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Poplars and willows as bioengineering solutions for riverbank flood protection – learnings from Cyclone Gabrielle

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Executive summary

Poplars and willows as bioengineering solutions for riverbank flood protection – learnings from Cyclone Gabrielle

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A survey of the bioengineering works (primarily mature willows and poplar trees) on a) the Tūtaekurī River within the Heretaunga Plains Flood Control Scheme and b) the Te Ārai River from Gisborne City water intake to its integration into the Waipoua Flood Protection Scheme was conducted 13 months after Cyclone Gabrielle. The survey assessed how the works sustained flood pressure, whether they fulfilled their intended role and how well they recovered in the year following the cyclone. Learnings will have practical relevance to other regions in New Zealand since such an event could occur anywhere in the country.

Cyclone Gabrielle is assessed as a 1-in-250-year event, and the resulting flood as having a 1-in-500-year return period. This was a significant test of capability of the bioengineering protection works on these two rivers.

With the exception of certain key locations along the rivers, the bioengineering works sustained record flooding, maintained bank stability, filtered some woody debris and their root systems remained largely intact. Frontline willow trees were flattened by the pressure of the flood water but not uprooted. They continued to separate the bank sediments from the flood waters minimising bank erosion.

Frontline willow protection failed to keep the flood water in the channel at one section of the Tūtaekurī river (Ebbetts/Dartmoor), they were pushed over by floodwaters but retained root integrity and are recovering. Flood damage in this section was assessed as serious to extreme and represented ~16% of the river length within the Tūtaekurī Flood Control Scheme. Approximately 78% of bioengineering works within the Tūtaekurī Flood Control Scheme experienced minimal or nil damage.

Woody debris transport and accumulation led to bridge structural failures on the Tūtaekurī and Hikuwai rivers and broke the city water pipe on Te Ārai River. The woody debris in the Tūtaekurī did not appear to be sourced from within the Flood Control Scheme. Visible sources of woody debris were seen in the upper reaches of the Te Ārai and other Tairāwhiti Rivers. Accumulation of mobile woody debris within the headwaters of the river catchments needs to be minimised.

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1 Introduction

1.1 The brief

An Envirolink proposal submitted on behalf of the River Managers Forum was funded to evaluate the effectiveness (strengths/failures) of flood protection bioengineering works within Hawke's Bay and Tairāwhiti-Gisborne rivers during Cyclone Gabrielle. This included identifying issues of concern and proposing options for increasing effectiveness.

Bioengineering solutions (trees – primarily poplar and willow cultivars) have been used to manage flood risk and erosion throughout NZ for decades and continue to be used as a cost effective and highly functional part of river management. This project looked at how bioengineering functioned within Hawke's Bay and Tairāwhiti, including performance in relation to flood flow effects, erosion control, stopbank protection, interception of silt and woody debris, and benefits to downstream receiving environments. Studying the effectiveness of different techniques, tree species, management, relative location, and age of trees were significant parts of the project. The conclusions derived will inform best-practice for river managers, to ensure bioengineering techniques are implemented and managed for optimal performance of river control schemes during flood events, and to minimise the downstream effects of flooding, sediment, and woody debris.

The main rivers chosen for this study were the Tūtaekurī River in Hawke's Bay, and the Te Ārai River in Tairāwhiti-Gisborne. The Tūtaekurī river is part of the Heretaunga Plains Flood Control Scheme and is highly managed as part of a comprehensive stopbanking system, along with extensive riverbank and berm erosion protection planting. The Te Ārai River is less actively managed and is an adjunct to the Waipaoa Flood Control Scheme, with the focus being on channel vegetation management and debris removal, along with localised riverbank erosion protection planting.

1.2 The event

The rainfall that accompanied Cyclone Gabrielle (13 & 14 February 2023) was of at least 250year return period for the Hawke's Bay and Tairāwhiti river catchments considered. Within Hawke's Bay the largest recorded rainfall was 538 mm over a 48-hour period at the Glengarry site, which is located at the Tūtaekurī catchment boundary. In the case of the Gisborne District, the largest recorded rainfall was 490 mm at the Hikuwai site, which is located within the Ūawa catchment north of Tolaga Bay.

Resulting flows in the Tūtaekurī River were in excess of 500-year return period, which overwhelmed the flood protection system, breached stopbanks, and caused extensive flooding. Extreme flood flows and woody debris blockage damaged or washed out several bridges, the most notable being at Dartmoor, Vicarage Road, Redclyffes, and Brookfields.

In the case of the Te Ārai River, the tree-congested channel and woody debris blockages increased riverbank overflow and flooding onto the lower valley floodplain. The main Gisborne City water supply, located at Waingake in the upper Te Ārai catchment, was disrupted for 3 months due to pipe bridge washout caused by a combination of the high floodwater flow and woody debris blockage.

1.3 The visits

In March 2024, 13 months after Cyclone Gabrielle, the study team visited sites within the Tūtaekurī river and catchment, particularly where there had been bioengineering protection failures, to qualitatively assess bioengineering planting and structure performance, the causes and extent of failures, and consider recommendations to increase resilience in future events of this magnitude. The opportunity was also taken to visit and comment on the SH50 site on the Waipawa River.

In April 2024, the study team investigated sites along and within the upper catchment of the Te Ārai River, the Ūawa-Hikuwai Rivers (north of Tolaga Bay), and the Waimatā River.

We report on the Hawke's Bay and Tairāwhiti/Gisborne rivers separately. Any recommendations are based on learnings from both studies, with general application to all catchment management schemes.

2 Catchment geomorphology

2.1 Tūtaekurī catchment

Topographically the Tūtaekurī catchment is identified by a series of ridges, generally oriented northeast-southwest. The catchment is comprised of the Kaweka Range, and hilly country southeast of the Maungaharuru Range with many steep bluffs and long slopes. The landscape is composed primarily of sandstone and mudstone from the Pliocene and Miocene eras. The greywacke based Kaweka Range provides a continuous supply of gravel to the Tūtaekurī River. The Kaweka Range is mainly within the Kaweka Forest Park, which provides most of the catchment's 23% of native vegetation land cover.

Most of the hill country slopes have a mantle of volcanic tephra soils, with younger rhyolitic ash typically atop andesitic ash. Steeper slopes may lack these soils, which may be leached in the upper layers. Prior to European colonisation and land clearance, the catchment was forested with podocarps and hardwoods. Vegetation has since been heavily modified, with most of the hill country converted into pasture. There are also large swathes of scrub, and 18% of the catchment is covered by exotic pine forest.

The tributary catchments comprise poorly consolidated and rapidly uplifted sediments, ranging from loose sands, conglomerates, and sandstones to limestones with frequent faulting. The farmed slopes over 25° have a high erosion potential, while the waterways are often within gorges or very steep sided narrow valleys. The Mangaone River is the dominant tributary of the Tūtaekurī catchment and appeared to be the main source of woody debris. Floodwaters from the main tributaries, along with their entrained sediment and debris, all combined to have a major impact on the downstream flood control scheme. It is likely that Mangaone-sourced flood debris was a major cause of downstream bridge destruction.

2.2 Tairāwhiti catchments

Tairāwhiti is a region with a young geology, located on an actively rising fold of the Earth's crust, the crest of which is the bush-covered Raukūmara Range. The high rate of uplift (4 mm a year), tectonic crushing, soft rocks, frequency of heavy rainfall, and removal of much of the original forest cover have all increased the rate of soil erosion. Twenty-five per cent of the North Island's most severely eroding land is found in Gisborne District. This presents a big challenge for current sustainable land use. A positive result of the erosion is that flat and gently rolling land is incredibly fertile. The Poverty Bay Flats are the single largest area of high-quality fertile soils in New Zealand (https://www.gdc.govt.nz/__data/assets/pdf_file/0026/9971/soe-report-2020-land-soil.pdf).

Exotic forestry was introduced over large areas of Tairāwhiti to replace pastoral farming and reduce rates of catchment erosion. During Cyclone Gabrielle downslope movement of forestry waste, and mature trees sliding off unstable steep slopes, were major contributors to the woody debris that contributed to channel blockage and water supply pipe bridge failure within the Te Ārai River, and blockage and wash-out of the Hikuwai No. 1 Bridge.

3 The rivers

3.1 Hawke's Bay

We surveyed the 27 km length of Tūtaekurī river within the Heretaunga Plains Flood Control Scheme, and briefly ventured into the Mangaone River catchment to get a sense of the connection between land slippage, riverbank erosion, and downstream flood effects within the Tūtaekurī River. We also visited the Waipawa River at the SH50 Bridge to view the effects of Cyclone Gabrielle on newly completed channel alignment and bridge erosion protection works.

3.1.1 Tūtaekurī River

The Tūtaekurī River rises in the Kaweka Ranges around 50 km northeast of Taihape. It is approximately 100 km long, and exiting the foothills crosses the Heretaunga Plains to join the Ngaruroro River and flow to the sea. The Mangaone River is the major tributary and rises to the southeast of the Puketitiri Bush near Te Pōhue, before flowing south to join the Tūtaekurī River at Dartmoor.

The Heretaunga Plains Flood Control Scheme manages the Tūtaekurī, Ngaruroro, and lower Tukituki Rivers, and provides flood protection to a 39,000-hectare floodplain area, including highly productive land and the cities of Napier and Hastings. The 27 km managed length of the Tūtaekurī River has a gravel bed, and meanders within an active channel fairway (Figures 1 & 2) bounded by bank edge vegetation. The berms extend from the active channel edge to the stopbanks, with continuous vegetation buffer zones along the fairway edge, and relatively open grassed areas with scattered trees extending to the stopbank.

