URBAN STREAM RESTORATION - EROSION CONTROL AND FISH HABITAT ENGINEERING

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ABSTRACT

The Mangakotukutuku Gully is located on the south western side of the Hamilton urban area and represents one of six urban gully systems with a connection to the Waikato River within Hamilton City.

The Mangakotukutuku Stream Care Group (MSCG) was established in 2006 in response to community concerns about the poor health of Mangakotukutuku Stream and the lack of attention being given to its ecological values. Tonkin & Taylor (T&T) has worked with MSCG since 2008 in developing restoration demonstration sites aimed at improving the health of the stream whilst engaging with and educating the local community.

T&T has developed four individual reach restoration plans and implemented physical works for two of those plans. This paper presents engineering design and construction issues associated with physical works for an offline mini wetland intended as native mudfish habitat, three different stream bank re-grading options incorporating soil filled containers, woody weirs for flow diversity, log overhangs, and novel stream bank fish refuge habitats targeting tuna (eel) and giant kokopu.

The paper presents key learnings including: soil container construction, advantages and disadvantages of the three bank re-grading options used, potential for community construction initiatives, construction of fish refuge habitats, woody weirs and log overhangs, and effects of sedimentation on those features. The performance of the stream bank erosion mat product used and associated variable vegetation uptake on the stream banks is also discussed. A design calculation method for anchored woody in-stream structures is also presented.

KEYWORDS

barriers, fish, habitat, restoration, stream

PRESENTER PROFILE

Bryn is an environmental and civil engineer based in the Tonkin & Taylor Hamilton office. Bryn has more than 10 years' experience in the field of integrated civil engineering and his experience includes development of restoration plans, design and supervision of physical works in urban streams, ponds, and wetlands including fish structure engineering. Bryn's fish structure experience includes design and development of fish passage, fish habitat and fish barrier solutions.

1 INTRODUCTION

1.1 PROJECT

The Mangakotukutuku Stream Care Group (MSCG) was established in 2006 in response to community concerns about the poor health of Mangakotukutuku Stream and the lack of attention being given to its ecological values. MSCG is working to promote wider community awareness of the ecological values of Mangakotukutuku Stream and are undertaking on-the-ground action aimed at improving the health of the stream. The focus of the MSCG is on the Mangakotukutuku Stream ecosystem and its associated freshwater habitats (such as springs and seepages) and complementing other initiatives that promote terrestrial values of Hamilton City's gully systems. MSCG has completed a number of restoration projects to date.

In 2008 MSCG commissioned T&T to develop a restoration plan to address stream bank erosion, improve in-stream habitat for native fish and develop a mini wetland creation/restoration plan within the Sandford Park reach of the stream. In 2011 the MSCG and T&T sought funding from the Waikato River Clean-up Trust (Waikato River Authority, WRA) to implement the stream and wetland restoration plans described above and to expand ecological restoration efforts to other parts of the stream.

WRA funding was awarded in 2012 and detailed design for erosion control and in-stream habitat (Project A) as well as a mini wetland (Project B) was commenced alongside preparation of two restoration plans (Projects C and D) for other stream reaches. Construction of Projects A and B was undertaken in the first half of 2013 by John Carter Constructors Ltd under the supervision of T&T.

1.2 OBJECTIVE

The principal aim of this project was to showcase what can be achieved with restoration of Waikato River tributaries flowing through urban centers by creating demonstration restoration sites on Mangakotukutuku Stream in Hamilton City.

The project also aims to:

- Control and/or repair existing stream bank erosion using a mix of riparian planting and ecologically sensitive engineering techniques
- Provide in-stream habitat features to improve fish habitat quality and diversity
- Restore an area of degraded park space by creating a wetland incorporating habitat suitable for native mudfish
- Critically review the work completed and share information with interested parties

1.3 CATCHMENT

The Mangakotukutuku Stream is located on the south western side of Hamilton City. The Mangakotukutuku Stream catchment is approximately 3,000 ha (refer Figure 1) with an impervious percentage of approximately 12% (Jones et al. 2012). The headwaters of the stream drain mainly agricultural land with the mid to lower reaches flowing through urbanised areas. The stream is subject to both agricultural and urban stormwater runoff, along with other pressures within the urban environment.

