FISH PASSAGE DESIGN FOR ECOLOGICAL CONNECTIVITY TO A STORMWATER FACILITY

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ABSTRACT

Designing stormwater facilities to provide fish passage is becoming increasingly important as stakeholders and communities realise the benefits of improving water quality, ecology and amenity values, and the impact of developments on threatened native freshwater fish.

The stormwater facility for the Burlington Lifestyle Village in Christchurch provides stormwater treatment using first flush wet ponds, a conventional wetland and floating wetlands within a wet pond. The inclusion of wet ponds provided an opportunity to enhance ecological value by providing a new habitat for native freshwater fish.

Fish access through culverts is vital for allowing fish movement into upstream waterways and stormwater facilities. However, structures used for flow control for stormwater basins are typically of a small diameter with resulting flow velocities exceeding the threshold at which freshwater fish passage is achievable. An added challenge was a requirement to provide 0.5 m flood storage above the wetland in a 2% AEP 48-hour event in accordance with the Styx Stormwater Management Plan but not inundate the wetland in all events up to a 10% AEP magnitude.

All new structures were designed to provide fish passage for native freshwater species from the downstream Styx River receiving waterway to the new stormwater facility and further upstream into Barclays Drain, whilst also ensuring the stormwater treatment and partial flood storage objectives were achieved.

This paper presents some of the fish passage structures designed for this site. This includes culverts with orifice plates designed to control outflow rates and allow fish passage, spoiler baffles constructed within the invert of culverts and ramped fishways with rock baffles in the base to slow flow velocities and provide small pools for fish to rest. The culvert spoiler baffles and rock baffles were designed to slow flow velocities and then optimised for the site constraints based on two-dimensional hydraulic modelling.

KEYWORDS

Fish passage, stormwater treatment, design, culvert

PRESENTER PROFILE

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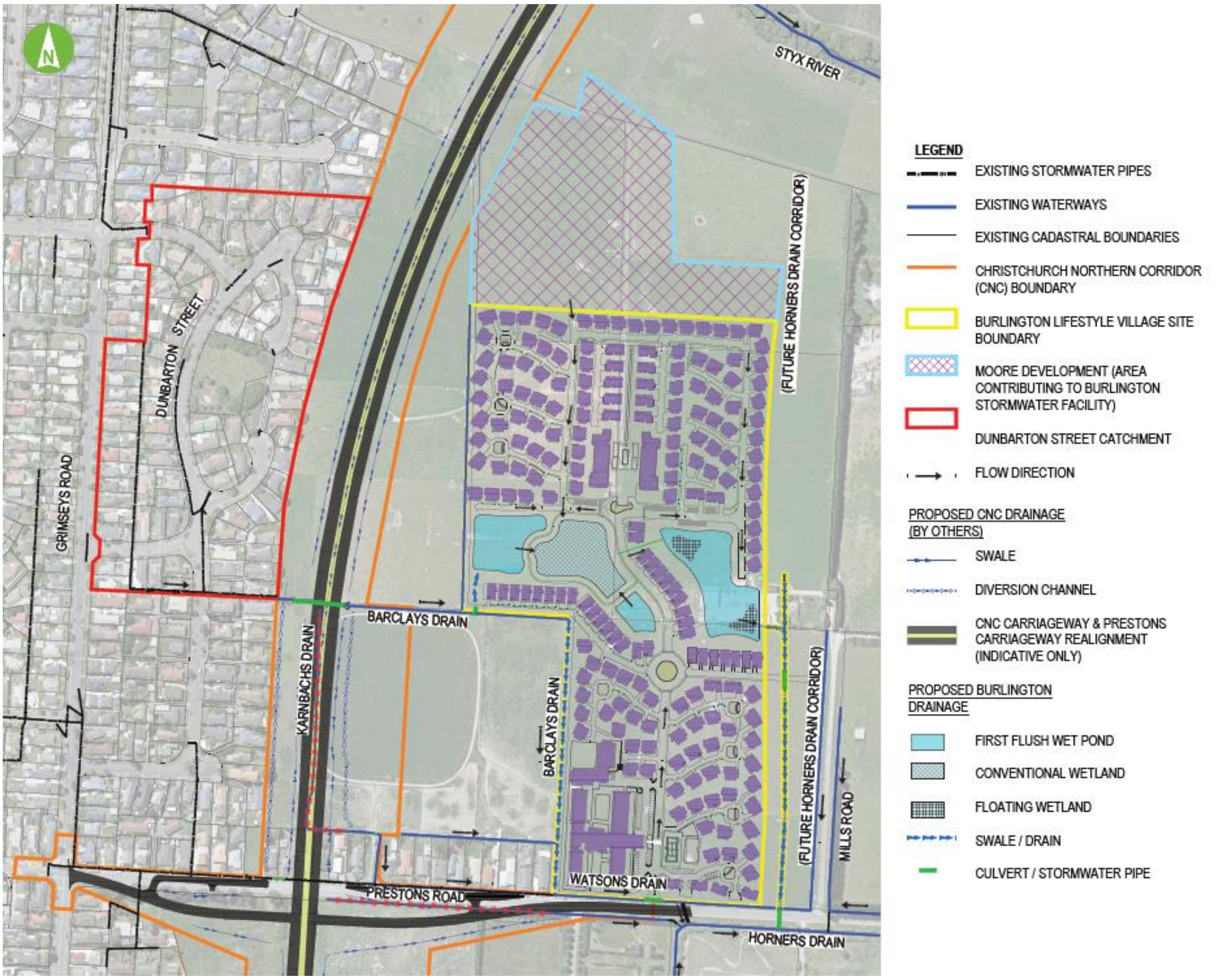
1 INTRODUCTION

Stormwater facilities are routinely used to convey, treat and attenuate stormwater run-off prior to discharge into downstream receiving waterways. Most of New Zealand's lowland fish migrate to and from the sea, so many stormwater facilities present a challenge to fish migration and constrain the habitat of native freshwater fish.

The Burlington Lifestyle Village stormwater facility provides stormwater treatment using first flush wet ponds, a conventional wetland and floating wetlands within a wet pond.

Figure 1 shows the Burlington Lifestyle Village site, contributing catchments and surrounding waterways.

Figure 1: Overview of Burlington Lifestyle Village Development



The Burlington Lifestyle Village Development is located immediately to the east of Barclays Drain, north of Watsons Drain and to the south of the Styx River. Flow from Barclays Drain will be diverted into the Burlington Lifestyle Village stormwater facility for treatment via a low-flow diversion weir. The inclusion of wet ponds was a highly desirable outcome for the developer however wet ponds are not a preferred first flush treatment solution for Christchurch City Council (CCC) who favour dry basins.

The opportunity to provide ecological connectivity from the Styx River to the new stormwater facility and naturalise some existing waterways was identified during the design process. An ecological assessment identified that existing utility drains were in poor ecological condition, and the stormwater facility provided an opportunity to create new freshwater fish habitat if ecological connectivity could be provided to the Styx River via Horners Drain.