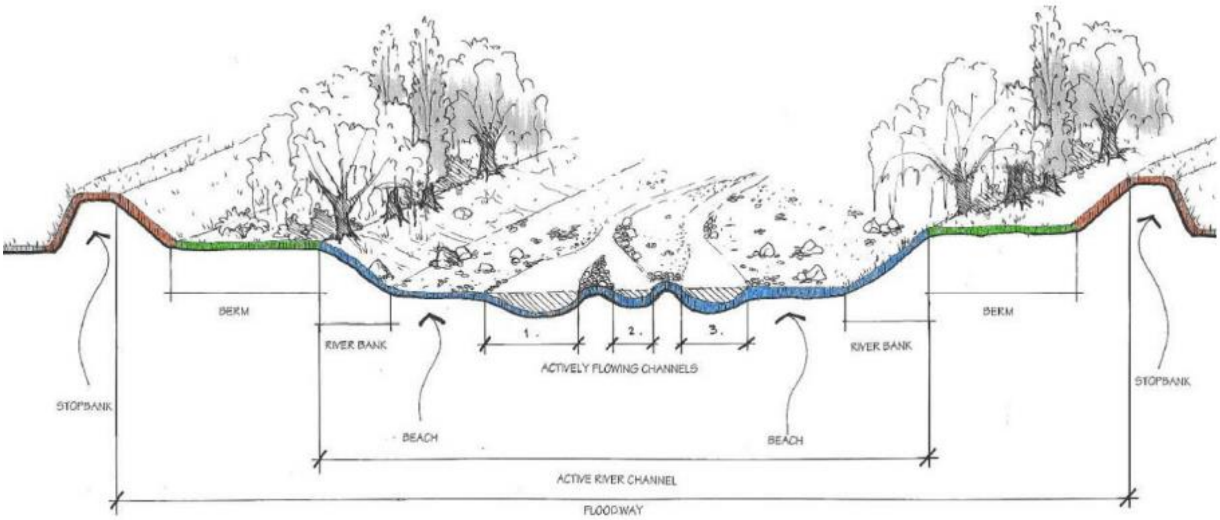

Figure 1. Schematic of river floodway.

Figure 2. Tūtaekurī River channel – downstream of Taradale.

3.1.2 Riverbank vegetation

The riverbank vegetation consists mainly of mature tree willow, which is strengthened by embedded structural erosion protection works such as groynes and rope and rail training lines. The berm buffer vegetation consists mainly of willow and poplar, with alternative trees such as alder and acacia becoming more prevalent downstream of Redclyffe Bridge. The river edge trees are willows close planted in rows, varying in number up to 5–6, with poplars frequently replacing willows in the 1–2 rows farthest from the river edge.

Riverbank and berm vegetation have the important functions of:

- maintaining the design channel fairway alignment;
- preventing riverbank, berm, and stopbank erosion;
- capturing and preventing downstream movement of flood debris;
- screening and preventing flood debris deposition on berms, stopbanks, and floodplains;
- providing tree material for bioengineering erosion and flood protection works; and
- reducing stopbank breach extent and outflow, and related berm erosion.

3.1.3 Maintenance activities

Ongoing maintenance activities such as herbicide weed control, debris removal, beach ripping (to help mobilise gravel and control weeds), and gravel extraction, are all vital to ensuring the channel fairway has a stable alignment and maintains flood capacity.

Minor bank erosion can be repaired by using bioengineering methods such as lopping, layering, trenching, or planting of willow, poplar, or other suitable trees. More substantial bank and berm erosion repair could also require channel realignment, plus structural bioengineering methods such as willow cabling, willow clumps, or anchored trees. Heavy structural erosion protection methods such as rope and rail groynes or training lines, rock linings, rock groynes, or articulated concrete block (Akmon) groynes, could be combined with bioengineering methods to repair serious bank erosion sites.

3.1.4 Waipawa River

The Waipawa River is a gravel bed river, which meanders within a relatively wide channel fairway (Figure 3). The river is managed for flood protection purposes as part of the Upper Tukituki Catchment Control Scheme. A comprehensive project was undertaken upstream of SH50, just prior to Cyclone Gabrielle, to secure the channel alignment and prevent damage to the SH50 Bridge. Section 6.2 discusses these works and their observed performance, especially in relation to the bioengineering methods used.

Figure 3. Hawke's Bay gravel bed rivers (left Tūtaekurī; right Waipawa at SH50) showing wide fairway, meandering channels, and low riverbanks.

3.2 Tairāwhiti − Gisborne

The three rivers we visited were very similar and provide a contrast with the Hawke's Bay rivers given the silty nature of their beds, their entrenched and confined channels, and the character of their riverbanks (Figure 4).

Figure 4. Tairāwhiti rivers (from left Te Ārai, Hikuwai, Waimatā) showing narrow silty channels and steep slumping banks.

3.2.1 Te Ārai River

The Te Ārai River is a tributary of the Waipaoa River with its confluence near the coastal mouth. The catchment is made up of plantation forest, native forest, and pastoral hill country, and the river has recognised ecological significance. Gisborne city sources 80% of its municipal water supply from the headwaters in Waterworks Bush. There were major log jams following Cyclone Gabrielle, and bank stability was compromised in many locations along the river.

The Te Ārai is a winding river, with a soft silt stone bed in the upper reaches, and a silt bed in the lower reaches. The lower reaches flow through horticultural land, with high and steep banks of the river composed of erodible and unstable sandy silt.

Section 6.3 discusses the results of the Te Ārai River site inspections, especially in relation to bioengineering.

3.2.2 Ūawa River

The Ūawa River enters the Pacific Ocean at Tolaga Bay. It has a catchment consisting of predominately managed forestry land extending northwest to inland of Tokomaru Bay. The middle section of the river is known as the Hikuwai River, which flows from the upper catchment tributary connections at Hikuwai, and downstream to Mangatuna where it joins the Ūawa River and flows over the Tolaga Bay flats. During Cyclone Gabrielle the Hikuwai River peaked at 14.3 m, which exceeded the flood warning level by 4.8 m, and the previous highest recorded level of 13.0 m during Cyclone Bola. The Hikuwai No. 1 Bridge was destroyed in the flood due to high flows and woody debris blockage. Gisborne District Council is preparing a Catchment Plan for the Ūawa catchment, but at this stage there is no ongoing channel maintenance works programme.

The Ūawa-Hikuwai River has a soft silt stone bed in the upper reaches, and a silt bed in the lower reaches. The lower reaches are sinuous with an entrenched channel, and high and steep banks composed of erodible and unstable materials. The banks are stabilised by woody vegetation (tree willow, silver poplars) particularly on the outside bends and where infrastructure (bridges, roads) needs protection.

3.2.3 Waimatā River

The Waimatā River enters the Pacific Ocean at Gisborne Port, with a catchment extending northward to the Waimatā Valley. The dominant land uses are pastoral hill country farming and managed forestry. The channel has a soft rock bed that transforms into a silt bed in the lower reaches. Outside of the city, the riverbanks are generally stabilised with silver poplar and tree willow, with natural mānuka stands in locations where native vegetation regeneration has occurred on the adjoining hills. During Cyclone Gabrielle the Waimatā River peaked at 10.9 m, which exceeded the flood warning level by 2.9 m. The Cyclone Bola flood level of 11.4 m remains the largest on record.

Although Gisborne District Council has implemented the Waimatā-Pakarae Catchment Plan, there is no ongoing channel maintenance programme for the Waimatā River.

Section 6.4 discusses the results of the Ūawa-Hikuwai River site inspections, especially in relation to bioengineering.

4 Historical catchment approach

In accordance with our brief, we only considered the bioengineering aspects of river and catchment management. Willows are the most common tree species used in river training and to protect stopbanks from flood damage. Tree willows have a wide-spreading root system, and along water courses they develop a root-mat close to the ground surface, which commonly extends to the water edge and below water level. This mat of fine roots stabilises the stream bed and river edge, protecting them from scouring.

For over 130 years, *Salix fragilis*, crack willow, was the main tree species for river protection work. Its fibrous root production is superior to other tree willows, making it invaluable in large rivers, but prone to obstructing small rivers and streams. Crack willows are sterile, but the branches are very brittle, and twigs or branches can break off and move downstream to regrow. Crack willow is troublesome where proper maintenance of its growth is neglected, and is an unwanted organism (it can't be propagated or distributed) under the National Pest Plant Accord. The less brittle *S. alba*, *S. matsudana*, and *S. matsudana x alba* hybrids are replacing *S. fragilis.* Novel tree willow cultivars developed by The New Zealand Institute for Plant and Food Research Limited (Plant & Food Research) and released to Regional Council nurseries for propagation provide options in size, sawfly and rust tolerance, and rooting capacity.

Osier willows, multi-stemmed medium-sized trees growing to 8 m, are used in river control planting (Figure 5). Examples are *Salix purpurea* 'Booth', *S. viminalis*, and 'Glenmark' (*S. glaucophylloides x viminalis*). Osiers have a fibrous root system, but without the superior structural root strength and depth of tree willows, so are not suitable as frontline protection in high energy rivers. However, they are a lighter tree on sloping erodible banks, they can be planted closer together, and the multiple stems are flexible in flood events. Willows and poplars grow naturally along river edges, and are well adapted to low nutrient gravel and sandy substrates.

Poplars are used to add protection behind tree willows at higher elevation (Figure 6). Poplar root systems do not have the fibrous root arrangement seen in willows, and are not tolerant of prolonged submergence in water. Poplar root systems are extensive (like tree willow root systems), and grow laterally, vertically, and obliquely at different depths. They are excellent for soil binding in the zones that are only periodically flooded. Poplars are larger trees than willows at maturity. Willows and poplars establish readily in gravel sediments when planted as poles down to the water table (Figure 5).

Figure 5. Willow pole growth after one season compared with shoot growth from a layered tree willow, located immediately behind and upstream of the poles, and installed simultaneously (left). Osier willow (*S. viminalis*) on the river edge (right).

Figure 6. Live edge protection along the Tūtaekurī River. The front edge willows are supported by rows of different poplar cultivars behind.

Tree management is necessary in using live protection in river protection works. Live edge protection is managed by mulching to reduce size, and by layering to add strength to the front edge. River fairways with gravel beds are prone to settlement by trees or weeds, particularly after flood events. They are kept free of vegetation by raking, bulldozing, and herbicide spraying (Figure 7). Edge protection trees are removed or relocated when they are interfering with the normal river flow, narrowing flow paths, or becoming weedy. Willow planting and removal are normal river bioengineering activities. Mature willow trees can be felled for layering, relocated and anchored in place for bank erosion protection, or pollarded for pole production. Multiple rows of trees provide a source of material for future protection works.

The reach of the Tūtaekurī River managed for flood protection purposes has stopbanks on both sides to protect farmland, communities, and infrastructure during periods of high flow. Planted live edge protection along the riverbanks, along with groynes and rope/rail training lines, and layering or anchoring of live trees, maintain the channel alignment and prevent bank and berm erosion. The berm and buffer zone vegetation also helps to control berm flows and prevent stopbank erosion.

Figure 7. Raking a fairway gravel beach to remove woody and other vegetation, Tūtaekurī River.

5 Impact of willow sawfly on policy and practice

Willow sawfly (*Nematus oligospilus*), a sawfly that feeds exclusively on willows, was first detected in Auckland, New Zealand in February 1997. Adults disperse rapidly by flight, and by April 1998 larvae were widespread in the Bay of Plenty and Tairāwhiti, where large numbers were damaging several different willow types. The larvae are external leaf-feeders, able to defoliate and even kill willow trees. They had little impact on osier and shrub willows. This pest posed a threat to soil stabilisation and riverbank erosion control programmes, which rely on relatively few species, including cultivars of willow most of which have been bred in New Zealand.

