum mean score of 45.7% (± 3.67%; Figure 12). This score indicated that birds were abundant at this site but included a mixture of native and exotic species. Site 3 had the lowest mean score (26.7% ± 15.0%). This score indicated few birds were observed and were mainly exotic species. Site 6 had the most variable score with a mean 34.4% (± 27.3%). In general, the variability of observed scores over time increased moving downstream.

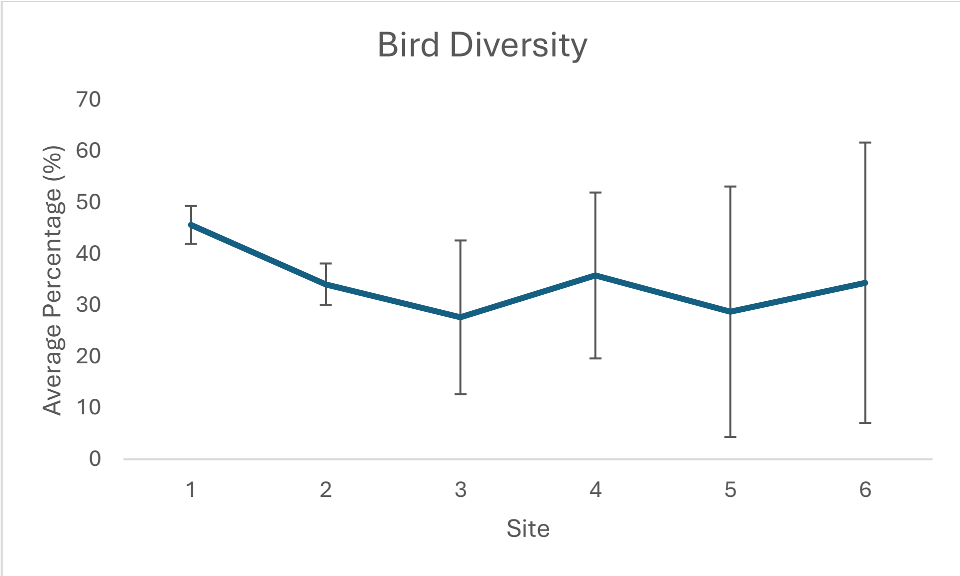


Figure 12. Mean scores (± standard deviation) for bird diversity assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Sound – Bird song

Hapū members also listened to bird song while carrying out cultural monitoring. A score of 0% indicates that no bird song was heard whereas 100% indicates that abundant bird song including native species was heard within the 10-minute assessment period (Appendix A). Site 1 had the maximum mean score of 43.3% (± 7.8%; Figure 13). This mean score suggests bird song was heard from exotic species. Site 5 had the lowest mean score with 13.5% (± 8.9%), indicate that little to no bird song was heard at this site, and what was heard was exotic species. Site 6 was the most variable site with a mean score of 28.4% (± 18.7%).

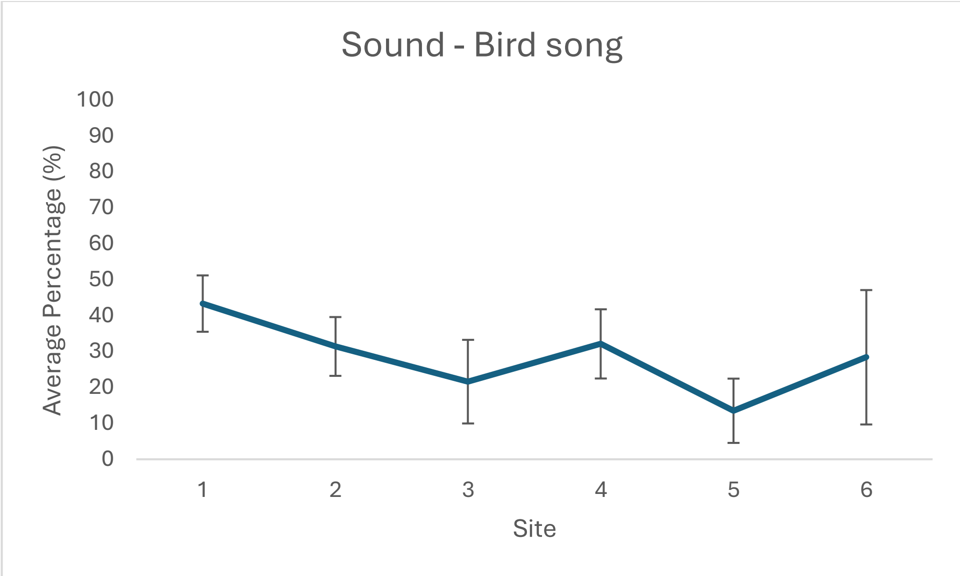


Figure 13. Mean scores (± standard deviation) for bird song assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Sound – Water flow

The sound of the flowing water was also listened to at each site during cultural monitoring. A score of 0% means that no sound was heard, whereas 100% reflects the continual sound of fast, turbulent flowing water (Appendix A). Site 2 had the maximum mean score with 40.6% (± 5.9%). This result indicated that the stream water rushing out of the aqueduct was heard by hapū members at this site. Site 1 had the lowest mean score (25.2% ± 5.9%). Site 4 was the most variable with a mean score of 35.6% (± 14.4%). Site 5 was the least variable with a mean score of 26.7% (± 4.1%; Figure 14).

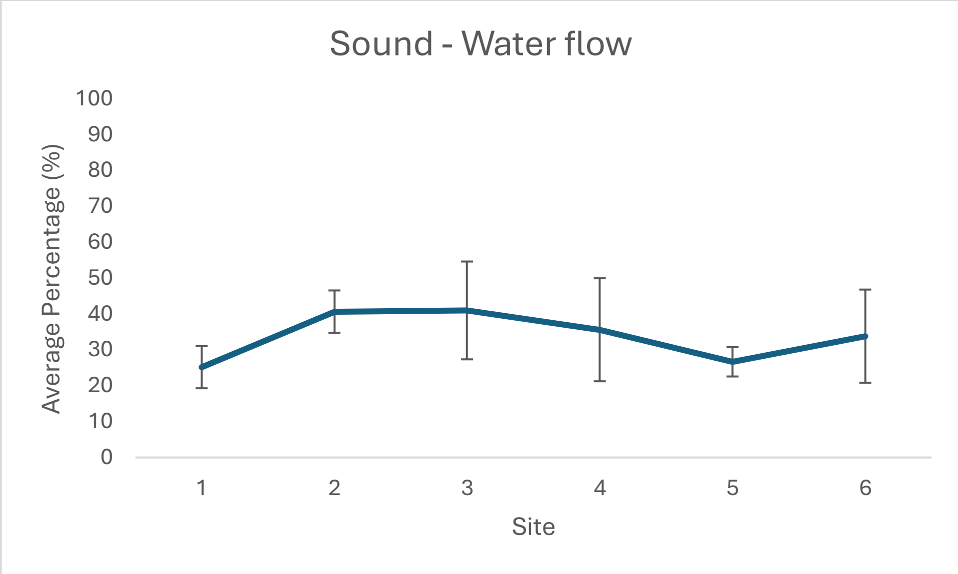


Figure 14. Mean scores (± standard deviation) for the sound of water flow assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Pollution

Levels of pollution were visually assessed at each site during cultural monitoring. A score of 0% indicates the presence of pollution (e.g., 'fly-tipped' rubbish, car parts or wrecks, dead animals and waste), whereas 100% indicates that no rubbish was present (Appendix A). Site 2 had the lowest amount of observed pollution with a mean score of 81.7% (± 5.9%; Figure 15). This score was indicative of occasional paru (rubbish) that would be easily removed from the stream. Site 5 had the lowest mean score with 64.7% (± 16.6%), indicating the presence of rubbish including car tyres. Site 4 was the most variable with a mean score of 78.3% (± 37.2%).

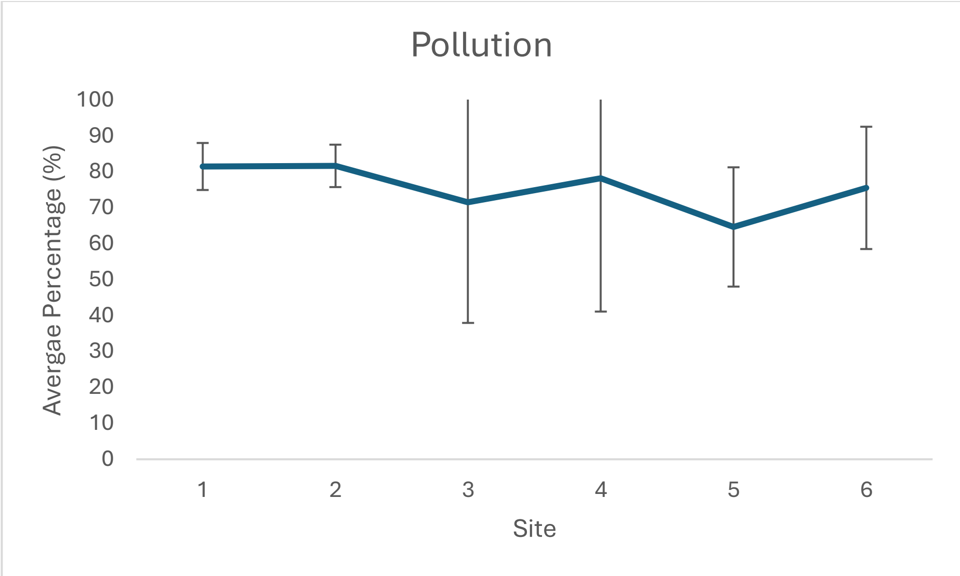


Figure 15. Mean scores (± standard deviation) for pollution (paru - rubbish) assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Engineering

Engineered (man-made) features present at each site were assessed during cultural monitoring. A score of 0% indicates that man-made structures (and engineering works) dominate the stream and riparian zone within 50 m of the site, whereas 100% indicates that there are no man-made structures present within the same reach (Appendix A). Site 1 had the lowest mean score with 17.3% (± 7.9%; Figure 16), indicating the presence of the concrete culvert that diverts the stream away from the tailrace. Site 5 had the highest mean score (54.3% ± 25.9%), indicating fewer man-made structures within the 50 m reach assessed.

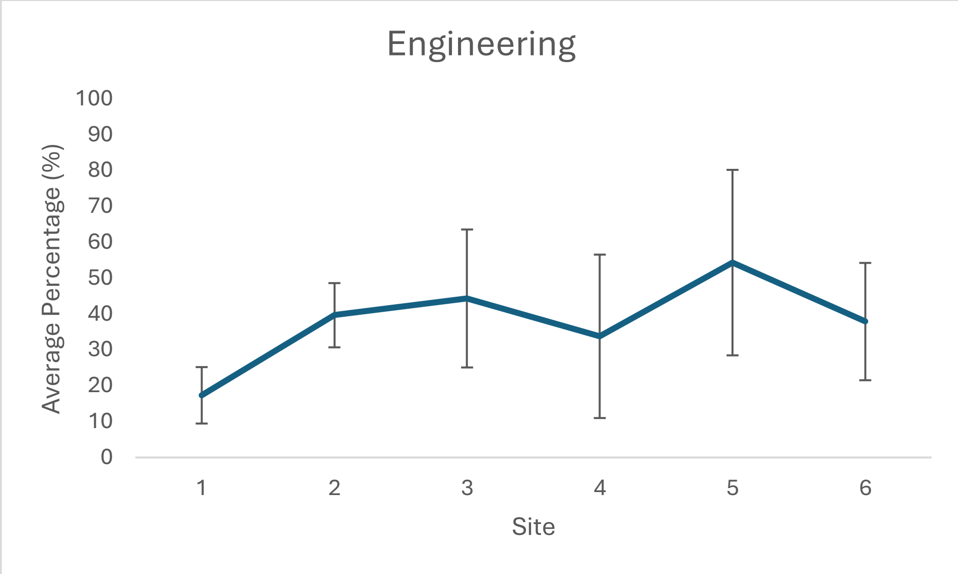


Figure 16. Mean scores (± standard deviation) for man-made features (engineering) assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Māhinga kai

The Māhinga kai attribute describes the availability of food (or other traditional resources) that can be gathered at each site. A score of 0% means that no traditional resources were available for collecting, whereas 100% indicates the presence of five or more traditional resource (Appendix A). Site 3 had the maximum mean score for the Māhinga kai attribute (44.3% ± 13.1%; Figure 17). This was indicative of at least two traditional resources being present. Site 2 had the lowest mean score for the Māhinga kai attribute, but also the lowest variability (25.7% ± 6.2%). This score was indicative of at least one traditional resource being present. Site 4 was the most variable with a mean score of 34.8% (± 14.6%).

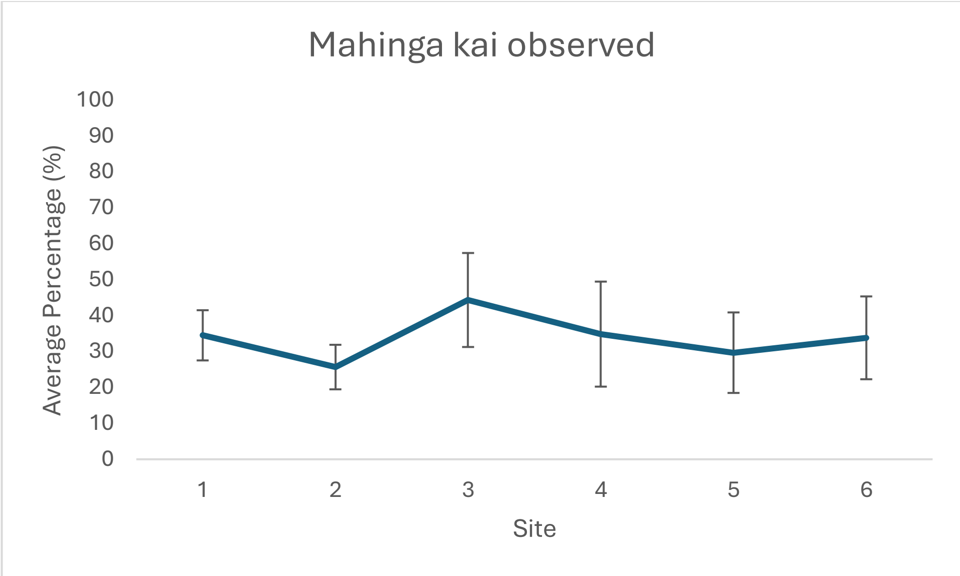


Figure 17. Mean scores (± standard deviation) for Māhinga kai availability assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Water clarity

The water clarity attribute was assessed during cultural monitoring. A score of 0% indicates turbid water with high concentrations of suspended solids (i.e., muddy), whereas 100% indicates water that was completely clear with little to no suspended solids (Appendix A). Site 1 had the maximum mean score of 92.5% (± 9.4%; Figure 18). This result was indicative of stream water with high levels of clarity. Site 5 had the lowest mean score for water clarity (62.3% ± 17.7%). Site 4 was the most variable with a mean score of 85.7% (± 36.5%). These lower scores indicated that hapū members could see organic matter particles in the water, but the water was not turbid (cloudy).

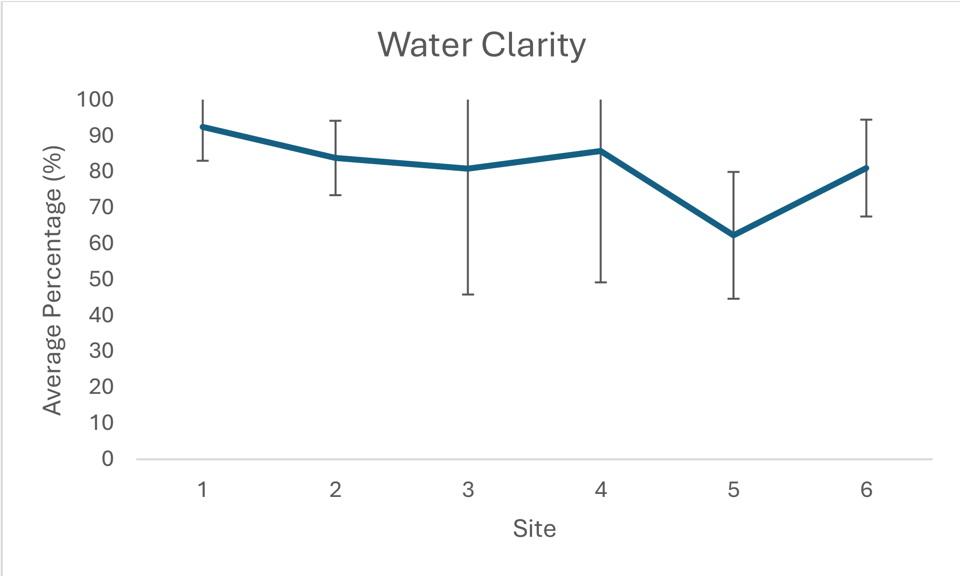


Figure 18. Mean scores (± standard deviation) for water clarity assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Odour

Hapū members assessed the odour of each site during cultural monitoring. A score of 0% indicates the presence of an offensive odour, whereas 100% indicates an abundance of pleasant odours (Appendix A). Site 1 had the maximum mean score for odour with lowest variability (73.5% ± 3.9%). This score was indicative of a mild, pleasant smell. Site 5 had the lowest mean score for odour (57.9% ± 8.1%). Site 4 was the most variable for odour with a mean score of 66.4% (± 33.2%; Figure 19), indicating the occasional presence of unpleasant odours.

Figure 19. Mean scores (± standard deviation) for levels of offensive odours assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Feel of the water

Hapū members assessed the feel of the water at each site during cultural monitoring. A score of 0% indicates water that is slimy to the touch, whereas 100% indicates water that feels clean, light, and fresh to the touch (Appendix A). Site 1 had the maximum mean score (90.4% ± 7.7%). This score was the least variable of the six sites (Figure 20) and indicated water that was clean and light to the touch, but with the possibility of some suspended fine sediment. Site 5 had the lowest mean score with 70.8% (± 11.0%). Site 4 was the most variable with a mean score of 88.8% (± 40.9%).

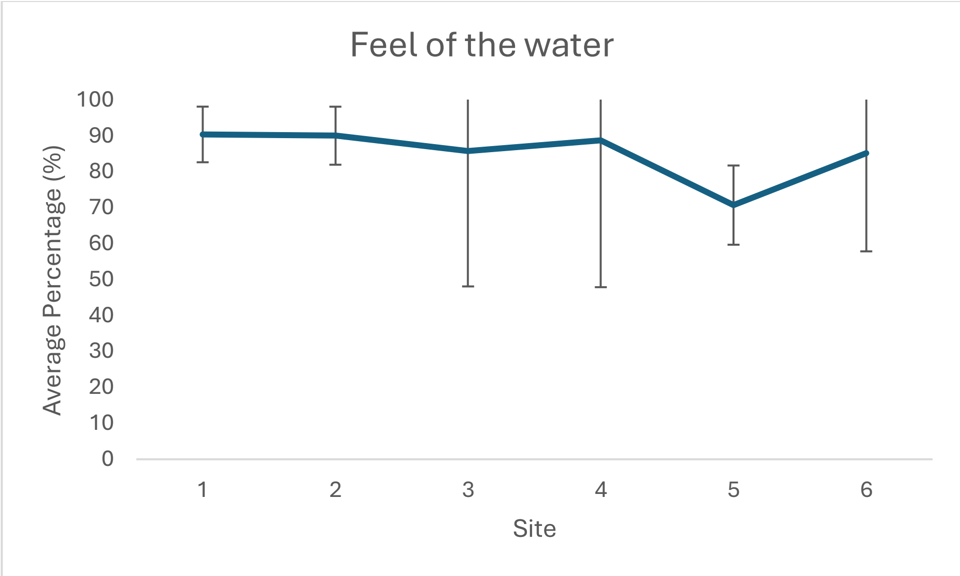


Figure 20. Mean scores (± standard deviation) for the feel of the water assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Water colour

Hapū members assessed the colour of water at each site during cultural monitoring. A score of 0% indicates the water is black whereas 100% indicates the water is completely clear without discolouration (Appendix A). Site 1 had the maximum mean score with 98.0% (± 10.1%; Figure 21). Site 5 had the lowest mean score with 65.1% (± 15.7%). Site 4 was the most variable site through time with a mean score of 88.8% (± 38.1%), possibly indicating episodic discolouration from a tributary upstream.

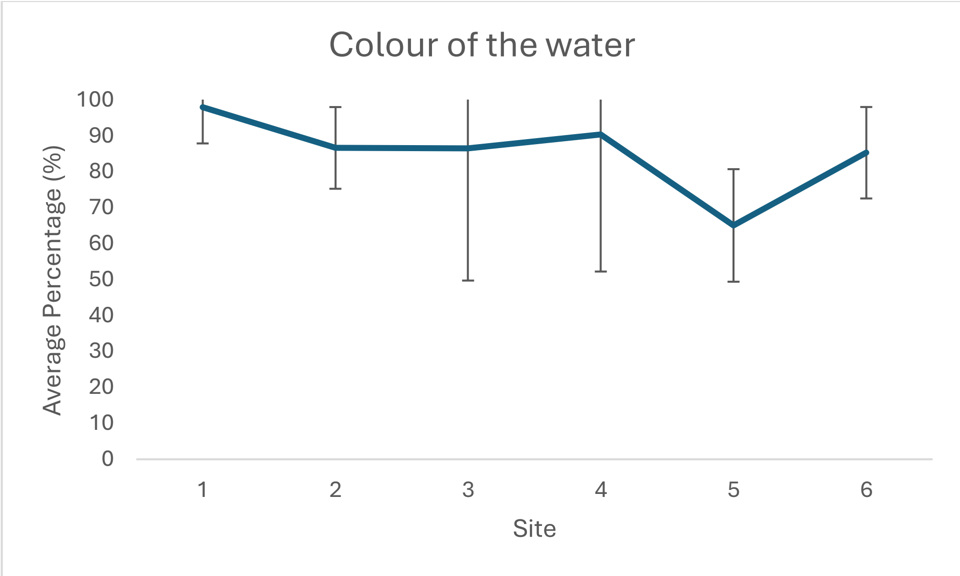


Figure 21. Mean scores (± standard deviation) for the colour of stream water assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Streambed colour

Hapū members also assessed the colour of the streambed at each site during cultural monitoring. A score of 0% indicates a streambed which is black whereas 100% indicates the streambed is natural in appearance (light brown – yellow – orange) and representative of the surrounding environment (Appendix A). Site 1 had the lowest mean score for streambed colour (46.9% ± 6.0%). This score was indicative of a light grey colour. Site 1 had the least variable score for this attribute across the six sites over time (Figure 22). Site 3 had the maximum mean score of 65.5% (± 23.7%). Site 4 was the most variable with a mean score of 54.2% (± 27.1%). This score was indicative of light grey – green colour.

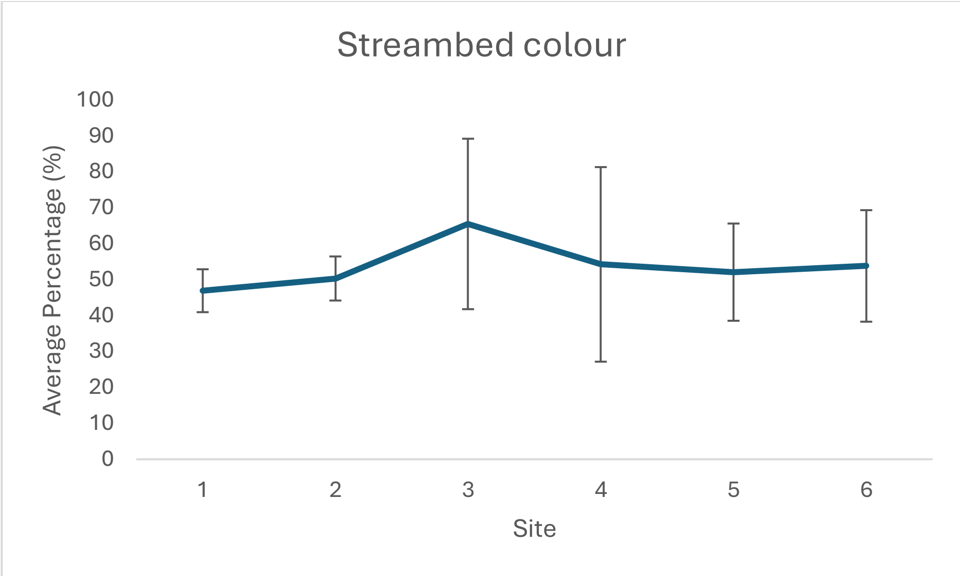


Figure 22. Mean scores (± standard deviation) for the streambed colour assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Wairua

During cultural monitoring, hapū members assessed the wairua (spiritual connection) felt at each site. A score of 0% suggests the site feels heavy, burdened, or sick. In contrast, a score of 100% suggests the site is light, rejuvenating, and maintains a close connection with the person(s) undertaking monitoring (Appendix A). Site 1 had the highest wairua (68.8% ± 4.0%). Site 1 also had the least amount of variability in wairua (Figure 23). Sites 4 (50.8% ± 29.4%) and 5 (50.8% ± 17.5%) had the lowest wairua. However, Site 4 had the most variability in wairua.

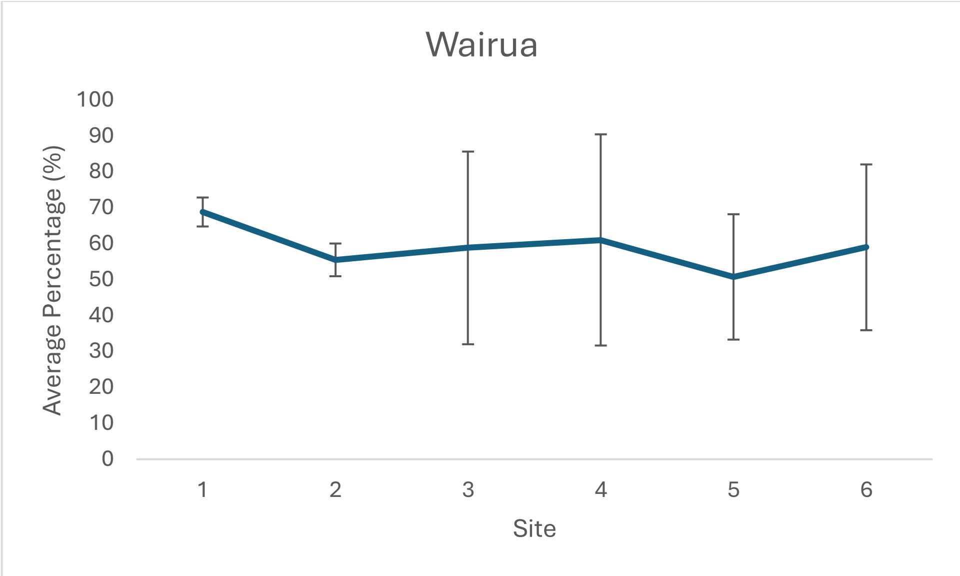


Figure 23. Mean scores (± standard deviation) for wairua assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for this attribute.

Ngāti Kurauia Cultural Monitoring Framework - Summary

Principal Components Analysis (PCA) was used to summarise the variance in the 16 attributes assessed for the cultural monitoring framework. The aim of the PCA was to provide an overview of the linear relationships between the sites and the attributes assessed (Figure 24). Three sites (Sites 1, 3, and 5) were more dissimilar than the remaining three (Figure 24a). Site 1 was positively associated with wairua, bird communities, and good water quality, and negatively associated with an absence of engineering (man-made) features, reflecting its proximity to the concrete diversion near the tailrace (Figure 24b). Site 3 was positively associated with healthy substrate, flowing water, Māhinga kai, macrophytes and riparian vegetation (Figure 24b). Site 5 was negatively associated with good water quality, smell, and desired habitat attributes such as riparian trees and low levels of pollution (Figure 24b).

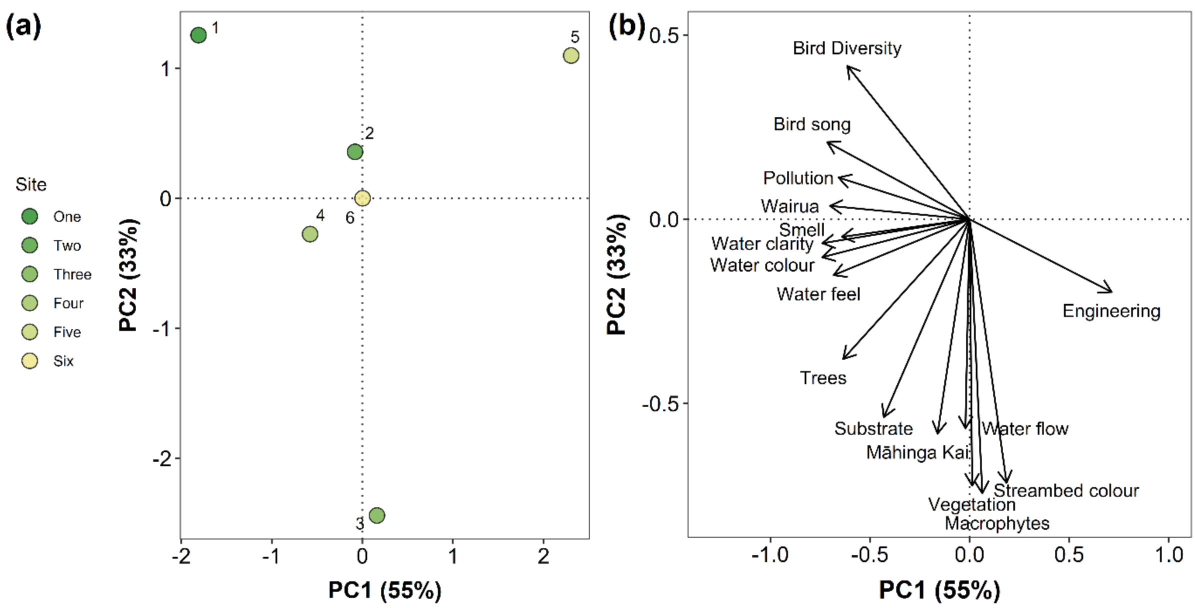


Figure 24. Principle components analysis (PCA) of the mean scores for the 16 attributes assessed using the Ngāti Kurauia cultural monitoring framework (CMF) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. (a) sites plotted according to their PCA scores for axis 1 and axis 2, each explaining 55% and 33% of the total variance, respectively, (b) vectors indicating the 16 attributes used to build the principal components.

Ngāti Kurauia Cultural Monitoring Framework – Supplemental

This section describes results for each site using a modified Mauri Model (MMM), similar to that of Hikuroa *et al.* (2011). Hapū members were asked to score each site in terms of drinking water, recreation, flood potential, geomorphological and vegetation changes, and whether each site has a particularly special spiritual connection to them. Each attribute uses a scale from -2 to 2, as opposed to the modified Likert scale (0-100) used for the Ngāti Kurauia CMF. Mean values along with standard deviations for the MMM are described here. However, the raw data is available in Appendix B.

When asked if hapū would drink the water without treatment, Site 1 had the maximum mean score (0.77 ± 0.69) whilst Site 5 had the lowest mean score (-1.43 ± 0.67; Appendix B). When asked if hapū would like to swim in the stream in its current state, most stated that they would. Site 5 was the exception as the only site returning a negative mean score (-0.67 ± 0.8; Appendix B).

When questioned if the stream is narrower or wider that before 1960, most hapū indicated that the stream has narrowed over time (Appendix B). The only exception was Site 3 which returned a positive mean score (0.21 ± 0.4) indicating a marginal widening. When asked about stream depth over time, the mean scores indicate that five of the six sites are now shallower than in the past. As with stream width, Site 3 was the only site that appears to have deepened over time with a mean score of 0.13 (± 0.18). Hapū were asked if the Tokaanu Stream is more or less likely to flood than before 1960. The scores indicated that the stream is more likely to flood at five of the six sites (Appendix B). Site 2 was the exception as the only site that hapū thought was less likely to flood with a mean score of 0.1 (± 0.17).

Regarding in-stream habitat, the mean scores from hapū indicate that all sites have suffered a decrease in habitat (Appendix B). Hapū were asked about sediment deposition over time. The responses indicate that most sites appear to have more fine deposited sediment than before. The only exception was Site 3 which had a mean score of 0 indicating that it is unchanged or hapū are undecided. When asked if the macrophyte community is more or less abundant than before 1960, the results were mixed. The mean scores from three sites suggesting less macrophyte cover, with the mean scores from the remained three sites indicating increased macrophyte cover (Appendix B). Macrophyte diversity was also considered. The mean scores indicate that there has been an increase in in-stream plant diversity at most sites. The only exception was Site 1, which had a mean score of -0.08 ± 0.2 (Appendix B).

Lastly, hapū were asked if the awa (Tokaanu Stream) at each of the sites has any special spiritual meaning to them. Responses fluctuated between sites (Appendix B), but there was overwhelming agreement that the awa holds spiritual significance for all those participating (Appendix B).

Cultural Health Index

I wanted to explore other ways of expressing the results from the Ngāti Kurauia Cultural Monitoring Framework for the Tokaanu Stream. To this end, I used mean scores from selected attributes assessed to calculate the Cultural Stream Health Measure (CSHM). The CSHM is an indicator of stream health from the Cultural Health Index (CHI) (Table 4).

Cultural Stream Health Measure

The assessment of Cultural Stream Health Measure (CSHM) involves eight attributes scored using a Likert scale (1 – unhealthy, 5 – healthy). These values were derived from the mean scores for selected attributes assessed using the Ngāti Kurauia Cultural Monitoring Framework. The highest CSHM score (3.2) was recorded at Site 3 (Table 4). The lowest CSHM score (2.7) was recorded at Site 5, closely followed by Site 1 (2.9). The remaining three sites (Sites 2, 4, and 6) all scored 3.0 (Table 4).