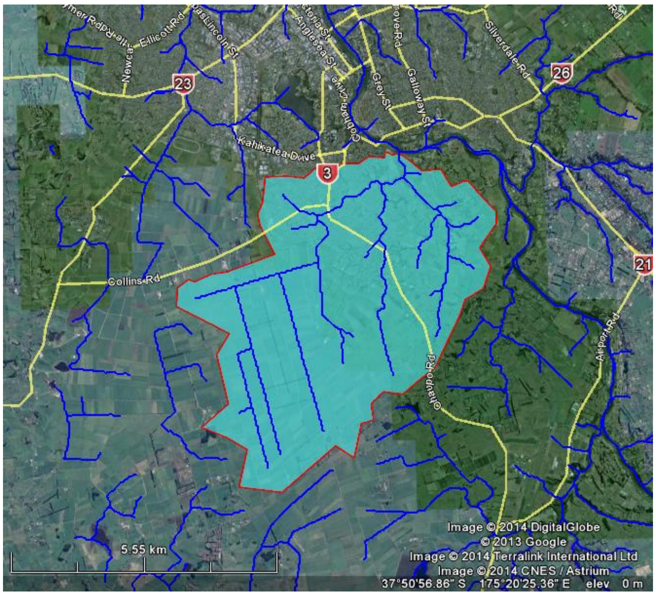

Figure 1: Mangakotukutuku Stream catchment. Aerial photo sourced from Google Earth (Copyright: 2014), stream locations from the REC database.

1.4 ENVIRONMENT

1.4.1 SITE

The subject site is located on a short (300m) reach of the Mangakotukutuku Stream within the bounds of Sandford Park, Hamilton. The site is immediately upstream of Peacockes Road. The road crossing of the stream at Peacockes Road includes a large c.3m diameter corrugated steel culvert approximately 30m long. The site is located approximately 500m upstream of the confluence with the Waikato River as shown in Figure 2.

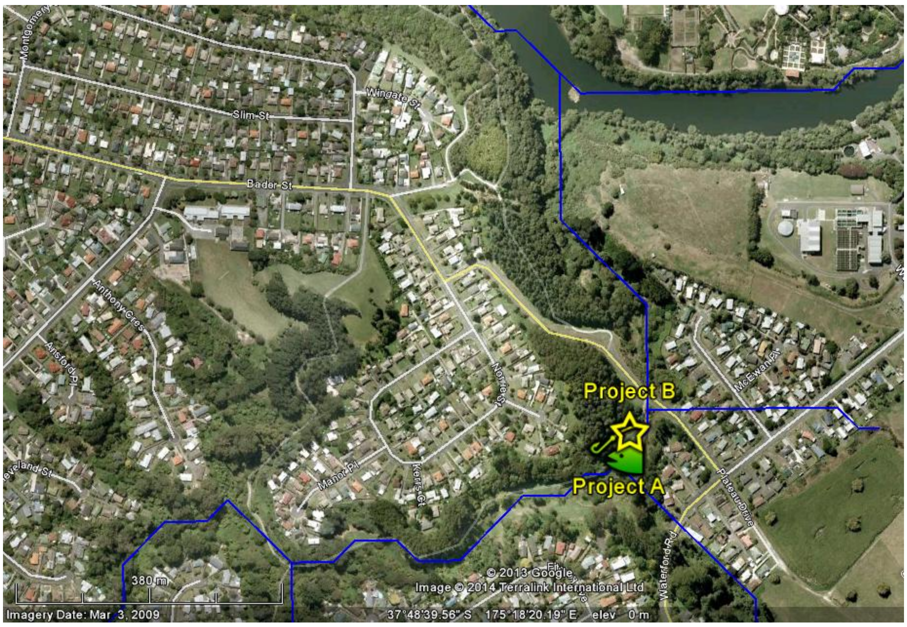

Figure 2: Site location. Aerial photo sourced from Google Earth (Copyright: 2014), stream locations from the REC database.

