GETTING ALL THE MULTIDISCIPLINARY DUCKS IN A ROW – STREAM WATERWAY DESIGN

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ABSTRACT

Waterways are often the most visible feature of a stormwater system for the communities they pass through. Communities can be highly engaged with their valued waterways and often seek ways to restore, interact with and improve their environmental sustainability. Therefore, waterway design must deliver hydraulic engineering performance, ecological values as well as other community concerns like aesthetics. This requires a balance of often conflicting perspectives.

Hydraulically, waterways need to convey baseflow, small storm freshes, and floods. However, the other drivers result in the form of a waterway being complex, needing to incorporate varying morphology, slope, ground conditions, vegetation, habitat features, engineering structures and spatial constraints, to list but a few. Accommodating all this is complicated by competing requirements; for example achieving flood conveyance while providing a healthy, sustainable habitat. The first would see wide, open, smooth, stable waterway cross-sections while the second seeks nearly the opposite with narrower, dynamic normal-flow channels incorporating shading, plant cover, bank undercutting and variations in velocity and depth.

This paper presents two different project examples where hydraulic, ecological, landscape and other multidisciplinary design elements have been successfully balanced, and identifies the key project features that can be applied in other waterway designs.

Firstly, Christchurch City Council's Dudley Creek Flood Remediation project aims to restore the pre-earthquake flood risk to the Flockton Street Area. It involves 2 km of flood channel widening through private property and road reserve, plus a 790 m flood bypass conduit.

In the second example, NZ Transport Agency's MacKays to Peka Peka Expressway on the Kapiti Coast includes over 5 km of new and enhanced waterway, to mitigate that lost to the Expressway. This too must balance the significant flood risk that is a feature of urban and rural areas around the project, while supplying suitable ecological mitigation.

KEYWORDS

Waterway, ecology, multidisciplinary, hydraulic performance, landscape

PRESENTER PROFILE

Amber has worked on a range of stormwater, water, and wastewater projects over the last six years as an Environmental Engineer in Christchurch. Amber's work has involved investigating flooding issues and flood risks, identification and design of solutions, and implementing projects to improve drainage infrastructure throughout the region.

Iain is a Civil Engineer who has focused on stormwater management across a wide range of infrastructure projects for the last fourteen years. He recently delivered the stormwater detailed design for the MacKays to Peka Peka Expressway being the culmination of five years of investigation, design and implementation.

1 INTRODUCTION

The importance of waterways to our communities has risen in recent years through the increase in environmental, amenity and cultural awareness, and because of their prominent positions in local neighborhoods. In addition, recent floods around the country have reinforced the significance of waterways as drainage conduits important to managing urban flood risk.

Lowland, urbanised waterways, the focus of this paper, have varying functions, physical features and amenity values, all of which interrelate. Historically, waterways with land drainage functions or in urban areas look and feel very different to those that have remained within reserves or more natural settings. Waterways to relieve upstream flooding or provide pastoral drainage are often engineered and maintained to this purpose.

Lowland streams today generally suffer from high nutrient, high sediment, high erosion, high seasonal algae, low riparian vegetation cover, decreasing fish passage, degrading water quality, degrading habitat and lowering capacity to sustain the full diversity of life. Changing the way we construct and manage urban waterways and their surrounding catchment is key to reversing this seemingly inevitable decline.

Waterways are complex systems with interacting functions and features, so to undertake a waterway design, these, along with how they vary, need to be understood and factored in as best as possible. A multidisciplinary understanding and regular communication on project aims and the evolving design is crucial. Different design disciplines will often assess waterway features in conflicting ways. Waterways require physical space and when this is constrained engineering solutions eventuate. Multiple waterway functions, features and amenity values can be accommodated in a design if the implications with each other are carefully understood.

2 CHARTERISTICS OF LOWLAND WATERWAYS

2.1 WATERWAY FUNCTIONS

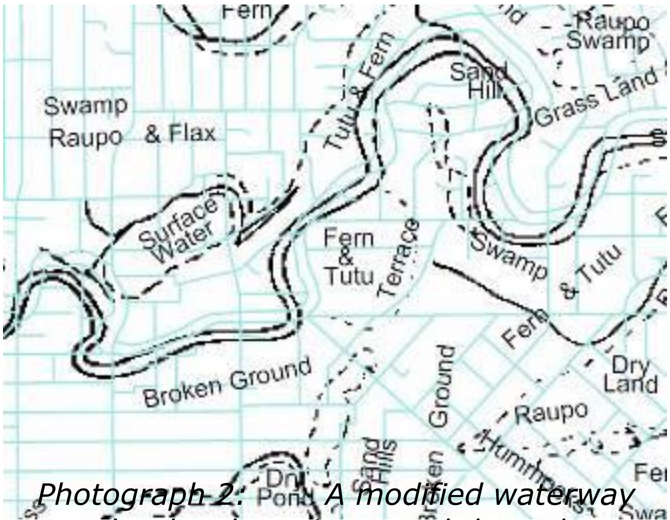
Waterways are a dominant feature of most natural drainage systems. In lowland areas, open channels and wetlands were typically formed in response to topography and over time developed into complex, interrelated systems. A natural waterway’s channel could vary greatly in terms of shape, grade, substrate and vegetation reflecting the landscape through which it passes (Figure 1 shows the waterway environment of pre-European Christchurch). A key feature of a natural waterway is that the flows and depths are relatively unconstrained within the waterway space. Groundwater baseflows, or spring-fed flows occupy the lower areas of a channel with “freshes” (i.e. flows from small storms) filling up the channel with increasing depth up to “bank full” (often as low as a 5 year Average Recurrence Interval (ARI) capacity) and a still larger floodplain or secondary channel area that conveys runoff from extreme flood events.