5.1 Response of policy and practice

The Plant & Food Research willow breeding programme (now funded by New Zealand Poplar & Willow Research Trust) developed new tree and osier willow hybrid cultivars utilising *Salix lasiandra*, *Salix lasiolepis*, and *Salix nigra*, all of which had leaf chemicals that discouraged sawfly feeding, and on which larvae struggled to mature to adulthood. With the support of the River Managers Forum, seeds of S *Salix lasiandra* and *Salix lasiolepis* were collected from river sites in California where willow sawfly is endemic, and brought back to broaden the genetic variability within the NZ germplasm collection. These became the parent material for hybridisation, along with cultivars already held within the germplasm collection in Palmerston North.

Bioengineering policy shifted from planting only willow towards species diversity (e.g. poplar, alder, acacia) to reduce bio-protection vulnerability. In practice, river engineers retained tree willows as front line edge protection, and planted other species dominated by poplar cultivars behind the willows. This provided a replacement bioengineering tool in the event of mass willow loss.

Continuing willow sawfly impact following devastating defoliations of 1998–2004 is localised and relatively minor. This sawfly breeds parthenogenically (i.e. it can breed even though only females are present in New Zealand). The possibility of future outbreaks is highly likely, as experienced in Argentina, but the frequency can only be guessed at.

6 River site observations and reflections

6.1 Tūtaekurī River

6.1.1 Organisation of riverbank protection

The general pattern of riverbank protection is a frontline of 1–3 rows of tree willows (*Salix fragilis, S. matsudana, S. alba, S. matsudana x alba* hybrids (primarily the male clone 'Moutere'), with 1–3 rows of poplars of various clones. Willows show up as being lighter green and poplars as darker green on Google Earth imagery.

An example of riverbank protection is the mid-Dartmoor site (refer Appendix 2) located on the true left bank opposite lower Ebbetts. The pre-cyclone riverbank and berm plantings consisted mainly of large to medium size tree willows, actively managed by lopping and layering. In addition to rope and rail training lines along the river edge, the berm included groynes to improve resistance to bank erosion.

The stopbank was set back 70 m from the riverbank, and most of the berm width was planted, which in normal floods would offer erosion protection to the stopbank. However, the cyclone flows significantly exceeded the floodway capacity, and the adjacent stopbank overflowed and breached. The siphoning-off of large breach flows from the main channel, combined with the directional effects of Ebbetts floodplain return flows, combined to wash out or flatten the berm planting. Fortunately, the river channel alignment held due to the combination of bank and berm erosion protection measures in place. The post-cyclone aerials showed partial regrowth of the poplars and willows flattened by floodwaters, which demonstrates the durability of the remnant erosion protection planting. The aerial photos below (Figures 8 & 9) show the pre- and post-cyclone riverbank and berm protection planting.

Figure 8. Pre-Gabrielle; Dec 2021.

Figure 9. Post-Gabrielle; Feb 2023.

6.1.2 Sites visited

We visited sites on the river (Table 1, Figure 10) where there was significant damage due to erosion or undermining of banks, overflows of channels and berms, stopbank breaches, and substantial outflows onto floodplains. There was significant deposition of woody debris and sediment associated with this. On the whole the bioengineering assets (bank, berm, and buffer zone plantings) performed well. However, in localised areas where stopbanks breached, or overflows onto berms and floodplain areas were concentrated, the bioengineering assets partially or completely failed.

Table 1. Location and damage features of the reported sites along the Tūtaekurī River. Grid references are taken from Google views so are approximate only.

Tūtaekurī River		
site	Location	Damage features
1	Mangaone confluence with Tūtaekurī 39°29'36" S, 176°43'22" E	Floodplain overflows. Loss of bank/berm trees, bank erosion, woody debris deposition
2	Dartmoor Rd Reserve 39°29'50" S, 176°42'07" E	Bank erosion & loss of bank/berm trees
3	Ebbett's upstream 39°29'50'' S, 176°43'1'' E	Major floodplain overflow. Loss of bank/berm trees, & downstream stopbank breach
Between 3 & 4	Ebbetts – between sites 3 and 4 39°30'20'' S, 176°44'11'' E	Flood layering of bank trees. Woody debris capture in berm trees. Stopbank breaches above and below this point.
4, 5	Ebbett's downstream and mid-Dartmoor 39°30'24'' S, 176°45'08'' E	Stopbank breaches both sides of river. Wash-out & flood layering of bank/berm trees. Berm erosion and silt & woody debris deposition.
6	Moteo 39°30'42'' S, 176°46'34'' E	Flood layering of bank trees, & localised berm tree loss. Berm erosion and stopbank breaches
7	Moteo – Vicarage Rd 39°30'40'' S, 176°47'12'' E	Flood layering of bank trees. Adjacent stopbank breach. Vicarage Rd bridge wash-out
8	Puketapu 39°30'57'' S, 176°47'39'' E	Bank & berm tree loss and flood layering. Stopbank breaches
9	Omaranui 39°31'17'' S, 176°47'45'' E	Stopbank breach site. Damage to bank & berm trees. Berm erosion
10	Omaranui 39°32'03'' S, 176°48'06'' E	Stopbank breach site. Damage to bank & berm trees. Berm erosion
11–14	Waiohiki – Redclyffe Bridge 39°33'01'' S, 176°50'07'' E	Partial bridge wash-out. Bank/berm erosion & tree loss
15–16	HB Expressway 39°32'58'' S, 176°51'26'' E	Berm & bank trees undamaged. Nil bank or berm erosion.
17	Meeanee – left bank 39°33'27'' S, 176°52'08'' E	Berm siltation. Bank trees flood layered, berm trees undamaged
18	Brookfields – right bank 39°33'37'' S, 176°52'08'' E	Berm siltation. Bank trees flood layered, berm trees undamaged
19	Brookfields – right bank 39°34'00'' S, 176°52'28'' E	Berm siltation. Minimal bank & berm trees. Brookfields Bridge wash-out
20	Awatoto 39°33'52'' S, 176°54'38'' E	Berm siltation. Minimal bank & berm trees. Downstream stopbank breach, with berm siltation & major debris accumulation on Rail Bridge.
21	Waitangi Reserve 39°33'39'' S, 176°55'16'' E	Wetland vegetation undamaged
22	Pakowhai Tree Nursery 39°34'03'' S, 176°53'60'' E	Berm siltation. Minimal bank & berm trees, undamaged.

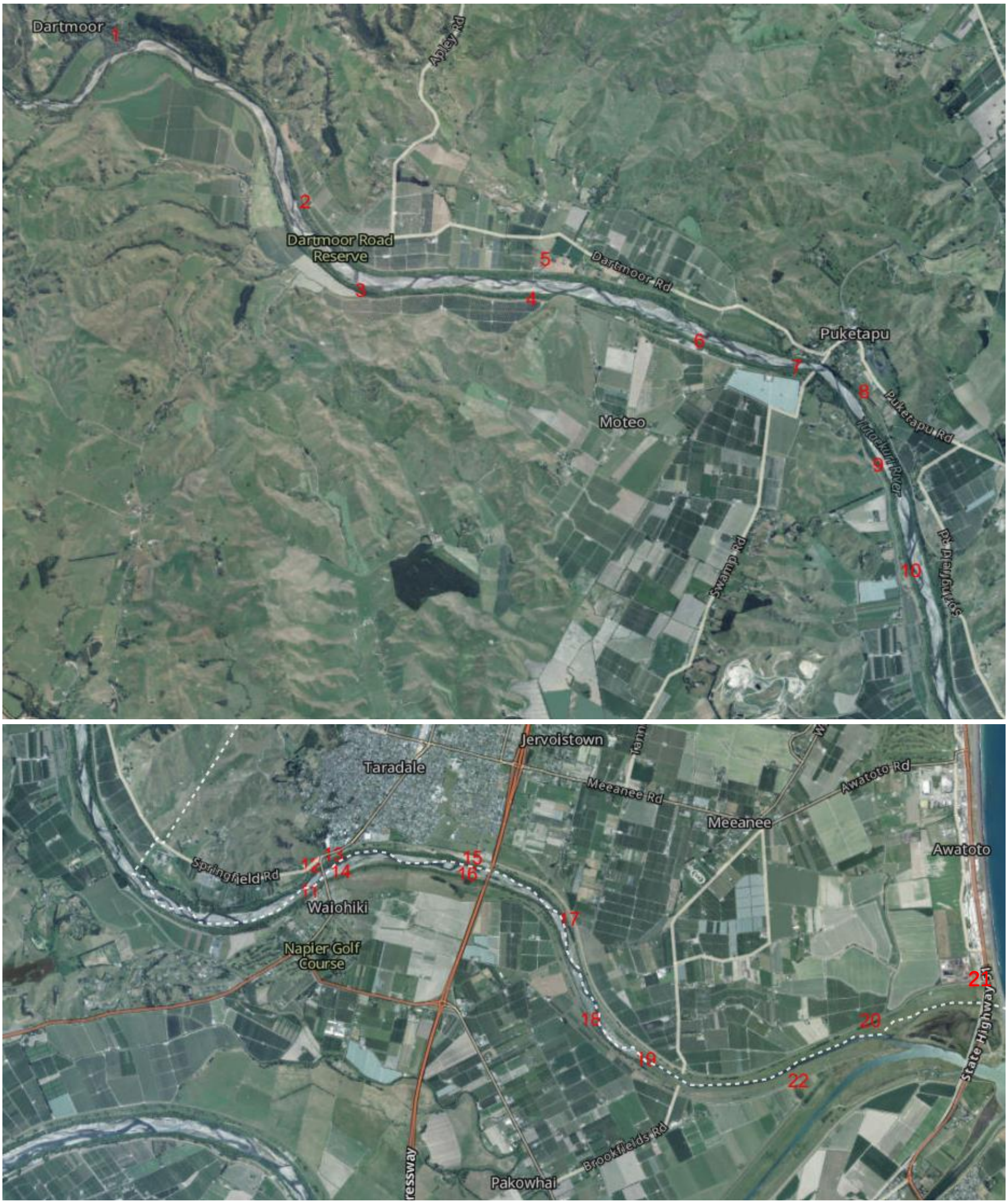

Figure 10. Inspection sites.

6.1.3 Observations

We paid particular attention to bank and berm protection trees, observing what happened to them in the flood, their general health, and evidence of management.