The opportunity for potential habitat enhancement was graphically portrayed with the capture of native adult inanga in Watsons Drain, adjacent to the development. Inanga, shown in Photograph 1, a whitebait species, had completed spawning in the lower Styx River, and had migrated upstream from the lower Styx River to rear. The facilitation of fish passage, and the development of aquatic habitat, will enhance the reproductive potential of these fish, a process ultimately contributing to the national whitebait fishery. This fish has a national conservation status of 'declining' so habitat enhancement is important. Another migratory fish in the development area was the shortfin eel, a common species that would also benefit from the proposed habitat enhancement.

Photograph 1: A healthy inanga near the development (Watsons Drain), just after spawning. This fish had migrated upstream from the spawning grounds in the lower Styx River.

A key constraint was the requirement to provide 0.5 m flood storage above the wetland in a 2% Annual Exceedance Probability (AEP) 48-hour event in accordance with the Styx Stormwater Management Plan (SMP) but not inundate the wetland in all events up to a 10% AEP magnitude. This design requirement has been achieved using a split-level wetland comprising of an upper level conventional wetland and lower level wet pond comprising floating wetlands, in which more frequent inundation of the wet pond can occur without affecting the health of the wetland plants.

Flow control structures for first flush basins and flood storage are typically small in diameter with resulting flow velocities exceeding the threshold at which fish passage is achievable.

To achieve an acceptable outcome, the stormwater facility was designed to enhance ecological value by providing a new habitat for native freshwater fish, like inanga, which would eventually be connected to the Styx River.

Ecological connectivity between all stormwater infrastructure was provided from Horners Drain to the Burlington Lifestyle Village stormwater facility and upstream to Barclays Drain. When the future Horners Drain connection is constructed by Council, ecological connectivity will be provided directly to the nearby Styx River.

When designing for fish passage through a system, the following key parameters need to be considered:

- Species likely to migrate upstream and their swimming ability.
- Maximum flow velocity.
- Minimum depth of flow.

All new structures were designed to provide fish passage, whilst also ensuring the stormwater treatment and partial flood storage objectives were achieved.

2 IMPORTANCE OF FISH PASSAGE

New Zealand's freshwater fish species are increasingly feeling the pressures of deterioration of water quality, loss and degradation of habitat and impediment of fish migration. At least 70% of New Zealand's native fish such as whitebait and eels are threatened or at risk (Boubée et al. 1999).

Native fish species migrate between different freshwater habitats to complete their lifecycles. If fish passage is overlooked in the design of infrastructure, movements of fish can be completely blocked or delayed from changes in streams; preventing fish from reaching their critical habitats they need to live, feed and breed (Franklin, 2016). The migrating behaviours of fish means that fish passage through culverts and other stormwater structures can be key to fish distribution to the wider system.

The following is a summary of the swimming classifications for diadromous fish (fish that require access to the sea from freshwater waterways) that are found in the Christchurch area (CCC, 2003):

- Anguilliform – relatively inefficient swimming ability but fish can move through interstices of rocks and vegetation and even leave the water provided their skin is damp. Fish species include eels and adult lamprey.
- Climbers – ability to climb the wetted perimeters of waterfalls, rapids and spillways. Fish species include juvenile eels, adult lamprey and juvenile common bullies.
- Jumpers – ability to leap out of the water using waves and turbulence if there is sufficient pool depth. Fish species include trout and possibly larger inanga and smelt.
- Swimmers – swimming action only around obstacles. Low velocity areas are used for resting when negotiating high velocity areas. Fish species include inanga, bullies and smelt.

More than half of New Zealand's indigenous species migrate upstream from the sea as juveniles (NIWA, 2018). Despite the ability of some to climb wetted surfaces, some are poor swimmers in comparison to larger fish and are easily confused by turbulent flows (Mitchell 1989). To ensure upstream fish migration, culvert design should enable the upstream passage of the fish least able to negotiate culverts, in Christchurch this is inanga (CCC, 2003).

Therefore, the design of fish-friendly culverts and weirs needs to consider the size and swimming ability of any species migrating upstream, as these will affect the design of the culvert or weir (CCC, 2003).

3 STORMWATER MANAGEMENT SOLUTION

The Burlington Lifestyle Village stormwater facility was designed in accordance with the stormwater management requirements in the CCC Styx SMP and CCC Waterways, Wetlands and Drainage Guide (WWDG). The key stormwater management requirements for this development from the Styx SMP and WWDG include the following:

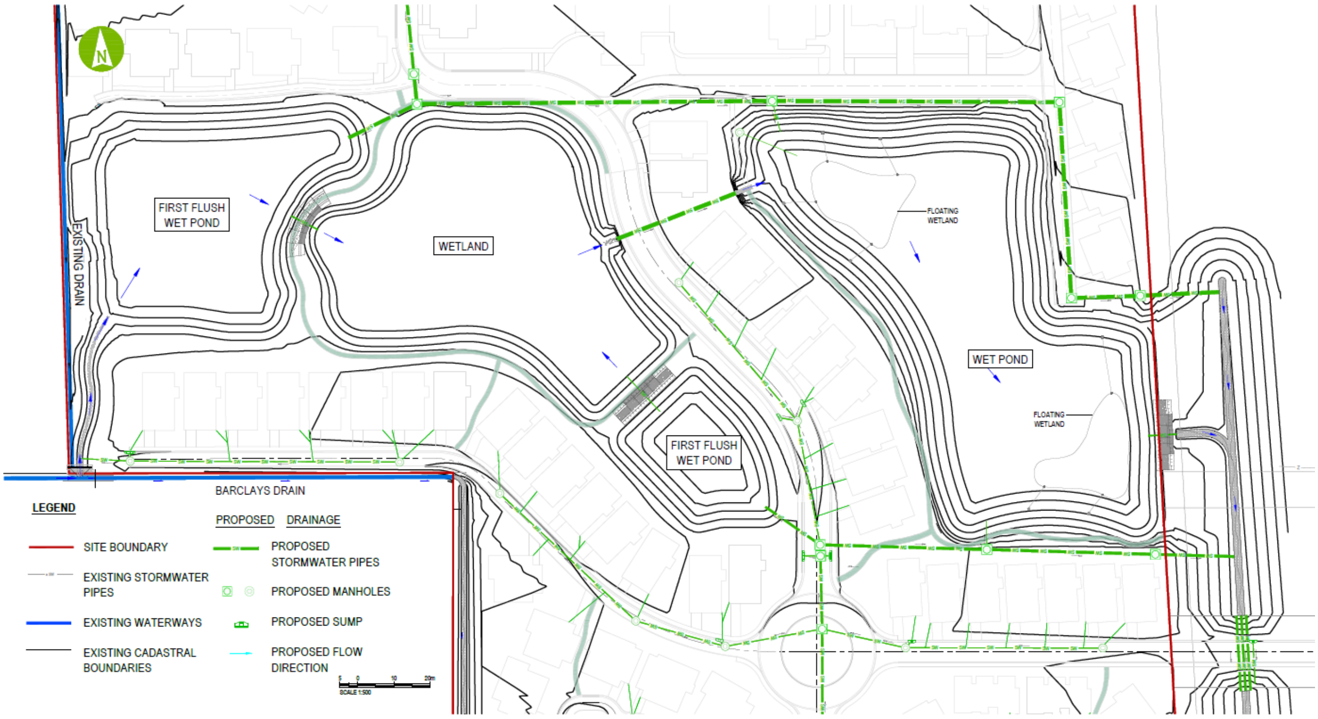
- First flush stormwater treatment typically with first flush basins.
- Secondary stormwater treatment typically with a wetland.
- Provide 0.5 m of partial flood storage above the wetland footprint in a 2% AEP 48-hour design event.
- The secondary treatment wetland cannot be inundated in all storm events up to a 10% AEP.