The site is characterized by the meandering channel of the Mangakotukutuku Stream. The true right bank generally has a narrow (2 to 5m wide) flood plain before sharply rising up a high (4m+), steep bank to an elevated terrace. The true left bank has a more variable (5 to 30m wide) flood plain before rising up a high (4m+) moderately steep bank to an elevated terrace. The flood plain (park ground level) within the site reach varies from approximately 16.4 to 17.4 mRL with the stream channel varying from 1.5 to 2.5 m deep.

1.4.2 FLOODING

The site is affected by flooding within the Waikato River. Estimated flood levels (ranges) within the Waikato River are provided in Table 1 below (interpolated from Jones, et al. 2012).

Table 1. Estimated flood levels.

AEP (%)	Interpolated flood level ranges (mRL)
10	14.4 to 15.2
50	15.5 to 17.0
100	+/- 18.5

Table 1. Interpolated Waikato River flood levels (Jones, et al. 2011)

The Peacockes Road culvert restricts flows within the stream and the site is located within a "Culvert Block and Associated Flooding" environmental protection overlay within the Operative District Plan (HCC, 2012). Figure 3 below shows the flood hazard area within the site *(HCC 2014)*.

Figure 3. Flood hazard area (HCC 2014)

1.4.3 GENERAL ECOLOGY

In a highly modified setting such as the Hamilton urban area, streams with high biodiversity values are rare. Relatively intact systems such as the streams draining the Mangakotukutuku Catchment therefore assume greater significance for biodiversity within the Hamilton City urban setting.

An aerial view of part of the Mangakotukutuku Gully system upstream of Peacockes Road is shown in Figure 4.

Figure 4: Oblique aerial image (looking south west) of the site upstream of Peacockes Rd, Hamilton City. Aerial photo sourced from Google Earth (Copyright: 2014).

Prior to 2008, riparian vegetation along the site reach comprised mainly rank grasses and weeds on both banks with occasional willow trees. The flood plain on the left bank comprised the open grassed area of Sandford Park. Since 2008, the riparian margin on both sides and the flood plain on the right bank has been progressively planted with native grasses, shrubs and trees. Weed species and willows remain abundant.

1.4.4 AQUATIC HABITAT

The Mangakotukutuku Stream through the trial reach is characterised by relatively uniform flow conditions with long, slow to moderate flowing runs predominating. Some deeper pool/run areas are also present. Bed gradients are low within the trial reach and are likely controlled by the fixed invert of the Peacockes Road culvert. For this reason and given the ongoing sediment supply from the contributing catchment, the lower Mangakotukutuku Stream through Sandford Park is likely to remain soft bottomed in the long term.

In-stream habitat diversity over the trial reach is relatively low and the dominant substrate comprises soft sediments. Other elements adding some diversity to the available in-stream habitat include the occasional accumulation of woody debris, bank overhangs, eroded bank slumps, overhanging vegetation and to some extent, urban debris. Woody debris is likely to be the key hard substrate providing physical habitat in the stream.

Some of the accumulations of woody debris in the stream appear to be relatively stable and associated with willow roots or larger branches either growing in or lodged in the stream. Other accumulations are less stable and are likely to be flushed out during flood flows, or possibly removed by HCC in order to maintain flood conveyance capacity. The natural input of wood to the stream from riparian margins is likely to be currently limited due to the lack of larger trees (other than willows) adjacent to the trial reach.

For the reasons above, the installation of stable hard substrates (woody debris) and stream margin cover was included in the restoration plan for the stream and are discussed below.

1.4.5 AQUATIC ECOLOGY

Several records of native fish within the Mangakotukutuku Catchment are included on the New Zealand freshwater fish database (administered by NIWA). Fish records for sites upstream and downstream of Peacockes Road are summarised in Table 2. Of the species listed in Table 2, giant kokopu and longfin eel are considered 'At Risk' (gradual decline) within the Waikato Region by the Department of Conservation (Hitchmough, 2005). More recent work (Allibone et al., 2010), considered that longfin eel, giant kokopu, inanga and torrentfish are at risk species and are in gradual decline.