Floodwaters damaged bank and berm plantings at several locations, e.g. confluence with the Mangaone River (site 1), Dartmoor Road Reserve (site 2), Ebbetts upstream (site 3); damaged bank and berm plantings as well as breaching stopbanks at Ebbetts downstream (site 4), mid-Dartmoor (site 5), Moteo (sites 6 & 7), Puketapu (site 8), Omaranui (sites 9 & 10); and breached stopbanks with minimal planting damage at Pakowhai (site 22) and Waitangi/Awatoto (site 21).

The tributary flows brought floodwaters, sediment, and woody debris into the Tūtaekurī River. Notably the Mangaone River contributed large flows and woody debris, which had a major impact on the Tūtaekurī River flood protection system and was likely the major cause of downstream bridge damage or destruction.

Figure 11. Regrowth of mature willows and poplars, flattened by overland flood flow return, contrasted with unaffected standing trees upstream.

Riverbank and berm tree willows were flattened (pushed over so that their trunks were lying horizontal or almost horizontal) at various points along the riverbank, on both left and right banks. These show up either as a single tree occupying the tree row along the bank, or as all the bank and berm vegetation when viewed in Google Earth. We describe this as severe (Table 2). Bank edge willows pushed over by the force of the floodwater have resprouted prolifically from both the stump region, and along the length of the trunk where bark is still present (Figure 11). Orientation of the pushed over trees away from rather than towards the river edge is not ideal as layering, but regrowth is impressive after less than 1 growing season, with upwards of twenty shoots 2–4 m high. These will be suitable as poles after another growing season, though harvesting access may make the exercise too expensive except for on-site use.

Bank edge willows flattened at several sites (2, 4, 5, 6, 7, 9) were at an orientation parallel with the flood flow. Orientation of the flattened trees to the channel fairway varied depending on whether the flow remained within the channel or was a stopbank or floodplain break out or return flow. There is a window of opportunity to reorientate some of the flattened trunks, by layering or burying/anchoring them before the next growing season.

Flattened willows were not uprooted, they were still anchored in the soil/sediment by live roots (Figures 12 & 13). Any reorientation should consider whether the live roots may be broken off, with resulting slowing of regrowth of shoots, particularly from the stump area.

Figure 12. Shoot regrowth, after one year, from a tree willow flattened from behind by floodwaters. The trunk-soil connection remained intact.

We consider observations we made at various sites along the river have general application in other catchment management schemes.

Flattened poplars (Figure 13) were more damaged. The trunk-soil connection was largely intact, but the prostrate trees will create management problems. Our recommendation is to remove them and replant replacement poles.

We assessed the extent to which the bioengineering aspects of the Tūtaekurī River flood protection system were impacted by floodwaters generated by Cyclone Gabrielle, and categorised the severity of the impact on a scale from minimal to extreme (Table 2). The assessment was of both sides of the Tūtaekurī river from the Mangaone to Tūtaekurī confluences, and used Google pre-flood (Dec 2021) and post-flood (Oct 2023) imagery. Of the 48 km of riverbank, 78.5% was assessed as having minimal impact; and 21.5% as having moderate, severe or extreme impacts. Two stretches of the river accounted for 16.3% of the 21.5% of bank damage greater than minimal (Table 3).

Figure 13. Shoots resprouting from flattened poplars. Almost all the bark was stripped by the abrasive floodwaters, leaving little opportunity for recovery from the trunk.

Table 2. Impact categories for woody vegetation lining the Tūtaekurī riverbank.

Impact category	Impact description	Length of river in this category (total length = 48 km)	% of length
Minimal	Negligible bank edge stress	37.70	78.5
Moderate	Bank edge flattening, single row	2.74	5.7
Severe	Bank edge flattening, >single row	6.65	13.9
Extreme	Bare ground with no vegetation remaining	0.92	1.9

Table 3. Impact severity for two stretches of the Tūtaekurī river most affected by Cyclone Gabrielle.

Location	Moderate (km)	Severe (km)	Extreme (km)	Total length (km)	% of riverbank length
Mangaone convergence	0	2.44	0.92	3.36	7.0
Dartmoor/Ebbetts between floodwater exit from fairway and re-entry at Ebbett's Hill	1.18	3.28	0	4.46	9.3

Bank edge erosion (that would indicate failure of the edge protection root system) was evident in very few places along the river.

Bank and berm protection planting should be aligned to direct flow back to the river channel, rather than onto the berm and towards stopbanks or floodplain. At locations such as mid-Dartmoor, where the flattened berm tree alignments were such that flows were directed towards the stopbank, significant work was undertaken to remove or realign these trees.

Scouring around partially buried flattened trees laying at an angle to the channel flow (as a result of the flood event) could weaken bank protection. These sites need support from layered and tied back trees aligned with the flow as per normal practice.

Willow trees which have fallen into the channel or onto the berm could be hard to uproot, and realign or relocate, due to stump and horizontal trunk regrowth in-situ (Figure 14).

Recommendation – cut through the fallen trunk somewhere above the stump to create two trees from one. Realign or relocate the cut off trunk as anchored or layered tree protection. This is suggested as a sensible approach to dealing with trees that have fallen on a poor alignment, either on the berm or into the channel. If left they could create a weakness in bank or berm protection.

Some parent trees were debarked (probably by woody debris abrasion rather than sediment abrasion) but were still sprouting from what bark was left.

Recommendation – that any debarked trunk be cut off and removed. They will always be a weak protection asset.

There was very little scouring of the ground and settling of sediment along the banks and berms of channels where floodwaters were contained between stopbanks. Flow exchange from channel to berm and back occurred within these reaches, but the bank and buffer vegetation proved very effective for soil conservation.

One year after the event there were large numbers of seedlings of willow and poplar and herbaceous species on the beaches within the fairway. Some beaches had been raked and there was no evidence of seedlings at those sites. Seedling propagation in the planted zone, where the light levels are low and the seeds are much less likely to be in contact with the ground, is unlikely to be an issue.

Recommendation – that channel fairway maintenance such as beach raking, herbicide weed control, and flood debris removal continue to be given priority.

Interlocking roots of adjacent willow and poplar trees showed high resistance to uprooting. Alders (*Alnus* spp.) and blackwoods (*Acacia melanoxylon*) however have a less robust root system and were washed out by floodwaters at some sites, e.g. at Redclyffes Bridge.

Recommendation – that suitable willows and poplars continue to be used for frontline riverbank and berm erosion protection, whilst recognising that other suitable trees have a role in complementing willow and poplar, as well as providing diversity.

Willow layering is conducted by partially cutting or breaking willow branches, so they remain anchored to the stump, but lay down the bank into the active channel. Layering helps prevent bank erosion and reinvigorates older willow trees, and should normally be undertaken on a 10- to 15-year cycle to maintain bank and berm vegetation. However, when undertaken over long periods alongside relatively narrow active channels, layering can narrow the channel and reduce flood capacity. Mulching of large willow branches from the top down is being undertaken in parts of Hawke's Bay, and should be considered for the Tūtaekurī River. This would help maintain tree (and root system) health, whilst reducing excessive tree bulk which creates flood performance and tree care cost issues.

Recommendation – that bank and berm protection plantings are maintained by appropriate planting, layering, and mulching as required.

Figure 14. Recovery of front row of tree willows layered by floodwaters in the main channel, one year on from Cyclone Gabrielle.

A detailed description of observations made at the sites along the Tūtaekurī River where the impact was most severe, illustrated with before, immediately after, and 13 months after, aerial photographs, is given in Appendix 2.

6.2 Waipawa River

A comprehensive project was undertaken upstream of SH50, and just prior to Cyclone Gabrielle, to secure the channel alignment and prevent damage to the SH50 Bridge. Works consisted of channel realignment, erosion bay infill, Akmon groynes, rope/rail groynes & training lines, and extensive tree planting (Figure 15). Infilled gravel areas closer to the river were planted with willow poles (*Salix matsudana x alba* hybrids), and poplar poles (*Populus x euramericana* 'Veronese') were planted higher up on the banks. Cyclone Gabrielle partially undermined the Akmon and rope/rail groynes causing bank erosion and channel realignment (Figure 16). A further flood in June 2023 further damaged these works upstream of SH50, resulting in bridge abutment wash-out and road closure.

Figure 15. Newly completed Waipawa River training works upstream of SH50 – prior to Cyclone Gabrielle.

Figure 16. Bank erosion with damaged Akmon & rope/rail groynes (left).SH50 Bridge wash out (right).

Figure 17. Willow and poplar growth in spite of flood damage.

Key points taken from this inspection were the surprisingly good condition of the newly planted willow poles, in spite of abrasion and breakage damage caused by floodwaters and debris. The poplar poles were in even better condition mainly because they were less exposed to flood damage. The root systems had established sufficiently to hold and prevent erosion of loose gravels. The normal approach of planting the willows closer to the water's edge, and the poplars on drier ground away from the river, proved to be successful (Figure 17). Another useful finding was how successful rope/rail groynes were in trapping woody debris, preventing local tree damage as well as downstream debris movement and related problems (Figure 18).

Figure 18. Debris capture by rope/rail groyne.

6.3 Te Ārai River

The Te Ārai is a winding river, with a soft silt stone bed in the upper reaches, and a silt bed in the lower reaches. The lower reaches flow through horticultural land, with high and steep banks of the river composed of erodible and unstable sandy silt.

6.3.1 River channel planting and stability

The riverbank planting consisted of a mixture of osier willows (*S. purpurea*) and tree willows (range of species including *S. fragilis*), often with poplar trees (*P. alba*, *P. xeuramericana*) also along the top of the bank.

The trees and shrubs were largely stable throughout the cyclone, with wash-out and downstream movement unusual. However, the numerous large trees significantly roughened the channel, capturing woody debris from up-catchment, and reducing flood capacity. A substantial programme of tree pruning and removal, combined with woody debris removal, was in progress to improve flood capacity. The intention is to improve maintenance of the river by continuing these activities, conducting herbicide spraying of undesirable regrowth, and taking care to plant appropriate trees and shrubs where needed for bank stability, and to prevent erosion of adjoining roads and farmland.

An understanding of the mechanism of bank erosion and/or instability is important to help determine the appropriate bioengineering method. Figure 19 shows several possible bank instability modes demonstrated in the Te Ārai (as well as the Ūawa-Hikuwai and Waimatā Rivers). The mechanism of bank saturation during flood (adding weight, increasing soil pore water pressures, and lubricating slip surfaces), toe erosion (especially on the outside of bends), and flood recession (removal of stabilising hydrostatic pressure) – all contribute to riverbank slope failures. These rivers have high suspended sediment loads, and deposit silts on the banks during quiet flood sequences, thus healing the slope failures and shrinking channel capacity. Riverbank toe erosion, slope failure, and channel enlargement during the next major flood repeats this natural cycle.