The stormwater management requirements within the Styx SMP were difficult to achieve for the site because capturing the 2% AEP 48-hour event above a wetland would also result in some storage above the wetland for events smaller than a 10% AEP rainfall event. The Styx SMP requirements are more suitable for stormwater facilities constructed at lower levels where the 0.5 m partial flood storage can be achieved by floodwater entering the stormwater facility from the Styx River in a 2% AEP 48-hour event.

Hydraulic modelling was undertaken using MIKE URBAN to estimate the depth of flooding within the secondary stormwater treatment device in a 10% AEP event for a number of storm durations. This hydraulic modelling identified that the stormwater treatment and partial flood storage objectives cannot be achieved in a single stormwater management device.

First flush stormwater treatment will be provided with wet ponds. To achieve the Styx SMP and WWDG stormwater management requirements, the treatment wetland has been split into an upper and lower level treatment device. The upper level treatment device will comprise a conventional stormwater treatment wetland and the lower level treatment device will comprise a wet pond with floating stormwater treatment wetlands. The floating wetlands in the lower wet pond have been designed to achieve the same level of treatment as a conventional wetland but these devices will not be inundated by storm events as the treatment media can move up and down on the surface of the wet pond. This level difference prevents the upper conventional wetland from being inundated in events smaller than a 10% AEP. Figure 2 shows a summary of the overall stormwater facility for the Burlington Lifestyle Village. The internal layout of the conventional wetland is not shown in this figure. The conventional wetland will incorporate deeper pools for fish to reside in and will be designed to ensure clear fish passage from the 1,050 mm diameter culvert to the upstream first flush basins.

Figure 2: Burlington Lifestyle Village Stormwater Management Facility

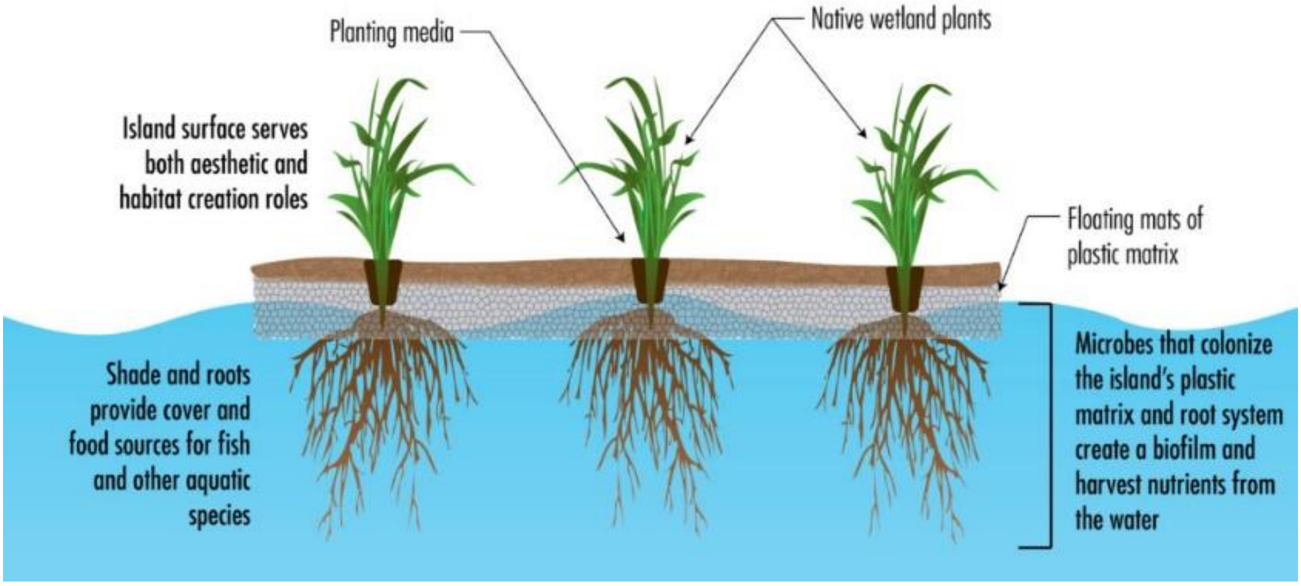


The floating wetlands will provide both ecological habitat, shading and food sources for fish and other aquatic species as they cover approximately 20% of the lower wet pond footprint. The stormwater facility for the Burlington Lifestyle Village has also been sized to provide stormwater treatment for an existing 8-hectare residential catchment located upstream of the site and proposed Christchurch Northern Corridor (CNC).

Photograph 2 shows an example of a floating wetland constructed for Rosedale Road West in Auckland, New Zealand. Figure 3 shows a typical cross section of a floating wetland.

Photograph 2: Floating Wetland at Rosedale Road West, Auckland (SPEL Environmental, 2018)

Figure 3: Typical cross section of floating wetland (KCI, 2014)



A number of new waterways will be constructed for the Burlington Lifestyle Village development. These waterways will comprise a rock-lined base with a meandering low-flow channel and batters planted with native species.

A groundwater bore will be used to ensure the stormwater facility remains wet in dry periods and will also be used to supplement baseflow within the reach of Barclays Drain adjacent to the site.

4 CONSTRAINTS TO FISH PASSAGE

Aspects of the stormwater infrastructure is designed to enable fish passage for species such as inanga whitebait and glass eels to swim from Horners Drain via the temporary Horners Drain and stormwater facility to Barclays Drain and Watsons Drain during and following rainfall events. When the future Horners Drain realignment is completed and invert level lowered, fish passage can be provided from Horners Drain to the Burlington Lifestyle Village stormwater facility. This will ensure fish passage is retained between the Styx River and the habitat created by the Burlington Lifestyle Village stormwater facility.

Designing fish passage to a stormwater facility has different challenges to designing fish passage for an in-stream structure. As the stormwater facility provides treatment and partial attenuation, fish passage cannot be provided in all rainfall events. Instead fish passage was designed for frequent water quality rainfall events. As there is a small baseflow through the system, this will be used to provide wetted surfaces for climbing and anguilliform fish species. Other challenges encountered are described in the following sections. Solutions for these challenges and other implemented fish passage elements are discussed in Section 7.