Table 4. Results from the calculation of the Cultural Stream Health Measure (CSHM) for each of the six sites on the Tokaanu Stream in the Lake Taupō catchment. The CSHM is part of the Cultural Health Index (CHI) and involves eight attributes assessed using a Likert scale (1-5) where 1 is poor and 5 is good. In this instance, I used mean scores from selected attributes assessed for the Ngāti Kurauia Cultural Monitoring Framework to derive the values used for the CSHM.

	Site					
Indicator	**1**	**2**	**3**	**4**	**5**	**6**
Catchment land use	2.5	2.5	2.5	2.5	2.5	2.5
Riparian vegetation	3.3	3.0	3.3	3.2	2.7	3.1
Use of riparian margin	3.3	3.3	3.9	3.5	3.3	3.5
Riverbed condition/sediment	3.0	3.5	3.7	3.4	2.1	3.1
Channel modification	0.9	2.0	2.2	1.7	2.7	1.9
Flow and habitat variety	1.6	2.1	2.3	2.0	1.7	1.9
Water clarity	4.6	4.2	4.0	4.3	3.1	4.1
Water quality	3.9	3.6	3.8	3.7	3.1	3.6
Mean	**2.9**	**3.0**	**3.2**	**3.0**	**2.7**	**3.0**

4.2 Conventional monitoring

This section presents the results of sampling undertaken using conventional scientific monitoring methods. Results from environmental indicators will be presented first. This includes results from physicochemical monitoring, water quality sampling, and habitat assessment. Following this, I will present results from ecological monitoring using structural (macroinvertebrates, eDNA) and functional indicators (cotton strip assay).

Physicochemical

The physicochemical measures (conductivity, dissolved oxygen, temperature, pH and water clarity) will be reported first. Results are presented in graphical form; however, raw data can be found in Appendix C.

Specific conductivity

Specific conductivity increased moving downstream (Figure 25). The lowest mean value was observed at Site 1 (98.9 $\mu S_{20^{\circ}C}$/cm) and peaked at Site 6 (240.0 $\mu S_{20^{\circ}C}$/cm). This was an overall increase of 143% on average, but the increase was gradual until Site 4. The rapid increase in specific conductivity at this site was expected due to the increasing amount of geothermal activity in the vicinity of the stream. The standard deviation also increased from Site 4 moving downstream, indicating more variable specific conductivities (Appendix C, Table C1).

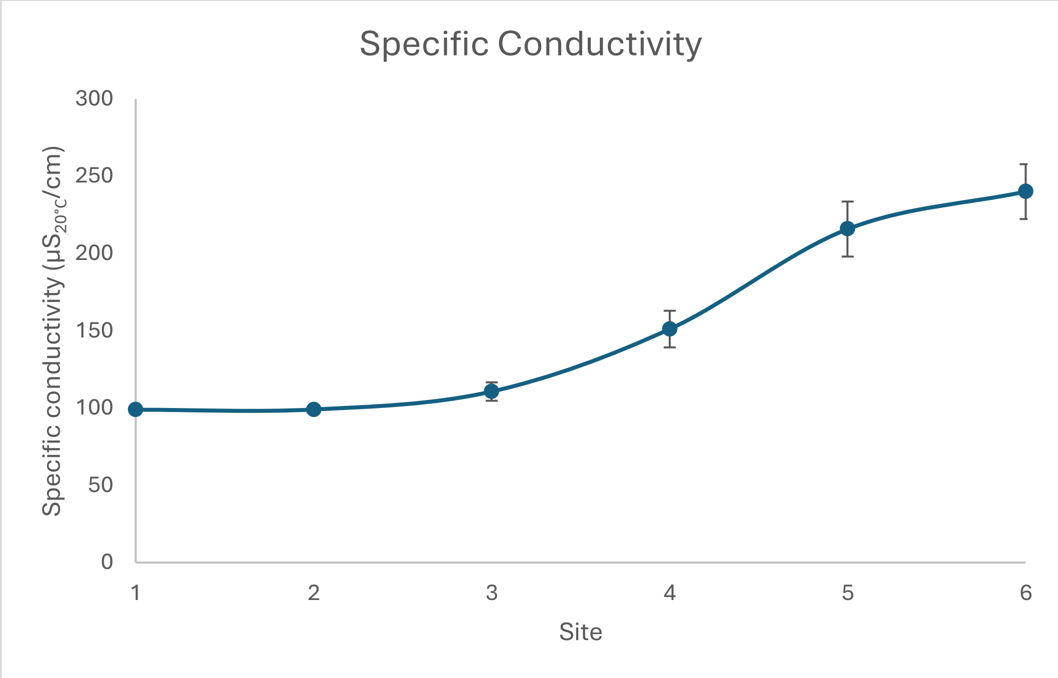


Figure 25. Mean specific conductivity (µ$S_{20°C}$/cm ± standard deviation) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on nine separate haerenga (assessment dates) during 2023/2024.

Dissolved oxygen saturation

Dissolved oxygen (% saturation) remained relatively consistent moving downstream, with a mean value of 93.3% recorded at Site 1 and a slightly lower mean value of 91.8% recorded at Site 6 (Figure 26). None of the sites reached supersaturation (>100%) except for one occasion. On the 14 December 2023, which was a sunny day, Sites 2, 3 and 4 all exceeded 100% dissolved oxygen saturation with value of 100.7%, 103.0% and 101.0% respectively (Appendix C, Table C3).

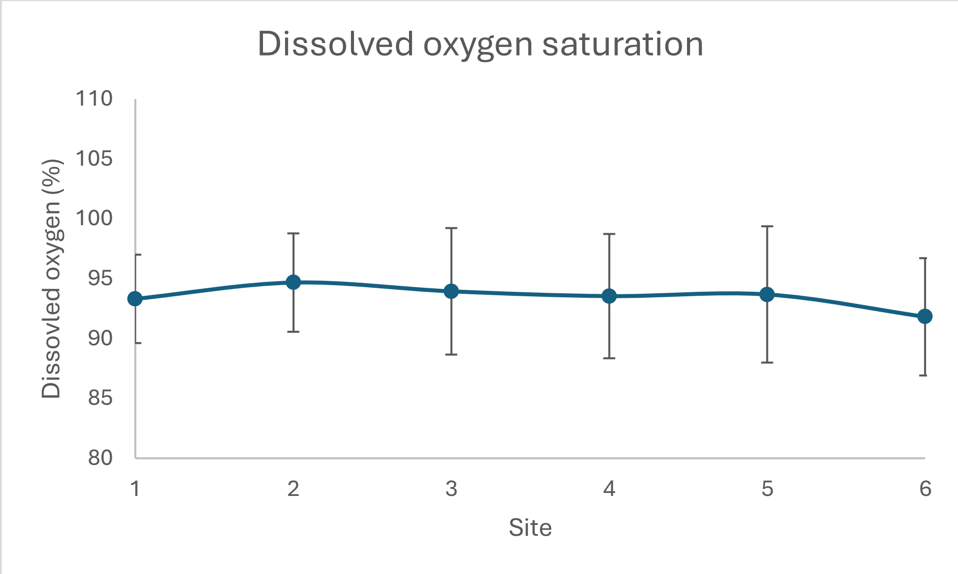


Figure 26. Mean saturated dissolved oxygen (% ± standard deviation) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on nine separate haerenga (sampling dates) during 2023/2024.

Dissolved oxygen concentrations

Dissolved oxygen concentrations (mg/L) decreased marginally moving downstream (Figure 27). Site 2 had the highest mean value (10 mg/L ± 1 standard deviation 0.24 mg/L). Site 1, while lower than Site 2, had a mean of 9.87 mg/L (± 0.29 mg/L), whilst Site 6 had the lowest mean dissolved oxygen concentration of 9.37 mg/L (± 0.66 mg/L) (Appendix C, Table C4).

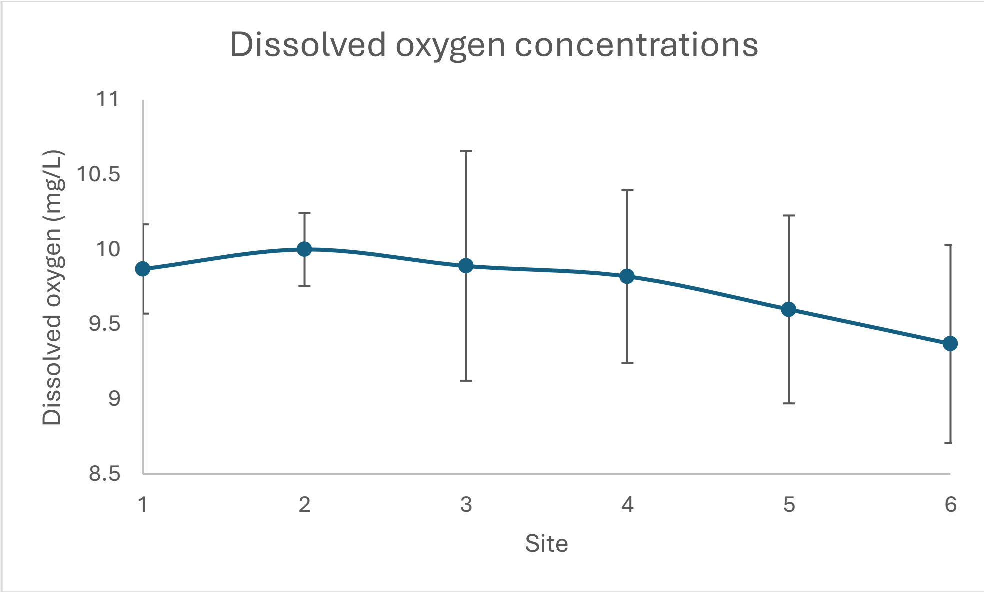


Figure 27. Mean dissolved oxygen concentrations (mg/L ± standard deviation) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on nine separate haerenga (assessment dates) during 2023/2024.

Temperature

Water temperature increased downstream from Site 1, showing a similar pattern to that of specific conductivity (Figure 28). The mean value at Site 1 was 12.8 °C and increased to 14.1 °C at Site 6. This was an overall increase of 1.3 °C on average, but temperature actually gradually decreased until Site 4. Like specific conductivity, the rapid increase in temperature at this site was expected due to the increasing amount of geothermal activity in the vicinity of the stream (Appendix C, Table C5). There was no indication of altered temperature dynamics due to the diversion (e.g., at Site 2).

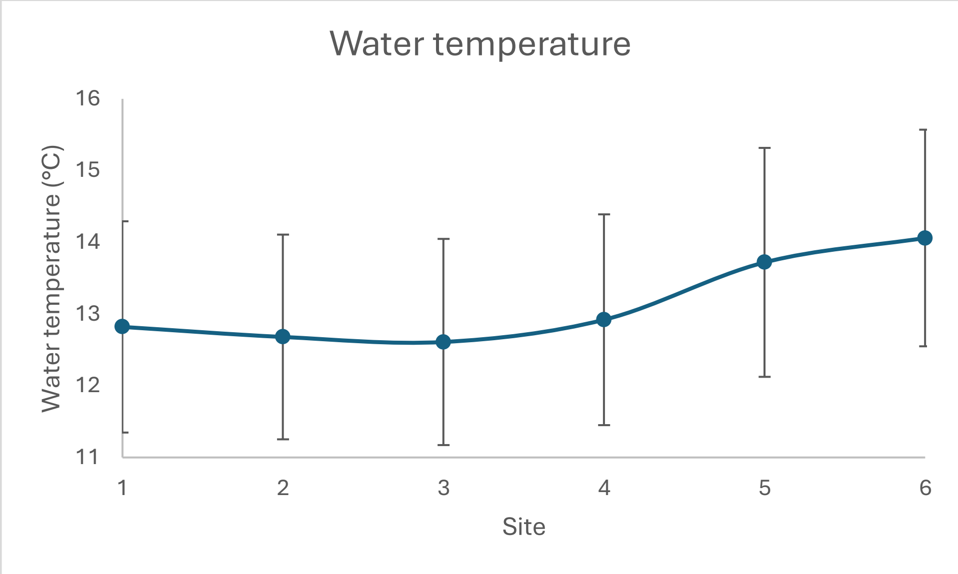


Figure 28. Mean water temperature (°C ± standard deviation) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on nine separate haerenga (sampling dates) during 2023/2024.

pH

Water pH showed a different pattern moving downstream from Site 1 on the Tokaanu Stream (Figure 29). Site 1 was slightly basic with a mean pH of 7.31 and peaked with a mean pH of 7.34 at Site 2. From Sites 3 to 5, pH decreased, with the lowest value mean of 7.05 observed at Site 5. At Site 6, pH had returned to being more basic with a mean of 7.32. Geothermal activity along with a piped point-source input may be causing the pH to lower at Sites 3, 4 and 5 – but these aspects will be discussed later. See Appendix C (Table C6) for raw pH results.

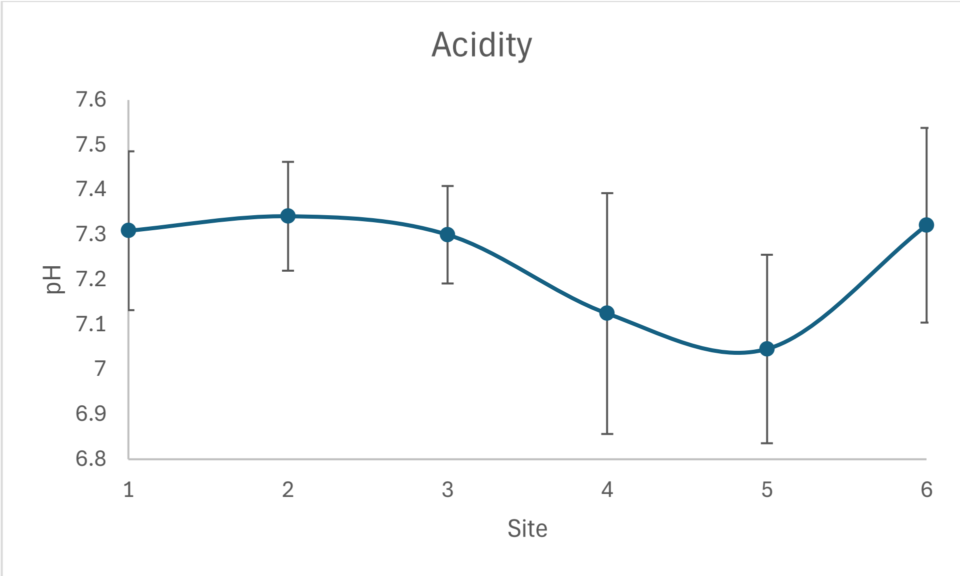


Figure 29. Mean pH (H[+] ± standard deviation) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on nine separate haerenga (sampling dates) during 2023/2024.

Water clarity

Water clarity varied at all sites over the duration of the year and overall, decreased longitudinally from Site 1 to Site 6. The mean water clarity at Site 1 was 93.4 cm and decreased to a mean of 83.0 cm at Site 6. Site 6 had the lowest standard deviation of all sites at 6.99 cm. Whilst the overall trend was of declining water clarity moving downstream, water clarity at Site 5 increased slightly (88.1 cm) relative to Site 4 (87.3 cm), although this was within the margin of error (Figure 30).

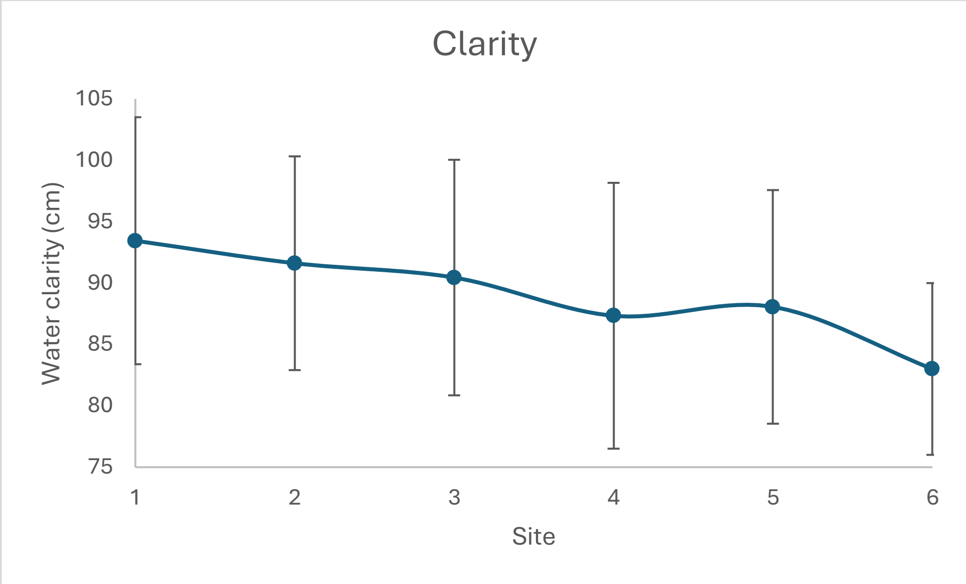


Figure 30. Mean water clarity (cm ± standard deviation) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on nine separate haerenga (sampling dates) during 2023/2024.

Water Quality

Water quality analyses were performed for nitrates and nitrates (g/m^3), total ammoniacal nitrogen (g/m^3), *E. coli* (CFU/100 ml), total nitrogen (g/m^3), dissolved reactive phosphorus (g/m^3), total phosphorus (g/m^3), and suspended fine sediment (g/m^3). Results are presented in graphical form; however, raw data can be found in Appendix C (Table C8).

Nitrate and Nitrite

Concentrations of nitrate and nitrite (g/m^3) from all six sites decreased along the length of the Tokaanu Stream (Figure 31). The highest retrieved levels were from the sampling period on 5 May 2024 whereas the lowest retrieved levels were from 15 July 2024. When compared to the NPS-FM 2020 (New Zealand Government, 2020), my results indicate that if these trends persisted, the nitrate and nitrite levels of the Tokaanu Stream would fall within Band A.

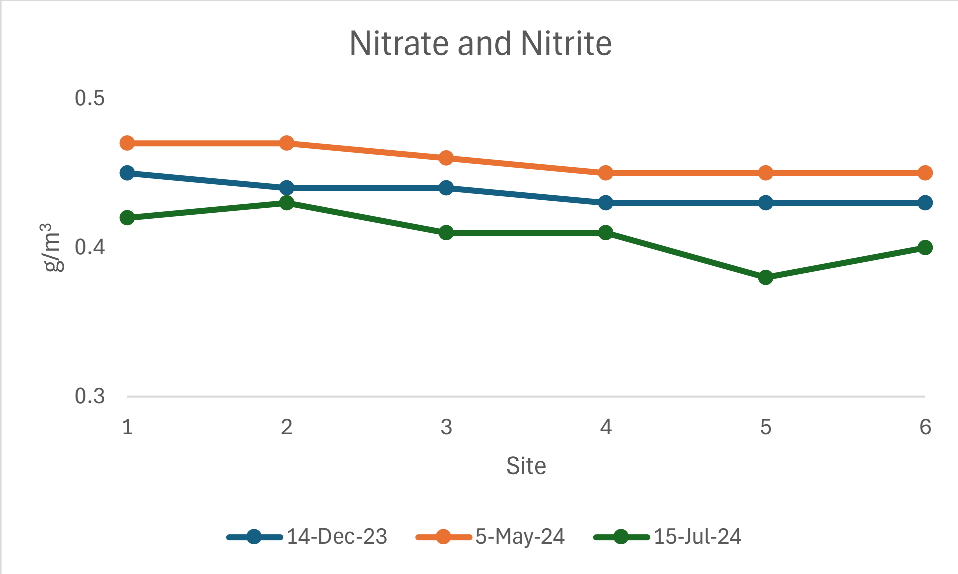


Figure 31. Nitrate and nitrite concentrations (g/m^3) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on three separate haerenga (sampling dates) during 2023/2024.

Total Ammoniacal Nitrogen

Total ammoniacal nitrogen concentrations (g/m^3) generally increased from Site 1 to 6 along the Tokaanu Stream (Figure 32). Despite a spike in concentrations on 15 July 2024, if these trends persisted, all concentrations would still fall within tolerable ranges within the Band A category when compared to the NPS-FM 2020 (New Zealand Government, 2020).

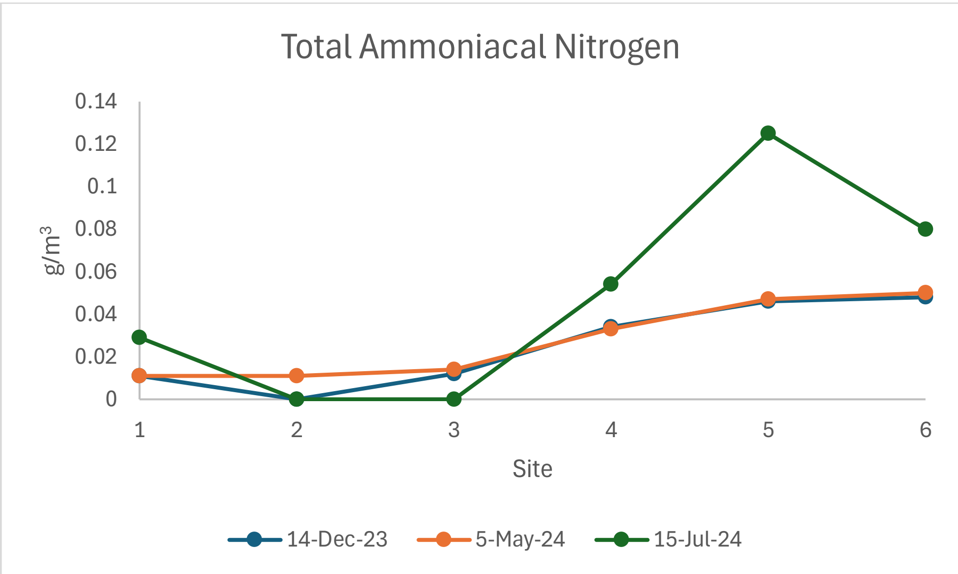


Figure 32. Total ammoniacal nitrogen concentrations (g/m^3) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on three separate haerenga (sampling dates) during 2023/2024.

Bacteria – *Escherichia coli*

Water samples taken during all three sampling rounds were analysed for *Escherichia coli (E. coli)* to estimate the colony forming units per 100 millilitres (CFU/100 ml) of this indicator bacteria. *E. coli* values generally increased from Site 1 moving downstream to Site 6. The highest concentration (190 CFU/100 ml) was recorded on the 15 July 2024 from a water sample collected at Site 6 (Figure 33).

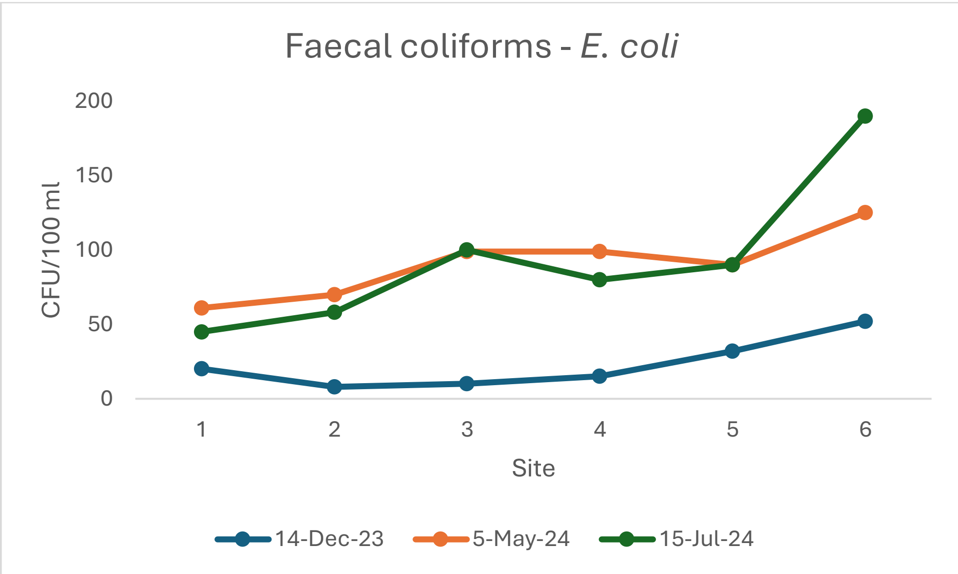


Figure 33. Escherichia coli (E. coli) *colony forming units per 100 millilitres (CFU/100 ml) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on three separate haerenga (sampling dates) during 2023/2024.*

Total Nitrogen

Total nitrogen concentrations (g/m^3) increased along the length of the Tokaanu Stream (Figure 34). There was a spike in concentrations on 14 December 2023 with highest value of 0.58 g/m^3 recorded at Site 3. Despite this, if these trends persisted the results would fall within band A of the NPS-FM 2020.

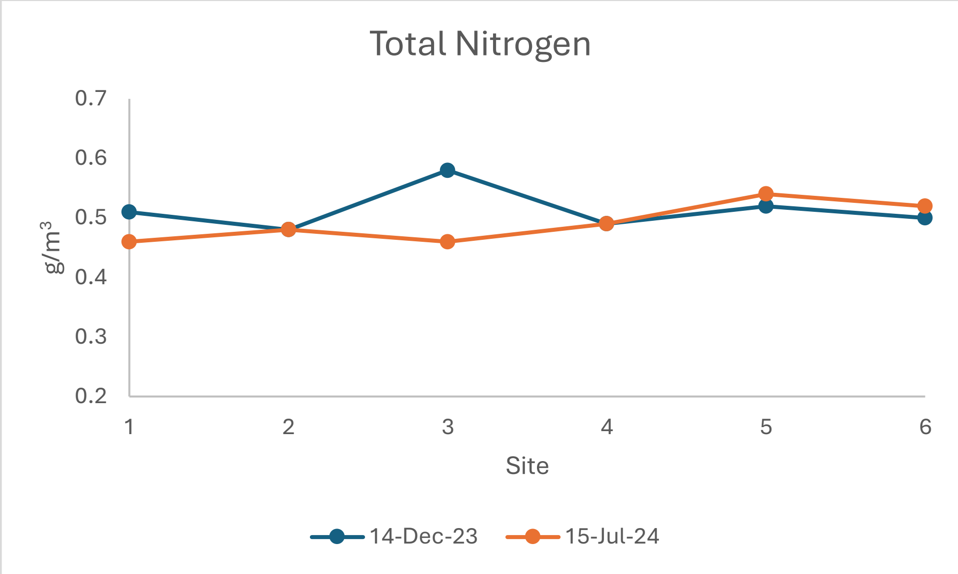


Figure 34. Total nitrogen concentrations (g/m³) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on two separate haerenga (sampling dates) during 2023/2024.

Dissolved Reactive Phosphorus

Dissolved reactive phosphorus (DRP) concentrations (g/m³) were high in the stream (Figure 35, Appendix C, Table C8). Concentrations generally decreased moving downstream. However, on two occasions (14 December 2023 and 15 July 2024) there was a small increase at Site 5. If these trends continued, all sites would fall into Band D of the NPS-FM 2020 (New Zealand Government, 2020), indicating that they were above the national bottom line for DRP.

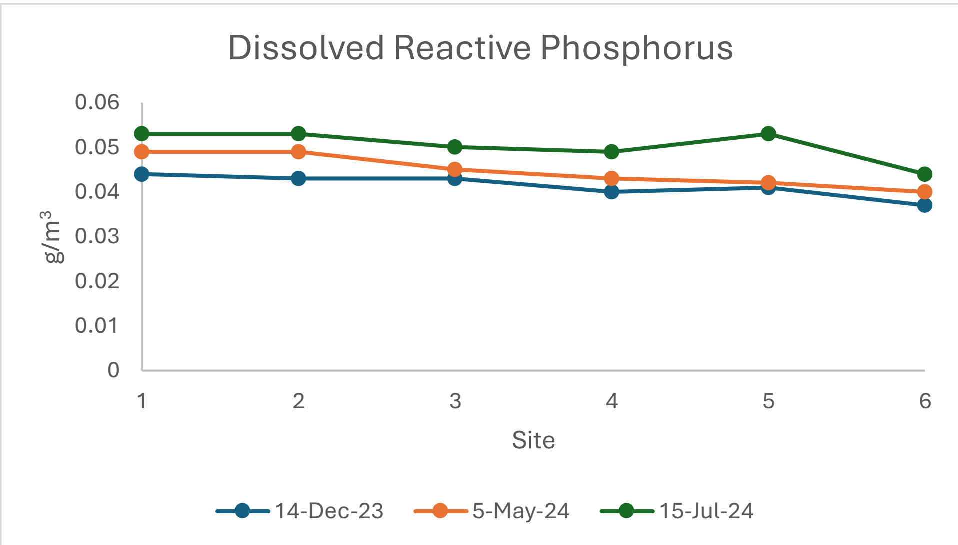


Figure 35. Dissolved reactive phosphorus concentrations (g/m³) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on three separate haerenga (sampling dates) during 2023/2024.

Total Phosphorus

Total phosphorus concentrations (g/m^3) showed little change along the Tokaanu Stream, apart from Site 5 (Figure 36). This site returned the highest concentration of 0.067 g/m^3 (67 mg/m^3) from the July sampling and then returned the lowest concentration of 0.049 g/m^3 (49 mg/m^3) during the December sampling.

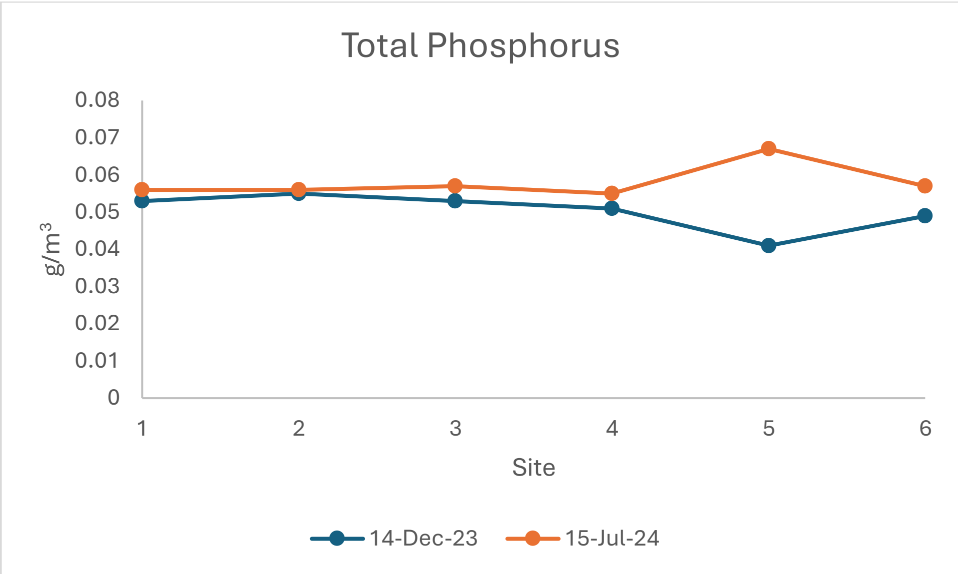


Figure 36. Total phosphorus concentrations (g/m^3) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on two separate haerenga (sampling dates) during 2023/2024.

Suspended Fine Sediment

Suspended fine sediment (g/m^3) was separated into organic suspended fine sediment (OSFS) and inorganic suspended fine sediment (ISFS).

OSFS decreased along the sample reach of the Tokaanu Stream (Figure 37). Site 1 had the highest mean OSFS concentration of 3.5 g/m^3 and a standard deviation of 3.9 g/m^3. This gradually declined to Site 6 with a mean OSFS concentration of 2.7 g/m^3 (± 0.9 g/m^3). All raw data can be found in Appendix C (Table C10).

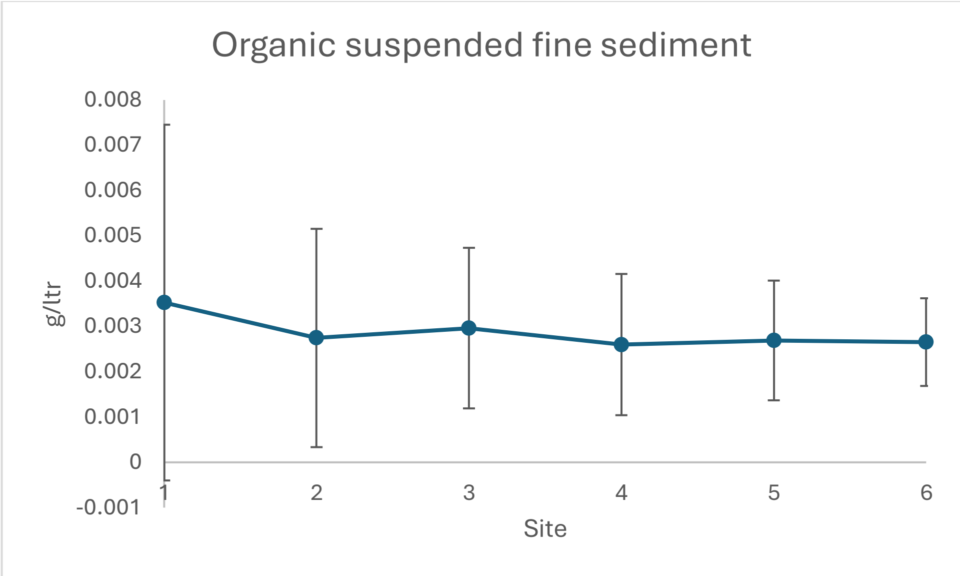


Figure 37. Mean organic suspended fine sediment concentrations (g/m^3 ± standard deviation) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on 11 separate haerenga (sampling dates) during 2023/2024.

ISFS concentrations were on average, relatively constant across the sites on the Tokaanu Stream (Figure 38). Site 1 recorded a mean ISFS concentration of 19 g/m^3 (± 19 g/m^3), whereas Site 6 had a mean 21 g/m^3 (± 18 g/m^3). ISFS increased from Sites 1 to 3, with a peak at Site 3 of 23 g/m^3 (± 18 g/m^3), before declining at Site 4 with a mean ISFS concentration of 18 g/m^3 (± 18 g/m^3). All raw data can be found in Appendix C (Table C9).