Shallow slide Rotational slip Slab failure

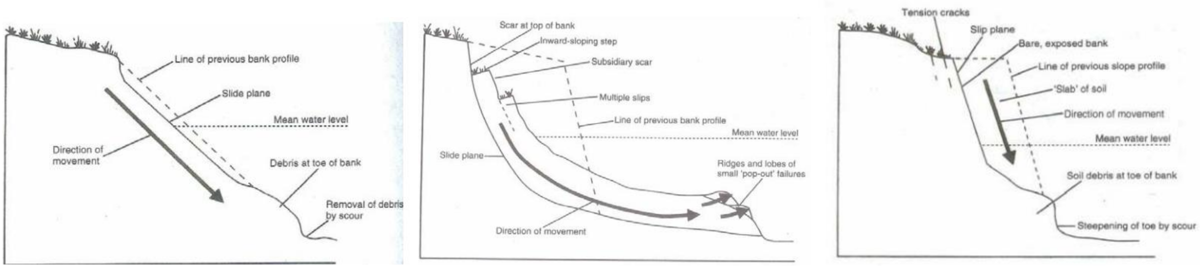

Figure 19. Riverbank slope failure modes.

Trees generally have a stabilising effect on riverbanks due to root system binding and drainage by evapo-transpiration. Large trees can however decrease stability due to their weight, possible windthrow, and floodwater drag and leverage effects. In the lower reaches of the Te Ārai for example, from the flood capacity and bank stability perspective, it may be optimal to maintain riverbank grass cover along straight lengths and on the inside of bends. Osier willows could be established on the outside of bends, with a combination of tree and shrub willows (or other bioengineering methods) on outside bends where erosion or slumping is threatening roads, high value farmland, or other valuable assets. Poplars have a place at the top of banks where root systems can help stabilise banks and provide aesthetic or shelter value.

Recommendation – establish osier willows on the outside of bends, with a combination of tree and osier willows (or other bioengineering methods) on outside bends where erosion or slumping is threatening roads, high value farmland, or other valuable assets.

Upper reaches in the hills

Tree willows, poplars and other tree species including some native species discontinuously line the river edge, concentrated along river stretches protecting infrastructure (road, bridges, Gisborne city water supply pipe).

Lower reaches across the plains

Single rows of tree willows and poplars were more concentrated along the lower reaches and sited on the top of the bank. Tree willows protected banks of most outside bends. Trees were present on one bank only at many stretches along the river. Sloping sides of the riverbank were protected by osier willows (for example, *Salix purpurea*) and other woody species. At the time of our visit much of the woody vegetation had been removed from the sides of the riverbanks along with the woody debris that accumulated in the channel following Cyclone Gabrielle. Observed stump diameters of the multi-stemmed osiers were in the range 12–18 cm indicating mature plantings.

6.3.2 Observations on Te Ārai River 13 months after Cyclone Gabrielle

In the upper reaches, fallen plantation pine trees (falling off steep shallow soil slopes) were observed at two locations (see Figure 20). We considered that other fallen pines had been caught up in floodwaters and carried downstream to break pipe bridges along the Waingake water supply pipeline and to create blockages at bridges and bends. Mānuka-clad steep slopes did not show tree toppling (Figure 20). There was some bank erosion, mostly at sites where the bank was unprotected and had experienced erosion previously. Comparing Google images pre- and post-Gabrielle, some woody vegetation had disappeared from sloping banks in a few locations, but numbers of trees were small, and likely a mix of osier and tree willows. In the upper reaches, before the river has left the hills, floodwaters tracked over farmland, and woody debris settled on pasture, among edge trees and within the channel.

Figure 20. Plantation pine covered steep slope, contrasted with mānuka covered steep slopes, upper Te Ārai River.

In the lower reaches, the sides of the channel were heavily silted but largely intact, with some erosion at outside corners with low protection. The bank edge showed little evidence of collapse. However, there was one outside bend where 4–5 large tree willows were missing, and at a site 200 to 300 m upstream another 3 tree willows were missing. They may have been removed intentionally by the landowner since the bank did not erode. Major channel log jams did not appear to produce erosion of the sides of the bank.

Except for a few sites, the river edges and bank were intact and protected by mature woody vegetation (Figure 21). Woody debris trapped in the channel had been removed, and the woody vegetation (largely osier willow) had been coppiced (Figure 22). Eroded outside bends had not yet been re-stabilised (Figure 23). There was no evidence of trees being flattened by floodwaters as noted on the Tūtaekurī River. This was no doubt attributable to the lower gradient and flood velocities in the Te Ārai River.

Figure 21. Typical bank vegetation on downstream Te Ārai River with dense osier willow on near bank.

Figure 22. Bank edge and slope vegetation in the lower reaches of Te Ārai River, with woody debris in the channel. The access track is facilitating woody debris removal from the channel.

Figure 23. Erosion of the bank on an outside bend, Te Ārai River. Heavily wooded inside bend traps sediment and narrows the channel.

6.4 Ūawa-Hikuwai River

Banks on the Hikuwai River showed a high degree of stability. Where tree willows were planted at the top of the bank there was little if any slumping (Figure 24). Fibrous willow roots occupied the bank profile down to the channel. We observed large roots in the banks, partially exposed by the floodwaters, which were running laterally at different depths, and with fibrous roots extending from them (Figure 24). This was clear evidence of how willow root systems hold steep banks intact. Erosion from the top of the banks was evident where drains entered the river, and where overland flow from a low point on the paddock flowed back into the river (Figure 25). Toe erosion and slumping of the bank occurred along stretches of the river, either with no trees planted at the top of the bank, or where unsuitable trees (mānuka, poplar, tōtara) were undermined (Figure 26). At several locations, we observed that poplars planted on the top of the bank, and close to edge, were undermined and toppled by floodwaters. One example was at Hikuwai No. 1 Bridge (Figure 27).

Outer bends which were well planted with trees showed little erosion, whereas outer bends devoid of trees lost sediment at the top and sides of the banks (Figures 28 & 29).

Figure 24. Willows lining the top of the bank, with roots visible down the sloping bank to the channel, Hikuwai River.

Figure 25. View of Hikuwai River showing stable sloping banks. Overland flow returning to the channel caused the erosion in the foreground.

Figure 26. Bank stabilisation by tree willows (right bank) contrasted with slumping into the channel on left bank (despite the presence of mature mānuka and other tree species).

Figure 27. *Populus x euramericana* poplar undermined by floodwater above No. 1 Bridge, Hikuwai River.

Figure 28. Densely treed outer bends suffered little bank erosion, but silver poplars (foreground, left bank) were undermined by toe erosion.

Figure 29. Sparsely treed outer bends showed more toe erosion and slumping.

6.5 Waimatā River

We assessed the cyclone's impact on the Waimatā River, along Riverside Road from above Donner's Bush Recreational Reserve to the outskirts of urban Gisborne. Pastoral land adjoined both sides of the river. The channel was entrenched with high banks and shallow flow. Woody debris of various types lined the channel edges. Google imagery pre- and post-flood showed substantially more loss of shrub/small tree vegetation than large trees from the riverbank. It also showed there was significant erosion on the true left bank, particularly, but not only, where there was no woody vegetation. Silver poplar (*P. alba*) trees were variously distributed along the true right bank, and there were some osier willows and tree willows. Bank erosion was generally absent where willows were concentrated (Figure 30). Mānuka trees were growing down to the edge of the steeper left bank, but this did not prevent significant erosion (Figures 31, 32). Floodwaters bent over poplars and osiers on the right bank with little resulting erosion. Woody vegetation stabilised the tributary streambanks adjacent to Caves Road but was less successful in stabilising banks of the Waimatā River. Evidence from Waimatā River observations are that mānuka root systems are inadequate to stabilise steep riverbanks in high flow events, and that poplar is not the best tree for frontline protection. The key lesson here is to use the right tree, in the right place, for the right purpose.

Figure 30. Tree willow on Waimatā River.

Figure 31. Mānuka roots exposed by bank erosion, Waimatā River. Poplars on opposite side partially destabilised by floodwaters.

Figure 32. Mānuka trees toppled by gullying of a stream running into Waimatā River.

Recommendation – woody plantings intended for bank stabilisation along rivers must have adequate root systems to bind sediment.

7 Recommendations

Flood protection bioengineering practices were severely tested in Cyclone Gabrielle. They proved their value in reducing damage to infrastructure, and for their quick recovery from flood damage, even in the most seriously damaged river sections. These recommendations largely support current practices, however, the importance of and opportunities for improved tree management are strongly emphasised.

For rivers with wide channels, low banks, and berms (typically gravel bed):

- Use tree willow rows for bank and berm edge protection (superior root characteristics).
- Mix up tree willow cultivars wherever possible (genetic diversity).
- Retain poplars as additional berm protection in the buffer zone area behind the tree willows.
- Use osier willows in back berm areas to reduce berm and stopbank erosion risk.
- Where berm erosion risk is low, maintain open back berms to improve flood capacity and reduce sediment deposition.
- Avoid planting of trees/shrubs on or near to stopbanks to prevent weakening by shading, windthrow, or root incursion.

For entrenched (typically silt phase) meandering rivers without berms:

- Generally use osier willow rather than tree willow to stabilise banks and improve flood capacity.
- Remove riverbank trees on inside bends to reduce stress on outside bends.
- Improve riverbank stability by siting poplar trees along the top of banks.
- Consider planting tree willows to prevent erosion damage to key assets.

General:

- Manage and maintain bank and berm tree vigour (by lopping, layering, topping, or mulching) as needed.
- Monitor and control weed or pest incursions (wilding willow, Old Man's Beard, willow sawfly).
- Source willow and poplar poles from managed trees as well as nurseries.
- Look for opportunities to site and/or align willow and poplar trees to capture flood debris.
- Site, select, and manage bioengineering tree varieties to avoid them becoming a source of woody flood debris.
- Continue research, development, and extension of improved willow and poplar varieties for flood control and catchment bioengineering.
- Manage size of willow and poplar trees by topping/pollarding (fine root system will self-prune with recovery within 2-3 years).
- Woody debris accumulation within the catchment, particularly upper reaches, creates significant risk when it floats free during flood events. Strategies should be developed to manage this risk. Examples are regular survey and removal of woody debris, and creation of debris barriers on berms. This is further explained in Appendix 3.