Table 2 – Summary of Mangakotukutuku Stream fish database records (from the freshwater fish database administered by NIWA)

Location	**Species**	**Year/s recorded**
Mangakotukutuku Stream downstream of Peacockes Road	Longfin eel (*Anguilla australis*)	1992, 2005
	Shortfin eel (*Anguilla dieffenbachii*)	1992
	Common smelt (*Retropinna retropinna*)	1992, 2005
	Common bully (*Gobiomorphus cotidianus*)	1992
	Torrentfish (*Cheimarrichthys fosteri*)	1992, 2005
	Koi carp (*Cyprinis carpio*)	2005
Mangakotukutuku Stream and tributaries upstream of Peacockes Road	Longfin eel (*Anguilla australis*)	1997, 2003, 2006, 2005, 2007
	Shortfin eel (*Anguilla dieffenbachii*)	1992, 1997, 2003, 2005, 2006, 2007
	Common smelt (*Retropinna retropinna*)	1997, 2003, 2005
	Common bully (*Gobiomorphus cotidianus*)	1997, 2003
	Torrentfish (*Cheimarrichthys fosteri*)	2006, 2007
	Inanga (*Galaxias maculatus*)	2003, 2005, 2006
	Banded kokopu (*Galaxias fasciatus*)	2003, 2005
	Giant kokopu (*Galaxias argenteus*)	2005
	Mosquitofish (*Gambusia affinis*)	2003, 2005, 2007

The Peacockes Road culvert on the main stream was considered to be a barrier to upstream fish passage under most flow conditions (Aldridge & Hicks, 2006). However, the diversity of species previously recorded above this culvert suggests that native species can negotiate this culvert by climbing wetted margins (e.g. eels and banded kokopu) and occasionally by swimming (e.g. inanga and smelt). Species with only moderate climbing ability such as giant kokopu and common bullies also appear to have been able to pass upstream. In 2010, MSCG undertook works on the downstream apron of the Peacockes Road culvert to improve fish access to upstream habitat for migrating juvenile fish such as giant and banded kokopu.

Longfin eels and giant kokopu are also likely to favour the habitat types already present within the trial area (see Section 1.4.4 above). Giant kokopu and longfin eel were therefore considered to be key target species for the restoration trial.

Aquatic habitat enhancement works also considered other native fish that are likely to frequent the soft-bottomed habitat through the project reach such as inanga and shortfin eels. The project reach was considered unlikely to be suitable for other native species recorded in the upper catchment such as banded kokopu and torrentfish that prefer higher elevation, smaller stream habitats (Baker & Smith, 2007) and higher water velocities respectively.

Macroinvertebrate diversity is currently limited within the main reach of the Mangakotukutuku Stream and mainly dominated by species that are tolerant of reduced habitat conditions (e.g. snails, worms and midges) (Collier et al. 2008). One of the most commonly used metrics for the assessment of stream habitat quality is the Macroinvertebrate Community Index or MCI. When MCI scores drop below 80, streams are generally considered to have poor water or habitat quality. From 1997 to 2004, MCI scores have averaged 81 for a site on the mainstream at Peacockes Road (MSCG, 2014).

Overall, the target species for habitat restoration were as follows:

- Priority 1 – giant kokopu and longfin eels
- Priority 2 – inanga and shortfin eels

In-stream habitat enhancement measures aimed at fish species will also have the potential to improve local macroinvertebrate diversity through the introduction of new stable hard substrates.

In addition to these species there are historical (anecdotal) reports of native ('black') mudfish (*Neochanna diversus*) in a small side stream of the Te Anau branch of the Mangakotukutuku Stream. A mini wetland feature previously considered for landscape enhancement was identified as a priority for the creation of new native mudfish habitat. Native mudfish are non-migratory and would need to be relocated to any new habitat site.

1.4.6 WATER QUALITY

Poor streambed stability has been identified as the major ecological stressor in the Mangakotukutuku Stream, followed by lack of habitat cover and metal contamination (Williamson, 2001). Peak flows from urban stormwater along with rural runoff contribute to streambed instability and poor habitat quality. The main part of Mangakotukutuku Stream running through Sandford Park has severe bank erosion as well as sediment deposition issues.

Approximately 70% of suspended sediment carried by the Mangakotukutuku is estimated to be derived from rural areas in the catchment (Williamson, 2001). The streambed is currently characterised by fine sediment build-up. Observed accretion of sediments within the trial reach is likely due to the Peacockes Road culvert which is expected to be the controlling factor on the stream bed gradient within the area.