4.1 FIRST FLUSH BASIN AND DETENTION BASIN OUTLET

The outlet structures from first flush wet ponds and the detention storage above the lower wet pond require small outlet structures to drain these basins over a long duration in accordance with requirements in the WWDG (CCC, 2003). These outlets are not ideal for fish passage and required special design consideration.

4.2 LONG AND STEEP CULVERT

The creation of an upper and lower level stormwater treatment device results in a level difference of 0.65 m between the normal water level (NWL) of the upper and lower treatment devices to ensure a partial flood storage of 0.5 m over the wetland footprint is achieved in the lower device. The creation of this level difference is not ideal for fish passage. A standard concrete culvert between these two devices would have a grade greater than 1%, flow depth less than 50 mm and velocity greater than 0.8 m/s. These conditions are not suitable to provide fish passage at a sustained swimming velocity and the culvert required special design consideration.

4.3 WATERWAYS

All new hydraulic structures on existing and proposed waterways can provide a barrier to fish passage if not appropriately designed. Additionally, the creation of new waterways can provide a barrier to fish passage if this is not appropriately considered. This is particularly true for the short reach of waterways upstream and downstream of the large 1,050 mm diameter culvert between the conventional wetland and wet pond containing the floating wetlands.

4.4 DIVERSION WEIR

A diversion weir within the Barclays Drain waterway was required as part of the design; although this will create a partial barrier to swimming fish, passage is still designed for climbing and anguilliform fish species. A low-flow structure will be provided through the weir for baseflow and to assist with fish passage.

5 EXISTING NEW ZEALAND REGULATIONS AND GUIDELINES FOR FISH PASSAGE

Freshwater Fisheries Regulations 1983 Part VI (Regulations 41-50) states that "culverts and fords may not be built in such a way as to impede fish passage without a permit from the Director-General of the Ministry for Primary Industries (Beattie, 1983). Therefore, a culvert or ford may not impede fish passage, otherwise approval must be sought from the Department of Conservation.

There is a large amount of literature about fish passage through culverts, predominantly from North America, for large adult salmonids which are strong swimmers. New Zealand's diadromous fish migrate upstream as juveniles and have poor swimming ability compared to large fish. Thus, international literature is often irrelevant to fish passage design in New Zealand.

The following references contain some information needed to understand the requirements for fish passage for New Zealand native freshwater fish.

- *Fish Passage at Culverts – A review, with possible solutions for New Zealand indigenous species (*Boubée et al. 1999*).* This document assesses a variety of designs for fish passage within culverts.

- *TP 131* Fish passage guidelines for the Auckland Region (Boubée *et al.* 2000). This document summarises the culvert issues as detailed above, but also considers fish passage design around other structures like weirs, including fish passes and fish ways.

- *TP366 Culvert Barrel Design to Facilitate the Upstream Passage of Small Fish guidelines (Stevenson. et al., 2008).* This document provides an in-depth analysis of different culvert baffle installations for effective fish passage.
- *Wetlands, Waterways and Drainage Guidelines, Part B Chapter 13 (CCC, 2003).* This document outlines local considerations for designing structures within Christchurch waterways.
- New Zealand Fish Passage Guidelines - For structures up to 4 metres (Franklin. et al., 2018). This document provides fish passage design guidance for a variety of waterway structures.

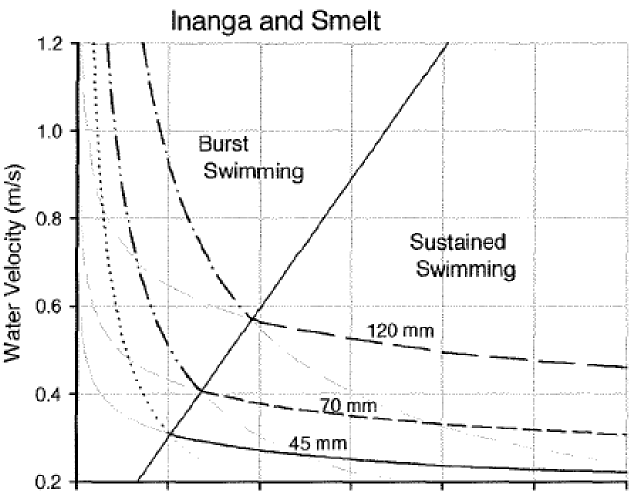
6 DESIRABLE FISH PASSAGE DESIGN PARAMETERS

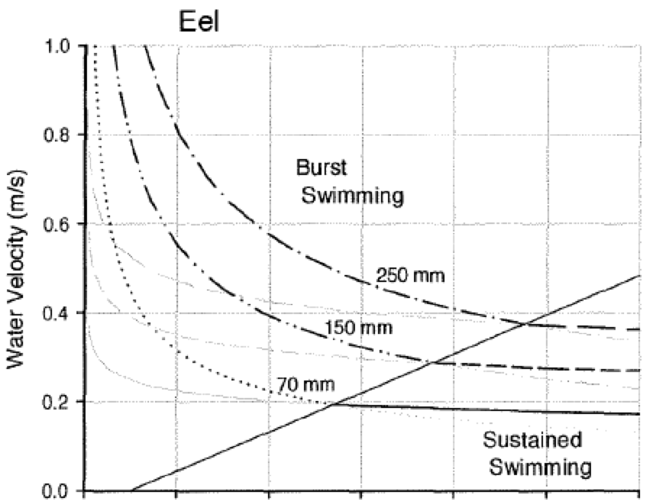
6.1 SUMMARY

Based on experience and observations from Boubée et al 1999, to ensure upstream fish migration, it is crucial to consider the size and swimming ability of fish likely to swim upstream when designing culverts. There are eight indigenous fish species in urban Christchurch that migrate upstream from the sea. These are the longfin eel, shortfin eel, inanga, common bully, giant bully, lamprey, black flounder and common smelt (CCC, 2003).

Swimming ability is commonly known to be proportional to the size of the fish. Two swimming speeds are described to explain swimming ability of small fish in Boubée et al. 1999; sustained speed and burst speed. Sustained speed is the speed at which fish can maintain for a long time without fatigue. Burst speed is commonly used to escape predators or feed and can only be maintained for a short amount of time before a rest is needed. Culvert design parameters such as length, flow depth and velocity need to be designed to suit a fish's ability to maintain these different swimming modes (CCC, 2003). Figure 4 shows the relationship between the size of fish, swimming distance and water velocity for the inanga/smelt and eel.

Figure 4: Maximum swimming distance vs velocity for the eel, inanga and smelt (CCC, 2003)





By catering for the passage of small fish it is assumed that larger fish will also be able to pass provided that the water depth is sufficient. For the Burlington Development, structures were designed to allow fish passage for fish least able to negotiate a culvert, in Christchurch this is inanga. Inanga must swim around obstacles and rely on areas of low velocity to rest in order to 'burst' to get through high velocity areas (CCC, 2003). However, if the opposing water velocity is sufficiently slow (see Fig. 5), and depending on size, inanga can swim aerobically through the culvert using the sustained swimming mode.