8 Bioengineering using willows and poplars – interface with research

There is considerable variety of tree and osier willow cultivars available through the willow and poplar breeding programme. The New Zealand Poplar & Willow Research Trust (NZPWRT) website (https://www.poplarandwillow.org.nz/) provides information on its cultivars and further support is available from Plant & Food Research.

8.1 Research funding

NZPWRT is funded by regional councils and unitary authorities to develop improved tree and shrub/osier willow and poplar cultivars for bioengineering purposes, as supported by technical information. The River Managers Group appoints a trustee to NZPWRT Board.

8.2 Willow and poplar breeding

NZPWRT funds Plant & Food Research to maintain a breeding programme, develop new improved cultivars, and create new knowledge about their qualities and field performance. New cultivars are developed by hybridisation of parent species or hybrids conserved as a gene pool. Stages in development are breeding, nursery evaluation, field evaluation, and release of experimental materials (as cuttings) to regional council nurseries for propagation and evaluation in their region. If the new cultivar adds sufficient value in practice it is given a registration number, name, colour code (for tracking in the nursery), and commercialised.

Selection criteria consider growth rate, tolerance to a range of environmental conditions (drought, disease resistance, palatability), brittleness, potential for weediness, and genetic variability in choosing whether to release or not a new cultivar.

New willow or poplar cultivars add bioengineering tools to the practitioner's toolbox.

8.3 Research priorities

Research priorities are drafted by the research provider, Plant & Food Research, and confirmed after consultation with river engineer and land management adviser representatives. Researchers monitor pest and disease incursions and climate change pressures, and provide options to strengthen the resilience of willows and poplars.

8.4 Communications

Plant & Food Research prepares written reports twice-yearly, and distributes the reports to NZPWRT, and regional council and unitary authority funders. Plant & Food Research provides updates to the River Managers Group through the River Manager Group's representative on the NZPWRT Board.

Cultivar information and identification guides, research briefs, fact sheets, and extension materials can be sourced from www.poplarandwillow.org.nz hosted by NZPWRT.

8.5 Registered willow cultivars in the national collection

Code	Name	Type	Sex
NZ 1184	*Salix matsudana* x *alba* 'Moutere'	Tree	M
NZ 1040	*S. matsudana* x *alba* 'Tangoio'	Tree	F
NZ 1401	*S. lasiolepis* x *viminalis*	Osier	M
NZ 1341	*S.matsudana* x *pentandra* 'Taitoko'	Tree	M
NZ 1402	*S. matsudana* x *alba* 'Cheltenham'	Tree	M
PN 608	*S. purpurea* 'Irette"	Osier	M
PN 220	*S. viminalis* 'Gigantea'	Osier	M
PN 247	*S. alba vitellina*	Tree	M
CM 4	*S. glaucophyloides* x *viminalis* 'Glenmark'	Osier	M

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Appendix 1. Notes from Ministry for the Environment report 'Overview of flood management legislation in New Zealand' by Johnson McSweeney Ltd 2006 (available online: https://riversgroup.org.nz/wp-content/uploads/2018/06/2.1-Overview-of-flood-management-legislation-in-NZ.pdf)

Regional government flooding roles and responsibilities:

- Design, build and maintain flood and catchment control schemes and works. Provide and maintain soil conservation reserves. (Soil Conservation and Rivers Control Act 1941)
- Build and maintain river flood and drainage schemes; flood information and warnings (Local Government Act 2002)
- Maintenance and provision of new and existing drains (Land Drainage Act 1908)
- Management of significant flood events in areas covered by the schemes (Civil Defence and Emergency Management Act 2002)
- Administer District Plans and issue resource consents and recommendations on designations (Resource Management Act 1991)

These acts are all subservient to the provisions of the Resource Management Act 1991 (RMA). Reference to the Public Works Act 1981 has also been inserted into these acts, thereby enabling private land to be acquired (and compensation sought) for flood management purposes. The primary role of the Land Drainage Act 1908 is to allow land to be drained for food production and 'urban' purposes. However, the many drainage schemes that currently operate in New Zealand also play an important part in controlling flooding given that in extreme flood events, lack of drainage leads to flooding of the subject land.

Appendix 2. Commentary on Cyclone Gabrielle damage and recovery at different sites on the Tūtaekurī River

Mangaone Confluence & Upstream

Notes:

The pre-cyclone channel fairway had an irregular width with tree island blockages. The riverbank and berm buffer plantings consisted mainly of large tree willows and poplars. Berm plantings were variable in width and density, and especially narrow along the true left bank upstream of the vineyard area. There did not appear to be significant understory vegetation regeneration by managed lopping, layering, and pole planting.

Toppled trees (primarily pines) were observed in gully bottoms feeding the upper reaches of the Mangaone River, which were sources of woody debris entering the Tūtaekurī River in future events. Attention should be given to removing these trees.

The cyclone produced extreme overflows onto the berms and floodplain, ripping out and laying over trees, causing berm and floodplain scour, and depositing silt and woody debris. The channel alignment did not alter materially, with localised bank erosion limited by tree plantings. Poplars were more likely to be ripped out than willow trees, which either remained standing, or were layered by the floodwaters. Recent pole plantings on the true left river edge opposite the confluence survived the flooding.

The site visit showed strong regrowth of layered or partially undermined bank and berm willows. The river channel and floodplain areas had been cleared of woody debris, which was carted away for processing, or chipped on site. The wider buffer plantings showed especially high resilience with minimal damage. There was substantial filtering and trapping of woody debris, which was especially obvious on post-Gabrielle aerial photos at the downstream end of the vineyard.

Pre-Gabrielle; Dec 2021

Post-Gabrielle; Feb 2023

Post-Gabrielle; Oct 2023

Figure A1. Aerial photos – upstream of Mangaone confluence.

Pre-Gabrielle; Dec 2021

Post-Gabrielle; Feb 2023

Post-Gabrielle; Oct 2023

Figure A2. Aerial photos Tūtaekurī & Mangaone Rivers confluence site.

Figure A3. Buffer zone planting.

Buffer zone with trapped woody debris.

Figure A4. Flood layered willows & willow root mat healing bank erosion.

Upper Dartmoor site

Figure A5. Views of Tūtaekurī River channel – Dartmoor Road.

Notes:

The channel upstream of the site had a curved alignment, with a relatively narrow channel fairway confined between hills and terraces. The fairway adjacent to the site was 50% wider, consistent with the downstream uniform fairway width. The pre-cyclone berm plantings consisted mainly of large and medium size tree willows. There were two bands of trees, one along the riverbank, and the other adjacent to the stopbank, with a relatively open area between. The plantings appeared to be actively managed by lopping, layering, and pole planting.

The cyclone produced extreme berm flows and adjacent stopbank overtopping with minor breaching. The upstream channel eroded the berm vegetation and cliffs alongside Dartmoor Road. This erosion bay progressed downstream to the site washing out half the berm width over a 400 m length.

A length of riverbank remained in place in spite of outflanking by berm erosion. This remnant included trees, probably anchored to the rope and rail training line embedded along the original riverbank. It is likely that the combination of the training line and berm plantings helped prevent erosion undermining of the stopbank and road.

The downstream buffer plantings were wider, denser, and showed exceptionally high resilience to the flood event.

Upper Dartmoor

Pre-Gabrielle; Dec 2021

Post-Gabrielle; Feb 2023

Post-Gabrielle; Jan 2024

Figure A6. Aerial photos of Tūtaekurī River at Upper Dartmoor .

Ebbetts Upstream & Downstream sites

Notes:

The Ebbetts upstream site is located on the true right bank opposite the upper Dartmoor site. The curved upstream channel alignment, and erosion on the opposite bank, helped increase flood currents on the Ebbetts side.

The pre-cyclone upstream site berm plantings consisted mainly of large and medium size tree willows, actively managed by lopping and layering. The riverbank was relatively low, and the downstream Ebbetts stopbanks had no influence on holding back overflows.

The cyclone produced extreme bank overflows, and over a 600 m length the berm vegetation was either lain over in place, or ripped out and carried downstream onto the floodplain. Although there was severe scour along this length of berm, the river edge held because of the combination of the rope and rail training line, and the flood layered trees and root systems. The post-cyclone aerials showed regrowth of the flood layered willows.

The stopbanks were overwhelmed and breached in multiple locations. The downstream buffer planting was wider, with poplars along the paddock side of the willows. Flood flows through these buffers were very deep and fast moving, but generally parallel to the river, which reduced erosive stress. These buffer plantings showed exceptional resilience to the flood event, and screened and captured mobile trees and woody debris.

The downstream site was located at the lower end of the Ebbetts floodplain, where overland flows were returned to the river by a large hill. These overland flows breached the stopbanks, and layered most of the willow and poplar berm plantings over a 350 m length.

The downstream site inspection showed exceptionally strong regrowth of the layered trees. Some layered trees had been de-barked due to abrasion from suspended sediments and debris. Often these trees had sufficient live bark material in contact with the ground to start regrowth. As for the upstream site, the rope and rail training line, and layered trees and root systems, prevented significant erosion of the river edge.

Ebbetts Upstream site

Pre-Gabrielle; Dec 2021

Post-Gabrielle; Feb 2023

Post-Gabrielle; Mar 2024

Figure A7. Aerial views of Ebbetts upstream pre- and post-Cyclone Gabrielle.

Ebbetts Downstream site

Pre-Gabrielle; Dec 2021

Post-Gabrielle; Feb 2023

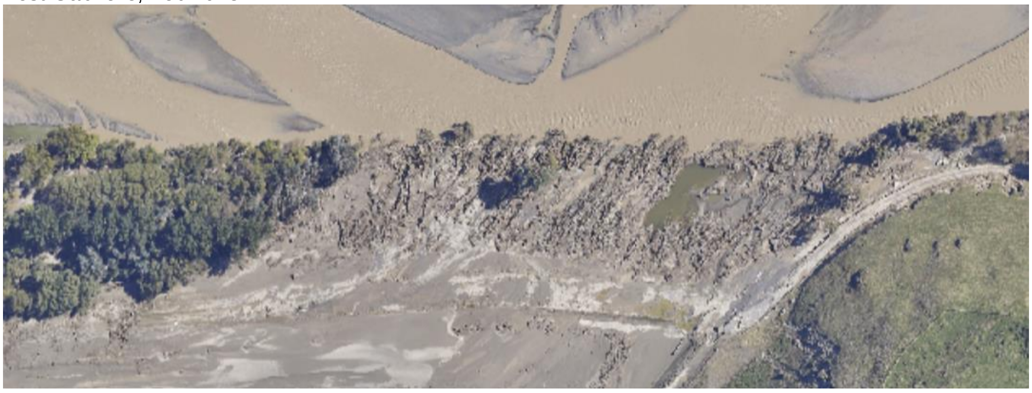

Figure A8. Aerial views of Ebbetts downstream site pre- and post-Cyclone Gabrielle.