In the upper reaches, humic substances from peat soils colour the water (Williamson, 2001), further downstream turbidity appears to be a combination of tannin staining from peat soils in the catchment and suspended sediments. The level of turbidity in the Mangakotukutuku is high enough to disrupt feeding and movement of some native fish (MSCG, 2014).

Based on a site assessment we considered that the trial reach is likely to remain characterised by high turbidity and fine bed sediments in the long term and this reflects the nature of soils in the catchment. Fine bed sediments are likely due to the ongoing input of fine sediments from the contributing catchment and accumulation of those sediments due to the fixed inlet level at the Peacockes Road culvert which controls upstream bed gradients.

1.4.7 GEOLOGY

Published geology (Edbrooke, 2005) indicates that the catchment includes multiple geological deposits, consisting mainly of Tauranga Group deposits.

A significant portion of the upper (south western) rural catchment encompasses the Rukuhia Peat Swamp (now effectively drained). The Rukuhia Peat Swamp consists of Holocene sediments of the Piako subgroup. This unit comprises soft, dark brown to black, organic-rich mud, muddy peat and woody peat.

The lower, extreme west and south eastern parts of the catchment include Holocene and Pleistocene sediments of the Piako and Walton subgroups.

Walton subgroup deposits underlie the elevated parts of the catchment and typically comprise pumiceous silts, sands and gravelly sands of volcanogenic origin. These deposits are strongly weathered and clay rich.

Hinuera formation (Piako subgroup) deposits occur as terrace deposits within the catchment and typically comprise cross bedded pumiceous silts, sands and fine sandy gravels with interbedded organic silts.

The lower gullies within the catchment, including the subject site, include Taupo formation (Piako subgroup) deposits and typically comprise pumicious sand, silt and gravel alluvium.

Site observations generally confirmed the presence of Taupo formation geology within the site extents but also identified some recent alluvial deposits within the flood channel overlying moderately welded ignimbrite deposits on the true right bank.

2 STREAM EROSION CONTROL

2.1 SITE OBSERVATIONS

Site inspections have been conducted by T&T staff on a number of occasions since March 2008. The main channel of the Mangakotukutuku Stream running through Sandford Park is typically characterized by near vertical, vertical or over vertical banks with regular bank failures. In general, the stream channel has severe bank erosion and fine sediment build-up on the streambed. A number of bank erosion features were noted within the site and typically included slumping and bank undercutting. Slumping has occurred in various locations over the trial reach and is most likely caused by stream flows undermining the toe of the bank and/or stream bank undercutting. Stream bank undercutting was observed at the outside of a number of bends over the site reach and is most likely caused by increased velocities and turbulence that naturally occurs at the outside of bends.

Figure 5 shows an overview of the observed erosion and stream features within the site reach. No new erosion sites were noted between the first site inspection in March 2008 and October 2008. Subsequent clusters of inspections in late 2011 and late 2012 identified some new sites and noted significant worsening of other sites.

Bank undercutting at one site (BRO4) was originally identified as critical due to its proximity to an existing walking/maintenance track and between 2008 and 2013 had migrated some 3-5m closer to the track. Another site (BRO3) was also very close to the track but degradation of the bank appeared to be much slower.