Natural waterways are invariably modified during urbanisation and agricultural development. Primarily, channels have been straightened, diverted and control attempted with engineered restraining measures, an example is shown in Photograph 1. These ‘utilitarian’ waterways sought to drain land for development or relieve flooding by increasing hydraulic efficiency, removing or reducing bank erosion, and containing water to within defined, generally small, channels.

However, such alterations adversely affect a waterway’s other amenity values. In addition, due to development on floodplain land, the consequences of breakout flows from these restrained channels is increased risk of nuisance flooding risk and severe damage to property and buildings. Recognising all of this, recently projects have begun to improve modified channels through naturalisation and restoration (Photograph 2). Often this is achieved through seeking to imitate natural processes.

New waterways are also constructed in areas of land being developed for wider urban, industrial, agricultural use or for water supply/irrigation reasons (Photograph 3 shows an example of the later). These can be constructed with ecological and amenity values in mind if the form and function of natural waterways is adopted, however, often simple channels are used from a desire for simplicity, low cost, or lack of land area.

Figure 1: Example of a natural waterway system, 1856 ‘Black Maps’ (Wilson, 1989) with the modern street layout overlaid



Photograph 1: A modified (timber lined) waterway, Dudley Creek upstream of Aylesford St, 2015

Photograph 2: A modified waterway that has been improved through naturalisation, Dudley Creek (Hills Rd to Slater St), 2015

Photograph 3: An irrigation water race and drainage channel, Waimakariri District, 2014

2.2 PHYSICAL FEATURES OF WATERWAYS

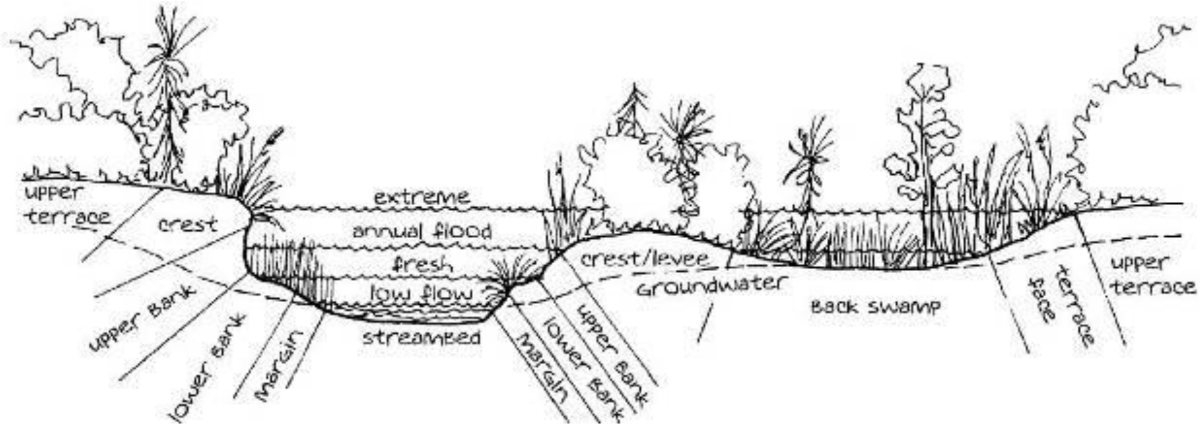
Waterways are a complex system of interacting features that need to be understood for a design to be successful, these features can be generally categorised as:

Climate and topography:
A macro-scale relationship that gives the local environment through which the waterway runs its fundamental nature. Waterways also have different receiving environments (a larger river, lake, wetland or the sea) and so downstream conditions will vary such as saline intrusion or tidal water levels.

Hydrological and groundwater regime:
The normal and extreme hydrological and groundwater conditions set the flow in the waterway.

Geo*metry and morphology:*
A waterway's geometry and physical extent can vary greatly, an example is shown in Figure 2. Incisions, overhangs, local bank instabilities, meanders, regions of fast and slow/shallow and deep flow (rifles, runs and pools) will vary along a waterway.

Figure 2: Waterway section example (Christchurch City Council, 2003)



Vegetation:
Riparian planting and vegetation will vary across the channel, banks, and floodplain. Vegetation impacts on other features through its shading, habitat, fauna, corridors, bank and bed stability, water quality, food source and debris loading amenities.

Soils and Geology:
The soil and geology will affect sediment and substrate regimes and channel shape and form. They also impact on the vegetation, sediment transport, water quality, and habitat opportunity.

Adjacent features:
The environment and man-made features surrounding a waterway impact on its form and function. These include such features as roads, buildings, walls and utilities. The surrounding land also impacts on water quality and quantity.

2.3 AMENITY VALUES OF WATERWAYS

Key amenity values and how they need to be considered in waterway design are noted below (the order of importance changes to reflect the specific needs of a project):

Drainage and Flood Management:
Drainage systems for base flows, stormwater, and flood events help enable land use and development. These need to cope with a range of natural conditions to reliably convey water. Increasing the capacity of waterways, providing safer features, providing for maintenance and operation, and designing flexible sustainable features will improve the drainage value of a waterway.

Ecology:
Modified waterways in New Zealand (especially in the urban landscape) are often characterised by homogeneous physical habitat and hydraulic conditions, high flood and low base flows, lack of riparian cover, an absence of refugia during high flow, fragmentation of migration pathways, light pollution, and poor water/sediment quality. The subsequent effects on biota inhabiting these systems is a general loss of biodiversity, the disappearance of more sensitive taxa (referred to as 'EPT' taxa) and an increase in pollution-tolerant taxa. This phenomenon is so similar world-wide that that it is referred to globally as the 'urban stream syndrome' (Walsh et al., 2005).

When undertaking a waterway design, the ecological value and function of the site and its connectivity to surrounding areas both existing and potential should be understood. Understanding the sensitivity of the local ecology to changes in waterway features is important to ensuring that their values can be protected and/or improved.