Figure A9. Woody debris capture in buffer zones.

Figure A10. Regrowth under debarked poplar (left). Layered & partially debarked willow regrowth (right).

Mid-Dartmoor site

Notes:

The mid-Dartmoor site is located on the true left bank opposite lower Ebbetts. The pre-cyclone berm plantings consisted mainly of large to medium size tree willows, actively managed by lopping and layering. In addition to upstream and downstream rope and rail training lines, the berm included groynes to improve resistance to bank erosion, no doubt in recognition of the channel fairway constriction from the hill on the opposite bank.

This site was strongly influenced by the directional effect of the cyclone's return flows from Ebbets floodplain to the river channel. These return flows pushed extra flows onto the mid-Dartmoor berm, increasing stopbank overflow and breaches onto the floodplain, and ripping out and layering berm trees. There was substantial berm erosion and large deposits of woody debris, a proportion of which will have come from the Ebbetts floodplain.

The river edge held due to the combination of the berm plantings, flood layered trees and root systems, training lines, and groynes. The post-cyclone aerials showed partial regrowth of the flood layered willows.

The berm had been cleared of fallen trees and woody debris, which was carted away for processing, or chipped on site. Some live trees had been realigned and trenched into the berm, and were regrowing well. However the berm remains relatively open and vulnerable, with further tree planting needed to improve flood resilience.

The buffer plantings upstream and downstream of the site were in very good condition, and showed exceptional resilience to the flood event, mainly due to berm flows running parallel to the river.

Pre-Gabrielle; Dec 2021

PostGabrielle; Feb 2023

Post-Gabrielle; Jan 2024

Figure A11. Directional effect of Ebbetts floodplain return flows & Dartmoor stopbank breach flows.

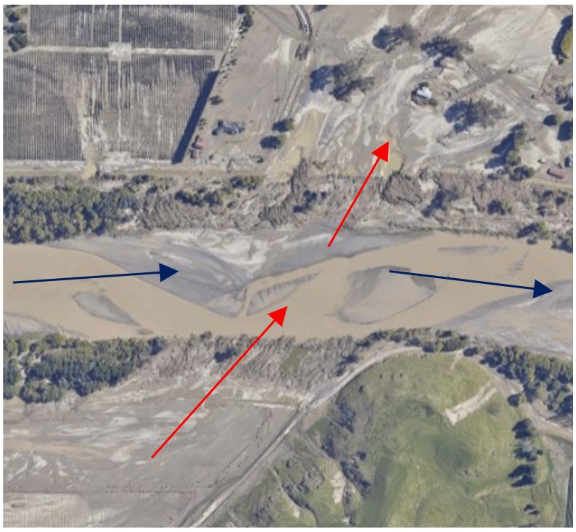

Figure A12. Directional flow of floodwater from Ebbetts across the channel to lower Dartmoor.

Moteo site

Notes:

The Moteo site is located on the true right bank downstream of Ebbetts. The overall berm width is relatively large, with a predominantly willow buffer alongside the riverbank, and an open berm area with chevron plantings extending to the stopbank.

Most of the buffer showed exceptional resilience to the cyclone. The inspection site, however, had a narrower buffer with less dense planting. This site experienced localised flood layering of berm trees along with minor bank erosion.

Post-cyclone regrowth of the layered willows along the berm and bank, and recent shrub willow plantings, were seen at this site.

Of particular note was the effectiveness of the buffer zone, adjacent to the major Moteo stopbank breach, in preventing the berm scour hole from connecting with the river channel. Such a connection would have increased berm and stopbank flood damage and resulting damage to floodplain property.

Overall, the buffer plantings upstream and downstream of the site were in very good condition and showed exceptional resilience to the flood event.

Figure A13. Pre-cyclone berm with buffer zone & chevron planting.

Pre-Gabrielle; Jan 2021

Post-Gabrielle; Feb 2023

Post-Gabrielle; Mar 2024

Figure A14.Aerial views of the Moteo site pre- and post-Gabriel.

Figure A15. Moteo stopbank breach – berm scour arrested by buffer zone.

Puketapu site

Notes:

The Puketapu site is located on the true left bank downstream of Puketapu Bridge. The pre-cyclone berm was relatively wide, with a continuous buffer alongside the riverbank, and open grazed area extending to the stopbank. The berm plantings consisted mainly of large and medium size tree willows. The plantings appeared to be actively managed by lopping, layering, and pole planting.

The cyclone produced extreme berm flows with adjacent stopbank overtopping and breaching. A section of buffer and bank protection planting at the upstream end of the site was ripped out. There was significant scour of the open berm area, and the buffer vegetation was mostly flattened over a 600 m length downstream.

Riverbank erosion was largely prevented by the combination of rope and rail training lines and edge vegetation. Downstream of the site the berm was substantially narrower, and the buffer planting extended the whole width from riverbank to stopbank. These berms showed high resilience to the flood event.

Post cyclone, the flood layered bank and berm vegetation showed strong regrowth. The upstream end of the site was strengthened with rope and rail groynes, willow trenching, and pole planting. Willow pole planting was also carried out to widen and infill open areas of the buffer. This work was establishing well.

Figure A16. Aerial views of the Puketapu site pre- and post-Gabriel.

Figure A17. Rope & rail groynes, willow trenching, and pole planting.

Figure A18. Flood layered willow regrowth & pole planting.

Figure A19. Newly planted willow poles.

Redclyffe Bridge – Waiohiki

Notes:

This site is particularly important given the bridge provides a key transport link south of Napier; the true left stopbank downstream of the bridge protects Taradale and Napier; and the true right stopbank upstream and downstream of the bridge protects the Waiohiki and Pakowhai areas.

The pre-cyclone buffer planting upstream of the bridge was somewhat variable in width and density. In comparison the downstream buffers were more uniform in width and density, and appeared more actively managed by lopping, layering, and pole planting. The buffer trees consisted mainly of large and medium size willows, with occasional poplars, alders, and wattles.

The cyclone produced extreme flows, with substantial stopbank overflows and breaches upstream of the bridge on the true right bank, and less severe stopbank overflows on the true left bank into Taradale. The central part of the bridge was blocked due to accumulation of woody debris along with other flood debris such as orchard trellis, posts, and wire. This blockage increased bridge loading and pier scour, resulting in partial bridge collapse and closure for an extended period.

There was substantial bank and berm erosion upstream at both ends of the bridge. Berm erosion also occurred adjacent to the newly upgraded Taradale stopbank. Fortunately these erosion sites didn't grow and cause bridge abutment washout or stopbank breach.

Post-cyclone repairs undertaken included debris removal from the bridge and channel, interim bridge repairs, scour hole filling on the banks and berms, and willow pole planting. Substantial further work will be needed to secure this vulnerable site.

Overall the buffer plantings upstream and downstream of the site were in very good condition, and showed exceptional resilience to the flood event.

Pre-Gabrielle

Post-Gabrielle; Feb 2023

Post-Gabrielle; Mar 2024.

Figure A20. Aerial views of the Redclyffe Bridge.

Figure A21. Berm erosion alongside Taradale stopbank (left). Taradale stopbank – post-cyclone berm repairs (right).

Figure A22. Redclyffe Bridge – cyclone debris removal (left). Redclyffe Bridge – interim repairs (right).

Appendix 3. Woody debris management

General

Tree vegetation, including poplar and willow, is vital for catchment and riparian health. Trees offer a variety of benefits, including soil conservation and erosion control, biodiversity and habitat enhancement, farm animal health, carbon capture, and landscape values. Forests, both native and exotic, also help reduce runoff and downstream flooding during heavy rainfall events.

In the majority of flood events tree vegetation provides these benefits without producing significant quantities of woody debris. However, the input of woody debris to river systems is not unusual in major floods, particularly in the case of extreme events such as Cyclone Gabrielle.

Large scale removal of catchment and riparian vegetation, as a means of reducing woody debris input to river systems, is likely to be counterproductive. A better approach to reducing woody debris input is to consider tree type, diversity, location, maintenance, and overall life cycle (including removal/harvest and replanting) as part of catchment and riparian management.

The screening and capture of woody debris, by structural or strategic planting methods, also offer potential for reducing woody debris problems.

Tairāwhiti

Plantation forestry (*Pinus radiata*) contributed large volumes of woody debris into waterways such as the Ūawa-Hikuwai and Te Ārai Rivers. Although waterways and bridges were largely cleared of Cyclone Gabrielle woody debris at the time of inspection, the team saw evidence of mature pine trees, as well as pruning/thinning waste, being carried downstream and deposited within the river channel, on bridges, and over floodplains. Woody debris contributed to the wash-out of pipe bridges along the Waingake water supply pipeline to Gisborne City (Figure A23 left) , as well as collapse of the Hikuwai River No. 1 Bridge (Figure A23 right).

Figure A23. Damaged Gisborne water supply pipeline & Hikuwai No.1 Bridge.

Modification of forestry practices to avoid tree planting or the stockpiling of forestry waste on unstable slopes and close to waterways will help reduce woody debris problems. In the upper Te Ārai and Hikuwai catchments there were hill slopes that had failed, carrying whole trees downslope into the river channel (Figures A24 & A25). Locations nearby with comparable slopes, and recently regenerated native vegetation, appeared to be more stable (Figure A26). If these slopes were to fail, the slower growing native vegetation would contribute less woody debris of smaller size than plantation forestry.

Figure A24. Major slip carrying mature pine trees into the river bed – Hikuwai catchment.

Figure A25. Forestry landing and woody waste pile undermining – Hikuwai catchment.

Figure A26. Hill slope vegetation contrast – forestry and native regeneration – Waimatā River.

In the case of the Waimatā River there was less evidence of plantation forest debris. The majority of in-channel woody debris appeared to consist of old silver poplar or willow trees, and more recent manuka/kanuka regrowth. The kānuka/mānuka helped prevent erosion on hillsides, but didn't prevent riverbank erosion and hill toe undercutting (Figure A27).

Figure A27. Undermined Mānuka/Kānuka trees deposited in riverbed – Waimatā River.

Riverbanks with younger willow and poplar trees, with less bulk and healthier root systems, appeared to stabilise the banks more effectively than the older trees or mānuka/kānuka. This suggests that more attention to tree variety selection and tree maintenance is likely to reduce woody debris input, as well as help stabilise roadside slips and riverbanks.