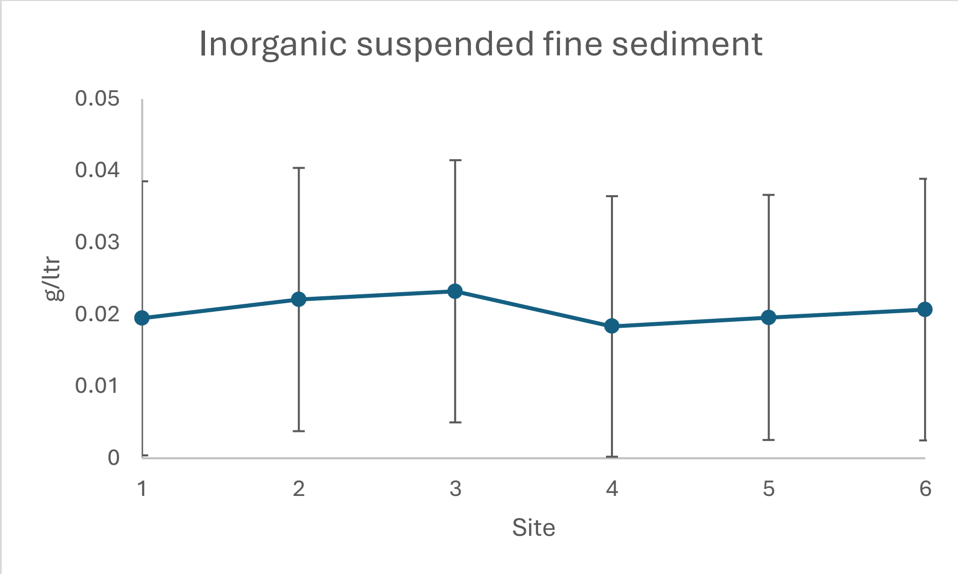


Figure 38. Mean inorganic suspended fine sediment concentrations (g/m³ ± standard deviation) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on 11 separate haerenga (sampling dates) during 2023/2024.

Habitat Assessment

In-stream habitat was assessed at each site. Deposited fine sediment cover, substrate composition, and stream hydrogeomorphology (stream profile, including depths and flow velocity) were in-stream habitat features assessed.

Deposited Fine Sediment

The streambed cover (%) of deposited fine sediment (DFS) was high across all sites, ranging from 45.8% to 83.3% (Figure 39). If these trends persisted through time, all sites would fall into Band D of the NPS-FM 2020. Whilst the overall trend was for % DFS to increase moving downstream, there were noticeable decreases in % DFS cover at Sites 3 and 4 (Figure 39) (Appendix C, Table C11).

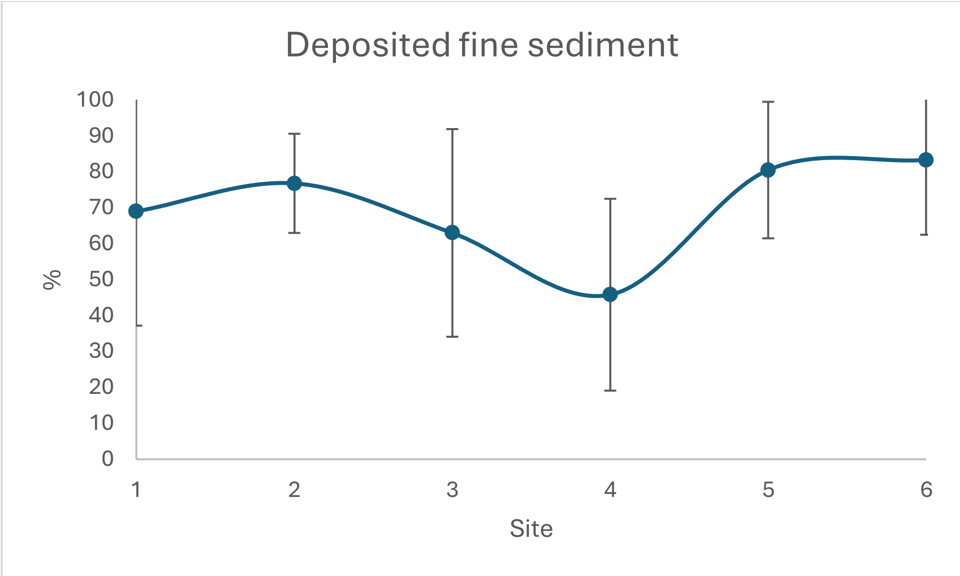


Figure 39. Deposited fine sediment cover (%), including standard deviation, at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed once on the 31 October 2024.

Benthic substrate composition

The inorganic substrate (% cover) of the Tokaanu Stream bed varied across sites (Figure 40). Coarser substrates, including pebbles, cobbles, and boulders decreased moving downstream, whereas sand and silt generally increased towards to the lake. The cover of fine gravels peaked at Site 4 before decreasing as they were overtaken by finer sands and silt (Figure 40).

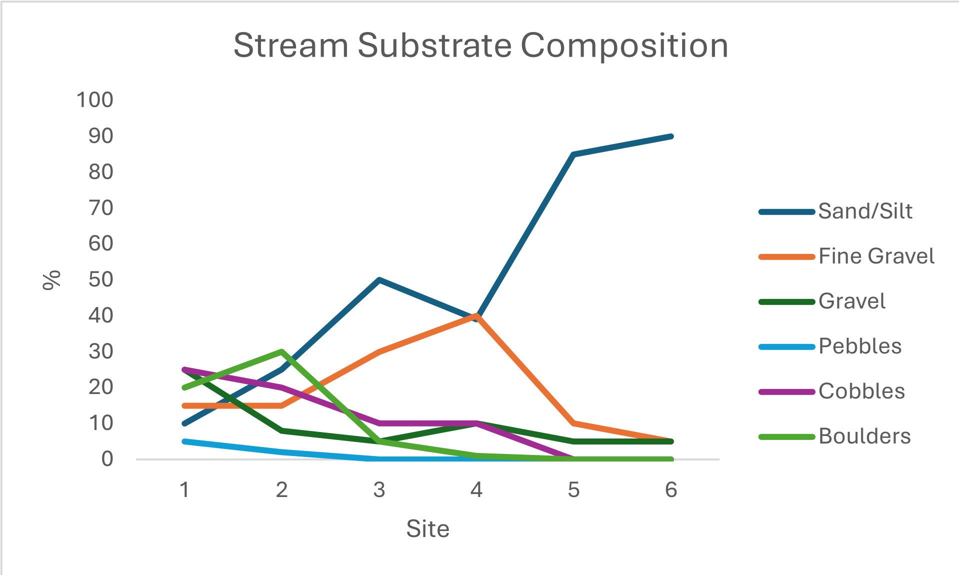


Figure 40. Benthic inorganic substrate composition at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was visually assessed once on the 31 October 2024.

Riparian Habitat Assessment

A rapid habitat assessment of riparian condition (the Riparian Condition Index – RCI hereafter) was undertaken once on the Tokaanu Stream during the sampling period. Full results can be found in Appendix C (Table C12). There was no systematic change in riparian condition moving downstream (Figure 41). Site 3 returned the highest RCI score of 51, or 78% of the theoretical maximum. Site 4 provided the lowest RCI score of 25, or 38% of the theoretical maximum. Other sites with low RCI scores included Sites 1 (32) and 2 (33).

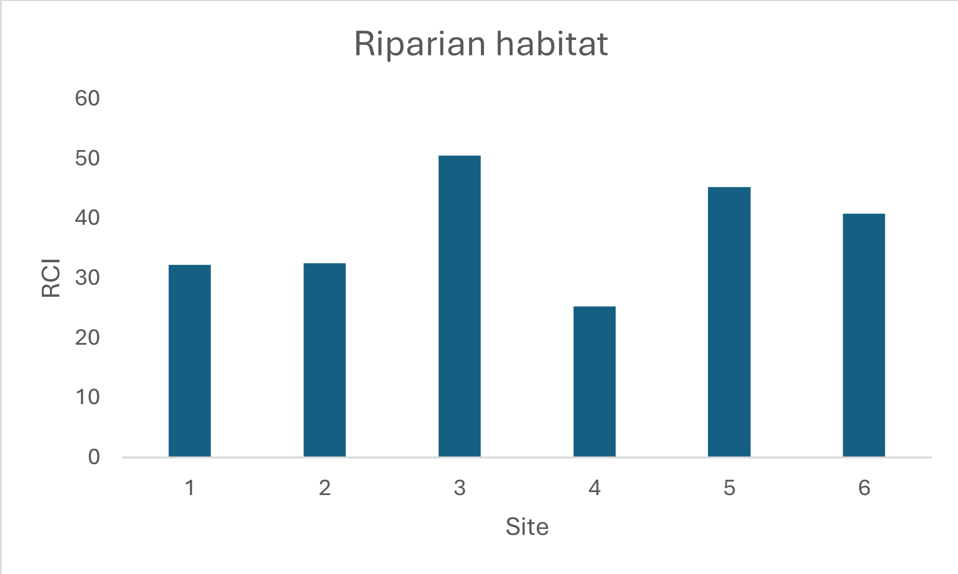


Figure 41. The Riparian Condition Index (RCI) scores were assessed on 18 January 2024 at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Sites 1 and 2 have a large amount of anthropogenic modification resulting from the development of the Tokaanu Power Scheme, while site 4 is the site of the Tokaanu hot pools.

Structural Indicators

Macroinvertebrate Community

The Tokaanu Stream's macroinvertebrate communities were sampled at all sites twice over two years (14 December 2023 and 31 October 2024). Full results from the macroinvertebrate community sampling can be found in Appendix D. During 2023, the highest macroinvertebrate diversity was found at Site 2 with 24 species (25% subsample effort), 16 of which were EPT taxa. Conversely, the lowest diversity was found at Site 6 with 16 species (50% subsample effort), 6 of which were EPT taxa reflecting a significant reduction in EPT taxa along the sample reach. In 2024, Site 2 remained the most diverse site and increased to 25 taxa (25% subsample effort), though EPT taxa decreased to 15 species. The least diverse site was also Site 6 with 14 species (25% subsample effort), though EPT taxa increased to 10 species from 2023.

There were shifts in macroinvertebrate community composition across sites and years (Figure 42). However, in general Sites 1, 2, 3 and 4 were more associated with EPT taxa including leptophlebiid mayflies (*Austroclima*, *Zephlebia*, *Deleatidium*), the gripopterygid stonefly *Zelandobius*, and the tipulid true fly *Aphrophila*. In contrast, Sites 5 and 6 were more likely to be associated with chironomid midges and the micro-caddisfly *Oxyethira* (Hydroptilidae).

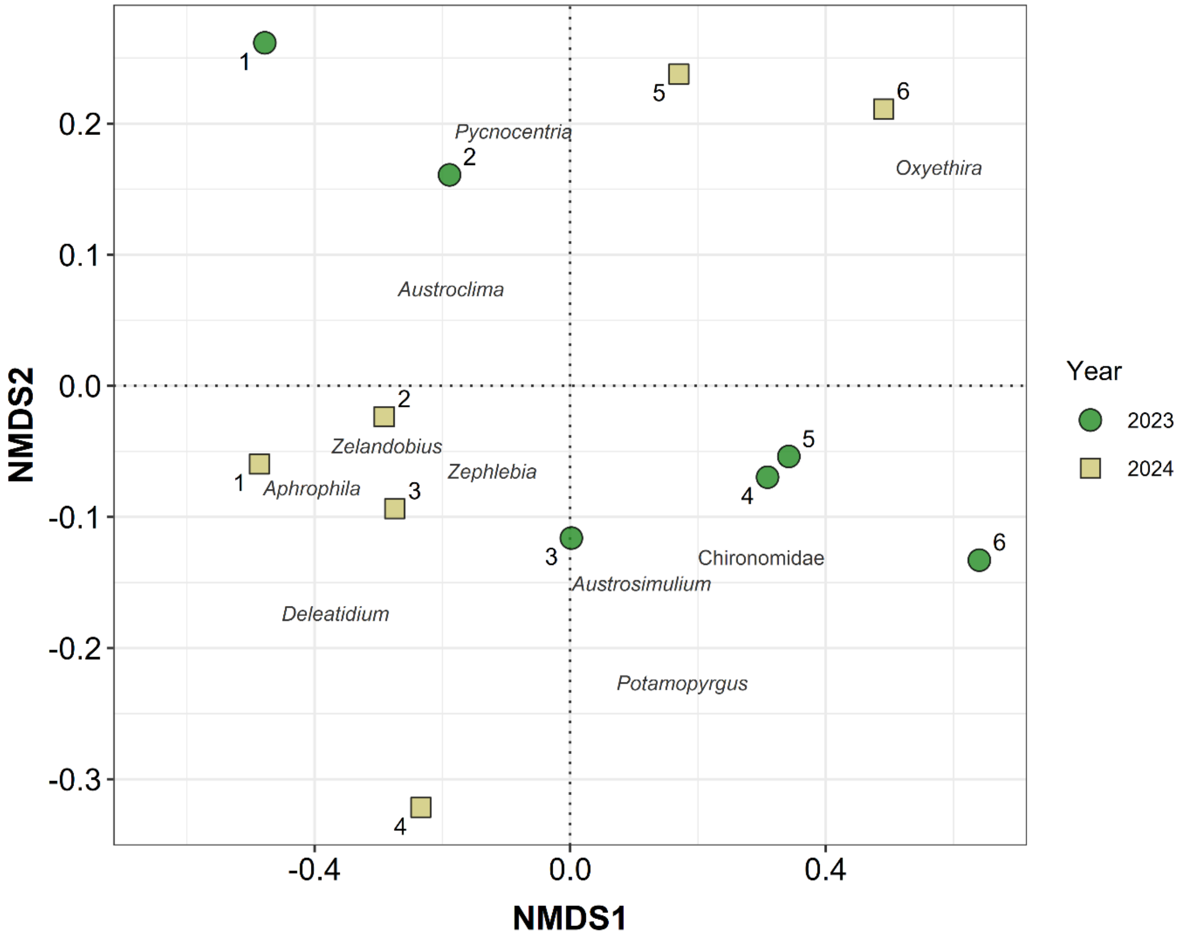


Figure 42. Non-metric Multidimensional Scaling (NMDS) ordination of macroinvertebrate communities at six sites on the Tokaanu Stream in the Lake Taupō catchment. Sites 1-6 were sampled twice (Summer in 2023 and 2024, respectively). The ten most abundant taxa are shown, accounting for 91% of all invertebrates identified. The stress of the ordination was 0.036.

Results for the Macroinvertebrate Community Index (MCI) in 2023 indicated a decline in stream health moving downstream (Figure 43). At Site 1, the MCI score was ~125, and this dropped to ~90 at Site 6. The pattern of declining stream health moving downstream was more equivocal in 2024. Site 1 again recorded the highest MCI score (~130), but the second highest score (~122) was recorded at Site 4. The lowest MCI score in the 2024 sampling was recorded at Site 6 (~102). Over two years, the MCI scores all exceeded the National Bottom Line (NBL) for this indicator under the NPS-FM 2020, although only one MCI score (Site 1 in 2024) reached the A band.

The quantitative MCI (QMCI) results from 2023 show a rapid decline in the macroinvertebrate community from Site 1 to Site 6 (Figure 43b). At Site 1, the QMCI score was ~6.9, and this dropped to ~2.5 at Site 6. Like the MCI scores, the patterns were more equivocal in 2024 (Figure 43b), whilst the second highest score was Site 4 (~5.6) before dropping to a minimum of ~3.1 at Site 6. Over two years, the QMCI scores at each site exceeded the NBL for this indicator at least once except for Site 6, which occupied Band D in both years. Only one QMCI score (Site 1 in 2023) reached the A band.

The average score per metric (ASPM) was calculated twice. The first ($ASPM_{national}$) was normalised to the NPS-FM 2020 standards, whereas the second ($ASPM_{local}$) was normalised to the best site (as indicated by maximum EPT richness) on the Tokaanu Stream.

In 2023, the $ASPM_{national}$ scores progressively declined moving downstream (Figure 43c). At Site 1, the $ASPM_{national}$ score was ~0.63, and this dropped to ~0.22 at Site 6. In 2024, the decline moving downstream was more equivocal, with the highest scores at Site 1 (~0.65) and Site 2 (~0.60). The next highest was Site 4 (~0.55), whilst Site 6 again had the lowest $ASPM_{national}$ score (~0.35). Over two years, the $ASPM_{national}$ scores all exceeded the NBL except Site 6 in 2023. Two sites (Sites 1 and 2) reached the A band in both years.

The $ASPM_{local}$ scores show similar patterns to the $ASPM_{national}$ scores with some exceptions. In 2023, $ASPM_{local}$ scores also declining moving downstream (Figure 43d), although the highest score was recorded at Site 2 (~0.71), before steadily decreasing to Site 6 (~0.37). In 2024, the highest scores were recorded at Site 1 (~0.71) and Site 2 (~0.66). The next highest was Site 4

(~0.62), whilst Site 6 again had the lowest $ASPM_{local}$ score (~0.49). Over two years, the $ASPM_{local}$ scores all exceeded the NBL. Two sites (Sites 1 and 2) reached the A band in both years, and three sites (Sites 3, 4 and 5) reached the A band in one of the years sampled, although for two of those sites (Sites 4 and 5) the year was 2024.

Ephemeroptera, Plecoptera and Trichoptera (EPT) richness and % abundance was also assessed. In 2023, Site 2 had the highest EPT richness with 15 species (Figure 43e). Site 3 was the next highest with 14 species. Site 6 had the lowest EPT richness with 5 species. In 2024, Site 2 again had the highest EPT richness with 13 species, whilst Site 1 was the next highest with 12 species. Sites 3 and 6 jointly returned the lowest EPT richness with 8 species recorded at both sites.

The relative abundance of EPT (% EPT hereafter) strongly decreased from Site 1 to 6 in 2023 (Figure 43f). % EPT was >80% at Site 1 and declined to ~5% at Site 6. In 2024, the decline was more equivocal, but Site 1 again recorded the highest % EPT (>80%) whilst the lowest % EPT was again recorded at Site 6 (~24%). Over both years, both Sites 1 and 2 had consistent % EPT whereas % EPT was higher at Sites 3, 4, 5 and 6 in 2024 when compared to 2023.

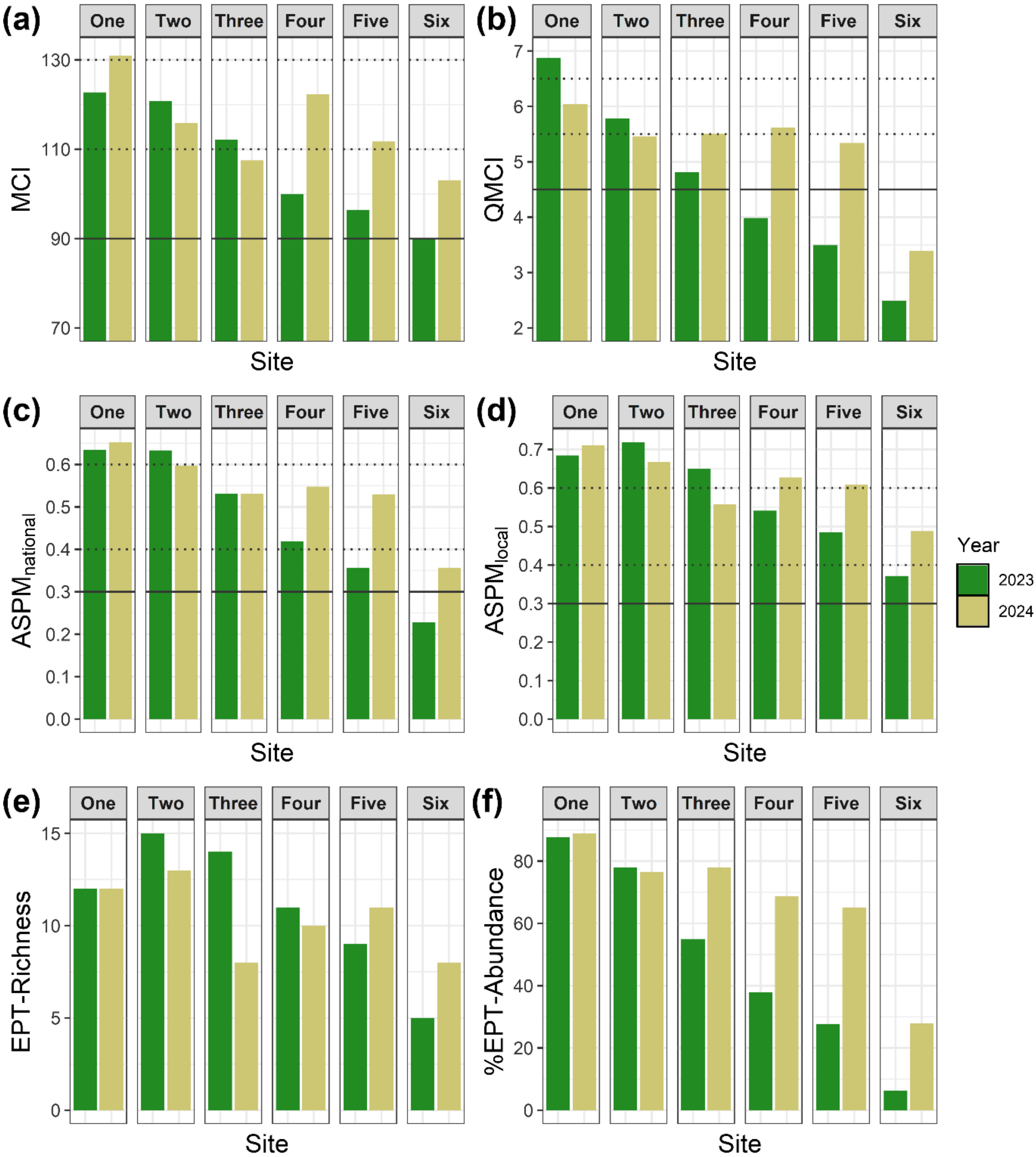


Figure 43. Macroinvertebrate indicators recorded at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled twice (Summer in 2023 and 2024, respectively). (a) Macroinvertebrate Community Index (MCI), (b) Quantitative MCI (QMCI), (c) Average Score Per Metric (ASPM) normalised according to the NPS-FM 2020, (d) ASPM) normalised according to the local reference, (e) Ephemeroptera, Plecoptera and Trichoptera (EPT) richness, and (f) EPT relative abundance. In plots (a) to (d) the dotted black lines indicate biocriteria bands (A-C) under the NPS-FM 20202, whereas the solid black line represents the national bottom line for band D.

There were linear declines in the macroinvertebrate community indicators with distance downstream (Table 5, Figure 44). Only the % EPT differed between years, being higher across all sites in 2024. The difference between years was not significant at α=0.05 for the MCI and the $ASPM_{national}$ scores. There was significant interaction between distance downstream and sampling year for the QMCI, indicating that the slope of decline was steeper in 2023 when compared to 2024. The same difference in slopes was not significant at α=0.05 for the $ASPM_{national}$ scores.

Table 5. Probability values and goodness of fit (R^2) statistics from general linear models (GLMs) testing the influence of distance (km), year of sampling (2023, 2024), and their interaction on the six macroinvertebrate community indicators used to monitor the ecosystem health of the Tokaanu Stream in the Lake Taupō catchment. MCI, Macroinvertebrate Community Index; QMCI, Quantitative MCI; $ASPM_{national}$, Average Score Per Metric normalised according to the NPS-FM 2020; $ASPM_{local}$, ASPM normalised according to the local reference; EPT, Ephemeroptera, Plecoptera and Trichoptera taxa; ns, not significant at α=0.1.

Index	**Distance** *p*-value	**Year** *p*-value	**Distance × Year** *p*-value	R^2
MCI	<0.001	0.051	ns	0.779
QMCI	<0.05	ns	<0.05	0.867
$ASPM_{national}$	<0.001	0.083	0.057	0.824
$ASPM_{local}$	<0.001	ns	ns	0.782
EPT-Richness	<0.05	ns	ns	0.593
%EPT-Abundance	<0.001	<0.05	ns	0.865

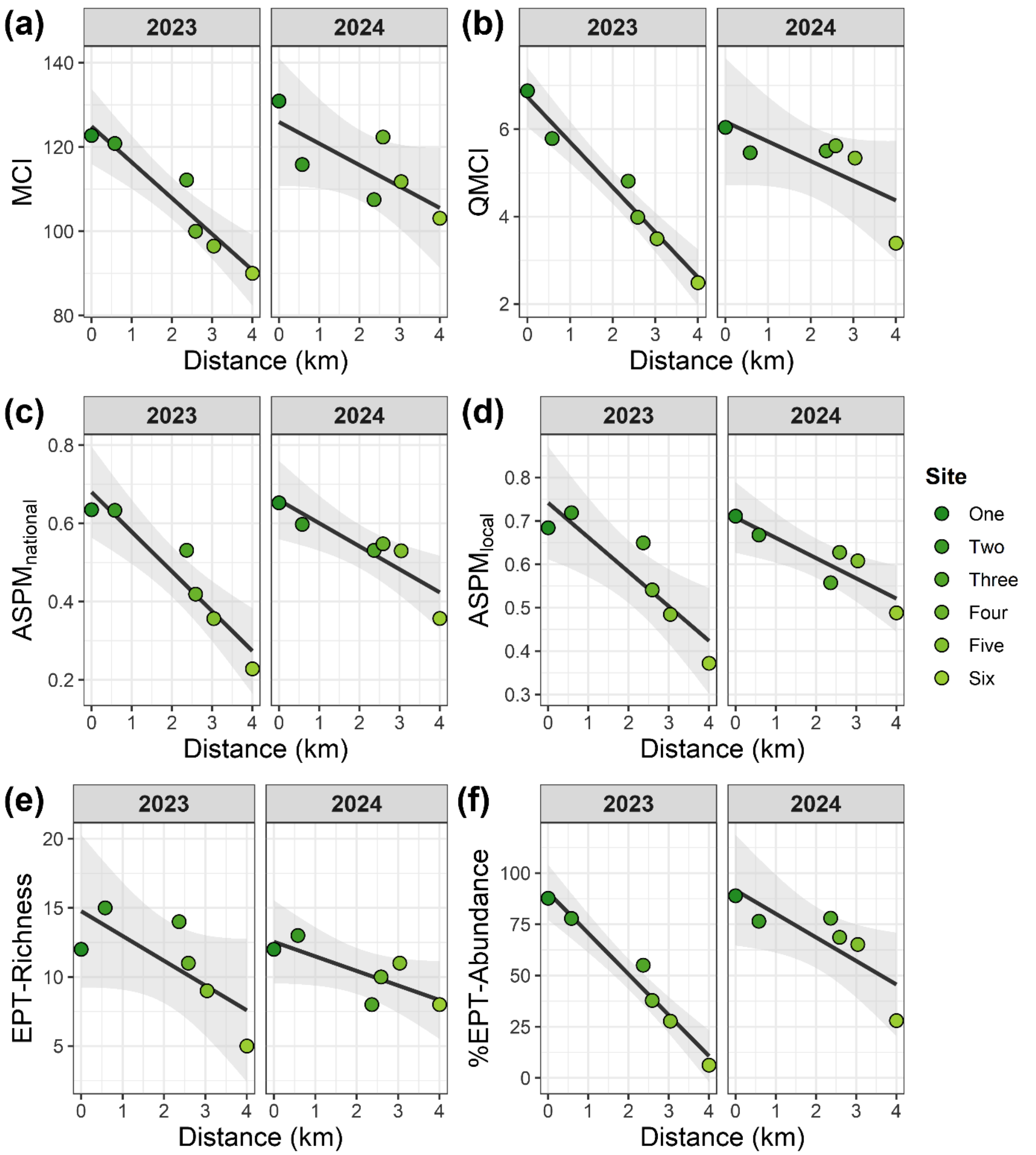


Figure 44. Longitudinal change in macroinvertebrate indicators recorded at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled twice (Summer in 2023 and 2024, respectively); here indicators are plotted relative to their distance downstream from Site 1 (the most upstream site sampled). (a) Macroinvertebrate Community Index (MCI), (b) Quantitative MCI (QMCI), (c) Average Score Per Metric (ASPM) normalised according to the NPS-FM 2020, (d) ASPM) normalised according to the local reference, (e) Ephemeroptera, Plecoptera and Trichoptera (EPT) richness, and (f) EPT relative abundance.

There were notable changes in the distributions and relative abundance of key macroinvertebrate taxa (Figure 45). Two taxa, the leptophlebiid mayfly *Deleatidium* and the tipulid crane fly *Aphrophila* were only found at Sites 1-4, with none detected at Sites 5 and 6 over the two years of sampling (Figure 45a,b). Similarly, the gripopterygid stonefly *Zelandobius* and the leptophlebiid mayfly *Austroclima* decreased in relative abundance moving downstream, but were not completely lost from Sites 5 and 6 (Figure 45c,d). Two EPT taxa that did not markedly change in relative abundances across sites were the conosuecid caddisfly *Pycnocentria* and the leptophlebiid mayfly *Zephlebia*, although both taxa showed reduced abundances at Sites 5 and 6 in 2023 (Figure 45e,f). Two taxa that showed idiosyncratic distributions across sites in both years were the simuliid sand fly *Austrosimulium* and the tateid snail *Potamopyrgus antipodarum* (Figure 45g,h). Finally, two taxa that generally showed elevated abundances at Sites 5 and 6 were the chironomid midges and the hydroptilid micro-caddisfly *Oxyethira* (Figure 45i,j).

The impact of instream remediation activities on Sites 4-6 were investigated using a BACI design with macroinvertebrate indicators as the response (Figure 46). There was a significant increase in the metric scores for the MCI, $ASPM_{national}$ and %EPT-Abundance at the impact sites (Sites 4-6) after the remediation activities (Figure 46a,c,f). Although the QMCI, $ASPM_{local}$ and EPT-Richness values all increased at the impact sites (Sites 4-6) after the remediation activities, these changes were not statistically significant (Figure 46b,d,e).

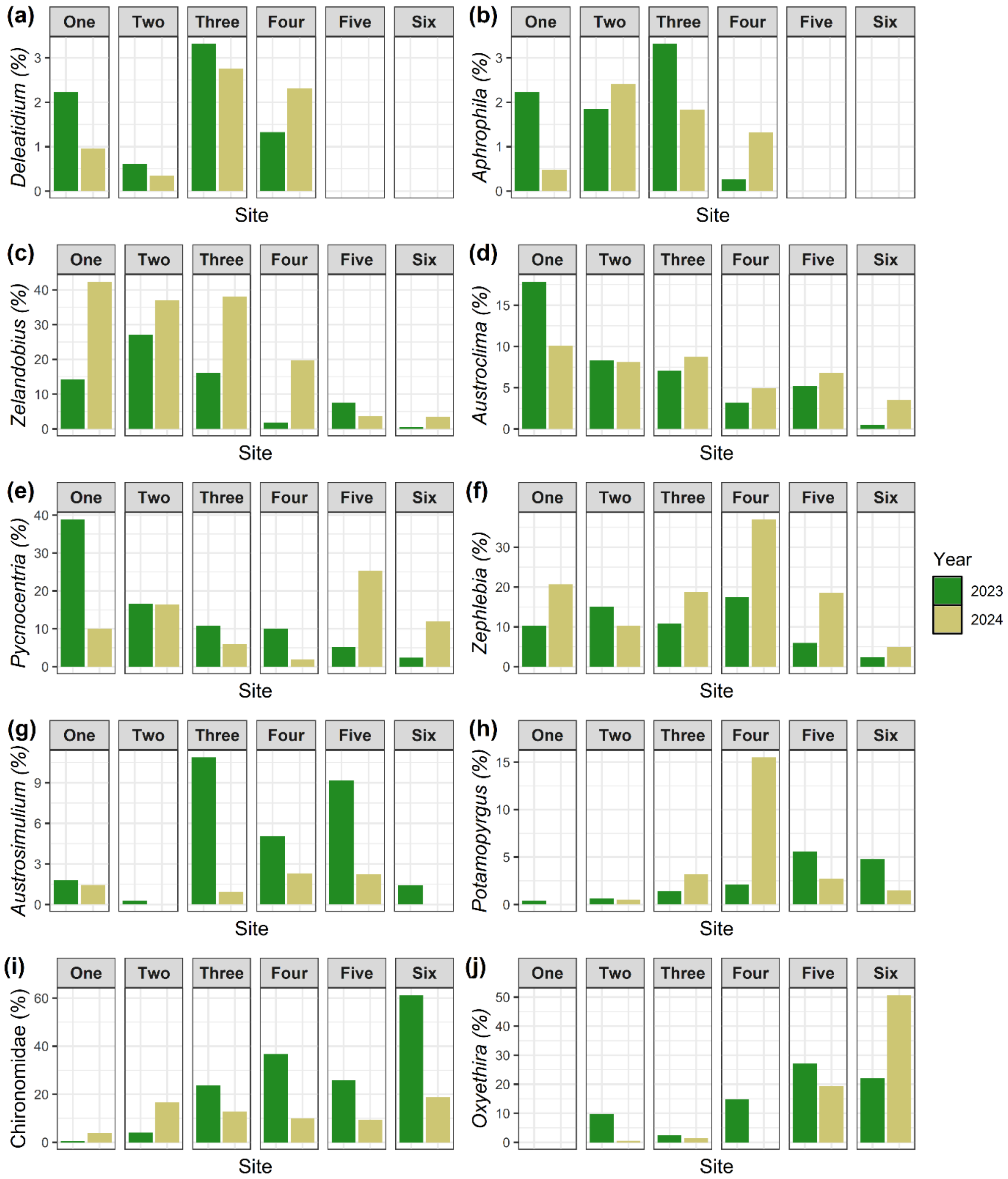


Figure 45. Relative abundances for selected macroinvertebrate taxa from NEMS kicknet samples collected at six sites on the Tokaanu Stream on the 14th December 2024 and 31st October 2024.