Landscape:
Waterways are important landscape features due to their visual prominence, both in public sites and through private properties. Waterways have a sense of character, and qualities that are appreciated such as a changing nature, the sounds generated when it moves, ripples with turbulence, and the reflections from its surfaces. Considerations for design include increasing visibility and public access, including learning and enjoyment opportunities, protecting and integrating important landscape features, improving image and identity and designing the waterway to blend in to the wider natural landscape.

Recreation:
Recreational activities associated with waterways can include boating, walking, wildlife watching, fishing and water play. Value can be enhanced through extending features such as walkways and cycleways, and increasing passive recreation (i.e. enjoyment of the natural environment) through access and visibility.

Heritage:
Examples of heritage values that may be associated with a waterway include brick and stone work of old bridges and culverts, wharves and warehouses, historical landforms and Maori heritage such as mahinga kai (food gathering), pa or settlement sites, and relevance to local tikanga and kaitiakitanga (connections/lore/guardianship of the waterway).

Culture:
Waterways have high value in societies. Issues of importance include protection of sacred sites and waters, the mixing of water, and protection or restoration of mahinga kai values. Design features such as place names, tree species, and habitat and cultural recreation activities may enhance cultural value.

3 WATERWAY ENGINEERING PROJECTS

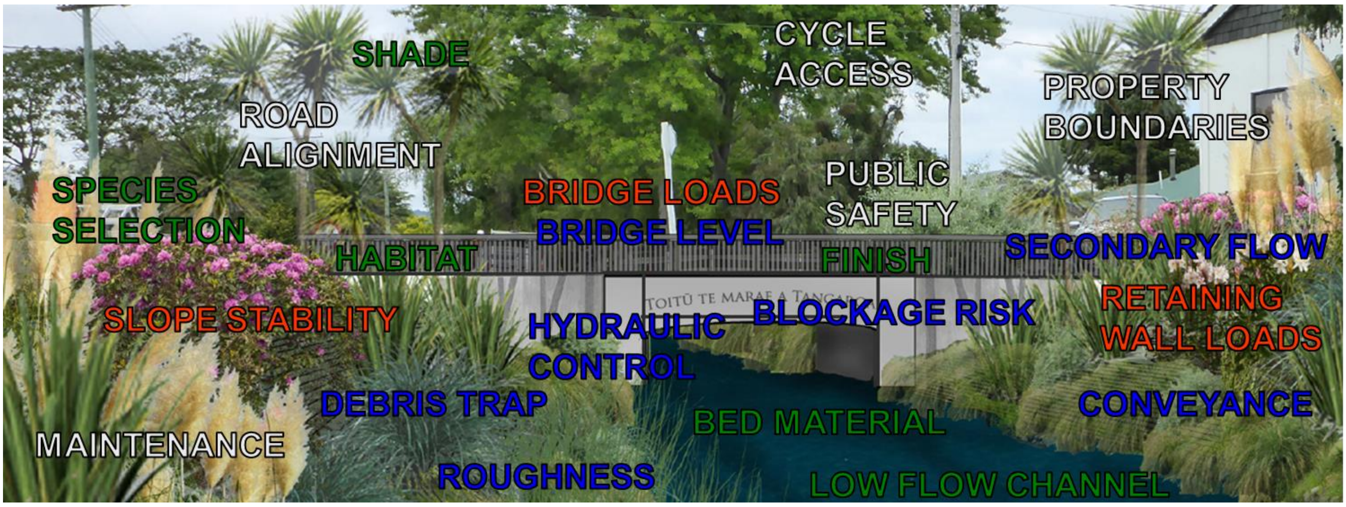
Waterway design projects may be the main purpose of the project, or the waterway element could be a smaller, secondary part of a much wider infrastructure project. Engineering projects do not often have singular aims and objectives. For example, a primary objective to achieve a certain drainage level of service, or level of flood risk management often comes with secondary objectives that require other design features and values to be achieved, as long as they do not compromise the primary objective. Commonly these secondary objectives include aims such as increasing ecological or landscape values and amenity functions of a waterway. These “secondary” objectives often become very important when a project has a strong public interest and can often, at first, appear to conflict with the wider project.

A great project team (typically with diverse expertise) will identify opportunities to enhance waterway features and amenity values. This ability is founded on all members understanding the key features and regimes of the waterway system. A multidisciplinary understanding is crucial to developing a design that delivers on project aims, and achieves the best value. For waterway design projects, core disciplines involved are civil/environmental engineers, ecologists, landscape architects, and, depending on the project specifics and scale, inputs from geotechnical and structural engineers, planners, hydrologists, hydrogeologists, manaaki whenua, water quality scientists, constructors, cost estimators, and operations and maintenance staff could also be significant.

The multidisciplinary aspect of waterway design requires that strong project planning is undertaken to coordinate work and communicate design aims. Design changes in one discipline will often affect others, and so regular, open minded communication in a team committed to joint outcomes is crucial for project success.

Figure 3 depicts how one waterway section has numerous features where different disciplines may come into conflict. For example, a hydraulic engineer will look to reduce vegetation as it poses a blockage risk and effects conveyance but the ecologist will target achieving a viable habitat with better connectivity and enhanced landscape values.

Figure 3: Some multidisciplinary features in a waterway to be considered in design



4 DUDLEY CREEK FLOOD REMEDIATION

4.1 PROJECT SUMMARY

Dudley Creek flows through the Christchurch residential suburbs of St Albans and Shirley, across private property and alongside roadways, discharging to the Avon River. The Avon River in this area is tidally influenced, as are the lower reaches of Dudley Creek.

Dudley Creek has a catchment area of approximately 717 ha, and a history of flooding in some areas. The Canterbury earthquakes have worsened flooding in some parts of the catchment, particularly in the Flockton Street area. Significant flooding was experienced through the catchment in the March and April 2014 Christchurch flood events (Photograph 4). The Dudley Creek flood remediation project is tasked with waterway improvements and pipe works to return the Flockton Street area to its pre-earthquake flood risk. This primary project objective is supplemented by secondary targets including improving the amenity values along the waterway, considering additional flood risk benefits over and above the primary objective and providing enhanced ecological habitat along the waterway.