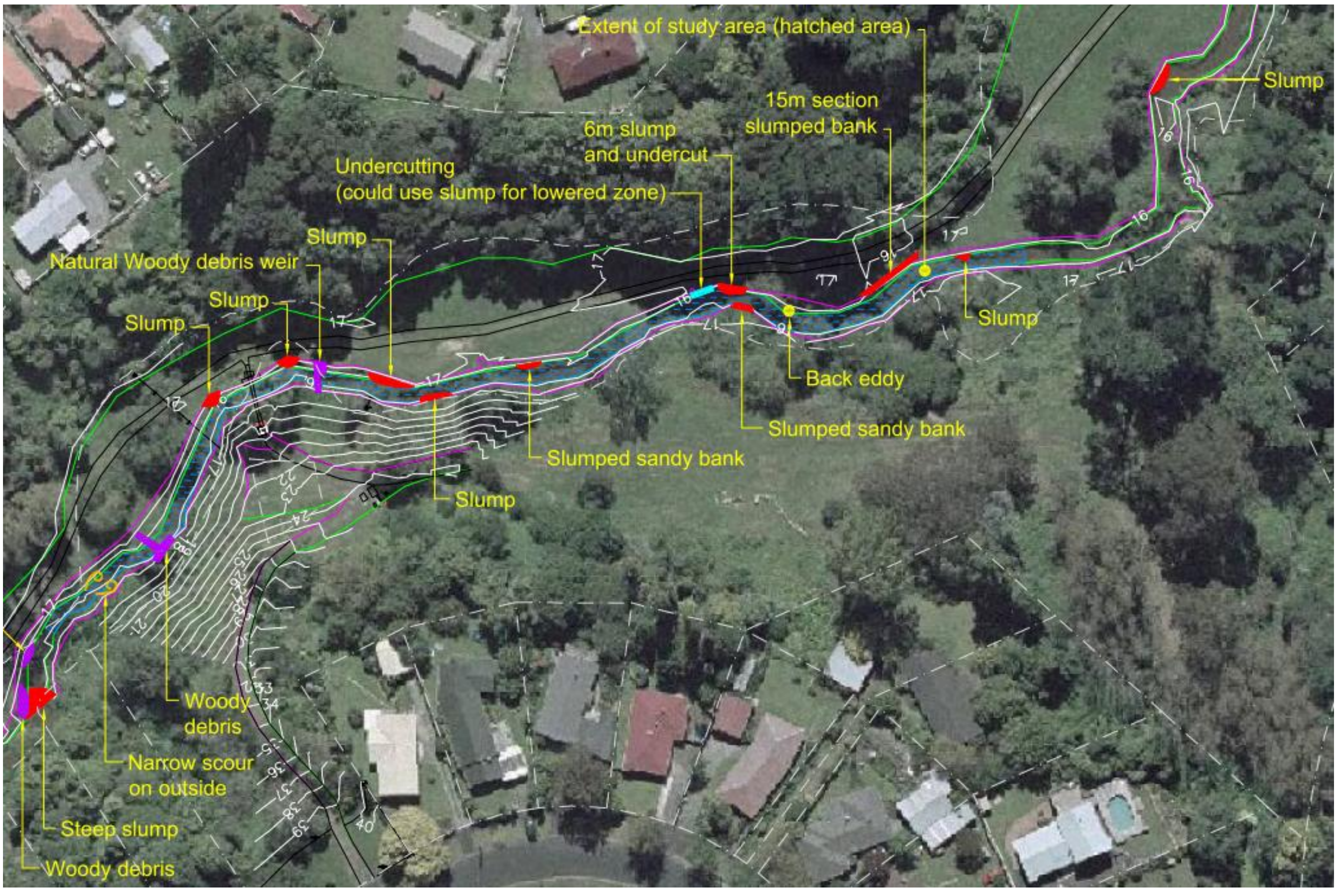

Figure 5 shows an overview of the observed erosion and stream features within the site reach.

2.2 CONCEPT DESIGN

A number of methods were considered for stream bank erosion protection and were outlined in a 2008 report prepared for MSCG by T&T (Earwaker, et al. 2008). A key element of the options report was to consider construction costs and the ability for the MSCG and community to undertake construction. Erosion protection methods considered, in order of least to most cost, included:

- Maintain the status quo
- Riparian planting
- 'Soft' engineering works
- 'Hard' Engineering works

Riparian planting and 'soft' engineering works were favoured and a number of Bank Re-grading Options (BROs) for improving bank stability and controlling erosion were developed and included:

- Bank re-grading (battering)
- Bank terracing (battering with mid-slope flat bench)
- Bank re-grading or terracing with toe protection
- Flood channel protection (ground cover erosion mats)
- Flood plain protection (plantings)

In consultation with MSCG, it was decided to trial channel bank battering and terracing using a combination of soil containers and biodegradable erosion matting to stabilise four of the slumped or undercut areas identified. In combination with the above MSCG would progressively undertake riparian planting over the full reach. Additional fish habitat structures are discussed in Section 3. It was also decided to undertake the trial works using a civil contractor rather than community power.

2.3 DETAILED DESIGN

Detailed design of the four trial stabilisation areas (BROs) progressed, with consideration given to materials, cost and ability for future community construction initiatives.