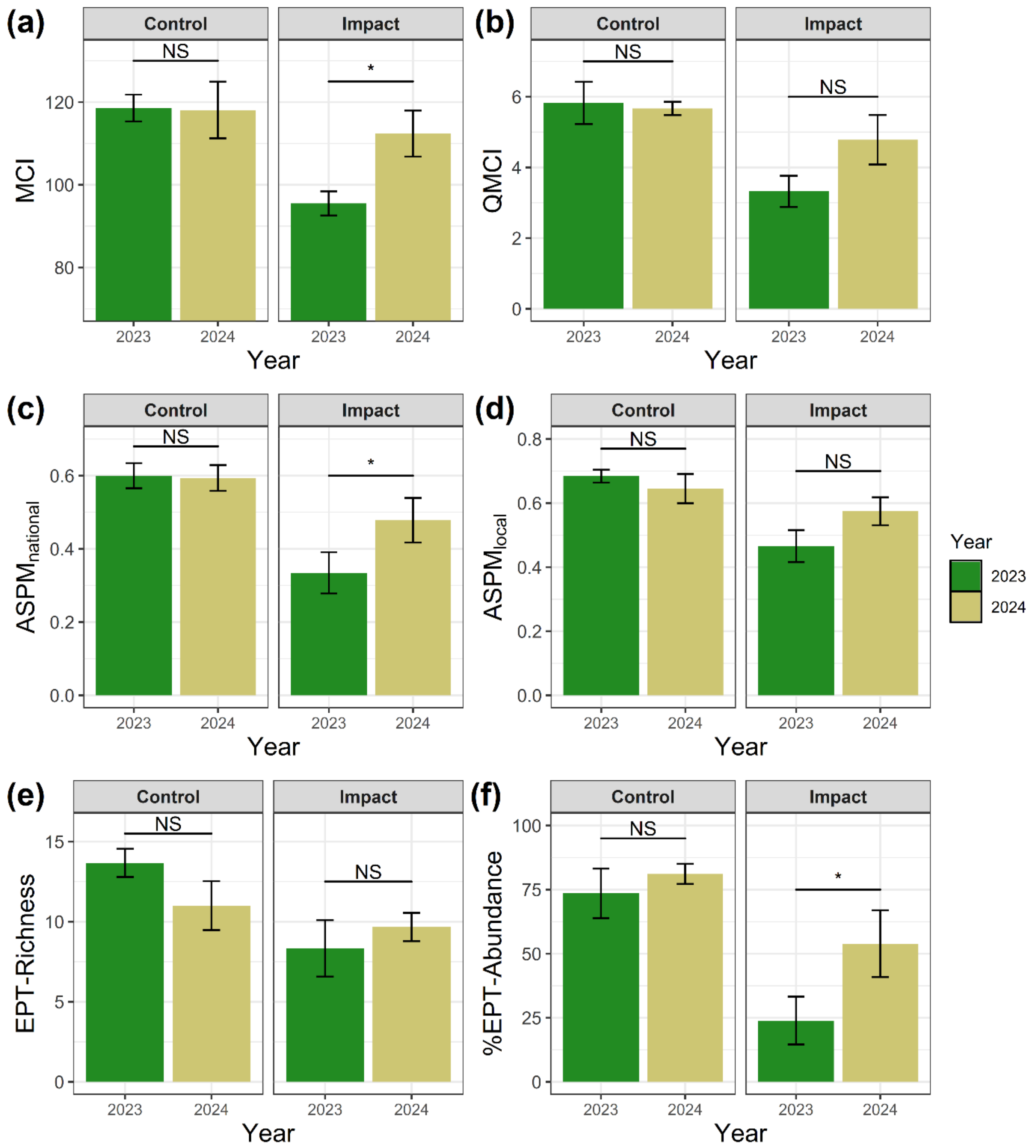


*Figure 46. Mean (± standard error) macroinvertebrate indicators recorded at control (Sites 1-3) and impact (Sites 4-5) sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled twice (Summer in 2023 and 2024, respectively). In 2024, prior to sampling, instream remediation works led to changes in benthic habitat at the impact sites. In this context, I have used the invertebrate data from both years to create a BACI (Before-After, Control-Impact) design, with 2023 (Before) and 2024 (After) data enabling the comparison. (a) Macroinvertebrate Community Index (MCI), (b) Quantitative MCI (QMCI), (c) Average Score Per Metric (ASPM) normalised according to the NPS-FM 2020, (d) ASPM) normalised according to the local reference, (e) Ephemeroptera, Plecoptera and Trichoptera (EPT) richness, and (f) EPT relative abundance. NS, not-significant at α=0.05; * P<0.05*

Environmental DNA

Environmental DNA (eDNA) samples were collected from the Tokaanu Stream on two dates. Two sites (Sites 1 and 6) were sampled on 14 December 2023, and one site (Site 6) on 8 July 2024. Results from eDNA for freshwater fish and kōura (freshwater crayfish) are presented in Table 6. Species which were detected at all locations regardless of sampling date include common bullies (*Gobiomorphus cotidianus*), kōaro (*Galaxius brevipinnus*), rainbow trout (*Oncorhynchus mykiss*), and kōura (*Paranephrops planifrons*). Species only found at Site 6 include brown trout (*Salmo trutta*), brown bullhead catfish (*Ameiurus nebulosus*), and goldish (*Carassius auratus*). One seemingly transient species, the common smelt (*Retropinna retropinna*) was not detected at Site 6 during the July 2024 eDNA sampling, despite being detected there in December 2023.

*Table 6. The presence of freshwater fish and kōura (freshwater crayfish) detected in environmental DNA samples collected from selected sites on the Tokaanu Stream in the Lake Taupō catchment. Sites 1 and 6 were sampled in December 2023, whereas only Site 6 was sampled in July 2024. (N), Native species; (I), introduced species. *Indicates low read counts. Images retrieved from niwa.co.nz on 15 July 2024.*

Date Sampled		**14 December 2023**		**8 July 2024**
Species		**Site 6**	**Site 1**	**Site 6**
	Common Bully (N)	Present	Present	Present
	Brown Trout (I)	Present	Absent	Present*
	Kōaro (N)	Present	Present	Present

	Brown Bullhead Catfish (I)	Present	Absent	Present
	Goldfish (I)	Present	Absent	Present*
	Rainbow Trout (I)	Present	Present	Present
	Common Smelt (N)	Present*	Absent	Absent
	Kōura (N)	Present	Present	Present

Functional Indicator

Cotton Strip Assay

The Cotton Strip Assay (CSA) was used as a functional indicator to assess ecosystem functioning (cellulose degradation) in the Tokaanu Stream. The CSA was carried out in 2023 and 2024 at all six sites. In 2023, tensile strength loss rates (k day^{-1}) were faster at Sites 1 to 4 when compared to Sites 5 and 6 (p<0.001; Table 7, Figure 47). Site 3 had the fastest tensile strength loss rate (k day^{-1}). In 2024, tensile strength loss rates (k day^{-1}) were faster at Sites 1, 3, and 4 when compared to Sites 2, 5, and 6 (p<0.001; Table 7, Figure 47). Site 3 again had the fastest tensile strength loss rate (k day^{-1}). Across years, Site 2 had a significantly slower tensile strength loss rate (k day^{-1}) in 2024 (Table 7, Figure 47). Conversely, Site 5 had a significantly faster tensile strength loss rate (*k* day^{-1}) in 2024 (Table 7, Figure 47). Similar patterns were observed when considering cotton degradation using the other tensile strength loss rates (Table 7, Figure 47).

Table 7. Probability values and goodness of fit (R^2) statistics from general linear models (GLMs) testing the influence of site, year of sampling (2023, 2024), and their interaction on tensile strength loss (TSL) of cotton strips used to monitor the ecosystem health of the Tokaanu Stream in the Lake Taupō catchment. ns, not significant at α=0.05.

TSL	**Site**	**Year**	**Site × Year**		R^2
	p-value	*p*-value	*p*-value	Year | Site	
k day^{-1}	<0.001	ns	<0.001	2, 5	0.486
k degree-day^{-1}	<0.001	ns	<0.001	2, 5	0.609
% day^{-1}	<0.001	ns	<0.001	2, 5	0.375
% degree-day^{-1}	<0.001	ns	<0.001	2, 5	0.555

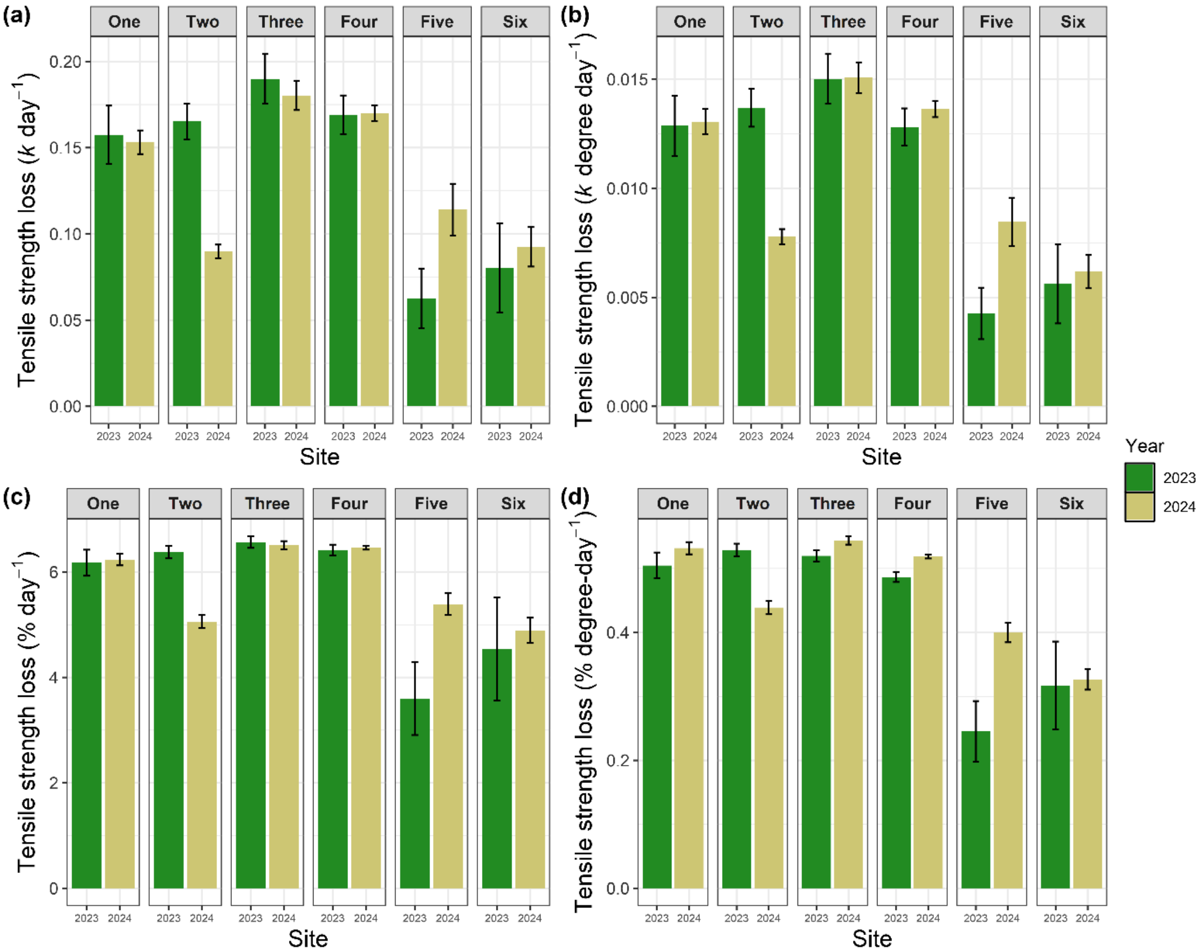


Figure 47. Tensile strength loss (TSL) rates for cotton strips deployed at all six sites on the Tokaanu Stream in the Lake Taupō catchment. TSL was assayed in 2023 and 2024. (a) TSL (k day^{-1}) where k is the coefficient for the exponential decay curve, (b) TSL (k degree-day $^{-1}$) where k is corrected for stream temperatures, (c) TSL as the percentage lost per day, (d), TSL as the percentage lost per degree-day.

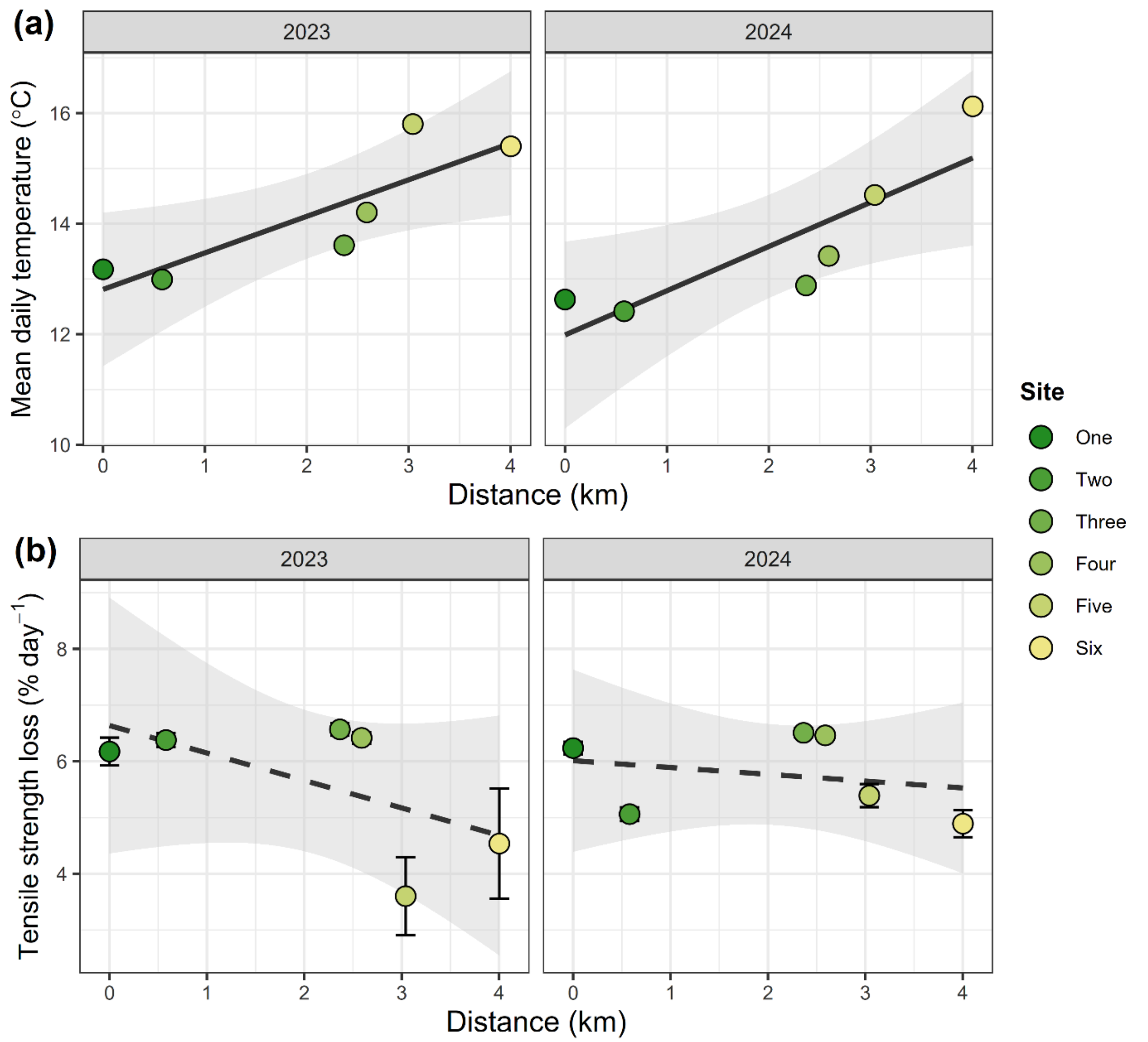


Figure 48. Longitudinal change in mean daily temperatures (°C) (a) and mean tensile strength loss (± SE) of cotton strips (% per day) (b) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled twice (Summer in 2023 and 2024, respectively); here mean temperatures and tensile strength loss are plotted relative to their distance downstream from Site 1 (the most upstream site sampled).

Mean daily temperatures in 2023 and 2024 increased moving downstream from Site 1 on the Tokaanu Stream ($p<0.05$; Figure 49a). There was no significant linear relationship between distance downstream and cotton strip tensile strength loss (Figure 49b).

The experiment in 2024 testing different deployment methods for the cotton strip assay. The first method ("Low") was the same as that deployed in 2023, while the second method ("High") incorporated a 10 cm polypropylene riser to lift the cotton strips out of the sediment. The two methods returned similar profiles across sites (Figure 50), with some exceptions

(Table 8). Using the decomposition coefficient *k* day^{-1} for tensile strength loss indicated that there were differences across sites. Sites 2, 5, and 6 had slower breakdown rates than Sites 1, 3, and 4 (p<0.001). The faster tensile strength loss rates (*k* day^{-1}) using the "Low" method of deployment were not statistically significant at α=0.05. Likewise, tensile strength loss rates (*k* day^{-1}) using the "Low" method at Site 3 were not statistically significant at α=0.05. The same patterns were observed using temperature-corrected tensile strength loss rates (*k* $degree\text{-}day^{-1}$), except for Site 3 where tensile strength loss rates were significantly faster using the "Low" method (p<0.05), and Site 5, where tensile strength loss rates were not significantly faster using the "Low" method at α=0.05 (p=0.058). Assuming linear decay rate for cotton strip decomposition using the percentage loss rates of tensile strength rates (% day^{-1}, % $degree\text{-}day^{-1}$) meant any potential treatment effects were non-significant (Table 8). The same site effects described above applied to the percentage loss rates of tensile strength rates (% day^{-1}, % $degree\text{-}day^{-1}$). See Appendix D, Table D4, for all results.

*Table 8. Probability values and goodness of fit (R^2) statistics from general linear models (GLMs) testing the influence of site, treatment (Low, High), and their interaction on tensile strength loss (TSL) of cotton strips used to monitor the ecosystem health of the Tokaanu Stream in the Lake Taupō catchment. ns, not significant at α=0.1; *sites where the interaction was not significant at α=0.05.*

TSL	Site	Treatment	Site × Treatment		R^2
	p-value	*p*-value	*p*-value	Tmt | Site	
k day^{-1}	<0.001	0.056	ns	3*	0.514
k $degree\text{-}day^{-1}$	<0.001	0.055	ns	3, 5*	0.647
% day^{-1}	<0.001	ns	ns		0.568
% $degree\text{-}day^{-1}$	<0.001	ns	ns		0.760

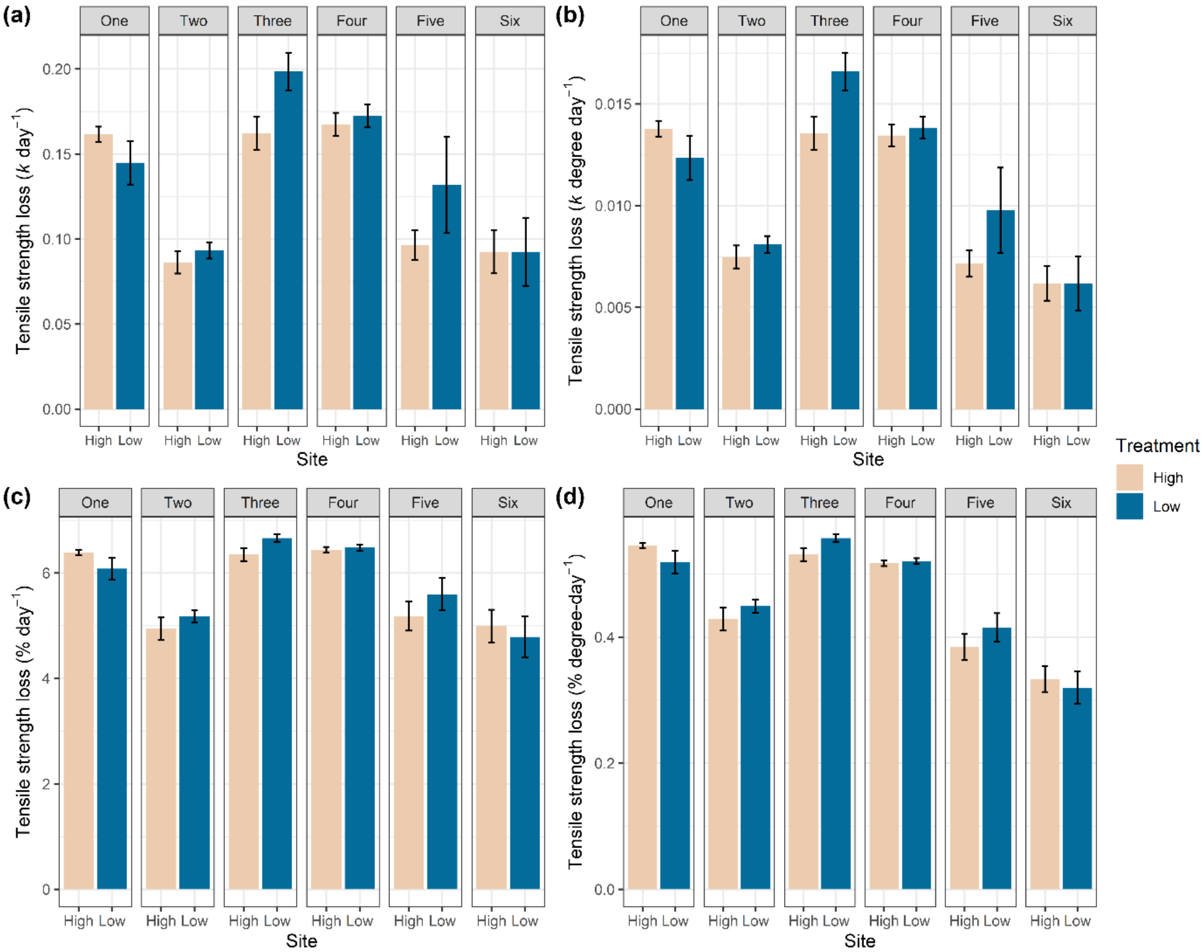


Figure 49. Tensile strength loss (TSL) rates for cotton strips deployed in 2024 at all six sites on the Tokaanu Stream in the Lake Taupō catchment. Cotton strips were subjected to one of two treatments (Low, High) where their position in the water column was manipulated. (a) TSL (k day^{-1}) where k is the coefficient for the exponential decay curve, (b) TSL (k degree-day $^{-1}$) where k is corrected for stream temperatures, (c) TSL as the percentage lost per day, (d), TSL as the percentage lost per degree-day.

5 Discussion

5.1 Preface

Over the duration of this study, I have encountered narratives about the Tokaanu Stream which help explain the motivation for change expressed by Ngāti Kurauia. Their lived experiences have created a dialogue within the hapū, activated kaitiaki, and enabled mana motuhake. This transformation has been an essential catalyst for the collaborative research I have undertaken with Ngāti Kurauia. Aside from technical reports by Wildlands Consultants (Shaw, 2010) and OPUS Consultants (OPUS, 2012) there is little recent information, anecdotal or otherwise, about the Tokaanu Stream. In this regard, I hope my thesis will help narrow this knowledge gap. I have taken an approach weaving together Mātauranga Māori and contemporary scientific monitoring to better understand the ecological and cultural health of the Tokaanu Stream. My study is the first of its kind for this awa, but more work is required. Ngāti Kurauia and I encourage more mahi rangahau (research) to advance our understanding of Te Taiao and further enhance the mana of the hapū.

A key feature of my project was developing a bespoke cultural monitoring framework in collaboration with Ngāti Kurauia to recognise the ecological and cultural values important to them. This framework can now be used alongside contemporary scientific monitoring approaches to monitor the ecological and cultural health of the Tokaanu Stream in their rohe. Specifically, this relates to where Ngāti Kurauia assert mana whenua status in the downstream portion of the Tokaanu Stream from State Highway 47 to its delta entering Lake Taupō. My collaboration with Ngāti Kurauia offers a transformational approach to biomonitoring by using contemporary methods to support Mātauranga Māori, as opposed to Mātauranga Māori playing a supporting role. Through the application of Kaupapa Māori, Mātauranga Māori, and contemporary biomonitoring approaches I sought to address three key predictions about the ecological and cultural health of the Tokaanu Stream:

1. The diversion above the Tokaanu tailrace is an impediment to a natural flow regime in the Tokaanu Stream evidenced by altered hydrology, changes in thermal dynamics and benthic substrate downstream.
2. The urban dwellings of Tokaanu Village contribute to reduced water quality due to stormwater inputs and potential leakage from damaged sewerage infrastructure and septic tanks.
3. The impacts of the diversion and urbanisation are degrading the ecological and cultural health of the Tokaanu Stream with potential negative impacts on the receiving environment of Lake Taupō.

Although these key questions were important aspects of my research and will be explored further in my discussion, I also wanted to achieve other goals. I was able to meet key objectives over the duration of my study, including:

- Collaborating with Ngāti Kurauia to create a cultural monitoring framework that adds to their kete of knowledge.
- Increasing the involvement of hapū members with their immediate environment and thus strengthening their connection to Te Taiao.
- Generating baseline data sets that can be used for multiple purposes.
- Identifying drivers which may be causing negative impacts for Ngāti Kurauia and the Tokaanu Stream.

Each sampling site along the Tokaanu Stream was chosen by hapū members in a participatory approach. These six sites were chosen because of their applicability to my project, their cultural significance, and how well they represented key changes in the catchment. Each site was also chosen on their accessibility and safety, due to environmental risks including geothermal activity. The Lake Taupō catchment is a geologically active area in the central North Island. It contains active puia, and frequently experiences earthquake swarms (GeoNet, 2025) with some swarms consisting of more than 2000 earthquakes (GeoNet, 2017).

- Site 1 possessed a mixture of natural streambed transitioning to a concrete-lined channel for the Tokaanu Stream diversion.
- Site 2 was located at the engineered outflow from the aqueduct flowing underneath the main road crossing the Tokaanu tailrace. The outflow has been artificially armoured with boulders to help prevent the erosion of the streambed at the aqueduct discharge.
- Site 3 has a bridge enabling vehicle access to the urupā (graveyard). It was described as being representative of the former Tokaanu Stream state with less disturbance from land-use and hydrogeomorphic changes.
- Site 4 was immediately adjacent to the Tokaanu Hot pools and the beginning of perpetual diffuse geothermal inputs to the stream. The stream may be affected by regular maintenance for the pools which are a local tourism venture.
- Site 5 was chosen because it was directly downstream of the Tokaanu Village and was located beside a council reserve allowing easy and safe access to the awa.
- Site 6 was selected as most downstream reach of the Tokaanu Stream before it reaches its delta with the lake. It also met other selection criteria, including access.

5.2 Key results

Contemporary methods, typically with a Western science bias, are the standard approach when monitoring the ecological health of streams in Aotearoa. However, there is value in weaving conventional approaches with a traditional ecological knowledge (TEK) perspective embracing Mātauranga Māori. By doing this, both worldviews are seen, acknowledged, and accounted for. Whilst cultural monitoring frameworks already exist in Aotearoa, many hapū find these exclude the values they care about. My research introduced the Ngāti Kurauia Cultural Monitoring Framework (CMF), a bespoke tool developed to allow hapū to assess their traditional values, recognizing that existing biomonitoring frameworks may not fully capture local cultural perspectives. This framework ensures that Ngāti Kurauia's voices are heard and, subsequently, have equal opportunity for inclusion in management decisions affecting their awa.

Site 1, through discussion, was considered by many haerenga attendees to be the exemplar of what the Tokaanu Stream should look like when compared to Sites 2 – 6. In many facets like bird diversity, bird song, and water clarity, which all scored the highest at Site 1, my research agreed with these sentiments. However, for other attributes including engineering, streambed colour, and the sound of water flow, Site 1 was assessed as the worst of all six sites.

Using the Ngāti Kurauia CMF, Site 3 was determined to be the most pristine site of all six sites. Attributes scored over all haerenga determined Site 3 has the highest mean values for intact riparian cover, beneficial in-stream vegetation, substrate colour and size, and māhinga kai. The presence of abundant harakeke in the riparian zone was notable at this site. While Site 3 was determined to be the best site using the CMF, the primary reason for this was the absence of multiple poorly scoring attributes, thus helping lift it above the other five sites.

Site 5 was widely agreed to be the lowest scoring of all six sites when using the CMF with 9 of 16 attributes returning the lowest values. Included among these was wairua, pollution, birdsong, absence of a riparian margin along the true right bank, and substrate classification. Moreover, other attributes including the colour and feel of the water, odour and water clarity were lowest at Site 5, potentially resulting from a point source input at this location. Interestingly, Site 5 had the highest score for engineering (indicating the relative absence of engineered features) despite its close proximity to commercial ventures, the main road that runs through Tokaanu, and the Taupō District Councils effluent management system.

Water quality in the Tokaanu Stream is a significant concern due to various anthropogenic influences and natural factors. Regional councils in New Zealand typically monitor water quality, but the Tūwharetoa Māori Trust Board (TMTB) holds unique authority for monitoring Lake Taupō waters, including the Tokaanu Stream, under Section 33 of the Resource Management Act. Water quality data for the upstream State of the Environment (SOE) monitoring station is publicly available through the LAWA website and covers NPS-FM attributes like ammonia, nitrate, dissolved reactive phosphorus (DRP), and *E. coli*. However, this monitoring station is located near the spring source of the Tokaanu Stream beside Tūrangi and does not describe the state of the awa further downstream. My research indicates fluctuating levels for these contaminants in the stream segment sampled downstream of the SH47 bridge. For instance, ammonia concentrations increase downstream of the Tokaanu Village, likely due to raw sewage inputs from leaking septic tanks and broken sewer pipes. Faecal coliform bacteria, indicated by *E. coli* concentrations, pointed to increasing faecal contamination moving downstream. The source of this bacterium likely included domesticated mammals, wildlife, and potentially faulty sewage infrastructure. Nitrate concentrations, while generally stable in my samples, have historically fluctuated. High levels of nitrite can pose health risks, but the concentrations of observed nitrate and nitrites were consistently <1 g/m^3 in my sampling. The high concentrations of dissolved reactive phosphorus, often linked to human activity, are strongly influenced by the volcanic geology of the Tokaanu Stream.

My study also considered macroinvertebrate communities, eDNA and functional indicators to provide a more holistic and rigorous view of the Tokaanu Stream's health. While historical macroinvertebrate data for the Tokaanu Stream was scarce, my research provides two years of NEMS data at six sites downstream of the SH47 bridge. These results reveal a community that becomes increasingly tolerant to pollution moving downstream, as indicated by the NPS-FM attributes including the Macroinvertebrate Community Index (MCI). Key sensitive taxa including the mayfly *Deleatidum* and the crane fly *Aphrophila* were lost from Sites 5 and 6. The exact reasons for these changes remain uncertain, but it is likely the increased geothermal inputs moving downstream have negative impacts on sensitive macroinvertebrate taxa. There was some evidence that instream channel remediation works in 2024 may have improved benthic habitat as evidenced by higher macroinvertebrate metrics at Sites 4-6. Environmental DNA (eDNA) analysis provided insights into fish and māhinga kai (traditional food) species presence. The eDNA sampling indicated the presence of taonga species like kōaro (*Galaxias brevipinnis*) in the catchment and seasonal variation in pōrohe (*Retropinna retropinna*) presence at the most downstream site. The cotton strip assay (CSA) was used to assess microbial activity and surprisingly showed a decrease in activity with increased stream temperatures at Sites 5 and 6, potentially due to toxic contaminants from geothermal inputs.

My discussion will further explore how the Tokaanu Power Scheme diversion may have detrimentally altered the stream's natural flow and sediment regimes, while the Tokaanu

Village's urban development and aging infrastructure potentially contribute to water quality issues. I also consider the role of geothermal inputs, which may also contribute to declining stream health through natural and anthropogenic processes. These impacts point to the complex interplay of human impacts and natural processes on the stream's ecological and cultural health. Ultimately, I argue that my findings suggest a need for a second monitoring site near the Tokaanu Village. Monitoring this site would more accurately reflect the stream's overall condition, as the current upstream site may not capture the full extent of anthropogenic impacts in the catchment as the stream flows towards Lake Taupō.

5.3 Cultural Monitoring Framework

Why develop a bespoke framework?

Developing a bespoke (custom-designed) cultural monitoring framework is crucial, especially in contexts like Aotearoa where indigenous knowledge systems like Mātauranga Māori are recognized as vital for environmental management. Each iwi and hapū have their Mātauranga Māori/Mātauranga Pūtaiao, often developed over generations through observation and reasoning. More recently this traditional ecological knowledge (TEK) has included approaches grounded in Western science, such as the monitoring framework used in the Cultural Health Index (Tipa & Teirney, 2006a; Tipa & Tierney, 2003). These tools have been instrumental in helping to develop the techniques used to assess and report on the health of the Tokaanu Stream.

Over the last 30 years, and in-line with the United Nation's Declaration on the Rights of Indigenous Peoples (Morgan *et al.*, 2021; United Nations, 2007), multiple frameworks have increased tangata whenua engagement and participation within the environmental stewardship and research space. This includes Gail Tipa and Laurel Teirney's Cultural Health Index (Tipa & Teirney, 2006a; Tipa & Tierney, 2003), Kepa Morgan's Mauri Model (Morgan & Manuel, 2020; Wilkinson *et al.*, 2020), Richard Jefferies and Nathan Kennedy's Kaupapa Māori Outcomes and Indicators Kete (Jefferies & Kennedy, 2009), and Ian Ruru's Mauri Compass (mauricompass.com, N.D.), among others.

After investigating the existing cultural monitoring frameworks with Ngāti Kurauia kaumatua, it was agreed that none of these were suitable for Ngāti Kurauia. Hapū members recognized that while the existence of numerous indigenised tools is an impressive development, these approaches were not fit for their purpose. Ngāti Kurauia wanted the 'right tool for the right place' (i.e., developed by them for them) rather than another tool ill-suited to describing local conditions and aspirations. Therefore, a bespoke framework, which weaved together Ngāti Kurauia values, beliefs, and long-term aspirations was developed to adequately reflect the Ngāti Kurauia worldview. The development of a bespoke framework helps reduce any inherent bias from external actors (Morgan *et al.*, 2021; Tipa & Tierney, 2003). This bespoke cultural monitoring framework included semi-quantitative attributes assessed by Ngāti Kurauia alongside the conventional quantitative methods used for stream health monitoring.