Photograph 4: A collection of Dudley Creek flood photographs (Jacobs, 2014)

Dudley Creek, dominated by urban land use, is a highly modified natural waterway with a low gradient (typical grade of approximately 1:1,000). The flow is therefore slow and the bed predominantly made up of silts and sands that overall offers poor habitat values. The riparian vegetation characteristics consist of mown grass with intermittent native plantings and some deciduous exotic trees.

Ecological surveys of Dudley Creek in May 2015 found an aquatic invertebrate community of limited diversity, with only 17 invertebrate taxa (McMurtrie & James, 2015). The community was dominated by snails and crustaceans, which are typical of Christchurch's low gradient, urban waterways and are tolerant of poor water and habitat quality. The ‘clean water’ EPT taxa were virtually absent and biotic community scores (such as the MCI score) ranked on a scale of fair to poor. There is a possibility that the invertebrate community of Dudley Creek was also badly impacted by the large deposits of liquefaction sand that smothered the stream channel following the February 2011 earthquakes.

In contrast to the poor quality invertebrate community, the fish community was found to be diverse, supporting seven native fish species (shortfin eel, longfin eel, common bully, upland bully, giant bully bluegill bully, inanga), three of which have a threat classification of ‘at risk – declining’ (McMurtrie & James, 2015). Greater densities of fish were found at sites where there was better cover (such as larger instream substrate like rocks, logs, and tree roots, overhanging bank vegetation, and gaps in rock edging or undercuts along earth banks). The close distance to the coastline and lack of any fish migration barriers were considered partly responsible for the diversity of native diadromous fish species.

There are mature trees along both sides of the waterway, providing amenity value for this area. However, changes in ground conditions caused by the earthquakes have affected a number of these and an assessment of found that over 30 percent had a life expectancy of less than 10 years and more trees may die in the future.

The recreational values surrounding Dudley Creek are mainly limited to the opportunity for passive recreation on private properties that form the creek’s setback and banks. Any opportunity for instream recreational values is constrained by the width of the creek’s channel (1.5m to 4.0m), while the water quality due to microbial contamination is not considered suitable for contact recreation (ECan, 2007). Footpaths alongside the roads and local community center are utilised by the public, and eel and bird feeding activities are undertaken.

4.2 WORKS INVOLVED

The proposed project works include:

- 2 km of waterway widening works on Dudley Creek, and the lower reaches of St Albans Creek and Shirley Stream. The widened channel generally incorporates a narrow low flow channel (1.5 to 2.1m), a low bank that will be regularly overtopped with small freshes (referred to as a ‘freshplain’) and a much wider flood channel at a higher level.
- Culverts, bridges, retaining walls, and other structure upgrades along the widened waterway.
- A 790 m bypass pipeline, bypass inlet structure on Dudley Creek upstream of Petrie Street, and outlet structure to the Avon River at Medway Street.

Figure 4: Extent of Dudley Creek Flood Remediation works

4.3 CHALLENGES / CONFLICTING DEMANDS

The key challenge of the waterway design was the limited space available. The land needed for the waterway channel, construction activity, and operation and maintenance activities, was severely limited due its urban developed and private ownership surrounds. Moreover, as the topography and gradients are flat, a large channel section is required to convey design flood flows. There is limited storage and attenuation in the area, and flooding is an existing and serious issue.

The surrounding environment meant that getting the "tie ins" right to adjacent features such as roads, buildings, bridges and other services was critical. The community was engaged and felt a strong connection to the waterway and as the waterway is very visual, existing landscape (established mature trees), ecology and recreation amenity values (pathways and access) are highly regarded by the public. This exacerbates the effects of the spatial restrictions, leading to conflict between hydraulic and ecological/landscape performance. A specific example is where, for ecological reasons, planting should be variable, dense, and overhanging the low flow channel, to provide shading, habitat, and to enable healthy planting to be sustainable. Conversely, hydraulically this type of planting reduces the conveyance capacity of a stream by reducing the flow area, increasing hydraulic roughness, increasing blockage risk (through capture of debris and plant clumping) and increases debris creation.

4.4 DESIGN FEATURES / SOLUTIONS

A key design feature was the collection of project information and the platform that was used for sharing it. Data collected early in the project included topographic survey, arbocultural survey (detailed tree survey - type, age, size, condition, drip line), ecological survey and condition assessments (site walkovers, invertebrate survey, electric fishing, water and sediment quality data), services and utilities survey data, hydraulic model results, and other infrastructure works in the area. All data was collated in 12d modeling software, where the multidisciplinary team could use it to undertake design and coordination tasks.

Figure 5: Multidisciplinary information (channel area, bank slope, tree drip lines property and road boundaries) for Dudley Creek design

Channel earthworks design was undertaken in 12d. An ideal average cross-section was derived from preliminary hydraulic modelling results and hydraulic calculations. It was then refined in detail, taking into consideration local features such as adjacent services, or significant trees. Other parameters such geotechnical bank stability, channel access requirements, and the required shape and variability for landscape and ecology features were taken into account and progressively a channel design evolved. The developing design could then be outputted electronically into hydraulic models for testing. Thus the modelling could test design details and changes such as varying cross-sectional area, varying stream bed gradient / 'freshplain' / low flow channel levels and shape, varying planting and roughness, and accommodating local channel restrictions (for features such as a significant tree or property constraints).

With the necessity for such a wide, flat flood channel in order to convey large flood volumes a means of maintaining ecological integrity during low flow conditions was needed. This was achieved by maintaining, or where possible narrowing, the existing low flow channel width with the use of constructed banks set just above the baseflow water surface. At only 100 mm above the normal water level, this created 'freshplains' that become inundated with even a small increase of flow, thereby providing for flood flow capacity.