2.3.1 BANK RE-GRADING

Bank re-grading was limited by the proximity to the existing access tracks and the desire to maintain as much of the existing park space as possible.

BRO1 was selected to trial a 2H:1V slope batter utilising a single row of soil containers at the toe and full height erosion control matting.

BRO2 was selected to trial a 1H:1V slope batter incorporating a 600mm wide mid-slope bench utilising a soil containers up to the mid-slope bench and full height erosion control matting.

BRO3 and BRO4 were selected to trial a 1H:1V slope batter utilising full height soil containers and erosion control matting.

All BROs were to be trialled using short grass cover rather than riparian plants to assist in monitoring of the performance of each feature.

Schematic representation of the selected options are shown in Figure 6 below.

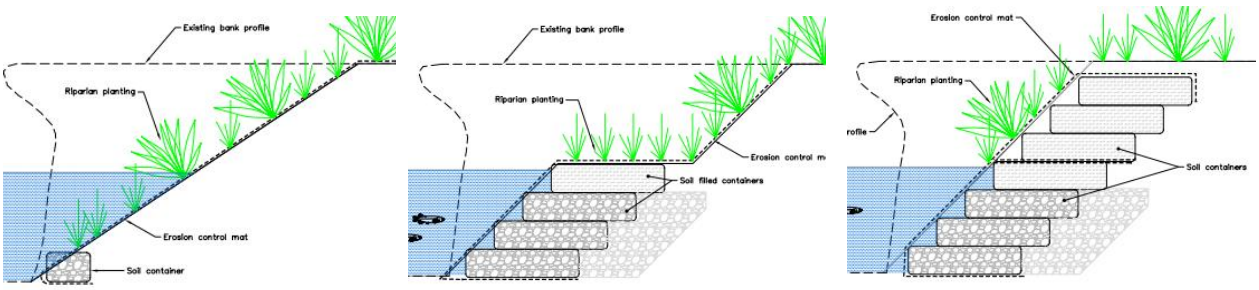

Figure 6. Schematic representation of bank re-grading options (BRO1, BRO2, BRO3/BRO4).

2.3.2 SOIL CONTAINERS

A number of different soil container options were considered including:

- large (1-2m3) geotextile containers
- Small (20-40 litre) geotextile and PE containers
- Continuous 'soil sock' type containers.

Large and continuous 'sock' containers were discounted due to the specialist equipment required and we considered that the small containers would be more suitable for future community based initiatives.

Small geotextile and PE containers were investigated and costs were found to be a significant factor. Geotextile containers were in the order of $10 each where PE containers were typically less than $1. Small (600 x 900 mm) PE containers were selected for the trial works.

In order to utilise excavated soils from bank re-grading, soil containers were generally filled with materials won from site (silts and sands). Soil containers below the normal 'summer' water line (approximately 200-400mm deep) were filled with GAP40 metal. GAP40 was chosen over native soils to provide additional weight at the toe, to provide better foundation strength, reduced potential for settlement under saturated conditions and ease of placement below the water line. GAP40 was selected over drainage metal or larger rock due to price and ease of handling (shovelling) into containers. Soil containers were fixed closed by rolling the open end and securing with three heavy duty cable ties.

2.3.3 EROSION CONTROL MATTING

A number of different erosion control matting options were considered and in essence came down to either synthetic or biodegradable products. In this instance we selected biodegradable products as a better fit with the project. Biodegradable erosion control matting products available were limited to coir (coconut) fibre or coir fibre and wool combinations.

Very little, if any, longevity, strength or strain data for biodegradable products was available to assist in design selection and typically only density (g/m^2 of mat) was available. We requested and received a number of product samples and simply manhandled them to get an idea of tear strength. The only longevity reference available was a claim for a 450g/m^2 mixed coir fibre/wool product indicating a 2-3 year life in 'wet conditions'.

The product selected was a 900g/m^2 coir fibre coarse core (rope like), open weave (net like) product. However, immediately upon award of tender it became apparent that this type of product was not available in stock and, to avoid construction delays, a 450g/m^2 mixed coir fibre/wool fine core, closed weave product was substituted. Photograph 1 below shows samples of the selected and substituted products.