Ngāti Kurauia Cultural Monitoring Framework

The Ngāti Kurauia Cultural Monitoring Framework (CMF) was developed over an extended period through wānanga with Ngāti Kurauia. After the initial engagement period, and subsequent presentation made to the Tokaanu Marae Committee seeking permission to move ahead, a pānui was circulated among hapū members as well as via online social networking platforms to attend wānanga. Word of mouth and invitations were extended to other people including neighbouring hapū (Ngāti Tūrangitukua, Ngāti Turumakina, Ngāti Te Mahau), the

Tokaanu Stream Management Committee, Genesis Energy, and Dr Francis Burdon, a stream ecologist from the University of Waikato who acted as my academic supervisor for this study.

Attendees discussed what values they hold when they go to the Tokaanu Stream, alongside what they 'look for' when deciding if the stream is healthy or not. After a robust discussion 16 attributes were identified. Considering the number of attributes, hapū members were asked during wānanga tuarua (the second development workshop) if they had an order of preference if they had to reduce the number of variables for field sampling. The resounding response was that all variables were as important as each other and that, while it may change after my research had concluded, they must all be included or no research would be allowed.

A Likert scale was used to score all CMF variables to produce semi-quantitative results in line with Tipa and Tierney (2003). However, for this CMF the Likert scale ranged from 0 to 5 expressed as 0% to 100%. Each increment held a description based on hapū feedback, accounting for 20% of ecosystem health. This differs from the approach used by Tipa and Tierney (2003) whose scale for the cultural stream health measure ranges from 1 to 5 and is scored accordingly (Appendix A). The sole exception for the Ngāti Kurauia CMF was 'Wairua', which purposefully did not include descriptors for each increment as it was impossible to articulate what wairua means for every individual. Therefore, each person was encouraged to employ best judgement, or what Harmsworth *et al.* (2008) called, listening to the "feeling in your puku" (p.430), when allocating a score (0% or 100%) for this variable.

The attributes chosen by members of Ngāti Kurauia were vegetation adjacent to the stream (exotic vs native), percentage cover vegetation immediately adjacent to the stream, vegetation in-stream, stream substrate, bird diversity, sound – bird song, sound – water flow, pollution, engineering, māhinga kai, water clarity, odour, feel of the water, water colour, streambed colour, and wairua. Many of the attributes relate directly to stream properties also assessed using conventional scientific methods. These methods included the assessment of deposited fine sediment (SAM2), riparian condition (Rapid Habitat Assessment, RHA), and water clarity (water clarity tube). The scores for each attribute using the Ngāti Kurauia CMF ranged between people. This was expected as the approach used to score attributes is subjective and depends on the judgement of each participant. However, by scoring attributes as group, and repeating the cultural monitoring on several haerenga, I hoped that a general consensus for each attribute would emerge at each site.

CMF Attributes

While there are 16 attributes, many of these could be grouped together. These groups would include vegetation, morphology, wildlife, kai, pollution, engineering, and wairua. However, for the purposes of my discussion, all attributes will be addressed individually.

Riparian vegetation

Exotic trees and shrubs have been increasingly observed across the country with many being notified on various regional pest management plans. Although it has been 15 years since it was released, Wildlands Consulting were the last known organisation to produce a report summarising the plants present within the Tokaanu Stream catchment (Shaw, 2010). Members of Ngāti Kurauia have undertaken works based on the proposed workplan suggested by Shaw (2010). Specifically, this occurred at sub-catchment scales with many willows (*Salix* spp.) being poisoned.

This attribute compared the exotic vegetation immediately adjacent to the Tokaanu Stream with native species. The riparian margins at all six sites have a mixed population of native and exotic species. The true right bank of the Tokaanu Stream has the most anthropogenic modification including roads, housing, and grassed areas. While the true left bank still has some impacts, it appears to contain more native plant species.

Further development of this attribute in the Ngāti Kurauia CMF could involve delineating between banks, as done for the rapid habitat assessment. Scoring each bank individually would help interested parties to better understand the true extent of differences between the two banks in the lower section of the Tokaanu Stream. Furthermore, it would also assist in proposing targeted remediation or mitigation works.

Riparian vegetation cover

Riparian vegetation is integral to the healthy function of streams as it provides shade and habitat, stabilizes banks, and contributes wood, detritus and prey used by aquatic species. Intact riparian margins create continued corridors where birds can go for shelter, food, and connection between communities (O'Brien, 1994). Areas with intact riparian margins tend to be more resilient to erosion and can have markedly lower levels of sediment entering the system (Gluckman *et al.*, 2017). These values are recognized by Ngāti Kurauia.

The intactness of riparian vegetation varied along the sample length of the Tokaanu Stream. This variation was mainly due to anthropogenic management including the Tokaanu Stream diversion. However, other aspects are also instrumental in affecting riparian vegetation intactness. Most notable is the Tokaanu hot pools and neighbouring residential houses which abut the Tokaanu Stream.

Site 3 was dominated by harakeke and raupō, with some pockets of blackberry. This site had the most intact riparian vegetation of all six sites as scored using the CMF. However, participants returned the second highest standard deviation when scoring Site 3 for this attribute, indicating some disagreement in the vegetation cover offered by the harakeke and raupō.

Like above, this attribute would benefit from assessing each bank separately. Doing this would better describe the actual riparian condition and help target any proposed remedial works. Furthermore, participants need to ensure an accurate assessment of the current environmental state is made, whilst carefully acknowledging their positive recollections of past conditions.

In-stream vegetation

New Zealand has at least 113 known macrophyte species within its streams. However, only 35 of these species are native (Gluckman *et al.*, 2017). This reflects an indigenous aquatic macrophyte community which is constantly threatened by invasive species. This problem can be exacerbated when people do not know the difference between native and exotic species.

Depending on the person and community, there are many exotic macrophyte species that could be considered beneficial. A prime example is watercress (*Nasturtium officinale*), native to Europe, Asia, and North Africa, which has become naturalised to New Zealand's waterways and is valued as kai and rongoā Māori (Raukawa Charitable Trust, 2020).

Although not an aquatic macrophyte, its proximity to the stream at several sites suggest that harakeke (flax) is another native species that could be considered for its multiple values. The fibre from harakeke is favoured for rāranga and rope making (Phillips & Marden, 2006; Riley, 2004), and it provides other ecosystem services including bank stabilisation.

Haerenga attendees discussed how there are numerous beneficial plants fringing the Tokaanu Stream. However, just as often, discussion focussed on the non-beneficial plants that were present. These discussions were vigorous at Sites 3 and 4 when attendees reminisced about the watercress from their youth with beds so dense you could walk across the stream.

While hapū members were disappointed at the perceived loss of the watercress, they were happy about the levels of harakeke and raupō. This was particularly noticeable from Sites 3 to 6, although Site 4 did not have the density for these species that Sites 3, 5 and 6 had, likely due to the geothermal activity in the vicinity of the hot pools.

A positive step for future monitoring would be for qualified experts to work with Ngāti Kurauia in identifying what plants are considered beneficial or otherwise. This input would support active hapū members engaged in monitoring the Tokaanu Stream, as well as encouraging others who may want to become more active in the future.

Stream substrate

Stream substrate was assessed by visually observing the composition of the streambed. This attribute was also measured using the more quantitative SAM2 protocol.

Streams that maintain fast flows can self-regulate as suspended fine sediment cannot settle to fill interstitial spaces (Poff *et al.*, 1997). Anecdotal evidence suggests the Tokaanu Stream has been severely impacted by changes to the natural flow and sediment regimes. This includes increased sedimentation in several reaches. The results from the Ngāti Kurauia CMF alongside anecdotal evidence garnished from discussions with hapū members describe changes to the substrate composition of the Tokaanu Stream. The results from the SAM2 protocol indicated that fine sediment covers large portions of the streambed at all sites assessed.

Ngāti Kurauia believe the Tokaanu Stream has declined in recent decades, shifting from a stream which had large swimming holes to one which is shallow and predominantly wadeable. Ngāti Kurauia indicate that although the Tokaanu Stream had reaches where sand was prevalent, particularly around Site 3, they have observed an accelerated decline in streambed health from sedimentation.

When undertaking future monitoring it would help to take a streambed core or grab sample. This could be useful as it would show attendees the substrate constituents, which can be difficult to determine from the streambank. Furthermore, samples could be processed to determine constituent ratios, deepening our understanding of substrate composition.

Bird diversity

Manu (birds) are renowned for their uses around Ngāti Tūwharetoa. Many birds, including Moa (extinct) and Tītī (locally extinct), were once part of the diet of Ngāti Kurauia and have since been replaced with more contemporary species. We assessed bird diversity at all sites.

The diversity (and abundance) of manu at each site was highly variable in space and time. This may have been because of differences in the weather, the noise of attendees scaring away manu, or other reasons including seasonal migrations and other behavioural responses.

Kererū (Wood Pigeon, *Hemiphaga novaeseelandiae*), Tui (*Prosthemadera novaeseelandiae*), and Pīwakawaka (Fantail, *Rhipidura fuliginosa*) were the most common native species observed at Sites 1 to 3. These species changed as we traversed downstream. We observed more Pūkeko (*Porphyrio melanotus*) using adjacent wetlands, alongside fantail.

Of all sites, Site 6 constantly had a high amount of disagreement among the monitoring team. This may have been for a variety of reasons, including that Site 6 was more exposed being the closest to the lake with more low-lying vegetation, and that it was the final sampling site on each haerenga. As the final site, participants were often observed to be noticeably louder, possibly due to excitement as the day's monitoring was coming to an end. This noise may have scared away birds and affected our ability to record manu at this site.

Looking to the future, it may help to randomise the site order for monitoring. The simplest solution would be to alternate between moving upstream or downstream between sites. However, any changes must be discussed and agreed upon as kaumatua participating prefer order and predictability in terms of what they are doing and when.

Sound – Bird song

Alongside bird diversity through visual observation, bird song was also used to determine if there were any species present, but not visible. Each site was visited for a minimum of 30 minutes with this metric encouraged to be the final metric to score. This was to assist birds to adjust to the monitoring team being on-site.

Of all six sites, Site 1 had the highest amount of birdsong with Tui, Kererū, Fantails, Sparrows (*Passer domesticus*), and the occasional Korimako (Bellbird, *Anthornis melanura*) recorded. Tui and Fantails were the most common year-round alongside sparrows and did not seem to mind inclement weather. Moving downstream the avian populations song changed from a chorus of pleasant songbirds to the abrupt call of the Pūkeko resident in downstream wetland areas. Sites 3 and 5 had the lowest birdsong levels of all six sites, however, they were also immediately adjacent to roads with semi-regular traffic.

In the future, it would be worth considering monitoring this attribute during either the dawn or dusk chorus. This would be more reflective of the resident avian community but could also be more pleasant for the kaitiaki undertaking the monitoring.

Water flow

Water flow was assessed at each site as Ngāti Kurauia kaumatua would recall how the stream would sound during their youth. This attribute proved challenging at times as the streamflow was relatively quiet and could only be heard when standing downwind of the sampling site. This challenge could often be exacerbated by traffic noise and an aging participant population. As such, this may have impacted the results as the mean values for this metric were low with the highest value, taken from Site 3, being 41%.

To improve monitoring this attribute I recommend kaitiaki stand downwind of the monitoring point so that the opportunity to hear stream flow is maximised. Furthermore, I would encourage this measurement to only be taken during gaps in traffic, when background sounds are at a minimum. Lastly, I would encourage this attribute to be monitored as close to the stream as possible, provided it is safe to do so.

Pollution

Pollution levels have been increasing around New Zealand's communities for decades. Illegal dumping (fly-tipping) creates significant distress and financial challenges to many towns. In Gisborne, a medium-sized town on the east cost of the North Island, illegal dumping has increased from 150 tonnes in 2021 financial year, to more than 300 tonnes in 2023; an increase of more than 100% in a relatively short period of only 2 calendar years (Gisborne District Council, 2024).

Pollution of this nature is also a problem around Lake Taupō. In 2016, the amount of illegally dumped rubbish removed from the town's parks was as high as 93 tonnes. However, this did not include larger illegal dump sites (Taupō District Council, 2016). More recently, pollution events around Lake Taupō have increased with illegal dumping recorded in several locations including State Highway 41 below the Waituhi Scenic Lookout.

There is a strong social stigma attached to 'fly-tipping' in the Taupō district (Taupō District Council, 2016). This sentiment is shared by residents of the Tokaanu settlement which is generally kept tidy and free of rubbish. Regardless of whether the pollution is in the stream, or adjacent to it, hapū members believe it is unsightly, a cause of potential illnesses, and would like to see this problem addressed.

During my research pollution levels varied at the six sites. Items of rubbish observed in the stream ranged from building materials, to drink containers, food wrappers and animal remains. At Site 5 there is a significant amount of pollution, both in-stream and adjacent to the stream. This includes vehicle tyres dumped in the stream and local art (which attendees consider to be unsightly) on the stream bank.

Site 2 was the cleanest in terms of rubbish, returning a mean value of 81.67%, and Site 1 also returned a similar mean value of 81.5%. These scores suggest both sites have only occasional rubbish which is easily collected and disposed of. However, Site 2 had several sets of animal remains dumped during the year. It was also the only site to have kōura remains observed. These remains apparently washed from upstream, caught in a recirculating current on the true left bank on multiple occasions.

Engineering

The engineered surrounds of the Tokaanu Stream were discussed as a major point of concern at every wānanga. During every haerenga these man-made features left participants feeling heavy-hearted. Overwhelmingly, these features surrounded the Tokaanu Power Scheme and the Tokaanu Stream diversion. Concerns were expressed about how both impacted the stream and geothermal field. Ngāti Kurauia also discussed, at length, the impacts of these anthropogenic disturbances on their tikanga, kawa, māhinga kai, and mana.

Site 1 was the site of greatest concern, with a mean score of less than 1% for this attribute. It also had the lowest standard deviation indicating the unanimity that Ngāti Kurauia have regarding their concerns about the diversion and neighbouring power station. These results, coupled with the issues raised by attendees including diminished mana, increased sedimentation, and declining māhinga kai all point to the discontent felt by hapū. Clearly, Ngāti Kurauia have tangible concerns relating to the engineered sections of the Tokaanu Stream.

Simultaneously, however, attendees are happy there were no detected introduced species upstream of the diversion apart from rainbow trout which is also considered kai. Furthermore, residents were pleased that firm consent conditions were placed upon Genesis Energy for the Tokaanu Power Scheme. They would like to see more stringent conditions and further engagement in the future.

Examples of engineering, which attendees noticed, included the Tokaanu Stream diversion and accompanying canal (Site 1), the aqueduct exit and state highway (Site 2), the bridge traversing the Tokaanu Stream to the urupā (Site 3), the large sealed carpark and tourist attraction at the Tokaanu Hot Pools facility (Site 4), the pipe discharging geothermal waters (Site 5), and the state highway bridge and smaller infrastructure spanning the most downstream extent of the Tokaanu Stream at Site 6.

Māhinga kai

Kevin Collier and colleagues (Collier *et al*., 2017) describe māhinga kai well as "the place for, harvesting, collection, hunting and gathering of food resources." (p.1). While not as important in a contemporary age, many Ngāti Kurauia attendees reflected fondly on their youth and the abundance of māhinga kai that was available to them prior to the development of the Tokaanu power scheme.

Changes in the catchment have led to pressure on māhinga kai and a resulting decline in not only kai, but also mana. Pressures identified by Ngāti Kurauia include the disconnection of the Tokaanu Stream by the Tokaanu power station, historic fragmentation of habitats and reduced wetlands, point and non-point contaminant discharges, sedimentation, pest plant and fish species, and channel modification. Similar concerns have also been discussed by Collier *et al.* (2017) and Gluckman *et al.* (2017). Other areas like the Motueka catchment also reflect these concerns (Basher, 2003).

According to kaitiaki, Site 3 has the most kai species with a mean value of 44.3% (between 2 and 3 species). However, while attendees agree Site 3 has the most kai available, the extent which food is available is subjective. Noticeably, this was observed with younger attendees identifying grapes and blackberry as kai, while some older attendees would include Raupō (Bulrush, *Typha orientalis*), Rārahu (Bracken Fern, *Pteridium esculentum*) and Tī Kōuka (Cabbage Tree, *Cordyline australis*).

To assist in determining what is traditional or contemporary kai, Ngāti Kurauia could create a field guide. The field guide could include species used as kai, rongoā, or other uses that Ngāti Kurauia consider beneficial. An initial site visit could document the presence of these species. This could be then used to assist hapū when undertaking ongoing monitoring.

Water clarity

Water clarity can indicate whether there has been disturbance upstream leading to erosion and sediment inputs (Ministry for the Environment, 2022). I collected water samples at each site with a clean white plastic bucket to assist Ngāti Kurauia to physically determine the clarity of the water. This also had the benefit of whānau being able to smell and feel the water without the risk of falling into the stream. The monitoring whānau found this approach to be novel, while also exciting as they were able to literally connect with the awa.

I also assessed water clarity and suspended sediment using more quantitative methods. Water clarity was frequently assessed using a water clarity tube. This frequently returned a maximum value of 100 cm, indicating that the use of a black disc might be more appropriate for the Tokaanu Stream. The single black disc recording from the upstream SOE monitoring site was 1.3 m, confirming the excellent water clarity of the awa further upstream. I also took water samples which I processed in the laboratory to measure the levels of suspended fine sediment.

The results for the CMF varied at each site over the course of the year; however, the general trend shows one of longitudinal decline in water clarity from Site 1 (92.5%) to Site 6 (62.33%). This trend is supported by the water clarity tube results which also show a longitudinal decline coupled with an increase in suspended fine inorganic sediment concentrations (g/m^3).

There are multiple diffuse sources of sediment along the lower Tokaanu Stream. The main diffuse sources are through erosion caused by a variety of factors. Vehicles were observed disturbing the soil at Site 2 which would then get carried into the stream from surface flows during rain events. There are several tributary streams flowing from the flanks of Tihia which carry predominantly silt and sand into the Tokaanu Stream, particular during rain events (OPUS, 2012). These are the Tupatomatua, Omāwete, and two other streams which the OPUS (2012) report identifies as sub-catchment 3 and sub-catchment 4. In addition to these four streams, the Papanetu Stream (slightly upstream of State Highway 47), also enters the Tokaanu Stream. The Papanetu, Tupatomatua, and Omāwete streams have been noted as reaching elevations of up to 1165 m ASL on the northern fringes of the Tihia massif. This creates a significant amount of potential energy which can erode loosely compacted soils, increasing the sediment load in the Tokaanu Stream.

During one of my sampling rounds, a large suspended fine sediment plume was observed at Site 4 which lasted more than 5 minutes. This plume, which occurred on a sunny day, was observed to completely obscure all clarity and resembled 'milky tea'. Discussions with residents confirmed this was not an uncommon phenomenon.

In the future, it would be worthwhile considering increasing the frequency at which fine suspended sediment and turbidity is monitoring. This could be achieved if an additional SOE monitoring station was in the vicinity of the Tokaanu Village. Alternatively, the installation of a continuous turbidity meter within the Tokaanu Stream could help better describe the frequency and duration of these events. Furthermore, the inclusion of a black disc monitoring regime could gather better data on water clarity. Efforts could be made to further build the capacity of Ngāti Kurauia kaitiaki to monitor these attributes and develop a longitudinal dataset describing water clarity in greater detail.

Odour

Odour was assessed using each participant's olfactory sense. Participants were encouraged to smell a water sample retrieved using a clean plastic bucket as well as the surrounding environment to decide if the odour of the environment was suitable for Ngāti Kurauia.

Site 1 had the highest mean score indicating a mildly pleasant smell throughout the year. Site 5 was the lowest scoring of all six sites and was noted as having an unconsented geothermal discharge which would occasionally have unpleasant odours. Furthermore, there is sewage infrastructure at the interchange of Puanga Street and Matariki Street which has the occasional unpleasant odour. Site 2 had a similar mean score to Site 5. Site 2 had regular offal and animal remains dumped either in, or adjacent to the sampling site, potentially leading to foul odours at this site.

Feel of the water

Ngāti Kurauia use the feel of the water to tell them what other possible contaminants may be present within the water column. By touching the water, they were able to 'connect' with the awa as their tūpuna had, and determine if the water had a gritty, greasy, or slimy texture. Having the attendees approach the stream directly introduced a hazard. To mitigate risks caused by inclement weather, elevated stream levels, erosion-prone banks or ailing health conditions, I took a water sample from the stream for hapū to touch.

While most results were above 85%, there was a longitudinal decline in the feel of the water along the study reach. Most noticeably this was at Site 5 immediately downstream of the unconsented geothermal discharge from a neighbouring motel.

Improving the monitoring of this attribute for attendees could involve allowing them to retrieve the water sample. This change would provide training and increase the agency of participants. These actions are necessary for the assessment of water-based attributes to continue in the future, since it would be hapū doing the monitoring.

Water colour

Ngāti Kurauia used water colour to assess the health of the Tokaanu Stream alongside the other attributes. The Tokaanu Stream usually has water of high clarity, therefore, when the stream has high suspended sediment concentrations or tannin-staining, kaitiaki can undertake to determine the origin of these attributes.

Water samples were collected using a white bucket for assessment by kaitiaki. Site 1 had the best colour of all six sites, with Site 4 the second best. Site 1 does not appear to have as many natural or anthropogenic impacts as Sites 2 to 6. This helps to explain the lack of colour and excellent water clarity of the stream at this site. Site 4 had the second highest score and stands in contrast with most other attributes and might be due to the input of the Tupatomatua Stream upstream of this site. Alternatively, there might be a spring (or ground water) entering the stream upstream of this site. There is a large pool which could affect the behaviour of the hyporheic zone downstream. There is also a wetland area immediately upstream of the sampling point which could be associate with an upwelling spring. Less likely is that the pool and wetland enable particles to fall out of suspension due to the reduced stream velocities leading to improved colour. Site 5 received the lowest result of all six sites. This is likely due to the discoloured inputs from piped geothermal discharge.

To improve the assessment of this attribute it would be worth taking water samples at all six sites and then assessing them together simultaneously. This would involve six white buckets. Additional samples could also be collected to increase the spatial replication. Once completed, the mean value would give a more accurate assessment of this attribute.

Streambed colour

Streambed colour was the last of the streambed observations and was visually assessed. Due to the Tokaanu Stream's underlying geology, the natural streambed colour is a mixture of light brown, yellow and dull orange.

Most streambed values suggest the Tokaanu Stream is impacted by sedimentation or a periphyton mat (possibly a cyanobacteria). Low-scoring streambed colours ranged between light grey and green. Site 3 was the highest scoring site and is incised compared to all the other sites as the stream flow has cut through the substrate over the decades. Site 3 was most like the natural state of the Tokaanu Stream according to hapū members. These results from Site 3 made sense, as it also has the most intact riparian margins that not only intercept light, therefore limiting algal growth, but also bind fine sediment.

Wairua

Wairua was difficult to measure and is reflected in the [lack of] explanatory notes on the Likert scale used in the Ngāti Kurauia CMF. Attendees were encouraged to use their best 'personal' judgement, tap into their wairua, and see the landscape through the eyes of their tūpuna.

If the Ngāti Kurauia CMF was used by other actors to assess the Tokaanu Stream, it might be difficult for them to undertake this measure if they do not whakapapa to the Ngāti Kurauia rohe. Due to this it may be best to either exclude this attribute in the CMF, or as Harmsworth *et al.* (2008) explains, listen to the "feeling in [their] puku" (p.430) as an alternative to wairua in this context.

While wairua did decline from Sites 1 to 6, it did not decline in a linear fashion. As the most upstream site with the clearest water and high-scoring vegetation metrics, Site 1 had the highest wairua value of all six sites. Site 6, however, did not have the lowest wairua. This was reserved for Sites 5 and 2 which have significant anthropogenic impacts that affected the wairua as scored by attending hapū.

Overall assessment using the CMF

While many CMF attributes align with conventional scientific monitoring parameters (e.g., fine sediment, riparian condition, water clarity), the CMF provides a unique, subjective, and holistic perspective. Our findings showed inorganic fine sediment increased downstream, while organic sediment decreased, particularly below wetlands. The framework also revealed strong Ngāti Kurauia concerns about engineering impacts on the stream, especially near the Tokaanu Power Scheme and diversion, which they link to declining mana and māhinga kai. Water clarity generally declined downstream, correlating with increased inorganic sediment. Specific sites were identified for different issues, such as Site 5's odour and water feel concerns due to an unconsented geothermal discharge, and Site 2's pollution from dumped animal remains. Despite some attribute scores showing variation among participants (as expected given the subjective nature), future refinements like separate bank assessments for riparian attributes, expert collaboration on plant identification, and improved sampling logistics (e.g., randomizing site order, taking core samples for substrate, and sampling during dawn/dusk chorus for bird song) are recommended to enhance the framework's application and facilitate consensus-building during ongoing hapū-led monitoring.

Cultural Health Index

The Cultural Health Index (CHI) was developed to enable iwi to become more involved in monitoring activities and decision making within their area(s) of interest. The CHI weaves together Mātauranga Māori and contemporary scientific approaches to create a ground-breaking monitoring framework (Tipa & Teirney, 2006b; Tipa & Tierney, 2003). Initially developed for use in Te Wai Pounamu (Aotearoa's South Island), it has gained traction in recent decades and is now, arguably, the most prominent cultural monitoring framework in use across Aotearoa (Tipa & Teirney, 2006a).

The CHI articulates Māori values for monitoring the environment. It was created through consultation with kaumātua and iwi resource managers. Key indicators were identified and ultimately streamlined to enable easy use by rūnanga when quantifying traditionally qualitative attributes (Tipa & Tierney, 2003). In their 2003 research, Tipa & Tierney (2003) acknowledge that the use of the CHI may not be appropriate for use in all parts of Aotearoa. The CHI was developed for southern streams and conditions, which differ from streams in Te Ika-a-Māui (Aotearoa's North Island). This includes streams in the Lake Taupō catchment such as the Tokaanu Stream. In these instances, either an entirely new framework would need to be developed, or, as Tipa and Tierney (2003) discuss, the CHI amended so the stream health indicators suit local conditions and attitudes.

The CHI has three focus areas which include the significance of the site being monitored, a māhinga kai attribute, and a cultural stream health measure (Ministry for the Environment & Stats NZ, 2020; Tipa & Teirney, 2006a; Tipa & Tierney, 2003; Townsend *et al.*, 2004). While the CHI is arguably the most recognisable Māori-centric framework for stream monitoring, some hapū and iwi find the output difficult to understand. This is because the full CHI output contains the status of the site, a māhinga kai attribute, and the cultural stream health measure score (e.g., A-1/2.3/4.5). This scoring system can be confusing and overly complicated for some hapū and iwi as it requires either a prior understanding of the framework, or a key to aid interpretation. While there are other cultural monitoring frameworks used across Aotearoa (Ataria *et al.*, 2018; Morgan, 2018; Rainforth & Harmsworth, 2019), Ngāti Kurauia insisted on the development of an entirely new cultural monitoring framework which was bespoke and developed specifically with them in mind.

To find a middle ground between the CHI and the Ngāti Kurauia CMF, I developed a way to used selected attributes from the Ngāti Kurauia CMF to calculate the cultural stream health measure (CSHM) score. This approach offers the best of both approaches, by retaining Ngāti Kurauia's mana but also enabling them to calculate the CSHM score using their CMF. This approach was useful in that it further highlighted the problems with Sites 1 and 5 on the Tokaanu Stream, whilst identifying the state of Site 3 as the most desired of the six sites monitored.

5.4 Water quality

Freshwater systems globally are increasingly impacted by human activities, with these effects particularly pronounced in low-lying areas exposed to degraded water quality and complex chemical interactions (Orr *et al.*, 2024). In Aotearoa New Zealand, regional councils are mandated to monitor water quality. A notable exception to this monitoring mandate is with Ngāti Tūwharetoa who uphold mana whenua around Lake Taupō and its immediate catchment. Tūwharetoa Māori Trust Board (TMTB), acting on behalf of Ngāti Tūwharetoa, were the first iwi authority in Aotearoa New Zealand to successfully utilise Section 33 of the Resource Management Act (RMA) to transfer powers from a local authority (Waikato Regional Council) regarding water quality monitoring around Lake Taupō. TMTB now monitors waterbodies in the Lake Taupō catchment with funding provided by the Waikato Regional Council. While the TMTB is the only iwi authority in New Zealand who has successfully enacted Section 33, this unique arrangement does not relieve Waikato Regional Council of its responsibilities. The council must still respond to incidents occurring within Lake Taupō or the catchment which lies within its geographical boundary.

Monitoring water quality can be challenging because physicochemical conditions are dynamic and rarely the same on subsequent visits (Scarsbrook, 2002). Regional councils around Aotearoa New Zealand are required to frequently monitor water quality, often monthly, to better capture the underlying variability in physicochemical conditions. Water samples collected by regional councils and unitary bodies are processed and the resulting data used for State of the Environment (SOE) reporting. When results raise concerns under the NPS-FM, councils are required to investigate further and mitigate harmful effects in the catchment. The data is also uploaded to the publicly available Land, Air, Water Aotearoa (LAWA) website (LAWA, 2023). LAWA has long-term river health data for more than 1500 streams and rivers across Aotearoa, one of which is the Tokaanu Stream with the sole monitoring station located near Tūrangi. This data contains information on concentrations of ammonia, nitrate, dissolved reactive phosphorus, potentially pathogenic bacteria (*Escherichia coli* – *E. coli*) alongside other physicochemical parameters like water clarity (LAWA, 2023). The data available on LAWA also include macroinvertebrate data collected for SOE monitoring. The monitoring sites used for macroinvertebrates often do not align perfectly with those used for water quality. This problem is exemplified by the Tokaanu Stream, where no routine macroinvertebrate monitoring has been undertaken.

Nutrient pollution

Ammoniacal nitrogen

Ammonia (NH_3) is a significant pollutant in freshwaters, with a range of detrimental effects on aquatic ecosystems, primarily due to its direct toxicity to aquatic organisms and its role in eutrophication (Camargo & Alonso, 2006; Collier *et al.*, 2017; Edwards *et al.*, 2024). I measured total ammoniacal nitrogen concentrations on three occasions at the six sites in the Tokaanu Stream. My results showed consistently low concentrations of ammoniacal nitrogen at Sites 1, 2, and 3 before a drastic increase moving downstream of the Tokaanu Village. Specifically, concentrations increased downstream of the Tokaanu hot pools (Site 4) and continued to increase downstream at Sites 5 and 6. Concentrations at Site 6 were almost 12 times that observed upstream. The sources of this ammoniacal nitrogen remain uncertain. However, the

Taupō District Council (2021) in their wastewater plan acknowledge that there are ongoing challenges with leaking sewerage pipes and infrastructure including septic tanks.

Collier *et al.* (2017) suggests that elevated ammoniacal nitrogen could also be the result of increased densities of pest fish. In my eDNA samples, I detected the presence of goldfish and brown bullhead catfish at Site 6, but these non-native fish were not detected further upstream at Site 1. It is plausible that excretion from these fish contribute to altered nutrient dynamics.

Over 20 years of water quality monitoring on the upper Tokaanu Stream has shown levels of ammoniacal nitrogen to be generally steady at 0.01 g/m^3. However, my results indicate how condition further downstream may not match that observed near the spring source. Based on my limited sampling, the lower section of the Tokaanu Stream appears to remain in band A for this attribute under the NPS-FM (New Zealand Government, 2020), potential mitigation measures could be explored to prevent levels of ammoniacal concentrations increasing to band B or higher.

Total oxidised nitrogen

Total oxidised nitrogen (TON) is calculated as the sum of nitrates and nitrites from a water sample. Concentrations and loads of TON are important they assist in determining how much soluble nitrogen is available for use by algae and other plants (Camargo & Alonso, 2006). While it is important to understand the concentrations of TON, it is also important to understand the implications of each component. High nitrite concentrations have been linked to a decreased ability for organisms to retain oxygen in haemoglobin. Consequently, excessive nitrite concentrations in drinking water can cause significant health effects for pregnant woman such as premature birth, low birth weights, and 'blue baby syndrome' (Minnesota Department of Health, 2025). The Minnesota Department of Health (2025) and Richards *et al.* (2021) have linked some cancers and thyroid issues to excessive concentrations of nitrate. Not only do excessive concentrations of TON add stress on aquatic organisms and pose human health risks, but it can also lead to increased levels of eutrophication in streams and receiving environments. In streams, high TON concentrations can lead to excessive algal growth leading to loss of benthic habitat and altered ecosystem metabolism (Bernot *et al.*, 2010; Smith *et al.*, 1999).

I measured TON concentrations on three occasions at the six sites in the Tokaanu Stream. Sites 1 to 6 showed stable TON levels (<0.45 g/m^3) that were lower than the upstream SOE monitoring station. Over 20 years of SOE water quality sampling has shown TON concentrations to fluctuate over time at the upstream monitoring site. Between 2004 and 2021 the median was 0.43 g/m^3, consistent with the concentrations seen in my sampling.

There was a marginal decline in concentrations moving downstream across my six sites. Reasons for the lower concentrations at my sites compared to contemporaneous sampling upstream remain uncertain. Decreasing concentrations moving downstream may be due to increased uptake by benthic microbes and macrophytes, in combination with increased denitrification by natural wetlands at the stream margins and connected off channel (Appendix C, Table C8). The potential sources of TON within the Tokaanu Stream catchment may be linked to historic and contemporary agriculture, past industrial practices, and problems with sewage including damaged or faulty infrastructure (Rutherford, 1984). Understanding the long-term trends for this contaminant is important for the Tokaanu Stream and Lake Taupō.