The regular inundation of these low planted banks would provide additional food resources for fish (for example, eels are known to utilise temporarily inundated areas to feed on terrestrial invertebrates) as well as additional refuge for aquatic biota during times of elevated flow. Vegetation planted in these zones would also provide for a level of sediment trapping during elevated flows, and additional nutrient uptake, thereby in part contributing to some small improvement the water quality of the base flow channel. Recreating this natural linkage of the low flow channel with its floodplain was a key component to improving ecosystem function.

To maintain flood flow capacity the choice of plants for the 'freshplain' area was invariably limited to low stature plants. There was a difficulty in finding locally sourced native species that would survive in this relatively harsh environment (i.e. species that could tolerate regular inundation but also survive dry periods) whilst retaining a low stature (of 150 mm height when bent over in flood flows). With such low stature planting there is a risk that invasive exotic species will become established and overtop the smaller native species, so regular maintenance will be required to maintain the flood capacity of the system.

Shading of the small channel was another critical ecological design feature, as the low gradient and thus low velocity of the system, exotic macrophytes (aquatic weeds) would quickly grow throughout the channel with high sun exposure, thereby creating maintenance and flood capacity issues. Native plants tolerant of wet conditions and reminiscent of the original taller vegetation of the area (cabbage tree, lancewood, and kahikatea) will be planted within the 'freshplain' at a spacing designed to limit the impact on flood capacity. This was complimented with a mix of other native tree species further out and up the banks. Exotic tree species, a feature of the existing urban area, are included in the design but placed further back from the stream to try to reduce the amount of leaf-litter input during their autumnal leaf-fall, which can deplete oxygen levels in small slowing streams such as Dudley Creek.

The waterway edge was formed using 300–700 mm rock edging and in sections of channel realignment, the silt bed was replaced with gravels. The low flow channel was designed to vary in width within an otherwise relatively straight channel alignment along private property boundaries. Boulders for the stream edge were placed with close construction oversight to achieve as much ecological benefit as possible. Placement of rocks to form a rough edge provided variation in flow (backwaters, eddies etc) at the bank-water interface, and orientation of the rocks to exploit variation of rock geometry resulted in small undercuts and crevices to provide spawning surfaces and refuge areas for smaller fish species (Photograph 5). Two forms of longfin eel cover were also installed. Sections of two meter eel pipes ('tuna townhouses') were installed behind the rock edge, while eel caves (additional capping stones covering a larger area of voids underneath) were constructed in front of the rock edging (Photographs 6 and 7).

Photograph 5: Dudley Creek Work Package 1 low flow channel and 'freshplain' under construction December 2015

Photograph 6 & 7: Left: Eel pipes ('tuna townhouses') being installed along the rock edging for Dudley Creek Work Package 1. Right: Eel caves similar to this one along the Avon River also provide cover for larger eels (© EOS Ecology)

Construction of the channel is being undertaken 'in the dry' with short (40 m) sections isolated from the flow and fished out prior to construction commencing. For the first 200 m of waterway widening a total of 170 fish (including shortfin eel, longfin eel, common bully, upland bully, giant bully, bluegill bully and inanga) were rescued from the construction area and released further downstream. It would be unlikely that these fish would have survived had they not been removed from the site, so their recovery represents a considerable ecological benefit to the project as well as a social one, given the high interaction of the local community with their stream and in particular its fish (including a number of property owners who feed the eels). Likewise tree removal was timed to avoid disturbance to nesting birds, migrating butterflies, and other biota.

Given the interest in the work from the local community and location of a number of schools near to the stream, project ecologists and construction contractors are visiting schools to show them how the work will be undertaken and the construction and safety gear used, the fish and invertebrates that live in the stream, to talk about the ecological features of the new channel design, and how they might monitor the stream to look at its recovery over time. Resources were also developed to educate them about the features of a stream and urban area that are good and bad for aquatic ecology. Throughout the project, any opportunities to improve safe access along the waterway are being taken up, including features such as pathways and visibility.

Early public and stakeholder consultation was undertaken on the project on bypass options. Following consultation, a Multi-Criteria Analysis (which scored each option against a series of predetermined criteria including flood reduction, cost, environment (ecology, landscape, heritage, culture, community, and construction effects), long term sustainability, and risk) was used to identify a preferred option. Feedback received during the consultation process was used in this process. The selected bypass route and design enabled the lower reaches of Dudley Creek to remain unwidened, and thus the retention of existing valuable landscape and amenity values along the waterway. The bypass inlet has been design to allow a 3-monthly "fresh" to continue to flow down lower Dudley Creek. In flood events larger than this, flow will begin to flow down the bypass, with some continuing down the water channel. This gives flow variability down Dudley Creek, while creating the required flood capacity (through the bypass).

5 MACKAYS TO PEKA PEKA EXPRESSWAY

5.1 PROJECT SUMMARY

The MacKays to Peka Peka (M2PP) Expressway is a new 16 km long four lane road on the Kāpiti Coast through mostly low lying land. It is mainly off line from the existing State Highway 1 so has many new waterway crossings (16 perennial and intermittent waterways/drains, 13 "named" streams and the Waikanae River). Together these require eight bridges, several large-span box culverts, and over 22 large diameter piped culverts. The project also diverts several waterways out from beneath the Expressway footprint. In all, 2956 m of waterway is affected.

The environment is a mix of coastal dune lands and peat floodplains. All of the waterways in Kāpiti play an important role the managing the extensive flood risk and providing drainage service. They also play a crucial role in habitat for lowland fish, plant and invertebrate species, Mahinga kai, and as important life staging areas for a number of upper waterway species (i.e. spawning sites and corridors between habitats).

M2PP's resource consent conditions cover a range of stormwater management issues with requirements enforced on flood impact, erosion protection and water quality treatment. Notably, outside of the Expressway designation, the consent conditions limit any increase in the 100-year ARI event flood level to no more than 50 mm above existing. Conditions also require significant waterway ecological enhancement, including creation of new high value waterways, as part of a wider effect mitigation program inside the designation, as well as avoidance of a range of water quality and quantity effects.