6.2 FLOW VELOCITY AND CULVERT LENGTH

The maximum distance inanga can swim sustainably, and therefore the maximum length of a given culvert, is related by the formula below (Boubée et al. 1999).

$$D_{max} = 2130\,\frac{L^{3.94}}{V_w^{\;5.25}} \qquad (1)$$

Setting D_{max} to the design length of the culvert (i.e. 35 m), the length (L) of the inanga to 50mm, an opposing water velocity of 0.23 m/s is obtained.

The equation to calculate the sustainable swimming speed for inanga (V_{sus}), for a sustainable swimming time (t) is:

$$V_{sus} = 5.29\,L^{0.63}t^{-0.16} \qquad (2)$$

For small inanga whitebait (50 mm), sustainable swimming velocities are in the order of 0.21 to 0.24 m/s depending slightly on the length of time the whitebait is swimming to negotiate the culvert (30 minutes to 1 hr). This is close to the experimental results obtained by (Mitchell 1989).

For small whitebait, the culvert edge velocity will need to be somewhat less than the sustainable velocity, if culvert velocities were to exceed sustainable swimming speed. A culvert edge velocity is taken as the zone out to 100 mm from the culvert edge (Boubée et al. 1999).

Therefore for this project, a target maximum velocity of 0.3 m/s was set for structures and waterways to enable fish passage of inanga. If this cannot be achieved, a 50 to 100 mm zone and resting pools should be provided on either side of the culvert with velocities below 0.3 m/s (Boubée et al. 1999). Ideally edge velocities within stormwater pipes and channels should not exceed 0.15 m/s to provide passage for the weaker swimming species which prefer to travel along the edge where velocities are slower.

6.3 FLOW DEPTH

A target depth of water of 20% of the culvert diameter or a minimum of 100 mm of water was set as the design criteria for fish passage for this project. While this seems shallow, inanga, juvenile eels, and native bullies are small fish, and do not require significant depth.

By achieving these design parameters native species will be typically able to navigate through structures via sustained swimming. Structures that require burst swimming for native species to navigate should be avoided where possible.

6.4 OTHER DESIGN CONSIDERATIONS

6.4.1 DARKNESS AND SHADING

Darkness is not considered a critical factor for the facilitation of fish passage. It is noted that the transition of light to dark and dark to light when passing through a culvert may cause fish to hesitate or pause while they acclimatise to changing conditions, hence lengthening the swimming time of the fish and potentially increasing fatigue and reducing passage. Some fish species have been found to only move upstream during daylight hours. Therefore it recommended to maximise the amount of light reaching the centre of long culverts (Boubée et al. 1999).

6.4.2 SMOOTH WETTED EDGES

For climbing fish species, smooth edges and transitions are highly favourable when negotiating wetted surfaces to allow species to easily climb to the top without harm or slipping as they reach the edge. Sharp edges at the inlet and outlets can create eddies which can prevent climbing eels successfully moving between the spray zone and water. As such, sharp edges will be rounded to prevent eddies forming.

7 DESIGNING FOR FISH PASSAGE

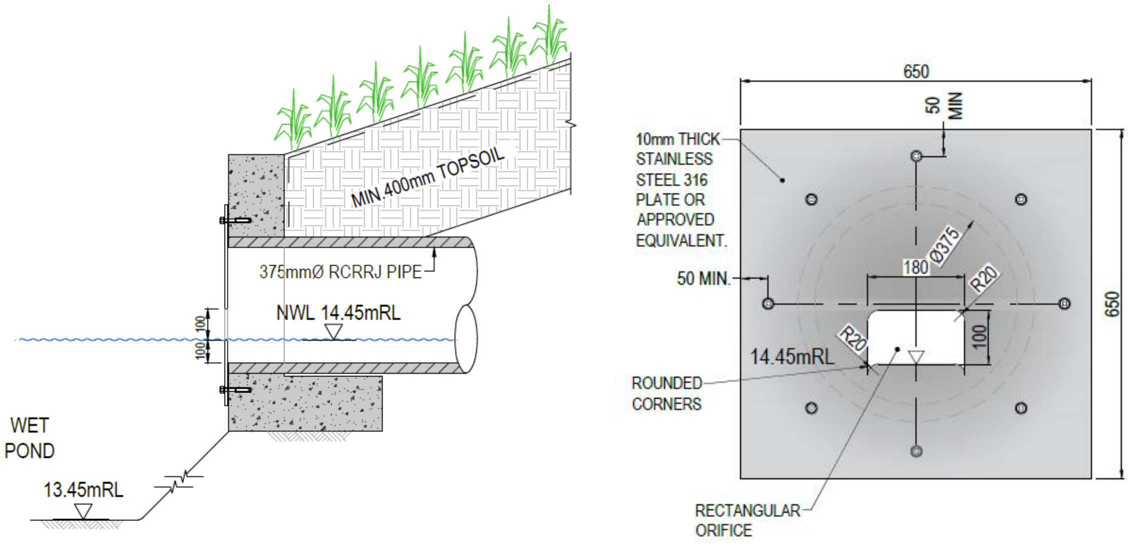
7.1 FIRST FLUSH BASIN AND DETENTION BASIN OUTLET

Outlet structures of the western first flush wet pond and the lower wet pond (comprising floating wetlands) are required to have a small cross-sectional area to control the rate at which stormwater enters the conventional wetland from the wet ponds and ensure that the partial flood storage can be provided above the lower wet pond in a 2% AEP 48-hour storm event.

The outlet structure for these devices will comprise a single 375 mm diameter circular concrete pipe with invert levels set lower than the flow control orifice invert and laid at a flat longitudinal grade (1:1000) to allow ponding within the culvert to a minimum of 100 mm. The inlet structure to the 375 mm diameter culvert will comprise an orifice plate to control flow rates and provide fish passage. Water velocity downstream of the rectangular flow control orifice will be less than 0.3 m/s, so fish can approach the flow control orifice without difficulty, especially along the culvert sides. The corners of the rectangular flow control orifice will be rounded in accordance with NIWA/DOC Fish Passage at Culvert Guidelines (Boubée et al. 1999) to allow fish to quickly traverse the flow control orifice barrier without moving far from the culvert wall. The rounded bottom corners of the rectangular orifice will approach to 100 mm of the culvert edge so they are within the edge zone (50-100 mm in Boubée et al. 1999). Figure 5 shows a typical detail of the outlet of the first flush basins and wet pond providing partial flood storage.

The culvert length was made as short as possible and the larger pipe diameter and orientation was selected to allow light to enter this structure to further encourage fish passage. A grated inlet will be provided to capture litter and floating debris whilst not impeding fish passage. A deeper pool will be provided at the outlet of these structures in the stormwater facility to provide somewhere for fish to rest before swimming through these structures.

Figure 5: First Flush Basin and Flood Storage Wet Pond Outlet Structure. Outlet structure detail (left) and orifice inlet plate detail (right).



7.2 CULVERT BAFFLES

An oversized 1,050 mm diameter culvert between the upper conventional wetland and lower wet pond (comprising floating wetlands) was selected to provide light in the culvert and to encourage fish to swim upstream to the conventional wetland.