Dissolved reactive phosphorus

Dissolved Reactive Phosphorus (DRP), also known as orthophosphate, is a critical and often problematic nutrient in freshwater ecosystems (Smith *et al.*, 1999). It is the most bioavailable form of phosphorus, meaning it is readily taken up and utilized by aquatic plants and algae. When DRP concentrations are elevated, it can trigger a cascade of negative ecological effects, primarily driving eutrophication (Schindler, 1974). Excessive concentrations of dissolved reactive phosphorus (DRP) in freshwaters is often thought to be a consequence of human activities including increased erosion, urban runoff, damaged or inadequate sewerage infrastructure, and fertiliser applications (Gluckman *et al.*, 2017; Orr *et al.*, 2024). However, areas with phosphorus-rich geology due to volcanic activity can have naturally high concentrations of DRP (Burdon & Özkundakci, 2023).

Due to its location in the Taupō Volcanic Zone (TVZ), the Tokaanu Stream's springhead arises from a volcanic landscape, and this is reflected in its water chemistry. Although little research has been conducted on the nutrient dynamics of the Tokaanu Stream, the underlying geology is similar to the Rotorua region which also has high levels of DRP in spring-fed streams (Gluckman *et al.*, 2017). To combat naturally high levels of DRP in the Lake Rotorua catchment, the Bay of Plenty Regional Council, in consultation with the Te Arawa Lakes Trust, undergo an alum dosing of the Utuhina and Puarenga streams (Ling, 2016; Ling & Brijs, 2009). The aim of this intervention is to reduce the DRP load entering Lake Rotorua, and in turn, improve water quality as indicated by a higher Trophic Lake Index score.

The highest recorded DRP reading in the Tokaanu Stream was 0.091 g/m^3 and was taken on 23 November 2004, and the median concentration between 2004 and 2021 was 0.075 g/m^3 (LAWA, 2023), considerably higher than the concentrations seen in my sampling. All six sites on the Tokaanu Stream were sampled on three occasions spanning three different seasons (14 December 2023, 5 May 2024 and 15 July 2024). The median concentration observed at Site 1 was 0.049 g/m^3 (range: 0.042 - 0.053 g/m^3), and this dropped to 0.040 g/m^3 (range: 0.037 - 0.044 g/m^3) at Site 6. It is likely that this reduction is the result of uptake by benthic microbes and macrophytes, similar to that observed for TON. The Tokaanu Stream, alongside the rest of Lake Taupō waters is nitrogen limited when considering the Redfield ratio of Carbon:Nitrogen:Phosphorus (106:16:1). Therefore, alum dosing would not be a suitable means of managing risks associated with high DRP loads. Rather, mitigation of the potential nitrogen risk would be best implemented by a nitrogen cap, which has already been undertaken due to the Lake Taupō Nitrogen Trading Programme (Spicer *et al.*, 2021).

Microbial pollution

Escherichia coli (*E. coli*) is a widely used and highly effective indicator organism for assessing microbial water quality in freshwater ecosystems. Its presence in water indicates faecal contamination from warm-blooded animals including livestock (Chakravarthy *et al.*, 2019) and humans (Touchon *et al.*, 2020), thus signalling the potential presence of harmful pathogens that can cause illness. There are several species of pathogenic bacteria which can have negative impacts on human health. *E. coli* is widely used as a reliable faecal indicator bacterium in water quality assessments to indicate the presence of these potentially harmful pathogens in water sources (Cookson *et al.*, 2024). *E. coli* is important for my research as it indicates the presence of faecal contamination in the Tokaanu Stream and is a known contaminant of watercress (Collier *et al.*, 2017), an important māhinga kai species for Ngāti Kurauia.

Between 2013 and 2021, the median value for *E. coli* concentrations at the upstream SOE monitoring site was 11 colony forming units (CFU) per 100 ml, with a maximum of 900 CFU/100 ml. More recent *E. coli* results from monitoring by TMTB places the upstream SOE site into Band A of the NPS-FM 2020 (LAWA, 2023), with many results from the last five years returning values less than 20 CFU/100 ml. In my sampling of the Tokaanu Stream, I recorded a median concentration of 45 CFU/100 ml (range: 20 – 61 CFU/100 ml) at Site 1, with this indicator increasing downstream. Site 3 had a median concentration of 99 CFU/100 ml (range: 10 – 100 CFU/100 ml). Site 3 is a healthy wetland area and is known in the local community for its abundance of waterfowl and Pūkeko. The *E. coli* concentrations continued to increase downstream with a median of 125 CFU/100 ml (range: 52 – 190 CFU/100 ml) recorded at Site 6. Site 6 is immediately downstream of the Tokaanu Village and recorded the maximum concentration of 190 CFU/100 ml observed during my study. This concentration still falls within New Zealand's guidelines for swimming and recreational purposes of ≤540 CFU/100 ml (Gluckman *et al.*, 2017).

E. coli is known to enter the environment from a variety of sources. One major source in many Aotearoa catchments is from livestock mammals such as cattle. This poses an interesting point as the catchment of the Tokaanu Stream is not known for its farming. Rather, many households have an assortment of domesticated animals present including horses, dogs, cats, and chickens, all which deposit *E. coli* in their faeces. Wildlife may also be a source of faecal coliforms. The southern hillside from Tūrangi to Tokaanu is also a well-known māhinga kai with good populations of feral deer (*Cervus ephalus*) and pigs (*Sus scrofa*). However, as Gilpin *et al.* (2007) discusses, one must also remember the prevalence of *E. coli* in the faeces of waterfowl like the Black Swan (*Cygnus atratus*) and ducks (*Anas* spp.) with over 26,000 CFU in every gram of Black Swan scat (Gilpin *et al.*, 2007). Other avian sources of *E. coli* include pūkeko. Swans and ducks have become a growing concern for the residents of Tokaanu of the last 20 years. As one kaumatua discussed, ‘duck itch’ is now so pronounced that residents avoid swimming in the Tokaanu Stream and nearby Lake Taupō (George Asher, pers communication, 2025). Coupled with the risk of skin infections it is understandable that some hapū members will no longer enter their awa tūpuna for fear of becoming māuiui (unwell).

Other sources of *E. coli* include human wastewater from untreated or poorly treated sewage, failing septic tanks, and broken sewer pipes (Chakravarthy *et al.*, 2019; Gilpin *et al.*, 2007; Gluckman *et al.*, 2017). Faulty septic tanks and broken sewer infrastructure are also likely causes of the increased *E. coli* concentrations in the Tokaanu Stream. To confirm this requires microbial source tracking targets from human, ruminant and avian source of contamination (Cookson *et al.*, 2024). Management options for the Tokaanu Stream include replacing damaged septic tanks while also repairing damage to any reticulated sewer lines, as this may also help reduce ammoniacal nitrogen pollution (see above). As the feral animal population is transient and a valued food source for residents it may be more difficult to manage these sources. However, encouraging hapū to control these species through customary harvesting may be beneficial for water quality and kai sovereignty.

Limitations of the current SOE monitoring site

The Tokaanu Stream has a springhead at its origin near the outskirts of Tūrangi, and the current SOE monitoring site for the catchment is located just downstream of the puna (spring). I believe the current site is not reflective of the overall condition of the Tokaanu Stream. Whilst it serves well as a site to monitor the puna, it provides misleading results for the overall stream as the conditions change moving towards the lake. The downstream segments of the Tokaanu Stream have several sources of human impact that are currently unaccounted for. Firstly, there are human dwellings in the downstream portion of the stream with associated anthropogenic impacts including urban runoff, inadequate sewage infrastructure, and loss of riparian vegetation. Secondly, the diversion around the tailrace is a major engineering feature that has pronounced consequences for downstream reaches. Sediment is regularly dredged from the diversion, and this can be mobilised and transported further downstream.

Whilst ignoring these features is acceptable for understanding how the upper stream is functioning, it is a near-fatal flaw for providing balanced results for the overall health of the catchment. As Gluckman *et al.* (2017) states, “longitudinal monitoring regimes [should be] appropriate to the nature of the catchment and its likely issues” (p. XIV). Moving forward, for the Tokaanu Stream to be adequately monitored in its entirety, it is worthwhile to consider the addition of a second sampling site in the vicinity of the Tokaanu Village. This portion of the stream has a series of anthropogenic impacts including leaking septic tanks, runoff from roading, and loss of riparian vegetation. Adding a second monitoring station here would provide a more accurate reflection of the stream's true ecosystem health before it enters Lake Taupō. We should keep the current site, as its long-term datasets would be valuable for comparison with the new, more appropriate location.

5.5 Habitat quality

Channelization

Channelization, the process of straightening, widening, deepening, or relocating natural stream channels, is often undertaken for flood control, navigation, or drainage improvement (Brookes, 1988). While it may offer short-term benefits for human activities, its impacts on stream habitat are overwhelmingly negative and can have long-lasting ecological consequences. It can lead to reduced channel sinuosity and increased flow velocities, removing the natural resistance that dissipates energy and thus resulting in increased erosion (Brookes, 1995). These effects also reduce habitat heterogeneity and lead to a more uniform distribution of fine sediment particles on the streambed (Harrison *et al.*, 2004). Channelization also severs the stream from its floodplain, thus preventing natural processes involving sediment deposition, nutrient cycling, and the provision of off-channel habitats that provide refugia during high flows (Lau *et al.*, 2006).

The course of the Tokaanu Stream has changed via natural and artificial processes over time. While the earthworks for the Tokaanu Power Scheme have majorly contributed to the realignment and channelization of the stream, it has also been extensively modified over decades for other reasons. Notably, sections near State Highway 41 (a crucial bypass route) were straightened to prevent flooding and ensure the road's operability. Within Tokaanu Village, at least two more channelized reaches exist, likely to improve hydraulic conductivity and reduce residential flooding, though anecdotal evidence from Ngāti Kurauia kaumatua suggests some straightening also occurred historically for log passage.

The channelization of the Tokaanu Stream, regardless of the origins, has fundamentally altered the stream's natural run-riffle-pool progression. Ngāti Kurauia considers the stream beds health a key monitoring attribute, a view shared by contemporary research, with the substrate varying from fine sand to coarser gravels and cobbles (OPUS, 2012). The particle size of the substrate is critical, as it provides habitat, refugia, and can influence the mobilization of nutrients and contaminants (Collier *et al.*, 2017). Future research is suggested to assess heavy metal contamination from both natural geothermal inputs and anthropogenic sources like the power infrastructure and hydrocarbons from State Highway 41.

My study used the Ngāti Kurauia Cultural Monitoring Framework alongside contemporary protocols like the Stream Assessment Method 2 (SAM2) and an amended Wolman Walk (SAM3). While the results showed similarities across these metrics, a complete alignment was not achieved. This discrepancy might be due to the kaitiaki (Ngāti Kurauia guardians) being unable to wade into the stream during monitoring, a necessary component for the SAM2 and SAM3 methodologies.

Fine sediment

Natural flow and sediment regimes are considered fundamental drivers of river condition (Wohl *et al.*, 2015). Larger substrate particles typically support greater numbers of macroinvertebrates with increased diversity (Quinn & Hickey, 1990). Coarser particles can provide crucial habitat that organisms need for their different life stages (Kemp *et al.*, 2011). There is evidence for sediment thresholds from hard-bottomed streams in Te Wai Pounamu, indicating that sedimentation can induce non-linear ecological responses (Burdon *et al.*, 2013).

Whilst channelization has likely affected the substrate composition of the Tokaanu Stream, it needs to be recognised that streams in the Taupō Volcanic Zone differ from other parts of Aotearoa in that the deep ash and tephra layers which are highly erodible can lead to extensive fine deposited sediment on the streambed (Burdon & Özkundakci, 2023). Such habitat features may not be closely linked to macroinvertebrate communities, due to high water quality from spring sources and greater habitat heterogeneity, unlike other parts on Aotearoa (Edgecombe, 2024).

Fine sediments may be mobilised during high-flow events and the regular maintenance of the diversion channel. Unsurprisingly, most of the suspended fine particles carried within the

Tokaanu Stream are sands and silts (OPUS, 2012). Suspended fine particles are known to clog and potentially abrade gill surfaces reducing oxygen uptake of fish and other species (Kemp *et al.*, 2011). Moreover, excessive levels of suspended fine particles can lower visibility and potentially make the stream less desirable for fish to navigate (Collier *et al.*, 2017). I chose to quantify fine suspended sediment using a mass-based, gravimetric approach. This is the most widely accepted and direct method for measuring total suspended solids (TSS), which includes fine suspended inorganic sediment. It involves physically separating the particulate matter from the water sample and measuring its ash-free dry mass. There were ten times the amount of inorganic suspended fine sediment when compared to the organic fraction and this increased downstream. Organic suspended fine sediments were the opposite and declined downstream. This might have been due to lower macrophyte cover as a consequence of channelization leading to changes in fine sediment dynamics. However, without sampling further upstream this idea can only be considered a hypothesis.

Kaitiaki should continue monitoring suspended fine sediment in the future, but the mass-based approach could prove problematic. The lack of access to a laboratory makes this method difficult to use. Furthermore, there may be reporting advantages to measuring suspended sediment using indirect approaches such as turbidity ("cloudiness") expressed in nephelometric turbidity units (NTUs). As Collier *et al.* (2017), New Zealand Government (2020), and Simpson *et al.* (2013) discuss there are only trigger values for NTUs under the NPS-FM. Thus, measuring suspended sediment using indirect approaches such as turbidity may be easier for the hapū if funding is made available for a portable turbidimeter.

Stream geomorphology

The segment of the Tokaanu Stream that I sampled had a low gradient. There was only a 1-meter fall over its course from Site 1 (362 meters above sea level) to Site 6 (361 MASL), resulting in a very gentle slope (topographic-map.com., 2025). The gradient is only 0.026%, an order of magnitude less than the world average river reach slope of 2.6 m/km or 0.26% (Cohen *et al.*, 2018). Despite this overall low gradient, there was considerable variation in flow velocities across sites.

Site 2 possessed the fastest flows due to the channel constriction and fall at the exit of the aqueduct. The effects of this manmade feature on stream flow velocities were likely exacerbated by the extended channel upstream lacking streambed roughness. The highest velocities were recorded in the channel thalweg (i.e., the centre of the outlet), reaching 0.8 $m^3 s^{-1}$. Site 3 was adjacent to a large wetland area, comprising of predominantly raupō and harakeke. This vegetation was present both upstream and downstream of the sampling site. The highest flow velocity obtained from this site was 0.44 $m^3 s^{-1}$. The channel was somewhat incised by the abundant riparian vegetation providing a channel constriction. These features contributed to a well-formed streambed with coarser substrate at this site.

Site 4 has a deep pool upstream which quickly transitions to a shallow (approx. 20 cm) run with a significant increase in velocity. This portion of the stream had the lowest percentage deposited fine sediment cover of all six sites. The low sediment cover of Site 4 is notable, as it reflects a state of the stream that residents recall from their memories. Other than the natural geomorphology at this site, there may be other reasons for its desirable properties. Recent macrophyte removal may have increased flow velocities and helped winnow out finer sediment. There is a large wetland immediately upstream, which may enable fine sediment deposition upstream.

Conversely, a major tributary (the Tupatomatua Stream) joins the Tokaanu Stream upstream of the sampling point. This tributary may have important effects on substrate composition by providing a supply of coarser pumice gravels and small cobbles from the slopes of Tihia. It may be that the diversion has greatly altered the natural sediment regime for the Tokaanu Stream, and that it paradoxically suffers from too much and not enough sediment simultaneously. Fine sediment may have accumulated via channelization and the loss of flushing flows. The diversion and other engineering features may have lessened the supply of coarser particles that can be mobilised during high flow events. There was some evidence of channel ‘armouring’ (coarsening) of the streambed at Site 3, indicating that this reach was sediment starved. In contrast, Site 4 is just downstream of the confluence with the Tupatomatua Stream and may have the sediment supply missing from upstream.

Water and sediment inputs are fundamental drivers of stream ecosystems, but river management has tended to prioritize flow regimes at the expense of the sediment regime (Wohl et al. 2015). In the Tokaanu Stream the diversion has a spillway before the stream flows into the aqueduct underneath the road. This engineering feature would divert floodwaters during rare high flow events to the Tokaanu tailrace. Combined with the sharp angles and concrete box channel of the diversion, these channel modifications likely lead to greatly altered flow and sediment regimes downstream. Thus, it seems likely the natural flow and sediment regimes have changed considerably since the implementation of the Tokaanu Power Scheme, a point acknowledged by the former Prime Minister’s Chief Science Advisor, Sir Peter Gluckman (Gluckman *et al.*, 2017).

Riparian habitat

A rapid habitat assessment protocol (RHA) was used to assess riparian condition adjacent to the stream on both banks at each site (Harding *et al.*, 2009). The RHA was used to calculate the Riparian Condition Index (RCI), a semi-quantitative index that provides an indicator of riparian condition independent of the riparian attributes assessed in the CMF. However, the RCI is subjectively assessed using 13 attributes on a Likert Scale, so can only be considered indicative and not fully quantitative. Nonetheless, it has proven to be a useful descriptor of riparian condition that helps link riparian impacts with stream ecological responses (Burdon *et al.*, 2013).

The benefits of incorporating the RCI in the research design were multifaceted. The RCI is widely accepted by the scientific community as a worthwhile tool to measure stream riparian condition. It has similarities to many cultural assessments in that it relies on quantifying attributes via a Likert scale using subjective assessment. This approach is also used in the cultural health index (Tipa & Teirney, 2006a, 2006b) and the bespoke Ngāti Kurauia cultural monitoring framework (CMF) developed in my study.

Like key attributes in the Ngāti Kurauia CMF, the RCI has a strong focus on riparian vegetation. However, unlike the Ngāti Kurauia CMF, the RCI also incorporates adjacent land-use, soil stability, drainage capacity, and bank slope (Harding *et al.*, 2009). Whilst useful for my study, further training for mana whenua in RHA would be required if they were to use the RCI as an additional metric. Conversely, because the RHA uses a similar approach to the CMF, it is a low-cost assessment resulting in an index that is easy to calculate and could have utility for kaitiaki.

The RHA for the Tokaanu Stream was undertaken at all six sites by a hapū member from Ngāti Kurauia. Using a single member was done due to the challenges in training hapū in a new method separate from the CMF. The RCI identified Site 3 as the site with the best riparian condition (a score of 51), which was a result congruent with the CMF. However, the RCI results suggested Site 5 is the second-best site in terms of riparian condition with a score of 40, a result in contrast to the CMF results for this site. Such disagreement is acceptable, since the CMF has been developed by hapū and views the awa through their cultural lens.

Ultimately, while the inclusion of the RCI is useful for my research, it is unlikely that hapū kaitiaki would want to incorporate it as an addition to the CMF. The RCI has been developed for a different purpose than the wants and needs of Ngāti Kurauia at this stage. However, when considering further development of the Ngāti Kurauia CMF, mana whenua may consider certain attributes in the RHA protocol worthy of inclusion in their monitoring.

5.6 Biodiversity

In stream ecology, structural indicators typically refer to the biological characteristics of the ecosystem that provide information about its physiochemical, habitat, and biotic complexity (Sandin & Solimini, 2009). Structural indicators help to measure the ecological integrity of the stream habitat. More simply, they can be considered indicators for "what is there" and generally rely on biotic indices derived from biodiversity data on key organismal communities. I investigated the macroinvertebrate community of the Tokaanu Stream and used environmental DNA (eDNA) to better understand fish communities. These structural indicators can be contrasted with the functional indicator I used to assess cellulose degradation (the cotton strip assay) discussed in the next section.

While little scientific research has been done on the lower portion of the Tokaanu Stream, most of what has been undertaken has focussed on the chemical and geological constituents of the surrounding landscape. Historic research focussed on the salmonid population as the

Tokaanu Stream was once considered a leading trout spawning stream and fishery (Shaw, 2010). The local community via Tokaanu marae, Genesis Energy, and the Tokaanu Stream Management Committee have allowed for some research to be conducted with the most recent work undertaken by Wildland Consultants (Shaw, 2010) and OPUS (OPUS, 2012). Wildland Consultants were engaged to provide an overview of the near stream catchment in terms of vegetation. Furthermore, Wildlands report provided suggestions on remediation and mitigation works for the this reach of the Tokaanu Stream (Shaw, 2010). OPUS Consultants, however, were engaged to assess the potential flood risk along the Tokaanu Stream and how to best mitigate any risk, particularly to the Tokaanu township and neighbouring area (OPUS, 2012).

Macroinvertebrates

Macroinvertebrates are pivotal in the functioning of any stream. Every stream has a distinct assemblage of macroinvertebrates which forms the macroinvertebrate community and can provide quality food for fish populations (Biggs *et al.*, 2008; Stark & Maxted, 2007). Often used as bioindicators (Orr *et al.*, 2024) it is essential to undertake frequent monitoring of the macroinvertebrate community as their responses are impacted by natural and anthropogenic pressures (Scarsbrook, 2002).

Macroinvertebrate communities are unique and can consist of highly sensitive or broadly tolerant species across spatial and temporal scales due to physicochemical and habitat influences. They can be used as indicators to measure freshwater quality due to their relatively sedentary nature, reasonably long lifespans, and predictable response to various environmental changes (Stark & Maxted, 2007). The Ephemeroptera (Mayflies), Plecoptera (Stoneflies), and Trichoptera (Caddisflies), also known as EPT, are highly susceptible to environmental change. However, other invertebrates are also used as indicators of stream health including non-EPT insects, worms, crustaceans, and molluscs.

Here I discuss results from the National Environmental Monitoring Standards (NEMS) monitoring undertaken at all six sites on the lower Tokaanu Stream on two occasions (Summer 2023 and 2024). The sampling was undertaken twice to generate a wider picture of the macroinvertebrate community, while creating a dataset that could assist the Tokaanu marae and the Waikato Regional Council in the future.

The NEMS monitoring protocol used a 0.5 mm mesh kick-net to sample macroinvertebrates semi-quantitatively. Firstly, the NEMS kick-net protocol is not fully quantitative, particularly when compared to using a Surber sampler. Therefore, the protocol avoids describing the densities of the taxa present, which can be useful for better understanding macroinvertebrate-environment relationships (Burdon *et al.*, 2013). The abundant fine sediment present in kick-net samples from the Tokaanu Stream caused complications on occasion. These fine particles, including clay, silt, sand and fine gravel, led to challenges in processing samples in the lab. Although I elutriated organic material including macroinvertebrates from the samples, this abundant inorganic material creates more 'background noise' and the potential for sampling errors.

The Macroinvertebrate Community Index (MCI) is a widely used and important tool in Aotearoa New Zealand for assessing the ecological health and water quality of streams and rivers. Each macroinvertebrate taxon has a tolerance value assigned to it. A tolerance value of 1 indicates a highly tolerant taxon that can survive or even flourish in polluted conditions, while 10 represents the most sensitive taxa that thrive in clean, healthy waters (Canning *et al.*, 2021; Stark & Maxted, 2007). The presence of stream macroinvertebrates and the associated tolerance values enable biomonitoring using the MCI. Other metrics like the quantitative MCI (QMCI), average score per metric (ASPM), EPT richness and % EPT abundance can also be used for biomonitoring.

The general trend from two years sampling shows a macroinvertebrate community that grows increasingly tolerant to pollution moving downstream along the study segment. Key sensitive taxa including the mayfly *Deleatidum* and the crane fly *Aphrophila* were lost from Sites 5 and 6. There are several potential reasons for these trends in the macroinvertebrate community data. My physicochemical and water quality sampling indicated that nitrogenous based pollution and fine sediment increased moving downstream. Nitrates, nitrites, and ammoniacal nitrogen are all toxic to instream species and can, therefore, lead to a population shift from highly sensitive to broadly tolerant species. Furthermore, the increased fine sediment levels can clog and abrade the gills of sensitive taxa, particularly EPT taxa that can have their large gills exposed.

In terms of habitat, flow conditions and benthic habitat moving downstream (i.e., at Sites 5 and 6) were less favourable for these taxa, although their complete extirpation from these two sites was striking.

Whilst the MCI declines downstream, the Tokaanu Stream sits equally on both sides of the national median MCI score of 103 (Scarsbrook *et al.*, 2000), with Sites 1 – 3 higher, and Sites 4 – 6 lower than the national median. However, caution is needed with interpreting my result based on two years of sampling. The macroinvertebrate attributes in the NPS-FM relies on median values from five years of annual sampling to ascertain status according to the set biocriteria and to guide management decisions. With a further three years of annual sampling needed to generate the data required for management, I recommend that macroinvertebrate monitoring continues for another three years at minimum. A more extensive dataset will provide a more complete picture by better describing natural variability and establishing the consistency of the trends shown by my research.

In 2024, the MCI for the Tokaanu Stream improved, with noticeable increases in the scores at Sites 4, 5, and 6. The exact reason for this improvement remains unclear, but it could be due to in-stream remediation works improving flow and benthic habitat conditions at these sites. During 2024, an external consultant (Nicholas Singers Ecological Solutions Ltd.) undertook stream remediation works to remove in-stream vegetation and debris between Sites 4 and 6. The goal of such remediation works are often to increase stream flow velocities, leading to localised scouring, and more habitat heterogeneity with coarser stream substrate (Gluckman *et al.*, 2017). The remediation works appeared to cause a decrease in water depths at Sites 4 and 5 with an increase in flow velocities, although these changes were not quantified. At Site 6 water depths appeared to have increased at the time of the 2024 sampling. The increase in depth at Site 6 was assumed to be because of Lake Taupō's influence on the lowest reaches of the Tokaanu Stream, with higher lake levels leading to flow backing up in the stream near its delta. However, the depths were not quantified and can only regarded as anecdotal, at best.

I used a Before-After, Controlled, Impact (BACI) design to assess the potential impacts of the remediation works on all macroinvertebrate metrics used. These metrics all increased at the impact sites after the remediation, and three were statistically significant, including the MCI. These changes indicated the potential positive influence of the instream remediation efforts on stream macroinvertebrate communities and ecosystem health. Other studies have shown the potential for instream remediation to positively affect macroinvertebrate communities, with effects generally strengthening where there are greater changes in benthic substrate composition (Hering *et al*., 2015). In my study, I did not quantify benthic substrate at all sites across both years, so I am unable to establish a causal link between the instream remediation efforts and the apparent response indicated by the macroinvertebrate metrics. However, these changes indicate that flow conditions at sites may be a limiting factor for some macroinvertebrates, leading to changes in key indicators.

Alternatively, Sites 1 and 2 had relatively intact riparian vegetation at both sampling points during 2023. However, for reasons unknown, the riparian margin had been altered before the 2024 sampling effort with the removal or severe pruning of woody riparian vegetation. This allowed increased light levels to make its way to the stream resulting in more in-stream autochthonous production and may have contributed to the lower values for some macroinvertebrate metrics, such as the QMCI. These changes could have confounded any comparisons using the BACI design discussed above.

In contrast to Sites 1 and 2, the macroinvertebrate indices reflecting abundances (QMCI, %EPT-abundance) increased at Site 3. The NEMS reach sampled at this site includes the confluence of the Tokaanu and Tupatomatua Streams. The Tupatomatua Stream flows from the slopes of the Tihia massif. The steep slope and upland source may deliver large amounts of sediment to the Tokaanu Stream during high flow events, some of which were observed during regular monitoring. Inputs of fine sediment may have caused a shift in community structure, although the greater dominance by the stonefly *Zelandobius* at this site in 2024 was mirrored upstream at Sites 1 and 2, and this EPT taxon is not thought to be fine sediment tolerant (Clapcott *et al.*, 2017). The increase of *Potamopyrgus* at Site 4 in 2024 is a result more consistent with an episodic pulse of fine sediment from the Tupatomatua Stream, although the in-stream remediation works could also explain the increased values for key macroinvertebrates at this site.

The Average Score Per Metric (ASPM) was developed by Kevin Collier in 2008 in an attempt to help consolidate multiple metrics and generate a single, parsimonious, outcome that is easy to understand (Clapcott *et al.*, 2017; Collier, 2008). The ASPM incorporates three metrics, the MCI, EPT richness (excluding hydroptilids) and % EPT abundance. These were chosen because they are widely recognised as being sensitive to environmental stress (Canning *et al.*, 2021; Collier, 2008). Whilst an effective indicator of stream health, care must be taken when using the ASPM. It may be unable to produce meaningful data if the metrics are inconsistent, such as having a high MCI and %EPT, but low EPT diversity (Collier, 2008). Furthermore, it may be less useful in streams more impacted by anthropogenic factors, such as high sedimentation rates and excessive periphyton growth (Collier, 2008).

Concerns regarding the ASPM and its applicability to the Tokaanu Stream were discussed during project development. This multi-metric index is normalised according to national guidelines, which might be less appropriate for my single stream study. Comparing the Tokaanu Stream with a national bottom-line based on the ASPM might be misleading (New Zealand Government, 2020). Thus, a local ASPM was also used by normalising the metrics used to the 'best' (most EPT rich) site on the Tokaanu Stream. I found the $ASPM_{local}$ score might be more appropriate for management decisions in the Tokaanu Stream, and the values in both years were being no lower than band B of the NPS-FM, with the exception of Site 6 in 2023 (band C).

Historical data relating to the Tokaanu Stream was sparse with no records found about the macroinvertebrates. My research has provided an important baseline that helps us better understand macroinvertebrate communities and ecosystem health in the Tokaanu Stream. What this new knowledge means for the future remains uncertain as the Tūwharetoa Māori Trust Board are responsible monitoring waterbodies in the Lake Taupō catchment ('Taupō Waters') which includes the Tokaanu Stream. However, the initiation of this sampling presents an opportunity should the Tūwharetoa Māori Trust Board and Waikato Regional Council wish to pursue it in the future and further build capacity within the iwi.

eDNA

Environmental DNA (eDNA) is increasingly being use for freshwater biomonitoring and is useful to indicate the biodiversity present within a catchment. However, there are concerns about data sovereignty. Some members of Ngāti Kurauia were concerned how the data would be used and did not want to have it available online. Concerns were raised about the extent of information that would be provided in this thesis. My thesis will present results for fish and māhinga kai species and I gratefully acknowledge the funding made available for this sampling.

eDNA was collected from the Tokaanu Stream on two dates. Due to the cost of analysis, sampling was limited to two rounds, with the first sampling two sites (Sites 1 and 6), and the second sampling Site 6. Discussions with Ngāti Kurauia have identified that Kōaro, Rainbow Trout, Brown Trout, Kōura, Morihana (goldfish), and common bullies are contemporary and traditional māhinga kai. Kōaro, Kōura, and Morihana are considered a taonga species with both brown and rainbow trout considered a contemporary taonga species due to their ability to provide sustenance. Historically, a report by Shaw (2010) has identified Rainbow trout, Goldfish, Common bullies and Kōaro as being present in the stream. DNA of these species was detected at Site 6 during the first sampling round. Other species detected included brown bullhead catfish, common smelt, and the common bully.

Further upstream at Site 1, only Rainbow Trout, Kōaro, Kōura, and the common bully were present. The exact reasons for the limited number of fish species present upstream is unknown. These species were either present before the Tokaanu Stream diversion was installed and have created resident populations, or they can successfully navigate the diversion despite the potential for restricted fish passage through the aqueduct. The flow velocities at the aqueduct discharge likely prevent species like common smelt from migrating further upstream. The absence of exotic fish (brown trout, goldfish and brown bullhead catfish) upstream indicates that reduced connectivity due to the diversion may create more favourable conditions for native species such as Kōaro by reducing predation and competition leading to larger populations, increased food availability, and less niche overlap. Dedicated fish surveys using traditional methods (electro-fishing, trapping) are needed to establish these patterns with confidence.

The second eDNA sampling round at Site 6 indicated some possible seasonal shifts in the fish community in the Lower Tokaanu. Common smelt were the only species not detected, which could be linked to their behaviour. Diadromous smelt spend most of their lives at sea but returning to freshwater as adults in summer and will typically spawn on sand bars of lower river reaches during autumn. The land-locked population in Lake Taupō may exhibit a similar behaviour, helping to explain the absence of smelt in the July (winter) sampling.

5.7 Ecosystem function

The cotton strip assay (CSA) was used as a functional indicator to further assess ecosystem health in the Tokaanu Stream. Although the CSA measures cotton degradation, it is a useful way to assess microbial activity. As nutrient concentrations and water temperatures increase, decomposition rates indicated by the cotton strip are expected to increase (Burdon *et al.*, 2020). This did not occur within the Tokaanu Stream during the monitoring in 2023, with decomposition rates decreasing at Sites 5 and 6 despite warmer, more nutrient-enriched stream conditions at these downstream locations. A second phase was deployed, incorporating two deployment methods (“low” and “high”) to test if burial by fine sediment confounded my results and explained the counterintuitive results at Sites 5 and 6.

The “low” deployment method was used during both sampling rounds. This method had individual cotton strips (CS) cable-tied directly to a light gauge chain laid along the stream bed. This subsequently became buried in sediment due to streambed mobility. The “high” deployment method incorporated a 10 cm section of polypropylene cord that was positively buoyant to lift the CS above the chain, with the aim to prevent sediment burial. The “high” method may have also reduced biotic interactions. When recovered, many CS had a noticeable amount of biofilm on them than those recovered from the “low” method. Furthermore, CS from the “low” method appeared to have been chewed. This could have been due to consumption by macroinvertebrates including Kōura and likely further degraded the CS. Consumption by macroinvertebrates could explain why, contrary to predictions, there was some evidence for faster decomposition at Sites 3 and 5 using the “low” method. However, the comparisons between deployment methods were mostly equivocal, and the consistently lower decomposition rates at Sites 5 and 6 indicated that another factor was responsible. To prevent cotton strips from being buried, future CSA tests could be deployed along the center of the Tokaanu Stream, where fine sediment is less prevalent than at the stream margins. However, increased flow velocities could lead to greater physical abrasion and potential dislodgement during high flow events.

Stream temperatures increased moving downstream, likely due to the increased levels of geothermal activity around the Tokaanu Village. Geothermal inputs enter the stream from diffuse and point sources. Toxic compounds in geothermal inputs, such as arsenic and mercury, could explain reduced microbial activity at these sites. The overall impact of the geothermal inputs remains unknown and would benefit from further analysis.