Waterways feature highly in the public perception of the environment on the Kāpiti Coast with several community interest groups adopting and caring for various waterways. However, extensive ecological investigations found all of the waterways to be degraded (yet with very dense native fish populations) with:

- highly modified, deeply incised and erodible banks
- sediment and macrophyte dominated beds
- lack of native riparian vegetated margins (often an abundance of exotic species)
- low macro-invertebrate diversity (dominated by resilient species), lacking in mayfly, stonefly and caddisfly species (which are sensitive to water quality and so indicators of healthy streams)
- elevated levels of contaminants (heavy metals, nutrients, E Coli, sediments) often low dissolved oxygen, high pH and low water clarity
- low to very-low scores in Stream Ecological Valuation (SEV) Macroinvertebrate Community Index (MCI), Qualitative Macroinvertebrate Community Index (QMCI) and Physical Habitat Assessment tests.

Nonetheless, the waterways fulfill an important function for the environment. The level of ecological impact from the Expressway project clearly needed to be redressed. It was agreed with the Regional Council to use NIWA's SEV-ECR methodology for assessing and mitigating the loss of the waterways. Essentially, the SEV provides a standardised method for stream assessments and calculation of "offset" mitigation based on a comparison against a relevant reference site and the principle of "no net loss". In order to do so, stream features are characterised such as width, depth, velocity, clarity, substrate composition, riparian vegetation, shade, temperature, dissolved oxygen, pH etc. The end result of the SEV assessments was (at the Board of Inquiry) a confirmed mitigation requirement of 5,246 m of stream needing to be enhanced. This was achieved through for example, riparian planting, or addition or re-creation (new stream) of habitat elements.

A specific example of how M2PP coordinated the ecology and hydraulics within this mitigation context is the Waimeha Stream as outlined below. This example also illustrates a very complex design beyond just balancing of hydraulics and ecology.

5.2 WORKS INVOLVED

A three part diversion of Waimeha Stream was the design chosen to allow for the construction of the 134 m long Te Moana Road bridge that carries the Expressway over Te Moana Road, a floodway, and the Waimeha Stream. The Waimeha Stream (Photographs 8 and 9) has a catchment area of 219 ha upstream of the Expressway and is fed from natural springs and discharge from part of Waikanae's town drainage network. It follows a gentle gradient to the sea, is tidally controlled and at this location it is in a pastoral setting in close proximity to residential areas.

The waterway's wetted width varies between 4 to 5 m (top of bank width of 10 m). At this level it has approximately 1.5 m depth of slow flowing water (no riffle/pool/run) with a sandy bed and eroding/slumping banks. The channel is prone to becoming overgrown with macrophyte water weed (Elodea and Egeria, but also water buttercup, parrots feather and monkey musk) which the Regional Council removes annually by excavator.

Photographs 8 & 9: Left: The Waimeha Stream up close and Right: aerial with the stream marked red. Note the proximity of residential areas upstream

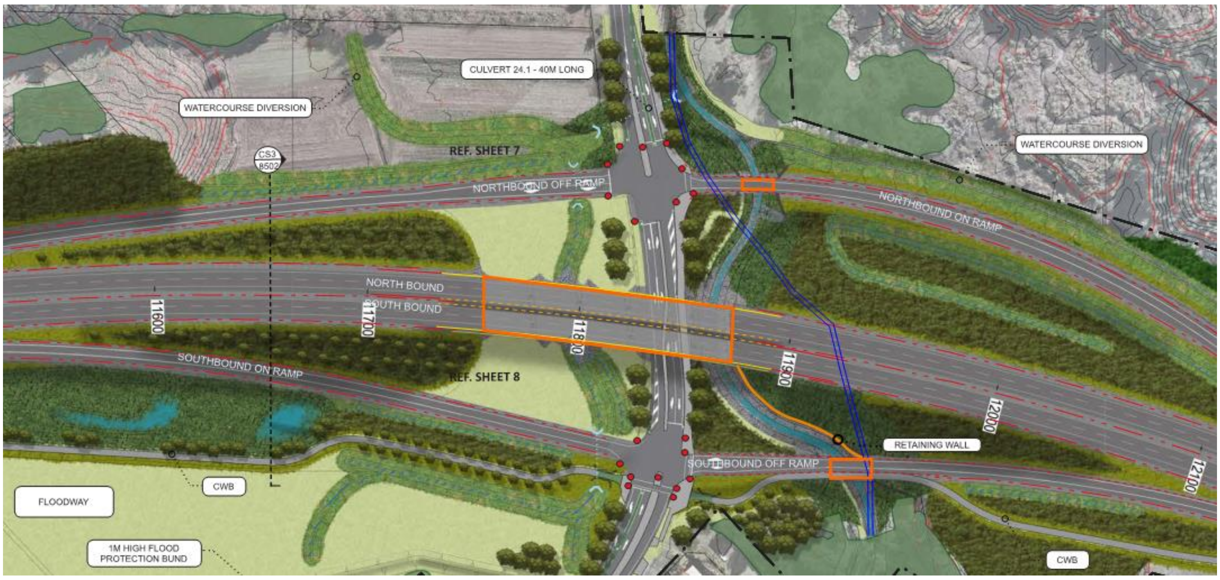
The existing ground level varies but is approximately RL 3.5 to 4 m. The normal flow water level is approximately RL 1.7 m and the 100-year ARI event flood level RL 3.4 m. Low or normal flow velocity is less than 0.2 m/s and even flood flow (12.5 m^3/s during the 100-year ARI storm) averages a slow 0.4 m/s due to the tailwater control (with a tidal storm surge) causing a low hydraulic gradient from the sea. It is this low velocity that minimises the hydraulic effect of the changes to the stream.