The culvert is at a 1% grade but still requires modification to reduce velocities and increase water depth to enable fish passage. Due to site constraints it was not possible to reduce the grade of this culvert.

A number of options in *Fish Passage at Culverts – A review, with possible solutions for New Zealand indigenous species (*Boubée et al. 1999*)* were considered:

- Offset baffles; short and perpendicular baffles on one side but long and 30 degree angled on the other.
- Slotted weir baffles; weir-shaped baffles perpendicular to the flow with a central slot.
- Weir baffles; small weirs installed at the invert of the culvert perpendicular to the direction of flow.
- Alberta fish weirs; essentially the same as a slotted weir but the slot does not extend to the invert of the culvert.
- Wall baffles; baffles installed at the wall of the culvert rather than at the invert, creating a v-notch cross section.
- Spoiler baffles; baffle blocks installed at the invert of the culvert in alternating rows of three and four blocks.
- Alberta fish baffles; baffle blocks installed at the invert of the culvert in a zig-zag configuration.

Two options were short-listed, spoiler bafflers and Alberta baffles (Figures 6 and 7), based on the ease of construction and effectiveness in aiding fish passage as suggested by Stevenson et al. 2008 and Boubee et al. 1999. The adoption of spoiler baffles in long culverts has been used previously in North Canterbury (Taylor & Chapman 2007). However while the adopted design had been tested on New Zealand indigenous fish for both spoiler baffles (Boubée et al. 1999), the local application has not been tried.

Figure 6: Plan view (right) and cross-section (left) of spoiler baffles with alternating sets of four and three baffles (Boubée et al. 1999).

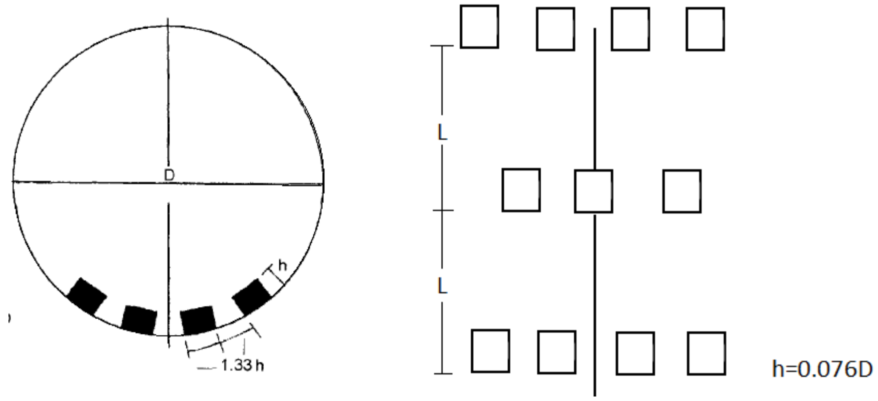
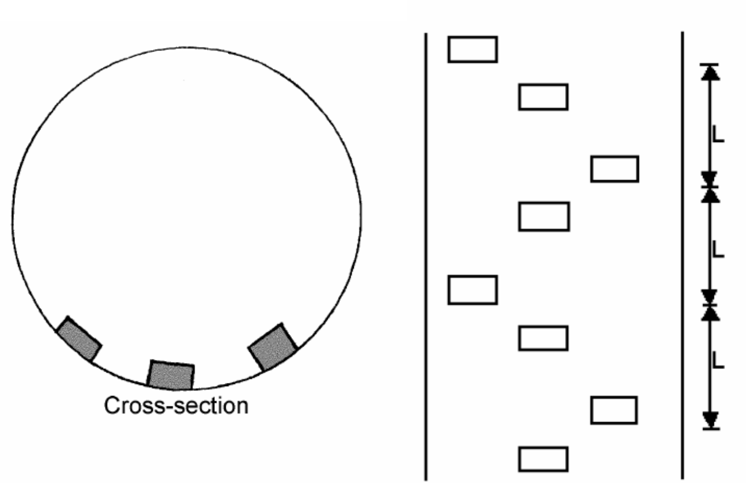


Figure 7: Plan view (right) and cross-section (left) of Alberta fish baffles. Note zig-zag arrangement compared to spoiler baffles (Boubée et al. 1999).



Two-dimensional (2D) hydraulic modelling with MIKE 21 was used to simulate the flow within the culvert including baffles to select the type of baffles and configuration that best met the requirements for fish passage.

Spoiler baffles similar to those recommended by *TP366 Culvert Barrel Design to Facilitate the Upstream Passage of Small Fish guidelines* (*Stevenson. et al., 2008*) were modelled with alternating rows of three and four blocks. The spoiler baffle blocks were a standard size of 250 mm length, 120 mm width and 120 mm height and had a lateral spacing of 120 mm and longitudinal spacing of 200 mm. Alberta baffles similar to those recommended by Ead, et al., 2002 were modelled with blocks of 100 mm length, 150 mm width and 100 mm height and lateral spacing of 100 mm and longitudinal spacing of 200 mm. Every effort was made to ensure that the modelling represented the actual size of the baffle blocks as accurately as possible.

The spoiler baffle and Alberta fish baffles configurations were modelled with an average flow of 10 L/s. This is the flow released by the two upstream first flush wet ponds during a water quality event (first flush depth up to 25 mm).

It was assumed that the material of the baffles would be low density polyethylene and a Manning's n of 0.011 was used at the base of the culvert. The topography of the culvert and upstream and downstream waterway profiles from the design were used.

Figures 8 to 11 shows the flow depth and maximum velocity in the culvert for a 10 L/s water quality event flow. Velocity vectors are shown to present the flow direction around the baffles.

Figure 8: Flow depth (with velocity vectors) for 1,050 mm diameter culvert with spoiler baffles included

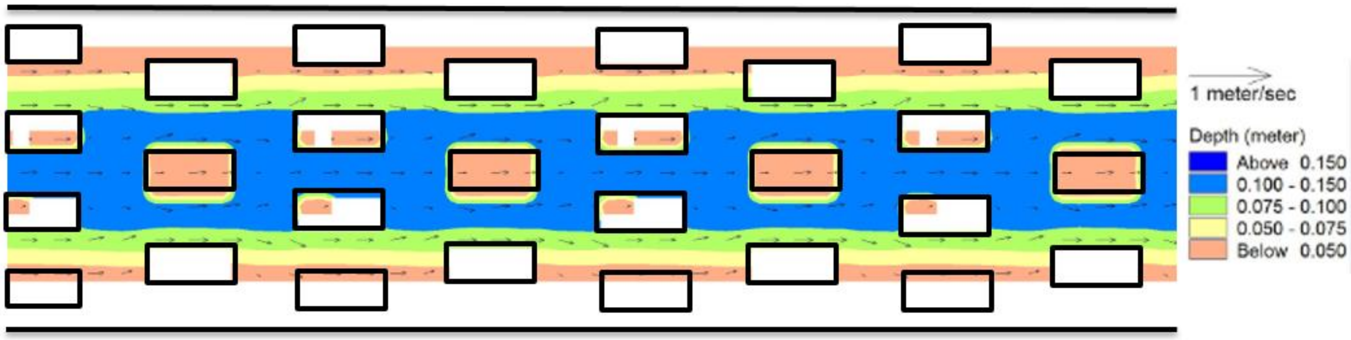


Figure 9: Maximum velocity (with velocity vectors) for 1,050 mm diameter culvert with spoiler baffles included