The Tokaanu Stream had not had the CSA used in the past and microbial responses to longitudinal changes were unknown. This assay pointed to some negative impacts of geothermal inputs suggested by some of the macroinvertebrate results. The CSA is a user-friendly biomonitoring method, and it would be beneficial to train Ngāti Kurauia for future sampling using this functional indicator. This would further empower them in biomonitoring methods and potentially facilitate collaboration with neighbouring iwi and hapū for broader assessments.

5.8 Synthesis

In my thesis research, I sought to address three key questions about the ecological and cultural health of the Tokaanu Stream that focused on hydrogeomorphological impacts of the diversion, the water quality impacts of urban dwellings in the vicinity of the Tokaanu Village, and the combined impacts of these drivers on stream health. Although I was unable to address some of these impacts explicitly, there are clues in my results that point to their relative effect on the Tokaanu Stream.

The natural flow regime

The natural flow regime (NFR) paradigm is a fundamental concept in river ecology and water resource management (Poff *et al.*, 1997). It posits that the natural, dynamic variability of streamflow over time is crucial for maintaining the ecological health, biodiversity, and integrity of river ecosystems. Building upon the NFR paradigm, a natural sediment regime perspective acknowledges how sediment is supplied, transported, and stored by nonlinear and episodic processes operating at different temporal and spatial scales than water (Wohl *et al.*, 2015). Both perspectives are important because both sediment and flow regimes have been highly altered by humans in many catchments. The implementation of the Tokaanu Stream diversion, resulting from the Tokaanu power scheme, has likely altered the natural flow regime of the Tokaanu Stream. The engineering features for the diversion include a concrete culvert with sharp angles (≥90°) before merging into a concrete aqueduct running beneath State Highway 47. The aqueduct discharges into a channelized stream channel that was artificially created, before finally returning to the original stream course 200 m downstream. Ngāti Kurauia believe these changes have been detrimental for the Tokaanu Stream, and there is some evidence in my research that supports these claims.

The Tokaanu Stream diversion potentially acts as a barrier to fish and kōura passage, thus affecting longitudinal connectivity. The concrete culvert contains little naturally occurring substrate, and does not have other features (e.g., baffles) retrofitted to aid fish passage. This situation results in laminar flows with little streambed roughness. Such flow conditions are a potential barrier for weak swimming fish (e.g., common smelt, smaller fish) and kōura. Thus, it is reasonable to expect that these species struggle to navigate the artificial section of the stream at the diversion. However, while the diversion likely impedes fish passage in conflict with current fish passage regulations, taonga species such as rainbow trout, kōaro, and kōura are present in the head waters, and exotic fish like brown bullhead catfish are restricted to the lower reaches.

The natural sediment regime is also impacted by the Tokaanu Stream diversion. As the stream flows around the first 90-degree right-hand bend, the fastest stream velocity occurs along the true-left canal bank resulting in suspended sediment falling out of suspension along the true-right bank. In line with the Waikato Regional Council consent conditions, Genesis Energy (the current operators of the Tokaanu Power Scheme) are required to remove sediment annually while ensuring stream flow does not exceed 2 $m^3 s^{-1}$ (OPUS, 2012). Coupled with a spillway that allows high flows to discharge straight into the Tokaanu tailrace, these features have likely altered natural flow and sediment-transport dynamics in the lower Tokaanu Stream. This potential problem has caused concern as downstream reaches may be periodically starved of finer sediment and gravels as they are deposited and removed from the stream before reaching lower reaches. Accumulated sediment in the tailrace may also displace floodwaters, meaning the flow volumes necessary for the spillway to come into operation (2 $m^3 s^{-1}$) are more easily reached. This would remove higher flows from reaching downstream, thus altering the natural flow and sediment regimes. This situation may also provide flood protection for the downstream community, but this benefit may have come at an ecological cost.

As indicated, there are positive aspects to the implementation of the Tokaanu Stream diversion. The diversion may prevent unwanted non-native fish from reaching upstream reaches. The spillway helps moderate flows and reduces the risks of flooding downstream (OPUS, 2012). The diversion, whilst problematic, does allow the streams base flow to continue downstream, as opposed to being diverted straight into the tailrace. While this mitigation was due to the Tokaanu Stream being a world class trout spawning stream, rather than providing for other ecosystem services, the fact that the stream still flows to its natural delta is notable. However, there is strong evidence that this 'Think Big' project from the Muldoon-era has left lasting consequences for the wairua of the Tokaanu Stream with multiple cultural and ecological factors severely impacted.

The urban stream syndrome

The "Urban Stream Syndrome" describes the consistent ecological degradation observed in streams that drain urbanized areas (Walsh *et al.*, 2005). This syndrome is characterized by a suite of interconnected symptoms, including altered hydrology (often resulting in "flashier" flows with rapid increases and decreases in water levels due to increased impervious surfaces and efficient stormwater drainage), elevated concentrations of pollutants like nutrients and contaminants, significant changes to the stream's physical channel morphology (such as widening, deepening, and instability), and a reduction in the diversity of aquatic life, often with an increase in more tolerant, invasive species. These pervasive impacts are primarily driven by urban stormwater runoff and the associated changes in land use, which disrupt the natural processes of stream ecosystems.

Some of the drivers associated with the urban stream syndrome may be affecting the Tokaanu Stream. The Tokaanu Village has a resident community of approximately 50 residents (Taupō District Council, 2021) and an active marae that often has guests overnighting for events. The village has a transient tourist population who visit for a variety of reasons including the Tokaanu hot pools, the Tongariro crossing, world-class fishing opportunities, and nearby alpine activities. While this tourism has positive economic and social benefits, it also creates environmental risks for the Tokaanu Stream.

For properties that are connected, raw sewage from the Tokaanu Village is sent to the Tūrangi wastewater treatment plant (WWTP) through a reticulated mains sewer network. For those that are not connected to the WWTP, septic tanks are used to service their needs (Taupō

District Council, 2021). Although most of the raw sewage from the village is reticulated, the Taupō District Council (2021) has identified that significant pressure is placed on the mains by flat grades, blockages, deteriorating pipes, a high-water table, and impacts on infrastructure caused by geothermal activity. The Taupō District Council (2021) does not identify properties without appropriate consents as creating environmental issues within the vicinity of the Tokaanu Stream. Furthermore, as earthquakes with the Taupō Volcanic Zone are often a daily occurrence, damage to sewage infrastructure including cracked pipes and septic tanks may be a source of environmental contaminants. The evidence from my water quality sampling suggests increased concentrations of the ammonia and *E. coli*, both of which might be the result of raw sewage entering the stream via surface and ground water flow paths.

However, the evidence from my water quality sampling is limited, due to low number of sampling rounds completed and the confounding effects of geothermal inputs in the lower Tokaanu Stream. Further sampling could help better establish the extent of this problem. Other methods, including source-tracing of *E. coli* using molecular methods would help to determine if increased faecal coliform counts are of human origin.

The multiple stressor paradigm

The third question I posed at the beginning of my thesis and this discussion was if different drivers (stream engineering, urban pollution) interact to adversely harm stream health. The multiple stressor paradigm in ecology recognizes that ecosystems are rarely impacted by a single environmental stressor in isolation. Instead, they are typically subjected to multiple stressors that co-occur in space and time, often with complex and unpredictable combined effects (Townsend *et al.*, 2008). To what extent the environmental issues facing the Tokaanu Stream interact remains to be seen. However, there is some evidence that excessive macrophyte growth may affect macroinvertebrate indicators of stream health. These macrophytes include native and exotic species, and their extent may be exacerbated by changes to flow and sediment regimes, along with nutrient enrichment and changes to light availability due to the loss of riparian vegetation. Understanding the impact of land use activities in the wider catchment would help identify if nitrogen availability is a contributing factor to changes in macrophyte communities in the Tokaanu Stream. This also suggests that current trigger values may not account for interacting stressors, thus ignoring potentially relevant environmental impacts.

5.9 Summary

Management recommendations

The overall lack of baseline data along the Tokaanu Stream proved to be problematic at times while undertaking this research. However, the lack of previous research provided an opportunity to develop baseline data while simultaneously engaging members of Ngāti Kurauia. My results, including assessments using the Ngāti Kurauia CMF, have provided the basis for a much needed, yet absent, dataset. Furthermore, as the CMF and associated sampling protocols have been gifted to Ngāti Kurauia, mana whenua can exercise mana motuhake and undertake ongoing monitoring. The results from the CMF show that key sites along the lower Tokaanu Stream have suffered from cultural and ecological decline (e.g. Site 5). Although disappointed, Ngāti Kurauia have reflected a sense of ease as their observations corroborated some of the evidence from conventional monitoring. The CMF results also describe changes in the environment with key sites in cultural decline despite the stream scoring highly in some conventional metrics.

In terms of the conventional metrics used, one must remain objective as many results show an environment that, while impacted, still rates highly. Metrics have been measured and, in line with the National Policy Statement for Freshwater Management (NPS-FM), placed into management bands. However, this research is preliminary and does not carry the weight of five years sampling needed to make management decisions using key indicators of ecosystem health. However, that some metrics measured confirm a decline in the Tokaanu Stream along the stream segment sampled is concerning. Some of these changes may be natural, with increased sedimentation as the stream gradient eases and natural pollution from geothermal inputs.

The reasons for declining water quality along the length of the Tokaanu Stream appear to be multifarious and include natural and anthropogenic factors. The potential sources include, but are not limited to:

- Broken sewage infrastructure and septic tanks
- Tokaanu Stream diversion and subsequent engineering works
- Geothermal inputs warming and polluting stream
- Increased erosion and sedimentation
- Surface runoff from roading
- Macrophyte growth including exotic species
- Riparian habitat degradation
- Volcanic sources of phosphorus
- Fertiliser runoff and groundwater infiltration
- Notified pest fish species
- Dumping of animal remains

While there are multiple drivers that impact upon the stream and its catchment, one could argue that there is no single factor contributing to its demise. Rather, to coin the phrase my illustrious supervisor would use, the Tokaanu Stream suffers due to 'death by a thousand cuts'.

While there is a current SOE monitoring site near the springhead, I argue that this site does not reflect the conditions for the entire stream. The current placement provides baseline data for the stream as the spring exits the aquifer but does not capture changes imposed by the diversion and urbanisation further downstream. Adding another monitoring site would be worthwhile and is not unprecedented. The nearby Kuratau River had another monitoring site added (LAWA, 2023), although the Kuratau is significantly longer and larger than the Tokaanu Stream. Nonetheless, a paired site approach works well to enable comparisons and identify changes as water flows towards Lake Taupō.

Suggestions for improvement

There are areas that I would have liked to have investigated further during this project. The hydrological impacts of the Tokaanu Stream's diversion and subsequent overflow zone were not investigated due to time constraints and technical challenges. The diversion is consented to carry a maximum flow of 2 $m^3 s^{-1}$ and has been engineered to overflow into the Tokaanu tailrace when conditions provide an excess flow (OPUS, 2012). To the best of my knowledge, the maximum flow limit was not reached during 2024, thus I was unable to record what happens during these high flow events. Incorporating stage height recorders would have added value to the research by providing an insight into the flow speed, height, and temperature of the stream over the course of the year. It was decided that stage height recorders would not be incorporated into the methodology as many hapū members were worried about the equipment being compromised, vandalised, or stolen.

The Tokaanu diversion accumulates sediment as it is deposited into the culvert where flows decrease. Investigating this further would help us understand the impact that sedimentary buildup has on the natural flow and sediment regimes. As part of Genesis Energy's resource consent, the Tokaanu Stream diversion must be dredged annually. It is my understanding that this did not occur during my sampling and consequently an opportunity to measure downstream impacts on water quality was missed. While Genesis Energy did not dredge the diversion during the sampling for my study, this is not to state that dredging did not occur. My sampling ended before the end of the 2024 and Genesis Energy may have cleared the sediment during December 2024.

Other areas for improvement include:

- As with the diversion, further study is warranted on the aqueduct which carries water in the Tokaanu Stream across the tailrace to better understand its potential role as a barrier to fish passage and if retrofitting is a necessary and viable option.
- The opportunity to work with the upstream hapū, Ngāti Tūrangitukua, was not possible during this research. It would have been advantageous to have continued the monitoring as far upstream as practicable, and to collect macroinvertebrate samples to complement the upstream SOE monitoring site.
- Interviews with kaumatua and kuia living in the Tokaanu area were initially planned. Unfortunately, these were unable to proceed and an opportunity to obtain anecdotal information on the stream was missed. This remains a possibility for future research.
- The CMF assessments for selected attributes could be separated into the true left and right banks. At each site, attributes involving riparian properties (vegetation, erosion,

engineering) could be scored for each bank. This would provide a clearer picture of where disturbance has occurred when Ngāti Kurauia are reporting their results.

- When measuring streamflow sound, it would be worth asking all attendees to stand downwind of the stream to more accurately measure sound.
- The use of a black disc could improve data when monitoring stream clarity. This method would be more suitable for the Tokaanu Stream than the water clarity tube due to generally high levels of water clarity. Training would be needed to build capacity with whānau and hapū, and it might not be feasible at all sites.
- Lastly, it would be prudent to create a field book that kaitiaki can use in the field. This could include a list of beneficial and non-beneficial plants, and which are native or exotic. It could also provide information on contemporary and traditional kai which Ngāti Kurauia have sustained them over the generations.

Possible methodological bias

Working with humans adds bias to any qualitative research (Malim, 2001). Occasionally participants would assess the sites based on historical features. To reduce bias, I would remind participants at the beginning of every haerenga that they must only record what they see in front of them at the time of monitoring. I would discuss the monitoring with attendees throughout the day to ensure they only recorded contemporary observations. If there was confusion, I would ask the participant to explain their thinking and encourage them to update their response if required. Another problem was the numbers of attendees undertaking the monitoring fluctuated throughout the sampling period, and low numbers could increase bias.

To overcome these problems in the future some solutions could be having a minimum number of attendees with less observation sheets, so kaitiaki can discuss what they are observing with each other. This could also help in the dissemination of knowledge across the generations, if different age groups were represented. Making monitoring an annual event (hui taurima) with associated activities could help encourage the wider hapū to participate. If a minimum number of attendees is not practicable, then a selected group of kaitiaki who are aware of the intricacies of monitoring would be advised.

Conclusions

My study investigated the ecological and cultural health of the Tokaanu Stream, highlighting the motivations for change within Ngāti Kurauia based on their lived experiences. Addressing a significant knowledge gap, my research weaved together Mātauranga Māori (traditional Māori knowledge) and contemporary scientific monitoring to understand the stream's condition. A key output from my study was a bespoke cultural monitoring framework developed with Ngāti Kurauia, designed to recognize their specific ecological and cultural values, thereby empowering their participation in environmental management. My study explored three key hypotheses: the impediment of the Tokaanu tailrace diversion to natural flow, the impact of urban dwellings on water quality, and the degradation of the stream's health due to the combined effects of the diversion and urbanization. My findings indicated concerning water quality issues from urban runoff and potentially faulty infrastructure, alongside changes in macroinvertebrate communities suggesting increasing pollution-tolerance downstream. These changes were confounded by natural and anthropogenic geothermal inputs moving downstream. Changes in the natural flow regime may have altered sediment dynamics and macrophyte beds, leading to adverse impacts on biota. My research advocates for a second monitoring site near Tokaanu Village to accurately capture anthropogenic impacts and emphasizes the need for continued mahi rangahau (research) to enhance understanding of Te Taiao (the natural world) and the mana of Ngāti Kurauia.

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7 Appendices

7.1 Appendix A

Appendix A. The Ngāti Kurauia cultural monitoring framework was developed alongside hapū members and utilised in the field to ascertain the cultural health of the Tokaanu Stream.

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**............................... **Date/Time:**.............. **Name:**..

Maramataka:.....................................

Variable: Vegetation - Trees / Shrubs adjacent to the stream

0	**1**	**2**	**3**	**4**	**5**
0%	**20%**	**40%**	**60%**	**80%**	**100%**
No trees/shrubs at all. Concrete or compacted dirt	All exotic trees and maybe some weeds	Mostly exotic trees/shrubs with some natives	Mixture of native and exotic trees/shrubs	Mostly native trees/shrubs with some exotics	Lush native trees/shrubs only

Notes Great place to list what you see. What can you name? What is useful/pests

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**............................... **Date:**.............. **Name:**..

Variable: Vegetation – In Stream

0	**1**	**2**	**3**	**4**	**5**
0%	**20%**	**40%**	**60%**	**80%**	**100%**
No plants in the stream	Only Non-Beneficial plants	More non-beneficial plants	Mixture of beneficial and non-beneficial plants	More beneficial plants than non-beneficial	Beneficial plants including watercress

Notes

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**............................... **Date:**.............. **Name:**...

Variable: Streambed substrate

0	1	2	3	4	5
0%	20%	40%	60%	80%	100%
Mud	Silty	Silty/Sandy	Sandy	Pebbles/Gravels	Rocks

Notes

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**............................... **Date:**.............. **Name:**...

Variable: Vegetation – Percentage (both sides of stream) vegetation cover immediately adjacent to the stream

0	1	2	3	4	5
0%	20%	40%	60%	80%	100%

Notes

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**............................ **Date:**............ **Name:**..

Variable: Bird Diversity

0	1	2	3	4	5
0%	20%	40%	60%	80%	100%
No Birdlife	Relatively few, only introduced birds	Abundant numbers, introduced only	Mixture of native and introduced. More introduced	Mixture of native and introduced. More native	Abundant native birds

Notes What species can you see?

Evidence of pests/threats? What pests/threats

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**............................ **Date:**............ **Name:**..

Variable: Sound – Bird song (at least 30 minutes onsite for manu to be brave and sing)

0	1	2	3	4	5
0%	20%	40%	60%	80%	100%
No bird song	Little bird song mainly from introduced species	Lots of bird song only from introduced	Mixture of native and exotic bird song	Mainly native song within 30 Minutes	Mainly native song within 10 minutes

Notes Do you know what bird is making that song?

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**................................ **Date:**.............. **Name:**..

Variable: Sound – Water flow

0 0%	1 20%	2 40%	3 60%	4 80%	5 100%
No Sound	Little to no sound	Mixture of little to no sound and flushing	Flushing Sound	Constant sound of normal flowing water	Continuous sound of fast flowing water

Notes

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**................................ **Date:**.............. **Name:**..

Variable: Pollution

0 0%	1 20%	2 40%	3 60%	4 80%	5 100%
Lots of paru/rubbish/ Cars/Dead animals etc	Lots of paru and difficult to collect	Mixture of paru and difficult to collect	Mixture of paru, needs dedication to dispose of	Occasional paru easy to collect	No pollution/Paru

Notes Debris and oil sheen/discolour.

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**................................ **Date:**.............. **Name:**..

Variable: Affliction / Engineering (Development) within, and immediately next to the stream

0	1	2	3	4	5
0%	20%	40%	60%	80%	100%
Structures dominate the streambed within 50m	Structures dominate stream side within 50m	More structures within 50m than not	Less structures dominating within 50m	Occasional structures within 50m	No structures present within 50m reach

Notes List human-made changes. Do you know of any changes made at this spot.

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**................................ **Date:**.............. **Name:**..

Variable: Māhinga Kai observed

0	1	2	3	4	5
0%	20%	40%	60%	80%	100%
No Māhinga kai	1 Māhinga kai species	2 Māhinga kai species	3 Māhinga kai species	4 Māhinga kai species	5+ Māhinga kai species seen

Notes List species observed. What Māhinga kai have you harvested from the awa, **and** from this spot.

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**.................................. **Date:**............... **Name:**...

Variable: Clarity of the water

0	1	2	3	4	5
0%	20%	40%	60%	80%	100%
All mud or thick sludge	Muddy, no sludge	Heavily cloudy water	Light cloudy water	Can see things floating but no clouds	Completely clear

Notes

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**.................................. **Date:**............... **Name:**...

Variable: Smell / Odour

0	1	2	3	4	5
0%	20%	40%	60%	80%	100%
Bad offensive smells	Marginal offensive smells	Light offensive smells	No smell	Mild pleasant smell	Abundant pleasant smells

Notes What can you smell?

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**................................ **Date:**.............. **Name:**..

Variable: Feel of the water

0	1	2	3	4	5
0%	20%	40%	60%	80%	100%
Slimy	Less slimy, very gritty	Very gritty	Gritty	Clean, light, but occasionally gritty	Clean, light, fresh

Notes

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**................................ **Date:**.............. **Name:**..

Variable: Colour of the water

0	1	2	3	4	5
0%	20%	40%	60%	80%	100%
Black	Dark Brown	Looks dirty	Heavily clouded	Lightly clouded	Clear

Notes

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**................................ **Date:**.............. **Name:**...

Variable: Colour of the streambed

0	1	2	3	4	5
0%	20%	40%	60%	80%	100%
Black	Dark grey	Light grey	Green	Green-Brown	Light brown – yellow – orange

Notes

Tokaanu Stream Field book

Location: 1, 2, 3, 4, 5, 6 **Weather:**................................ **Date:**.............. **Name:**...

Variable: Wairua

0	1	2	3	4	5
0%	20%	40%	60%	80%	100%
Heavy – Sick - Burdened					Light and rejuvenating

Notes

Would you drink the water as it is? If not, why not?	-2 No	-1	0 Undecided	1	2 Yes
Would you swim in the water as it is? If not, why not?	-2 No	-1	0 Undecided	1	2 Yes
Is the awa wider or narrower at this location than in the past?	-2 Narrower	-1	0 Same	1	2 Wider
Is the awa deeper or shallower at this location than in the past?	-2 Shallower	-1	0 Undecided	1	2 Deeper
Has the awa's potential to flood increased or decreased over time?	-2 Increased	-1	0 Undecided	1	2 Decreased
Are there differences in the in-stream habitat (sediment, macrophytes)?	-2 No	-1	0 Undecided	1	2 Yes
Is the sediment coarser or finer?	-2 Finer	-1	0 Undecided	1	2 Coarser
Are the macrophytes (plants in the stream) less or more abundant?	-2 Less	-1	0 Undecided	1	2 More
Are there more types of plants along the stream (composition, cover)?	-2 Less	-1	0 Undecided	1	2 More
Does the Awa have a special spiritual meaning for you?	-2 No	-1	0 Undecided	1	2 Yes

Please explain:

What biological changes have occurred (loss/gain of Māhinga kai, Koura, Taonga species, kōaro, birds etc)?

7.2 Appendix B

Table B2. Comparison of CMF mean values, standard deviation, and % variation (coefficient of variation) at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on five separate haerenga (assessment dates) during 2024 using the CMF which involved a modified Likert scale (0-100) for all attributes.

Attribute	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Vegetation - Trees / Shrubs beside stream	66.3	60.8	66.7	64.6	54.2	62.5
Std dev	4.8	5.5	28.2	30.9	9.4	5.2
% variability	7.2	9.0	42.3	47.9	17.4	8.3
Vegetation – % veg. cover beside stream	66.5	66.3	78.8	70.6	66.9	69.8
Std dev	5.0	5.1	32.1	36.6	15.3	13.7
% variability	7.5	7.7	40.7	51.8	22.9	19.6
Vegetation – In Stream	38.8	43.3	52.7	44.9	40.7	44.1
Std dev	4.5	5.1	19.5	21.8	7.6	8.2
% variability	11.6	11.7	36.9	48.4	18.7	18.6
Streambed substrate	59.7	69.0	74.3	67.7	42.4	62.6
Std dev	12.3	13.8	25.1	24.2	10.7	15.3
% variability	20.7	19.9	33.8	35.8	25.3	24.4
Bird Diversity	45.7	34.1	27.7	35.8	28.8	34.4
Std dev	3.7	4.0	15.0	16.2	24.4	27.3
% variability	8.0	11.9	54.1	45.1	84.9	79.4
Sound – Bird song	43.3	31.4	21.6	32.1	13.5	28.4
Std dev	7.8	8.2	11.6	9.6	8.9	18.7
% variability	18.1	26.1	53.9	30.0	66.3	65.9
Sound – Water flow	25.2	40.7	41.0	35.6	26.7	33.8
Std dev	5.9	5.9	13.6	14.4	4.1	13.0
% variability	23.3	14.6	33.3	40.3	15.3	38.4
Pollution	81.5	81.7	71.6	78.3	64.7	75.5
Std dev	6.5	5.9	33.7	37.1	16.6	17.0
% variability	8.0	7.2	47.0	47.5	25.7	22.5
Engineering	17.3	39.7	44.3	33.8	54.3	37.9
Std dev	7.9	9.0	19.2	22.8	25.9	16.4
% variability	45.4	22.6	43.4	67.4	47.6	43.2
Māhinga Kai observed	34.5	25.7	44.3	34.8	29.7	33.8
Std dev	7.0	6.2	13.1	14.6	11.2	11.5
% variability	20.2	24.2	29.5	42.0	37.8	34.1
Clarity of the water	92.5	83.9	80.8	85.7	62.3	81.1
Std dev	9.4	10.4	35.0	36.5	17.7	13.5
% variability	10.2	12.3	43.3	42.6	28.3	16.6
Smell / Odour	73.5	59.6	66.2	66.4	57.9	64.7
Std dev	3.9	4.0	29.8	33.2	8.1	12.9

% variability	5.4	6.7	45.0	50.0	14.0	19.9
Feel of the water	90.4	90.1	85.8	88.8	70.8	85.2
Std dev	7.7	8.1	37.7	40.9	11.0	27.3
% variability	8.6	9.0	43.9	46.0	15.6	32.0
Colour of the water	98.0	86.7	86.5	90.4	65.1	85.3
Std dev	10.1	11.4	36.8	38.1	15.7	12.7
% variability	10.3	13.1	42.5	42.2	24.1	14.9
Colour of the streambed	46.9	50.3	65.5	54.2	52.1	53.8
Std dev	6.0	6.1	23.7	27.1	13.5	15.5
% variability	12.7	12.2	36.2	49.9	26.0	28.8
Wairua	68.8	55.5	58.8	61.1	50.8	59.0
Std dev	4.0	4.6	26.8	29.4	17.4	23.1
% variability	5.9	8.2	45.6	48.1	34.4	39.1

*Table B2. Comparison of the Ngāti Kurauia cultural monitoring framework (CMF) and the cultural stream health measure (CSHM). The CMF mean was modified using the equation (X/100)*5 where X is the mean of 16 CMF attributes. CMF scores were determined from 5 haerenga during 2024 and the CSHM was assessed from 1 monitoring effort on 14 November 2024.*

CSH	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	**CMF**
Catchment land use	50.0	50.0	50.0	50.0	50.0	50.0	**Constant not assessed**
Riparian vegetation	66.3	60.8	66.7	64.6	54.2	62.5	**Vegetation - Trees / Shrubs beside stream**
Use of riparian margin	66.5	66.3	78.8	70.6	66.9	69.8	**Vegetation – % veg. cover beside stream**
Riverbed condition/sediment	59.7	69.0	74.3	67.7	42.4	62.6	**Streambed substrate**
Channel modification	17.3	39.7	44.3	33.8	54.3	37.9	**Engineering**
Flow and habitat variety	25.2	40.7	41.0	35.6	26.7	33.8	**Sound – Water flow**
	38.8	43.3	52.7	44.9	40.7	44.1	**Vegetation – In Stream**
	32.0	42.0	46.9	40.3	33.7	39.0	Average
Water clarity	92.5	83.9	80.8	85.7	62.3	81.1	**Clarity of the water**
Water quality	73.5	59.6	66.2	66.4	57.9	64.7	**Smell / Odour**
	90.4	90.1	85.8	88.8	70.8	85.2	**Feel of the water**
	98.0	86.7	86.5	90.4	65.1	85.3	**Colour of the water**
	46.9	50.3	65.5	54.2	52.1	53.8	**Colour of the streambed**
	77.2	71.7	76.0	75.0	61.5	72.3	Average

7.3 Appendix C

Table C3. Data and summary statistics (median, mean, standard deviation, maximum and minimum) for specific conductivity ($\mu S_{20°C}$/cm) from the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on nine separate haerenga (assessment dates) during 2023/2024. In two instances (8 July and 20 August 2024), Site 3 was unable to be reported due to user error.

Specific Cond	**Site**					
Date	**1**	**2**	**3**	**4**	**5**	**6**
14/12/2023	100.6	97.9	109.1	141	205	212.6
21/01/2024	100.2	99.4	113.4	174.5	243.9	253.4
4/03/2024	97.4	101.1	123	157.2	233.6	248.9
22/04/2024	99.4	99.3	106	153.1	221.2	243.4
27/05/2024	101.2	101.2	107	149.7	214.2	240.6
8/07/2024	101	100.9	-	142.5	194.8	230.4
20/08/2024	95.8	96.3	-	134.7	188.3	216.1
23/09/2024	97.3	97.1	107.1	147.3	216.3	246.6
31/10/2024	96.9	98.1	108.9	159.6	224.8	268.1
Median	99.4	99.3	108.9	149.7	216.3	243.4
Mean	98.9	99.0	110.6	151.1	215.8	240.0
Std Dev	2.0	1.8	6.0	11.8	17.8	17.7
Maximum	101.2	101.2	123.0	174.5	243.9	268.1
Minimum	95.8	96.3	106.0	134.7	188.3	212.6

Table C4. Data and summary statistics (median, mean, standard deviation, maximum and minimum) for ambient conductivity (µS/cm) from the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on nine separate haerenga (assessment dates) during 2023/2024 except for 4 March 2024. In two instances (8 July and 20 August 2024, Site 3 was unable to be reported due to user error.

Ambient Cond	**Site**					
Date	**1**	**2**	**3**	**4**	**5**	**6**
14/12/2023	81.4	79.4	86.8	112	162	168.2
21/01/2024	81.7	78.9	90.3	145.5	203	208.1
4/03/2024	Unable to measure this occasion					
22/04/2024	76.1	76.1	81.4	123.6	175.4	194.4
27/05/2024	75.8	75.7	79.9	115.6	192.7	188.2
8/07/2024	74.7	74.4	-	103.7	144.9	175.5
20/08/2024	69.7	69.9	-	98	139.6	162.9
23/09/2024	74.1	73.7	80.6	110.6	167.1	188.8
31/10/2024	73.5	75.7	83.9	124.1	179.3	213.2
Median	75.3	75.7	82.7	113.8	171.3	188.5
Mean	75.9	75.5	83.8	116.6	170.5	187.4
Std Dev	4.0	3.0	4.1	14.7	21.9	18.0
Maximum	81.7	79.4	90.3	145.5	203.0	213.2
Minimum	69.7	69.9	79.9	98.0	139.6	162.9

Table C5. Data and summary statistics (median, mean, standard deviation, maximum and minimum) for Dissolved Oxygen saturation (%) from the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on nine separate haerenga (assessment dates) during 2023/2024.

O^2 %	Site					
Date	**1**	**2**	**3**	**4**	**5**	**6**
14/12/2023	98.6	100.7	103	101	98.6	94.0
21/01/2024	97.1	96.8	98.4	98.6	99.7	96.2
4/03/2024	91.0	97.0	86.0	85.0	83.0	81.0
22/04/2024	92.8	93.7	93.7	94.5	95.6	96.9
27/05/2024	89.1	89.3	88.4	90.1	89.6	89.6
8/07/2024	92.5	93.5	93.2	92.7	95.2	89.4
20/08/2024	87.6	87.7	90.1	88.0	88.0	91.6
23/09/2024	95.4	95.9	95.8	94.4	94.3	92.0
31/10/2024	95.7	97.4	96.9	97.6	99.1	95.6
Median	92.8	95.9	93.7	94.4	95.2	92.0
Mean	93.3	94.7	93.9	93.5	93.7	91.8
Std Dev	3.7	4.1	5.3	5.2	5.7	4.9
Maximum	98.6	100.7	103.0	101.0	99.7	96.9
Minimum	87.6	87.7	86.0	85.0	83.0	81.0

Table C6. Data and summary statistics (median, mean, standard deviation, maximum and minimum) from Dissolved Oxygen concentrations (mg/L) from the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on nine separate haerenga (assessment dates) during 2023/2024 except for on 8 July 2024 due to user error.

O^2 mg/L	Site					
Date	**1**	**2**	**3**	**4**	**5**	**6**
14/12/2023	9.94	10.15	10.53	10.40	10.15	9.75
21/01/2024	9.94	9.94	10.15	9.92	9.78	9.44
4/03/2024	9.30	9.80	8.00	8.40	8.00	7.80
22/04/2024	9.83	9.88	9.88	9.87	9.82	9.88
27/05/2024	9.64	9.70	9.59	9.74	9.52	9.27
8/07/2024	10.26	10.36	10.44	10.11	9.92	-
20/08/2024	9.66	9.75	9.96	9.72	9.57	9.57
23/09/2024	10.18	10.24	10.27	10.06	9.72	9.53
31/10/2024	10.04	10.22	10.21	10.18	9.88	9.71
Median	9.94	9.94	10.15	9.92	9.78	9.55
Mean	9.87	10.00	9.89	9.82	9.60	9.37
Std Dev	0.30	0.24	0.77	0.58	0.63	0.66
Maximum	10.26	10.36	10.53	10.40	10.15	9.88
Minimum	9.30	9.70	8.00	8.40	8.00	7.80

Table C7. Data and summary statistics (median, mean, standard deviation, maximum and minimum) for water temperature (°C) from the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on nine separate haerenga (assessment dates) during 2023/2024.