The 100-year ARI flood is generally contained within the Waimeha channel banks at the Te Moana Bridge site with some minor out of bank flood plain flow where the topography dips. Further downstream and upstream flooding inundates much larger areas that are mostly urban residential and it is these areas where flooding is sensitive to changes related to the Expressway works and waterway capacity.

In terms of freshwater ecology the stream is recognised in the Regional Freshwater Plan as a significant native fish habitat. Its connectivity to the sea, via a small lagoon, is unimpeded although there is little upper stream habitat. There are at least 8 native species (long fin eel, short fin eel, inanga, giant bully, common bully, red fin bully, giant kokopu, banded kokopu) and most are in high abundance. The fish fauna is despite the aquatic habitat reflecting poor condition parameters, a mud and macrophyte dominated bed, periods of high turbidity, low SEV (0.34), low MCI (78), "fair" QMCI (4.7), and a small range of water contaminants in sometimes raised level.

Te Moana Road is a main arterial local road, and the site for a grade separated interchange with the Expressway (Figure 6). The Expressway bridge is over top of Te Moana Road (which stays at grade itself). The interchange involves three separate bridges over the stream: two single span bridges for the on/off-ramps (20 and 22 m spans) and the larger Expressway multi-span bridge. The project design involves diversion of the stream, in three stages, over approximately 235 m. The tighter radius stream sections are those parts beneath bridge decks or at the foot of retaining walls being lined with rock rip rap armouring.

Figure 6: Expressway over the Waimeha Stream and Te Moana Road. The existing stream course is marked with the twin blue lines, bridges orange.



Instead of widening the main channel for increased conveyance (with an associated reduction in water level which is viewed poorly from an ecological standpoint), the low flow channel was maintained by narrowing the bed, but above the water level the banks have been benched back to provide a flood berm. The meander radius was taken from existing sections of the stream elsewhere and aligns the channel so that the bridges have low skew and cross as close to possible to the apex of the meander. The sinuosity is also designed to seek to minimise the length of stream lost and present a more naturalised form. A pre-diversion morphology assessment measuring and describing the basic parameters was used to assist the new channel design.

5.3 CHALLENGES / CONFLICTING DEMANDS

From an ecological perspective the stream needed to at least replace the functions and values of the stream section being affected. It also had to meet an SEV score that would be acceptable to Council. This proved challenging and required inclusion of a mix of stream features that were not present in the existing stream but also additional off-site mitigation on another waterway was needed as even these features did not prove sufficient in their predictable increase in habitat value. These features needed to fit into the hydraulic performance criteria as well as integrate with the scour and bridge waterway designs.

The main challenge for this project example is one of space. The area is heavily congested with non-stream related features and nearby property boundaries and so the stream design had to compete with a wide range of other design disciplines, namely:

- Road geometry and traffic (horizontal and vertical clearance from the waterway, sight lines, safety distances and intersection geometry). The Expressway and on/off-ramp geometry set the plan arrangement based on safety and geometric roading requirements. This forms a constraint on the location and skew of the bridges as the roading needs to tie into Te Moana Road at its current level and allow for a bridge deck to be set above the flood level (with freeboard). This fixed the position of the northbound on-ramp bridge and the waterway diverted location.
- Geotechnical design imposed geometric constraints (stable bank and batter slopes) and required a Mechanically Stabilised Earth (MSE) wall and scour protection to be constructed parallel to the waterway (yellow line, Figure 6).
- Structural design of bridge skews, spans and deck thickness informed the clearance to flood level. Locations of the piers and abutments constrained the waterway diversion geometry. The number of crossings also impacted the hydraulic performance of the waterway in flood.
- Underground utilities such as the trunk gas main (supplying Wellington from Taranaki) that runs beneath the waterway just upstream of the site limited the extent of the diversion (red line, Figure 6).
- Pedestrian, cyclist and bridle path design such as the cycleway passing over the waterway as part of the southbound off-ramp bridge required bridge widening of an additional 3 m. The route is also popular with horse riders meaning wider paths are needed to accommodate them. Footpaths run along the stream side of Te Moana Road, the public will regularly use and have an elevated view over the waterway environment.
- Landscaping for specimen trees, riparian vegetation (sufficient to provide a littoral inputs and stream shading) and general landscaping, including in the MSE wall.
- Regional Council's maintenance activities including annual weed removal required access for an excavator (wherever practical). Ultimately three organisations would need maintenance access: the Transport Agency for their bridge structures and the protective armour, KCDC for local road systems and landscaping, and the Regional Council for the stream beyond the designation.
- Urban design of the small section of concrete terraced retaining wall beneath the Expressway bridge piers that projects onto the berm. Urban design principles also required the use of rounded river run rip rap which cannot be placed as steep as angular rock.
- Drainage systems for both the local road and Expressway outfall into the waterway. The local road involves a sump and pipe network and the Expressway runoff comes in via treatment and attenuation swales. An upgraded local road culvert has been set in to the bed of a branch drain to accommodate fish passage.
- The staging of all the different features has driven a complex construction methodology on the restricted site.

All of these disciplines, some of which one would not usually associate with stream design, required coordination, integration and alignment throughout the project programme.

5.4 DESIGN FEATURES / SOLUTIONS

The hydraulic performance challenges in waterway design required land and space to resolve. A compound channel section was used with a central low flow channel supplemented a by higher, normally dry flood berm. The bridge spans were relatively wide to achieve the 50 mm flood performance limit. The large size of the bridges helps to reduce debris blockage risks.