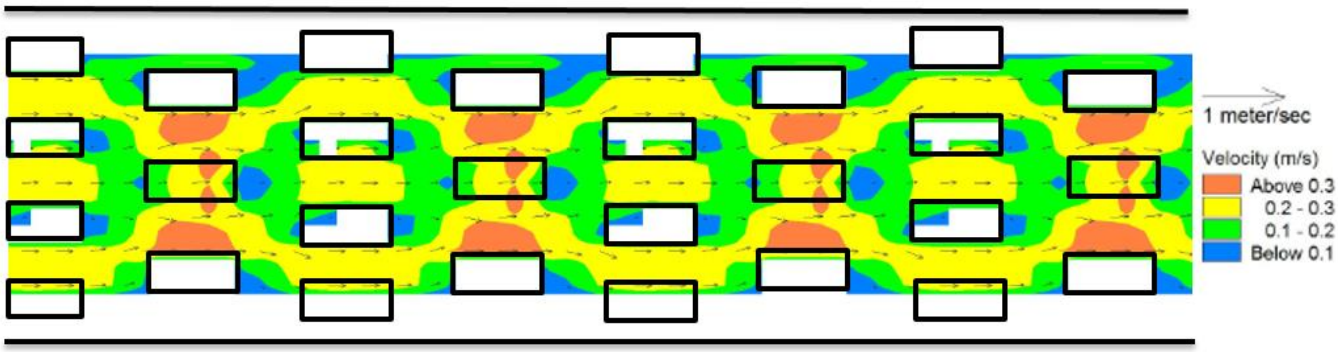


Figure 10: Maximum depth (with velocity vectors) for 1,050 mm diameter culvert with Alberta fish baffles included

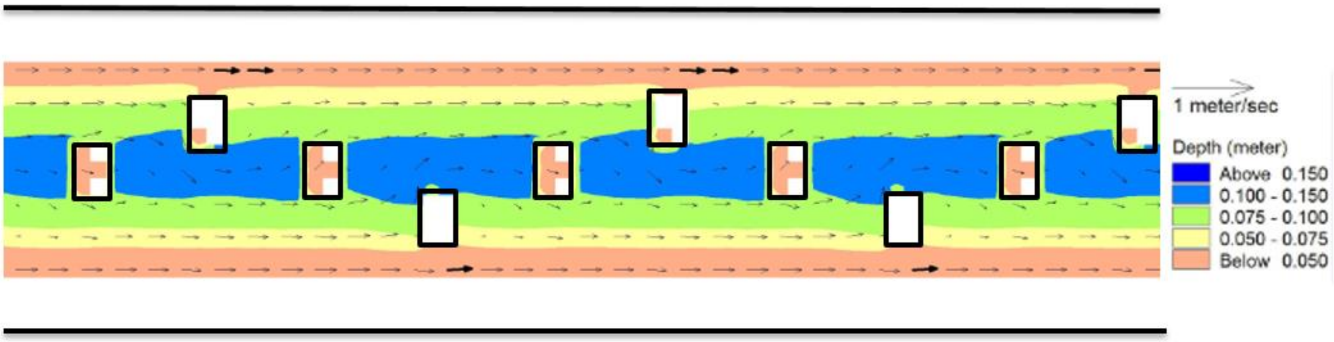
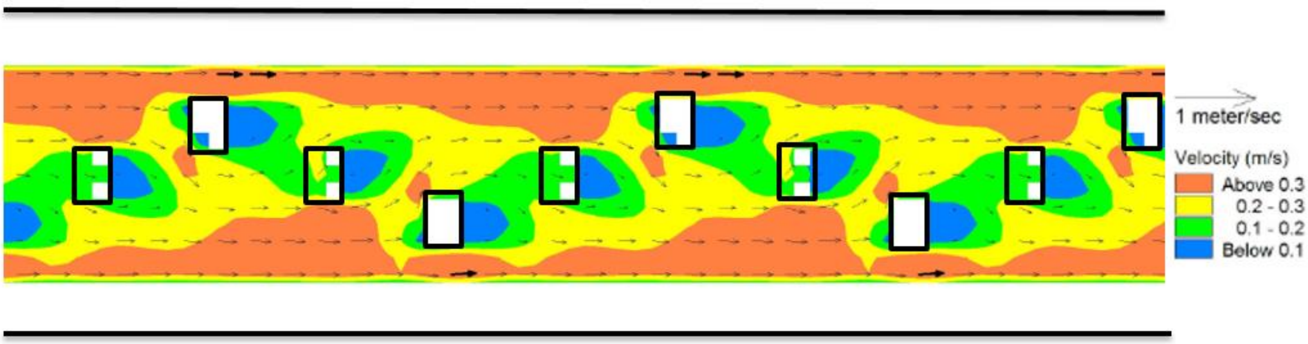


Figure 11: Maximum velocity (with velocity vectors) for 1,050 mm diameter culvert with Alberta fish baffles included*. Bolded velocity vectors are greater than 0.4 m/s.*



Both fish baffle configurations maintain a minimum flow depth greater than 100 mm and a clear path through the culvert with a maximum velocity of 0.3 m/s. Fish resting locations behind the baffles with velocities below 0.1 m/s are evident in both configurations. The spoiler baffle configuration also achieves lower edge velocities of approximately 0.15 m/s during water quality event flows. However, the Alberta baffle configuration has high culvert-edge velocities of up to 0.45 m/s which are undesirable for fish passage of native fish species. Based on these results the spoiler baffle configuration was chosen for the fish baffles in this culvert. This baffle configuration will allow native New Zealand freshwater species to migrate from the downstream wet pond (comprising floating wetlands) into the upstream conventional wetland and first flush wet ponds. It is also noted that when the lower wet pond fills due to partial flood storage that the lower and upper wetlands will have a constant water level, allowing unimpeded fish passage through the 1,050 mm diameter culvert without the need for the fish baffles.

Potential issues related to maintenance and reduction in capacity due to the fish baffles can be mitigated using a larger culvert. Being oversized, the culvert can convey storm flows greater than a 2% AEP event without inundating the upper conventional wetland. Significant accumulation of debris within the culvert is not expected given stormwater entering the culvert will have undergone first flush treatment and sedimentation in the upstream first flush wet ponds and secondary treatment within the upper conventional wetland. In large rainfall events, larger flows will flush the culvert from accumulated sediment.

In the event opposing water velocity becomes too fast, eels can still negotiate the culvert by climbing out of the water and wriggling through the spray zone just above the water surface (Boubée et al. 1999).