Within Tairāwhiti there were a number of instances where woody debris capture on river berms and floodplain areas reduced downstream movement of flood debris. This was a fortuitous outcome of berm tree location and alignment in relation to in-river and overland flow patterns. In the case of the Hikuwai River there were two sites, upstream of Hikuwai Bridges No. 3 & No. 1, where significant volumes of debris accumulated (see Figures A28 & A29).

Figure A28. Hikuwai River – woody debris capture sites.

Figure A29. Hikuwai River – woody debris capture – Sites A & B.

The lower reaches of the Te Ārai channel were badly congested with large trees (mainly willow) before Cyclone Gabrielle. This tree growth roughened the channel, reducing flow velocity and channel flood capacity, and increasing floodplain overflows. The in-channel trees may have reduced bank slumping and erosion and will have reduced downstream movement of up-catchment sourced woody debris (Figure A30). In rivers such as the Te Ārai there may be a compromise to be found between flood capacity, bank stability, and debris capture, by managing in-channel tree type, location, and size.

Figure A30. Te Ārai River – woody debris capture in lower reaches.

The Hikuwai and Te Ārai River examples suggest that strategic siting of tree rows, at locations such as at berm or floodplain overflow areas, on sharp bends, and upstream of bridges, could help debris capture and reduce downstream debris related damage. This type of approach would need to be implemented along with ongoing localised or extensive channel tree maintenance and debris removal works programmes (Figure A31).

Figure A31. Te Ārai River – results of extensive channel debris clearance & tree removal works post Cyclone.

Hawke's Bay

Tūtaekurī Catchment

In the case of the Tūtaekurī River catchment, the main woody debris source appeared to be the tributary Mangaone River. This catchment includes plantation forestry but is mainly pastoral hill country with a high erosion potential (Figure A32 left). The waterways are often entrenched within gorges or very steep sided narrow valleys, and heavily vegetated with a range of trees and shrubs (Figure A32 right). This waterway vegetation is vulnerable to wash out and downstream movement during flood events.

Figure A32. Pastoral hill country, Mangaone catchment. Entrenched Mangaone tributary stream channel.

The Cyclone Gabrielle Woody Debris Species Composition Assessment report, prepared by Ecological Solutions on behalf of Hawke's Bay Regional Council (link below), surveyed seven sites on the Tūtaekurī River located between the river mouth and upstream of the Mangaone confluence. The composition categories were pine (cut, fresh-cut, long resident, windthrow, pieces), willow and poplar (windthrow, no root ball), and other (mainly indigenous).

https://www.hbrc.govt.nz/assets/Document-Library/Cyclone-Gabrielle/Post-Cyclone-Gabrielle-2023-large-woody-debris-assessment-31.03.2023-FINAL-v1.pdf

The Cyclone Gabrielle Woody Debris Species Composition Assessment report gives some insight into the categories of tree material making up the woody debris, and the extent to which tree selection and management practices could reduce debris problems in future. For example, Figure A33 shows the woody debris composition at Dartmoor Road Bridge (Mangaone River) and Brookfields Bridge (Tūtaekurī River), respectively. Most of the material at the Dartmoor Road Bridge is pine, whereas at the Brookfields Bridge site it is willow/poplar. This seems reasonable given the Tūtaekurī River reach downstream of Dartmoor is managed for flood protection purposes, and the bank and berm vegetation is mainly willow and poplar.

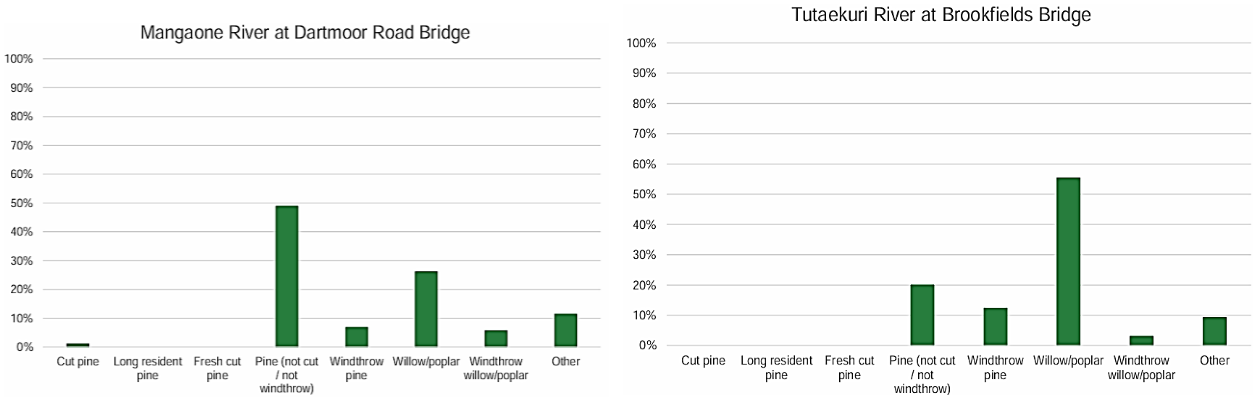

Figure A33. Woody debris composition at a) Dartmoor Bridge and b) Brooklands Bridge.

The upstream limit of river management on the Tūtaekurī River is the Mangaone confluence. There is no coordinated channel management work undertaken upstream of this along either the Tūtaekurī River or tributaries. Upstream extension of the Heretaunga Plains Flood Control Scheme or setting up of an Upper Tūtaekurī Catchment Control Scheme, would enable channel management works to be undertaken for flood and erosion control purposes. This could include tree management to reduce woody debris input to the lower reaches, thus reducing downstream risk of channel and bridge waterway blockage and related damage.

The Tūtaekurī River length downstream of the Mangaone confluence has berm vegetation buffer zones, which have been planted and are actively managed for erosion and flood protection purposes. These vegetation buffers consist mainly of willows and poplars which hold the channel edge, providing erosion protection to the riverbanks, berms, and stopbanks. The vegetation buffers also have an important role in filtering floodwaters, screening flood debris, and reducing woody debris movement and deposition onto berms, floodplains, and into the river channel. Another key consideration is that buffer vegetation should not wash-out, providing an additional source of woody debris to the downstream river system.

In general, the vegetation buffers satisfied these requirements in what was a substantial over-design flood event. Continued emphasis on developing and selecting tree and shrub varieties appropriate to the differing growing environments and flood-stress requirements is very important. Also maintaining tree (and root system) vigour by practices such as lopping, layering, topping/mulching, and replacement is vital.

Tree planting density and extent should optimise woody debris screening and capture. It is important along riverbanks to minimise tree bulk, and to maximise root mat extent and strength, to reduce bank erosion and woody debris production. Trees and shrubs with shallow/weak root systems are more easily undermined or pulled out by floodwaters, and trees with brittle branches (such as Crack Willow) are prone to flood breakage.

Clearly where trees (typically willow) are relocated and placed along riverbanks and/or in the riverbed to provide erosion protection (anchored tree protection), they should be anchored in place with rail irons, wire ropes, and anchor blocks. This encourages regrowth of the relocated trees, as well as preventing downstream movement as flood debris.

As was the case in Tairāwhiti, there were several instances where woody debris capture on river berms and floodplain areas reduced downstream movement of flood debris.

One example was the site on the Tūtaekurī River upstream of the Mangaone confluence. Figure A34 shows a large pocket of woody debris which has moved onto and over the floodplain to be captured landside of berm buffer vegetation. Figure A35 shows woody debris capture on both landside and riverside of buffer vegetation.

Figure A34. Floodplain woody debris capture–- Tūtaekurī & Mangaone River confluence.

Figure A35. Woody debris capture by berm buffer zones – riverside & landside.

Similar examples could be found further downstream on stopbanked river reaches. They suggest that strategic siting of vegetation buffers, at locations such as floodplain or berm overflow areas (such as Mangaone confluence and Ebbetts), and upstream of bridges, could help debris capture and reduce downstream debris related damage (such as at the Redclyffe Bridge). Factors such as the effect of such works on channel and stopbank flood capacity and erosion risk would need to be considered.

Figure A36. Woody debris on collapsed Redclyffe Bridge.

One issue that has become apparent since Cyclone Gabrielle is that bridges, and their waterway capacity, are critical elements of flood protection systems. Bridges, depending on their design and upstream woody debris input, can act as flood bottlenecks and are incredibly effective debris traps (Figures A36 & A37). This of course can stress bridges to the point of collapse – but equally important, reduce river flood capacity with resulting stopbank overflow, breach, and related flood damage. New bridges should be designed with generous waterway/flood capacity provision, allowing for climate change and future flood protection system upgrade. Bridge waterway designs could include a debris supply assessment – and ensure that debris capture is minimised (i.e. appropriate spans, pier spacings and design, and underside levels). Existing bridges could be retrofitted with debris deflectors or lifters (Figure A38), and measures for debris removal during flood should be considered.

Figure A37. Woody debris removal during flood.

Figure A38. Bridge debris fins.

Appendix 4. Resources for the river engineer

While there is some national reference material, many councils publish their own codes of practice and technical material in-house and make it available on their website. Much of the national reference material is not available online but may only be held in national and/or council archives or libraries.

Examples of national bioengineering resource material:

- Plant Materials Handbook for Soil Conservation – Volumes 1–3, 1995
- Introduced Forest Trees in NZ – 15. The Willows – NZFRI Bulletin No. 124, 1995
- Poplars and willows for soil erosion control in New Zealand. A.G. Wilkinson, 1999 (available online)
- The impact of bioengineering techniques for riverbank protection on ecosystem services of riparian zones. Symmank L. et al., 2020 (available online)
- River control and drainage in New Zealand: some comparison with overseas practices. A.R. Acheson, 1968. Ministry of Works (MOW). 295 p (available from the National Library)
- A design procedure for gully control by check dams. W.R. Howie ,1968. Water and Soil Division MOW. 45 p (available from the National Library, possibly in Regional Council libraries)

Examples of published codes of practice available online:

- Approved Code of Practice for Safety and Health in Tree Work: Part 3 River and Stream Operations. 1998. Jointly published by OSH, Te Tari Mahi. ISBN 0-477-03613-9
- Horizons RC Environmental Code of Practice for River works 2010
- Canterbury Regional Code of Practice 2019
- Hawke's Bay Regional Council Environmental Code of Practice 2017

Examples of technical material available online:

- https://riversgroup.org.nz/wp-content/uploads/2018/10/5.6.3-Rational-of-willows-for-flood-protection-OtakiI-R.pdf
- https://www.gw.govt.nz/assets/Flood-Protection/River-erosion-Repair.pdfpublished 2013
- https://www.waikatoregion.govt.nz/assets/WRC/WRC-2019/tr0741.pdf
- www.poplarandwillow.org.nz

A smart green future. Together.