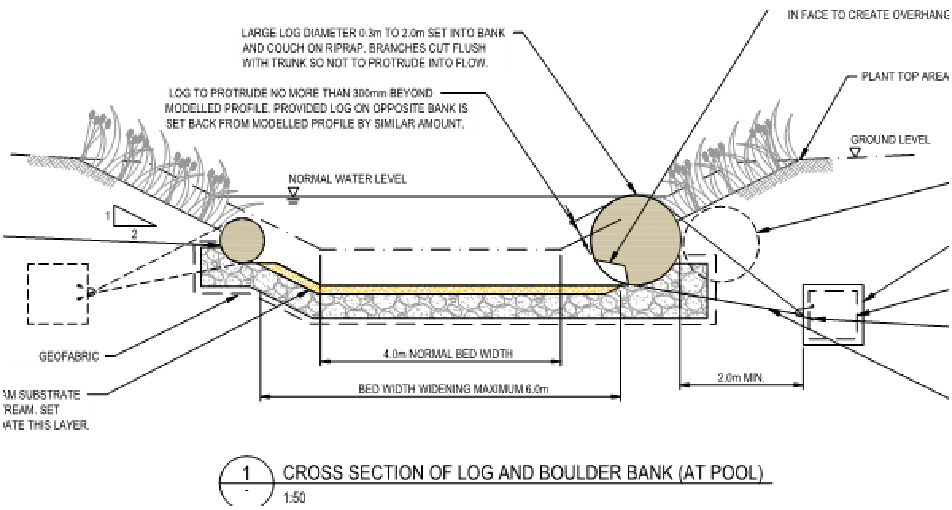
The maintenance route along the true left bank meant the riparian planting needed to be as close to the water as possible which proved a considerable challenge. Ongoing maintenance and management by machinery can cause challenges as an ecologically desirable outcome is to allow the system to evolve and accept a range of erosion, macrophyte, alga, wood debris dams etc. In order to meet the ecological targets several design features needed to be included as listed below. These were developed in close coordination with a range of engineering designers and based on modelling results:

- Channel Length: development of a meander that provides 235 m of new waterway channel to off-set against the 290 m lost (additional offset planting to another water course was also required).
- Width of wet bed: designed to match existing, typically 4.0 m but able to be locally widened to 5.5-6.0 m at the in-stream additional features. Wet bed width was subject to size of boulders and logs that can be obtained at the final position relative to the waterway bank so not to constrict the cross sectional area and reduce hydraulic performance.
- Water Depth: depth ranges with baseflow and tide conditions, and is generally over 1 m. Pools are generally 1.1 to 1.8 m deep, with a maximum depth of 2.0 m
- Normal flow velocity: designed to match as close as possible with existing (average of less than 0.2 m/s).
- Bed Surface Material: 90% sand, 10% gravel, 0% large cobble (the riprap in the stream bed is buried below the bed by 300 mm).
- Channel Complexity: two new habitats with pools and runs to add diversity to the current run habitat.
- Shading: attain a minimum (with re-vegetation) of 50% of the total riparian edge with a canopy of native trees and shrub species to provide some direct shading.
- Planting: to achieve erosion control immediately following earthworks (hydro-seed with inter-planting), riparian cover and stream shading on at least 50% of the channel, weed control (elimination of ecological weeds but not including aquatic weeds that are currently present) and areas of inter-planted riprap.
- In-stream additions: placement of large woody debris (10 tree trunks) and boulders (10 x 1 m^3) to add in-stream habitat complexity. Each pool created will receive at least one large tree log or boulder keyed into the bed or bank.

The inclusion of large tree trunks into the channel required careful consideration given the proximity of the downstream bridges (i.e. concern if they were mobilised in a flood they could damage and become snagged on downstream structures). They have been placed slightly skew to the channel with the upstream end buried into the bank and the whole trunk packed in with boulders, and been anchored with concrete block and cable deadmen. The common riprap bank detail also needed modification to accommodate the logs and large boulders without creating weak points (Figure 6). This detail is perhaps an extreme solution to installing woody debris but from the ecological perspective it was very important to have these habitat features. Construction is currently underway (Photographs 10 and 11).

Another of the most challenging aspects of the design was to minimise the extent of armouring as it prevents 'natural' erosion which creates holes and over-hangs (i.e. variable habitat). This was resolved through detailed consideration of the nature, location and form of armouring used, but also adding in the above noted logs and boulders to provide that habitat variability.

Figure 7: Construction detail of an in-stream habitat feature: deadman anchored tree trunks



Photograph 10 & 11: Left: construction underway. Right: Tree trunk habitat feature (awaiting planting), the northbound on-ramp bridge is in the background

In summary, the Waimeha Stream example illustrates the complexity of waterway diversions and that they often involve disciplines not always associated with waterway design. Therefore, communication and alignment of all of the designers is fundamental to a successful outcome. This takes some effort to achieve. Also, stormwater and hydraulic design of streams requires space and when this is constrained costly and detailed engineering solutions eventuate. Ecological stream features can be accommodated if the implications on conveyance and scour are carefully understood. While the solutions might not optimise all disciplines and compromises were made, the design many functions required better than if a multidisciplinary collaborative approach and design solution was not employed. In the Waimeha case, while aspects of the ecological solutions are not ideal, they are considerably better than historic approaches and will meet the consent condition requirements.

6 CONCLUSIONS

The two different project examples demonstrate how hydraulic, ecological, landscape and other multidisciplinary design elements have been successfully balanced, and identifies the key project features that can be applied in other waterway designs. Key takeaways from these projects include:

- Waterways are a system of complex and interacting functions and physical features that need to be understood for a successful waterway design.
- A multidisciplinary understanding and regular communication on project aims and the progressive evolution of a design is crucial to achieving the best multi-value outcome. Communication is key to coordinate multiple disciplines and particularly ecology and hydraulic designs need to be aligned. It is also essential that each specialist is not only expert in their own field (and therefore able to assess compromises and make sound judgment calls), but also has a sound working understanding of the other disciplines involved, and can see the wider picture of which is to be achieved.
- Waterway features generally require space and flexibility. Often space is constrained due to the surrounding environment, adjacent features, and conflicting demands of waterway features. Hard engineering solutions come about when space is constrained.
- Ecological stream features can be accommodated with careful consideration of the effects on waterway conveyance capacity and other features. One method used was to increase and vary the upper channel sections while maintaining a low flow ecological channel.

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