Water temp (°C)	**Site**					
Date	**1**	**2**	**3**	**4**	**5**	**6**
14/12/2023	15.0	15.0	14.4	14.0	14.0	13.7
21/01/2024	14.4	14.3	14.8	15.5	16.8	16.4
4/03/2024	12.9	12.9	13.1	13.7	14.5	14.8
22/04/2024	12.7	12.9	12.9	13.3	14.2	14.5
27/05/2024	11.8	11.8	11.7	11.9	12.8	13.8
8/07/2024	11.1	10.8	10.9	11.4	11.8	12.0
20/08/2024	10.8	10.8	10.6	10.8	11.5	12.0
23/09/2024	12.5	12.4	12.1	12.2	13.5	13.5
31/10/2024	14.2	13.2	13.0	13.5	14.4	15.8
Median	12.7	12.9	12.9	13.3	14.0	13.8
Mean	12.8	12.7	12.6	12.9	13.7	14.1
Std Dev	1.5	1.4	1.4	1.5	1.6	1.5
Maximum	15.0	15.0	14.8	15.5	16.8	16.4
Minimum	10.8	10.8	10.6	10.8	11.5	12.0

Table C8. Data and summary statistics (median, mean, standard deviation, maximum and minimum) for water pH from the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on nine separate haerenga (assessment dates) during 2023/2024.

pH	**Site**					
Date	**1**	**2**	**3**	**4**	**5**	**6**
14/12/2023	7.00	7.20	7.30	6.50	6.60	7.10
21/01/2024	7.05	7.12	7.07	6.92	6.85	7.52
4/03/2024	7.47	7.44	7.28	7.16	7.10	7.80
22/04/2024	7.43	7.44	7.41	7.31	7.29	7.31
27/05/2024	7.50	7.49	7.45	7.40	7.18	7.22
8/07/2024	7.29	7.32	7.25	7.25	6.97	7.32
20/08/2024	7.29	7.29	7.27	7.20	7.12	7.27
23/09/2024	7.40	7.39	7.35	7.16	7.18	7.14
31/10/2024	7.35	7.38	7.32	7.22	7.12	7.21
Median	7.35	7.38	7.30	7.20	7.12	7.27
Mean	7.31	7.34	7.30	7.12	7.05	7.32
Std Dev	0.18	0.12	0.11	0.27	0.21	0.22
Maximum	7.50	7.49	7.45	7.40	7.29	7.80
Minimum	7.00	7.12	7.07	6.50	6.60	7.10

Table C9 Data and summary statistics (median, mean, standard deviation, maximum and minimum) for Water clarity (cm) on the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on nine separate haerenga (assessment dates) during 2023/2024.

Clarity (cm)	**Site**					
Date	**1**	**2**	**3**	**4**	**5**	**6**
14/12/2023	100	100	100	100	100	100
21/01/2024	80.5	86	84	82.5	85	83
4/03/2024	76.0	79	75	69	74.5	76.5
22/04/2024	100	100	100	100	100	85
27/05/2024	100	100	100	82	86	82
8/07/2024	100	92	84	89	82	81
20/08/2024	100	86	85	83	83	76.5
23/09/2024	84.5	81.5	86	80.5	82	83
31/10/2024	100	100	100	100	100	80
Median	100	92	86	83	85	82
Mean	93	92	90	87	88	83
Std Dev	10	9	10	11	10	7
Maximum	100	100	100	100	100	100
Minimum	76.0	79.0	75.0	69.0	74.5	76.5

Table C10. Data and summary statistics (median, mean, standard deviation, maximum) for Nitrate and Nitrite (g/m3), Total Ammoniacal Nitrogen (g/m3), Total Nitrogen (g/m3), Dissolved Reactive Phosphorus (g/m3), Total Phosphorus (g/m3) and E. coli *(CFU/100ml) from the Tokaanu Stream in the Lake Taupō catchment. Nitrate and Nitrite, Total Ammoniacal Nitrogen, Dissolved Reactive Phosphorus, and* E. coli *were sampled on three occasions (14 December 2023, 5 May 2024 and 15 July 2024), while Total Nitrogen and Total Phosphorus was sampled on two occasions (14 December 2023 and 15 July 2024). Minimum concentrations not provided because they were deemed less important than the maximum concentrations for these water quality variables.*

Parameter	Site	14-Dec-23	5-May-24	15-Jul-24	Median	Mean	SD	Max.
Nitrates & Nitrites (g/m^3)	1	0.45	0.47	0.42	0.45	0.45	0.03	0.47
	2	0.44	0.47	0.43	0.44	0.45	0.02	0.47
	3	0.44	0.46	0.41	0.44	0.44	0.03	0.46
	4	0.43	0.45	0.41	0.43	0.43	0.02	0.45
	5	0.43	0.45	0.38	0.43	0.42	0.04	0.45
	6	0.43	0.45	0.40	0.43	0.43	0.03	0.45
Total Ammoniacal Nitrogen (g/m^3)	1	0.011	0.011	0.029	0.01	0.02	0.01	0.03
	2	<0.01	0.011	<0.010	0.01	0.01	0.00	0.01
	3	0.012	0.014	<0.010	0.01	0.01	0.00	0.01
	4	0.034	0.033	0.054	0.03	0.04	0.01	0.05
	5	0.046	0.047	0.125	0.05	0.07	0.05	0.13
	6	0.048	0.050	0.080	0.05	0.06	0.02	0.08
Total Nitrogen (g/m^3)	1	0.51	-	0.46	0.49	0.49	0.04	0.51
	2	0.48	-	0.48	0.48	0.48	0.00	0.48
	3	0.58	-	0.46	0.52	0.52	0.08	0.58
	4	0.49	-	0.49	0.49	0.49	0.00	0.49
	5	0.52	-	0.54	0.53	0.53	0.01	0.54
	6	0.5	-	0.52	0.51	0.51	0.01	0.52
Dissolved Reactive Phosphorus (g/m^3)	1	0.044	0.049	0.053	0.049	0.049	0.005	0.053
	2	0.043	0.049	0.053	0.049	0.048	0.005	0.053
	3	0.043	0.045	0.050	0.045	0.046	0.004	0.050
	4	0.040	0.043	0.049	0.043	0.044	0.005	0.049
	5	0.041	0.042	0.053	0.042	0.045	0.007	0.053
	6	0.037	0.040	0.044	0.040	0.040	0.004	0.044
Total Phosphorus (g/m^3)	1	0.053	-	0.056	0.055	0.055	0.002	0.056
	2	0.055	-	0.056	0.056	0.056	0.001	0.056
	3	0.053	-	0.057	0.055	0.055	0.003	0.057
	4	0.051	-	0.055	0.053	0.053	0.003	0.055
	5	0.041	-	0.067	0.054	0.054	0.018	0.067
	6	0.049	-	0.057	0.053	0.053	0.006	0.057
E. coli* *(cfu/100ml)	1	20	61	45	45	42	21	61
	2	8	70	58	58	45	33	70
	3	10	99	100	99	70	52	100
	4	15	99	80	80	65	44	99
	5	32	90	90	90	71	33	90
	6	52	125	190	125	122	69	190

Table C11. Data and summary statistics (median, mean, standard deviation, and maximum) for Inorganic Suspended Fine Sediment (ISFS) concentrations (g/m³) from the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on eleven separate haerenga (assessment dates) during 2023/2024. Minimum concentrations not provided because they were deemed less important than the maximum concentrations for these water quality variables.

Inorganic (g/m³)	Site					
Date	**1**	**2**	**3**	**4**	**5**	**6**
14/12/2023	36.0	48.0	25.6	38.4	40.0	38.2
28/12/23	23.6	33.4	38.2	1.8	25.2	26.2
22/1/2024	37.0	40.0	40.2	40.4	34.4	43.8
4/3/24	45.4	34.0	36.4	4.8	3.6	2.2
15/4/24	0.0	24.0	38.2	35.6	42.2	28.2
27/5/24	37.0	26.0	39.4	37.0	35.0	49.8
14/6/24	34.0	36.0	34.6	34.6	26.0	25.0
8/7/24	0.0	0.4	0.0	1.6	2.4	4.6
20/8/24	0.6	0.0	1.8	2.6	2.8	3.2
23/9/24	0.2	0.2	0.0	3.4	1.8	2.0
31/10/24	0.4	1.0	1.2	1.6	2.2	4.4
Median	23.6	26.0	34.6	4.8	25.2	25.0
Mean	19.0	22.0	23.0	18.0	20.0	21.0
Std Dev	19.0	18.0	18.0	18.0	17.0	18.0
Maximum	45.4	48.0	40.2	40.4	42.2	49.8

Table C12. Data and summary statistics (median, mean, standard deviation, and maximum) for Organic Suspended Fine Sediment (OSFS) concentrations (g/m³) from the Tokaanu Stream in the Lake Taupō catchment. Each site was assessed on eleven separate haerenga (assessment dates) during 2023/2024. Minimum concentrations not provided because they were deemed less important than the maximum concentrations for these water quality variables.

Organic (g/m³)	Site					
Date	**1**	**2**	**3**	**4**	**5**	**6**
14/12/2023	0.0	0.0	3.2	1.4	1.2	2.4
28/12/23	2.4	2.8	7.0	1.0	3.0	3.2
22/1/2024	13.0	0.0	4.4	2.2	5.6	1.8
4/3/24	2.0	6.4	4.6	2.0	1.0	2.0
15/4/24	2.0	3.8	3.2	3.4	2.8	3.6
27/5/24	9.2	3.8	1.4	6.4	3.2	1.4
14/6/24	3.2	7.2	2.0	3.6	3.8	4.8
8/7/24	2.2	2.2	1.8	3.4	2.6	2.8
20/8/24	2.0	2.2	1.6	2.2	2.8	2.6
23/9/24	0.8	0.6	1.2	1.0	2.4	1.8
31/10/24	2.0	1.2	2.2	2.0	1.2	2.8
Median	2.0	2.2	2.2	2.2	2.8	2.6
Mean	4.0	3.0	3.0	3.0	3.0	3.0
Std Dev	4.0	2.0	2.0	2.0	1.0	1.0
Maximum	13.0	7.2	7.0	6.4	5.6	4.8

Table C11. Mean values, Standard deviation and Coefficient of Variation for deposited fine sediment cover using the SAM2 method at each of six sites on the Tokaanu Stream in the Lake Taupō catchment. Monitoring was undertaken on

31 October 2024. Deposited fine sediment is variable downstream with Site 4 having the highest coefficient of variation and lowest average cover. This is also supported by Table C9 which has the lowest levels of suspended inorganic suspended fine sediment.

Site	Average of Fine Sediment cover (%)	Std. Dev of Fine Sediment cover (%)	Coeff. Var of Fine Sediment cover (%)
Site 1	69.0	31.8	46.0
Site 2	76.8	13.8	17.9
Site 3	63.0	28.9	45.8
Site 4	45.8	26.7	58.4
Site 5	80.5	19.0	23.7
Site 6	83.3	20.8	25.0

Table C12. Riparian Condition Index at all six sites on the Tokaanu Stream in the Lake Taupō catchment. Monitoring was undertaken on 18 January 2024. Sites 1 and 2 have a large amount of anthropogenic modification resulting from the development of the Tokaanu Power Scheme, while site 4 is the site of the Tokaanu hot pools.

Site	Date	Measure	Left Bank	Right Bank
Site 1	18/01/2024	Shading of Water	5	4
		Buffer Width	2.5	2
		Buffer Intactness	2.5	2.5
		Vegetation composition of buffer 30m from stream bank	3.5	2
		Bank Stability	3	3
		Livestock Access	5	2
		Riparian soil denitrification potential	2	2
		Land slope 0-30m from stream bank	4	5
		Groundcover of buffer 30m from streambank	2.5	3
		Soil drainage	2.5	2.5
		Rills/Channels	2	2
Site 2	18/01/2024	Shading of Water	5	5
		Buffer Width	2	2
		Buffer Intactness	4	4
		Vegetation composition of buffer 30m from stream bank	2.5	2.5
		Bank Stability	2.5	2.5
		Livestock Access	3	3
		Riparian soil denitrification potential	1.5	1.5

		Land slope 0-30m from stream bank	5	3
		Groundcover of buffer 30m from streambank	3	3
		Soil drainage	2.5	2.5
		Rills/Channels	2	3
Site 3	18/01/2024	Shading of Water	5	5
		Buffer Width	5	5
		Buffer Intactness	4.5	4.5
		Vegetation composition of buffer 30m from stream bank	4	4
		Bank Stability	5	5
		Livestock Access	5	5
		Riparian soil denitrification potential	4.5	4.5
		Land slope 0-30m from stream bank	4	5
		Groundcover of buffer 30m from streambank	4	4
		Soil drainage	4.5	4.5
		Rills/Channels	4	5
Site 4	18/01/2024	Shading of Water	2	2
		Buffer Width	2	2
		Buffer Intactness	2.5	2
		Vegetation composition of buffer 30m from stream bank	1.5	1.5
		Bank Stability	1.5	1.5
		Livestock Access	5	5
		Riparian soil denitrification potential	1.5	1.5
		Land slope 0-30m from stream bank	5	5
		Groundcover of buffer 30m from streambank	1.5	1
		Soil drainage	1.5	1
		Rills/Channels	2	2
Site 5	18/01/2024	Shading of Water	4	3
		Buffer Width	5	3
		Buffer Intactness	5	3

		Vegetation composition of buffer 30m from stream bank	4.5	2.5
		Bank Stability	4	3
		Livestock Access	5	5
		Riparian soil denitrification potential	5	2
		Land slope 0-30m from stream bank	5	5
		Groundcover of buffer 30m from streambank	5	3.5
		Soil drainage	5	3
		Rills/Channels	5	5
Site 6	18/01/2024	Shading of Water	3	4
		Buffer Width	3	4
		Buffer Intactness	4	4
		Vegetation composition of buffer 30m from stream bank	2.5	3
		Bank Stability	2	2
		Livestock Access	5	5
		Riparian soil denitrification potential	4	2
		Land slope 0-30m from stream bank	4	4
		Groundcover of buffer 30m from streambank	4	4
		Soil drainage	4	4
		Rills/Channels	5	5

7.4 Appendix D

Table D1. Macroinvertebrate counts from the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on two separate haerenga (assessment dates) during 2023/2024. These samples were collected on 14 December 2023.

Site	Method	Subsample	Order	Taxa	Count	Scan	Notes
One	NEMS (200 fixed count + scan)	0.5	Ephemeroptera	*Austroclima*	40		
			Ephemeroptera	*Coloburiscus*	1		
			Ephemeroptera	*Deleatidium*	5		
			Ephemeroptera	*Neozephlebia*	3		
			Ephemeroptera	*Zephlebia*	23		
			Plecoptera	*Zelandobius*	32		
			Trichoptera	*Hudsonema*	1		
			Trichoptera	*Hydrobiosis*	2		
			Trichoptera	*Zealandoptila*	1		
			Trichoptera	*Olinga*	1		
			Trichoptera	*Orthopsyche*		1	
			Trichoptera	*Pycnocentria*	87		
			Diptera	*Tanyderidae*		1	
			Diptera	*Aphrophila*	5		
			Diptera	*Austrosimulium*	4		
			Diptera	Chironomidae	1		*Harrisius* sp.
			Diptera	Empididae	1		
			Diptera	Eriopterini	1		
			Coleoptera	Elmidae	8		
			Megaloptera	*Archichauliodes*	5		
			Mollusca	*Potamopyrgus*	1		
			Platyhelminthes	Platyhelminthes	1		
Two	NEMS (200 fixed count + scan)	0.25	Ephemeroptera	*Austroclima*	27		
			Ephemeroptera	*Coloburiscus*	1		
			Ephemeroptera	*Deleatidium*	2		
			Ephemeroptera	*Ichthybotus*		1	
			Ephemeroptera	*Neozephlebia*	16		
			Ephemeroptera	*Zephlebia*	49		
			Plecoptera	*Austroperla*	1		
			Plecoptera	*Megaleptoperla*	3		
			Plecoptera	*Zelandobius*	88		
			Trichoptera	*Aoteapsyche*	6		
			Trichoptera	*Hudsonema*	1		
			Trichoptera	*Hydrobiosis*	1		
			Trichoptera	*Oxyethira*	32		
			Trichoptera	*Psilochorema*	3		

			Trichoptera	*Pycnocentria*	54		
			Trichoptera	*Triplectides*	1		
			Diptera	*Aphrophila*	6		
			Diptera	*Austrosimulium*	1		
			Diptera	Chironomidae	13		
			Diptera	Eriopterini	2		
			Coleoptera	Elmidae	10		
			Megaloptera	*Archichauliodes*	4		
			Mollusca	*Potamopyrgus*	2		
			Oligochaeta	*Oligochaeta*	2		
Three	NEMS (200 fixed count + scan)	0.25	Ephemeroptera	*Austroclima*	15		
			Ephemeroptera	*Coloburiscus*	2		
			Ephemeroptera	*Deleatidium*	7		
			Ephemeroptera	*Neozephlebia*	1		
			Ephemeroptera	*Zephlebia*	23		
			Plecoptera	*Stenoperla*		1	
			Plecoptera	*Zelandobius*	34		
			Trichoptera	*Aoteapsyche*	7		
			Trichoptera	*Hudsonema*	2		
			Trichoptera	*Hydrobiosis*		2	
			Trichoptera	*Neurochorema*		1	
			Trichoptera	*Oxyethira*	5		
			Trichoptera	*Psilochorema*	1		
			Trichoptera	*Pycnocentria*	23		
			Trichoptera	*Triplectides*		1	
			Diptera	*Aphrophila*	7		
			Diptera	*Austrosimulium*	23		
			Diptera	Chironomidae	50		
			Diptera	Empididae	3		
			Diptera	*Paradixa*	1		
			Coleoptera	Elmidae	2		
			Mollusca	*Potamopyrgus*	3		
			Oligochaeta	*Oligochaeta*	1		
Four	NEMS (200 fixed count + scan)	0.5	Ephemeroptera	*Austroclima*	12		
			Ephemeroptera	*Deleatidium*	5		
			Ephemeroptera	*Neozephlebia*	2		
			Ephemeroptera	*Zephlebia*	66		
			Plecoptera	*Zelandobius*	7		
			Trichoptera	*Aoteapsyche*	1		
			Trichoptera	*Hudsonema*	3		
			Trichoptera	*Hydrobiosis*	5		
			Trichoptera	*Oxyethira*	56		

			Trichoptera	*Pycnocentria*	38		
			Trichoptera	*Triplectides*	2		
			Diptera	*Aphrophila*	1		
			Diptera	*Austrosimulium*	19		
			Diptera	Chironomidae	138		
			Diptera	Empididae	2		
			Coleoptera	Elmidae	1		
			Crustacea	Ostracoda	1		
			Crustacea	*Paranephrops*		1	Released
			Mollusca	*Potamopyrgus*	8		
			Oligochaeta	*Oligochaeta*	7		
			Tricoptera	*Paroxyethira*	1		
			Tricoptera	*Zelandoptila*	1		
Five	NEMS (200 fixed count + scan)	0.5	Ephemeroptera	*Austroclima*	13		
			Ephemeroptera	*Neozephlebia*	1		
			Ephemeroptera	*Zephlebia*	15		
			Plecoptera	*Megaleptoperla*	1		
			Plecoptera	*Zelandobius*	19		
			Trichoptera	*Hudsonema*	1		
			Trichoptera	*Hydrobiosis*	3		
			Trichoptera	*Oxyethira*	68		
			Trichoptera	*Paroxyethira*	1		
			Coleoptera	Sciritidae	1		
			Diptera	*Paradixa*	1		
			Trichoptera	*Pycnocentria*	13		
			Trichoptera	*Triplectides*	3		
			Diptera	*Austrosimulium*	23		
			Diptera	Chironomidae	65		30 *Chironomus*, 1 Tanypodinae, 1 Orthocladiinae
			Crustacea	Ostracoda	2		
			Mollusca	*Physa*	1		
			Mollusca	*Potamopyrgus*	14		
			Oligochaeta	*Oligochaeta*	6		
Six	NEMS (200 fixed count + scan)	0.5	Ephemeroptera	*Austroclima*	1		
			Ephemeroptera	*Zephlebia*	5		
			Plecoptera	*Zelandobius*	1		
			Trichoptera	*Hudsonema*	1		
			Trichoptera	*Oxyethira*	46		
			Trichoptera	*Pycnocentria*	5		
			Diptera	*Austrosimulium*	3		
			Diptera	Chironomidae	128		1 Tanypodinae, 77 Orthocladiinae, 50 *Chironomus*

			Diptera	Empididae	3		
			Coleoptera	*Lancetes*	1		
			Odonata	*Xanthocnemis*	1		
			Diptera	*Ephydrella*	1		
			Diptera	Ephidridae	1		
			Crustacea	*Paranephrops*	1		Released
			Mollusca	*Potamopyrgus*	10		
			Oligochaeta	*Oligochaeta*	1		

Table D2. Macroinvertebrate counts from the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on two separate haerenga (assessment dates) during 2023/2024. These samples were collected on 31 October 2024.

Site	Method	Subsample	Order	Taxa	Count	Scan	Notes
One	NEMS (200 fixed count + scan)	0.25	Ephemeroptera	*Austroclima*	21		
			Ephemeroptera	*Deleatidium*	2		
			Ephemeroptera	*Zephlebia*	43		
			Plecoptera	*Austroperla*		1	
			Plecoptera	*Megaleptoperla*	1		
			Plecoptera	*Zelandobius*	88		
			Trichoptera	*Plectrocnemia*	1		
			Trichoptera	*Hydrobiosis*	4		
			Trichoptera	*Oeconesus*		1	
			Trichoptera	*Orthopsyche*		1	
			Trichoptera	*Polyplectropus*	3		
			Trichoptera	*Pycnocentria*	21		
			Diptera	*Tanyderidae*	1		
			Diptera	*Aphrophila*	1		
			Diptera	*Austrosimulium*	3		
			Diptera	Chironomidae	8		
			Diptera	Eriopterini		1	
			Coleoptera	Elmidae	4		
			Coleoptera	*Ptilodactylidae*		3	
			Megaloptera	*Archichauliodes*	3		
			Crustacea	*Paranephrops*	1		
			Nematoda	Nematoda	1		
Two	NEMS (200 fixed count + scan)	0.25	Ephemeroptera	*Austroclima*	47		
			Ephemeroptera	*Coloburiscus*	1		
			Ephemeroptera	*Deleatidium*	2		
			Ephemeroptera	*Neozephlebia*	9		
			Ephemeroptera	*Zephlebia*	60		
			Plecoptera	*Megaleptoperla*	8		
			Plecoptera	*Zelandobius*	215		
			Trichoptera	*Hudsonema*		3	
			Trichoptera	*Hydrobiosis*	2		
			Trichoptera	*Paroxyethira*	1		
			Trichoptera	*Oxyethira*	3		

			Trichoptera	*Polyplectropus*	2		
			Trichoptera	*Psilochorema*		1	
			Trichoptera	*Pycnocentria*	95		
			Trichoptera	*Triplectides*		3	
			Diptera	Tanyderidae	4		
			Diptera	*Aphrophila*	14		
			Diptera	Chironomidae	96		
			Diptera	Empididae	1		
			Diptera	*Hexatomini*	1		
			Coleoptera	Elmidae	7		
			Coleoptera	Hydrophilidae	1		
			Megaloptera	*Archichauliodes*	3		
			Crustacea	Ostracoda	3		
			Mollusca	*Potamopyrgus*	3		
Three	NEMS (200 fixed count + scan)	0.25	Ephemeroptera	*Austroclima*	19		
			Ephemeroptera	*Deleatidium*	6		
			Ephemeroptera	*Neozephlebia*	4		
			Ephemeroptera	*Zephlebia*	41		
			Plecoptera	*Zelandobius*	83		
			Trichoptera	*Hydrobiosis*	2		
			Trichoptera	*Oxyethira*	3		
			Trichoptera	*Pycnocentria*	13		
			Trichoptera	*Triplectides*	2		
			Diptera	Tanyderidae	1		
			Diptera	*Aphrophila*	4		
			Diptera	*Austrosimulium*	2		
			Diptera	Chironomidae	28		
			Coleoptera	Elmidae	1		
			Megaloptera	*Archichauliodes*	2		
			Mollusca	*Potamopyrgus*	7		
Four	NEMS (200 fixed count + scan)	0.5	Ephemeroptera	*Austroclima*	15		
			Ephemeroptera	*Deleatidium*	7		
			Ephemeroptera	*Neozephlebia*	2		
			Ephemeroptera	*Zephlebia*	112		
			Plecoptera	*Megaleptoperla*	1		
			Plecoptera	*Zelandobius*	60		
			Trichoptera	*Hudsonema*	1		
			Trichoptera	*Hydrobiosis*	3		
			Trichoptera	*Pycnocentria*	6		
			Trichoptera	*Pycnocentrodes*	1		
			Diptera	*Aphrophila*	4		
			Diptera	*Austrosimulium*	7		
			Diptera	Chironomidae	30		
			Diptera	Eriopterini	1		
			Coleoptera	Elmidae	3		
			Megaloptera	*Archichauliodes*	3		
			Mollusca	*Potamopyrgus*	47		
Five	NEMS (200 fixed	0.75	Ephemeroptera	*Austroclima*	15		
			Ephemeroptera	*Neozephlebia*	1		
			Ephemeroptera	*Zephlebia*	41		

	count + scan)		Plecoptera	*Stenoperla*	2		
			Plecoptera	*Zelandobius*	8		
			Trichoptera	*Hudsonema*	14		
			Trichoptera	*Hydrobiosella*	1		
			Trichoptera	*Hydrobiosis*	4		
			Trichoptera	*Oxyethira*	43		
			Trichoptera	*Psilochorema*	1		
			Trichoptera	*Pycnocentria*	56		
			Trichoptera	*Triplectides*	1		
			Diptera	*Austrosimulium*	5		
			Diptera	Chironomidae	21		
			Crustacea	*Paranephrops*	1		
			Mollusca	*Potamopyrgus*	6		
			Oligochaeta	Oligochaeta	1		
Six	NEMS (200 fixed count + scan)	0.25	Ephemeroptera	*Austroclima*	7		
			Ephemeroptera	*Coloburiscus*	1		
			Ephemeroptera	*Zephlebia*	10		
			Plecoptera	*Zelandobius*	7		
			Trichoptera	*Hudsonema*	5		
			Trichoptera	*Hydrobiosis*	1		
			Trichoptera	*Zealandoptila*	1		
			Trichoptera	*Oxyethira*	102		
			Trichoptera	*Pycnocentria*	24		
			Trichoptera	*Triplectides*	1		
			Diptera	Chironomidae	38		
			Crustacea	*Paranephrops*		1	Released
			Mollusca	*Potamopyrgus*	3		
			Oligochaeta	Oligochaeta	1		

Table D3. Macroinvertebrate summary data from the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on two separate haerenga (assessment dates) during 2023/2024.

Year	Stream	Site	Taxa richness	Simpsons Index	MCI	QMCI	Total Count
2023	Tokaanu	One	22	0.78	123	6.88	448
2024	Tokaanu	One	22	0.76	131	6.04	831
2023	Tokaanu	Two	24	0.85	121	5.79	1301
2024	Tokaanu	Two	24	0.79	116	5.46	2315
2023	Tokaanu	Three	23	0.87	112	4.81	845
2024	Tokaanu	Three	16	0.79	108	5.50	872
2023	Tokaanu	Four	21	0.80	100	3.99	751
2024	Tokaanu	Four	17	0.79	122	5.62	606
2023	Tokaanu	Five	17	0.83	96	3.49	249
2024	Tokaanu	Five	17	0.85	112	5.34	295
2023	Tokaanu	Six	16	0.58	90	2.49	209
2024	Tokaanu	Six	13	0.69	103	3.39	801

			EPT richness	EPT count	EPT perc	MCI std	EPT rich std	EPT perc std
2023	Tokaanu	One	12	393	87.72	0.61	0.41	0.88
2024	Tokaanu	One	12	739	88.93	0.65	0.41	0.89
2023	Tokaanu	Two	15	1013	77.86	0.60	0.52	0.78
2024	Tokaanu	Two	13	1771	76.50	0.58	0.45	0.77
2023	Tokaanu	Three	14	465	55.03	0.56	0.48	0.55
2024	Tokaanu	Three	8	680	77.98	0.54	0.28	0.78
2023	Tokaanu	Four	11	284	37.82	0.50	0.38	0.38
2024	Tokaanu	Four	10	416	68.65	0.61	0.34	0.69
2023	Tokaanu	Five	9	69	27.71	0.48	0.31	0.28
2024	Tokaanu	Five	11	192	65.16	0.56	0.38	0.65
2023	Tokaanu	Six	5	13	6.22	0.45	0.17	0.06
2024	Tokaanu	Six	8	224	27.97	0.52	0.28	0.28

			ASPM	MCI std local	EPT rich std local	EPT perc std local	ASPM_ Tokaanu	Distance_ (m)
2023	Tokaanu	One	0.63	0.94	0.48	0.88	0.68	0
2024	Tokaanu	One	0.65	1.00	0.48	0.89	0.71	0
2023	Tokaanu	Two	0.63	0.92	0.60	0.78	0.72	580
2024	Tokaanu	Two	0.60	0.88	0.52	0.77	0.67	580
2023	Tokaanu	Three	0.53	0.86	0.56	0.55	0.65	2366
2024	Tokaanu	Three	0.53	0.82	0.32	0.78	0.56	2366
2023	Tokaanu	Four	0.42	0.76	0.44	0.38	0.54	2589
2024	Tokaanu	Four	0.55	0.93	0.40	0.69	0.63	2589
2023	Tokaanu	Five	0.36	0.74	0.36	0.28	0.48	3041
2024	Tokaanu	Five	0.53	0.85	0.44	0.65	0.61	3041
2023	Tokaanu	Six	0.23	0.69	0.20	0.06	0.37	4003
2024	Tokaanu	Six	0.36	0.79	0.32	0.28	0.49	4003

Table D4. Cotton strip assays were undertaken at all six sites from the Tokaanu Stream in the Lake Taupō catchment. Each site was sampled on two separate haerenga (assessment dates) during 2023/2024. The first assessment deployed 8 cotton strips at each site. The second test deployed two tests (block 1 and block 2) at each site to investigate if results would differ if strips were raised above the stream bed, out of sediment. In 2024, block 1 was identical to 2023. However, in 2024, block 2 included a riser to lift the cotton strips off the stream bed.

2023				
Site	**Block**	**Strip**	**Days submerged**	**Tensile Strength (N)**
1	1	1	14	28.4
1	1	2	14	26.6
1	1	3	14	70.2
1	1	4	14	25
1	2	5	14	18.6
1	2	6	14	69
1	2	7	14	111.4
1	2	8	14	21.4
2	1	1	14	24.6
2	1	2	14	25.6
2	1	3	14	20
2	1	4	14	27.4
2	2	5	14	51.2
2	2	6	14	39.2
2	2	7	14	68.8
2	2	8	14	35.8
3	1	1	14	15.4
3	1	2	14	18.8
3	1	3	14	20.4
3	1	4	14	9.8
3	2	5	14	36.6
3	2	6	14	48.8
3	2	7	14	48.6
3	2	8	14	21.6
4	1	1	14	46
4	1	2	14	55.4
4	1	3	14	15
4	1	4	14	19
4	2	5	14	31.8
4	2	6	14	34.2
4	2	7	14	44.8
4	2	8	14	31.6
5	1	1	14	269.6
5	1	2	14	163.2
5	1	3	14	310.4

5	1	4	14	225
5	2	5	14	161.6
5	2	6	14	93.2
5	2	7	14	93
5	2	8	14	39
6	1	1	14	332.6
6	1	2	14	38.2
6	1	3	14	74.6
6	1	4	14	36
6	2	5	14	157
6	2	6	14	355.6
6	2	7	14	319.2
6	2	8	14	39.4

2024				
Site	**Block**	**Strip**	**Days submerged**	**Tensile Strength (N)**
1	1	1	14	62.8
1	1	2	14	37.4
1	1	3	14	48.4
1	1	4	14	47.4
1	1	5	14	37.2
1	1	6	14	47.8
1	1	7	14	55.8
1	1	8	14	47.8
1	2	1	14	61.4
1	2	2	14	52.8
1	2	3	14	31.2
1	2	4	14	45.6
1	2	5	14	139.8
1	2	6	14	42.2
1	2	7	14	55
1	2	8	14	112.8
2	1	1	14	112.8
2	1	2	14	156.4
2	1	3	14	126
2	1	4	14	125
2	1	5	14	97.2
2	1	6	14	170.8
2	1	7	14	215.4
2	1	8	14	119
2	2	1	14	109.8

2	2	2	14	129.6
2	2	3	14	124.4
2	2	4	14	142.2
2	2	5	14	153.4
2	2	6	14	120.8
2	2	7	14	138.2
2	2	8	14	83.2
3	1	1	14	59.4
3	1	2	14	97
3	1	3	14	36.2
3	1	4	14	34
3	1	5	14	63.6
3	1	6	14	34.2
3	1	7	14	44.2
3	1	8	14	35.4
3	2	1	14	26
3	2	2	14	50.2
3	2	3	14	16.4
3	2	4	14	36.6
3	2	5	14	38.4
3	2	6	14	15.6
3	2	7	14	40
3	2	8	14	21.8
4	1	1	14	49.6
4	1	2	14	44.2
4	1	3	14	48
4	1	4	14	23.6
4	1	5	14	46.8
4	1	6	14	57.8
4	1	7	14	42.2
4	1	8	14	46.4
4	2	1	14	47.6
4	2	2	14	27
4	2	3	14	56
4	2	4	14	28.4
4	2	5	14	38
4	2	6	14	50.2
4	2	7	14	42.4
4	2	8	14	46.4
5	1	1	14	94.6
5	1	2	14	130.6

5	1	3	14	129
5	1	4	14	86.8
5	1	5	14	79.6
5	1	6	14	235.2
5	1	7	14	139.2
5	1	8	14	105.2
5	2	1	14	46.2
5	2	2	14	98.2
5	2	3	14	113.2
5	2	4	14	108.4
5	2	5	14	106.6
5	2	6	14	5.4
5	2	7	14	194
5	2	8	14	115.8
6	1	1	14	95.4
6	1	2	14	44.6
6	1	3	14	191
6	1	4	14	193
6	1	5	14	196.8
6	1	6	14	119.2
6	1	7	14	153
6	1	8	14	103.2
6	2	1	14	90.8
6	2	2	14	127
6	2	3	14	196.4
6	2	4	14	20.6
6	2	5	14	142.4
6	2	6	14	197.6
6	2	7	14	194.2
6	2	8	14	232.2