Construction of spoiler baffles in New Zealand are relatively easy with the availability of pre-moulded low density polyethylene sheets with spoiler baffles. Figure 12 shows an example of a new sheet of baffles installed in a culvert and fish baffle sheets installed in an operating culvert after some time. These pre-moulded spoiler baffles will be used for this project.

Figure 12: Example of spoiler baffles similar to baffles proposed for the Burlington Lifestyle Village development (Rotational Plastics Ltd, 2018)

A headwall / wingwall structure at the inlet and outlet of the culvert was adopted to minimise the length of the culvert and swimming distance for fish. The apron of the headwall will be buried at a minimum of 300 mm below ground level to enable a rock-lined channel to be formed above the concrete apron at the inlet and outlet of the culvert.

7.3 GENERAL CULVERT DESIGN

The inclusion of new hydraulic structures within existing and proposed waterways was avoided where possible. When the inclusion of a new culvert could not be avoided they were designed to achieve the following attributes:

- Culverts were positioned so that their longitudinal gradient and alignment are the same as the stream bed.
- The culvert inverts were set 20% of the culvert diameter or a minimum of 100 mm below existing waterway invert levels to maintain this minimum flow depth through culverts. Where there were multiple culverts, one culvert invert was set lower than the invert of the waterway to facilitate fish passage while the rest remained at a higher level to facilitate higher flows.
- The longitudinal grade was selected to ensure that a minimum flow depth of 100 mm and maximum velocity of 0.3 m/s is achieved during water quality event flows.
- Culverts were oversized to ensure that in a water quality event that approx. 20% of the cross-sectional area only was occupied.
- The inlet and outlet structures will not have a headwall with exposed concrete apron.
- Inlet and outlet structures will comprise a cut pipe headwall in accordance with the CCC Construction Standard Specification (CCC, 2017). These culverts are cut back

to match the grade of the embankment and softened with both rock lining and plantings.

- The pipe lengths were reduced to be as short as possible. This was achieved by steepening planted batters in the location of these culverts.
- A deeper pool is typically included downstream of all culverts to provide a resting pool for fish attempting to negotiate the culvert.

7.4 RAMP FISHWAYS

A short reach of waterway both upstream and downstream of the 1,050 mm diameter culvert connecting the two wetlands were designed to be similar to ramp fishways in the 2018 New Zealand Fish Passage guidelines. The fishways have a 1.5 to 1.9% grade and will have vegetated batters, a rock-lined base and rock baffles in the base to slow flow velocities and provide small pools for fish to rest. The fishway will have a v-shaped cross-section to concentrate the base flow and low flows at the invert of the channel. Rocks will be embedded at the base of the ramp to slow flows, these will be grouted to prevent water seepage between the rocks.

2-D hydraulic modelling was also used to confirm the spacing of baffles formed with boulders and placed rock in the channel immediately upstream and downstream of the 1,050 mm diameter culvert to create pools and riffles that keep the average velocity less than 0.3 m/s, flow depth greater than 100 mm and create resting pools for fish during water quality event flows.

7.5 FISH PASSAGE THROUGH UPPER CONVENTIONAL WETLAND

Flow through a conventional wetland must be controlled and consistent with no short-cutting or channelisation of flow paths (CCC, 2003). The WWDG requires that wetlands are constructed in cells of length not exceeding 6 hours transit time. The hydraulic residence time for a constructed wetland needs to be 2 days minimum. The conventional wetland will incorporate deeper pools for fish to reside in and will be designed to ensure clear fish passage from the 1,050 mm diameter culvert to the upstream first flush basins.

Deeper pools will be provided in the conventional wetland in the location of pipe inlets and outlet. This will allow fish to rest after swimming upstream through the 1,050 mm diameter with fish baffles and prior to swimming through culverts into the upstream first flush wet ponds.

7.6 MEANDERING LOW-FLOW CHANNEL

It was identified that in a water quality event that the flow depth in proposed channels would be insufficient for fish passage. Therefore a meandering low-flow channel will be provided within all new waterways to ensure sufficient depth and velocity at which fish can swim upstream is achieved. The low-flow channel will allow flow to concentrate within it to create an upstream passage for fish to migrate into the Burlington Lifestyle Village stormwater facility. Photograph 3 shows an example of a meandering low-flow channel prior to riparian plant-out. Planting will be provided at the edge of meandering low-flow channels to provide shading and shelter from predators.

Photograph 3: Low-flow channel within the Cooks Lane reach of the Matuku Waterway currently under construction in January 2018.

7.7 BARCLAYS DRAIN LOW-FLOW DIVERSION WEIR

Flow from Barclays Drain is diverted to the Burlington Lifestyle Village stormwater facility via a low-flow diversion weir. The weir allows fish passage via a small opening at the invert of the drain and rounded edges at the overflow weir crest level. Weirs should be notched and impermeable to provide a well-defined pathway over and through the weir (Boubée *et al.* 2000). At the time of publication of this paper, a rock-ramp style weir similar to Figure 4-14 in the 2018 New Zealand Fish Passage Guidelines was being investigated for this low-flow diversion weir. Compared to a concrete weir structure, this design would enable easier downstream passage of eels from the larger first flush basin.

8 CONCLUSION

The design of the Burlington Lifestyle Village stormwater facility presented an exciting opportunity to provide a new upstream habitat for native freshwater fish despite stormwater management requirements that would traditionally impede fish passage.

This paper explains how provision of fish passage for native freshwater species from the downstream Styx River receiving waterway to the new stormwater facility and further upstream into Barclays Drain was achieved, whilst meeting stormwater treatment and attenuation objectives. Structures within waterways were designed to slow flow velocities to allow fish passage of inanga, the freshwater species least likely to negotiate a culvert due to its poor swimming ability. Flow velocities were therefore kept below 0.3 m/s and a minimum depth of 100 mm during water quality rainfall events.

Two-dimensional hydraulic modelling was used to demonstrate the effect of introducing fish baffles in a culvert and ramp fishway and then to optimise the size and configuration of design.

Low-flow channels and rock baffles were introduced within waterways to slow flow velocities, provide resting pools and sufficient water depth to enable fish to swim upstream. Weirs can be designed as a rock-ramp style weir to aid the passage of anguilliform and climbing fish species.

It is acknowledged that the inclusion of hydraulic structures will result in reduced fish passage connectivity however the best possible fish passage outcome has been provided for within the difficult stormwater management constraints of the Styx SMP.

Fish passage is often overlooked in the design of infrastructure. A small modification to the design of a culvert and waterway can easily be implemented to aid the migration of upstream fish passage for native freshwater species.

ACKNOWLEDGEMENTS

The authors would like to thank the developer Alpine View for their enthusiasm in creating a stormwater facility that provides ecological connectivity to the Styx River and incorporating a floating stormwater treatment wetland into this development.

We would also like to thank Aquatic Ecology Limited for their expert advice and guidance in this project.

Thanks to Jeff Ray, Regan Smith, Michelle Ruske and Jason Trist (Aurecon) for their work on this project as well.

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