Photograph 1: 900g/m^2 coir fibre selected product (left) and the 450g/m^2 mixed coir fibre/wool substituted product (right).

3 HABITAT ENHANCEMENT

3.1 IN – STREAM FEATURES

3.1.1 KEY HABITAT FEATURES

A literature review of the habitat preferences for the priority fish species was undertaken and presented in Earwaker et al., 2008. The key forms of habitat for target species included:

- Areas of low water velocity (< 0.1 m/s) in deeper pool areas (>0.5m deep) with features that provide in-stream cover for giant kokopu
- Features that provide in-stream cover for eel species in shallower run areas including bank overhangs, in-stream woody debris and overhanging riparian vegetation
- Areas of low water velocity (< 0.1 m/s) downstream of flow constrictions with features that provide good bank cover (overhanging banks or vegetation) for feeding inanga
- Overhead riparian cover and shade

3.1.2 OBSERVATIONS

Construction and monitoring of woody structures (T&T) and temporary small pipe (Waikato Regional Council) installations at other sites within Hamilton has indicated that these type of structures are utilized as habitat by fish species.

Electric fishing by T&T in a reach of the Te Awa o Katipaki Stream in Hamilton (Miller, 2013) has shown that the only fish found were associated with artificial woody (log overhang) and rock (large diameter rip rap) habitats.

Waikato Regional Council (WRC) have trialled temporary installations of short lengths of 150 mm diameter flexible corrugated plastic pipe at a small number of clear water stream sites in Hamilton. WRC has advised (pers. comm Bruno David) that visual (camera) inspections has shown that fish are willing to use this type of artificial habitat.

3.1.3 HABITAT ENHANCEMENT OPTIONS

The design approach to in-stream habitat enhancement through the project reach focuses on stabilising, enhancing, restoring or creating the features identified in Section 3.1.1 and included consideration of:

- Sympathetic, nature based engineering design – working with the existing physical and ecological features of the stream system
- Maintainability of works – recognition that works may require periodic maintenance over time, hence ensuring that designs facilitate this
- Cost minimisation – overall design concepts are kept simple and materials utilised for construction are minimised. Ideally works could be able to be constructed by hand by volunteers
- Stability – engineered habitats are likely to be more stable than natural woody debris that could be dislodged by stormwater flows

Identified habitat enhancement options included:

- Woody debris weirs (placed perpendicular to flow) to assist flow diversity and development of scour pools and low velocity zones while forming a riffle feature as flow passes over the weir
- Log overhangs (placed parallel to flow) to create in-stream cover

- Off-line, in-bank pipes of different sizes to create fish refuge tunnels and caverns for in-stream cover, and low velocity zone rest areas
- Grasses and trees planted directly adjacent the stream channel to provide bank cover and shade

3.1.4 DETAILED DESIGN

3.1.4.1 WOODY STRUCTURES

Key design considerations included:

- Stability and anchoring to prevent accidental blockage of the Peacockes Road culvert
- Durability of selected timber and any fittings
- Constructability.

A basic HEC-RAS model was developed for the stream reach based on detailed survey provided by Hamilton City Council. A simplified "no hydrology" model approach was adopted. The "no hydrology" approach ignored theoretical peak flow estimation and modelled an incremental range of flows under steady state conditions to estimate peak velocities. Peak velocities of 1.0 to 1.5 m/s were found to occur close to bank full flow (3 to 4 m^3/s) and a velocity of 1.5 m/s was adopted for design purposes. The HEC-RAS model was also used to compare the effect of woody weir structures (without altering bed levels as may occur after scour) on flow conditions. The woody weirs were generally found to have insignificant effect on flow depth or velocity at bank full flow.

A literature review of design guidance for woody debris installations was undertaken and the following method, assumptions and equations (Eqn's 1 to 6) were developed based on available literature (Brooks, A. et al. 2006, D'Aoust et al., 2000 and Roan et al., 2007) and engineering judgement.

Design assumptions for design of a single-log weir sitting on the stream bed included:

- Referenced equations (Brooks, A. et al. 2006) apply to this case
- No uplift on log or anchors occurs
- No drag on anchors occurs
- Soil backfill over bank keyed log is ignored as an anchor ballast (i.e. full bank scour assumed)
- Passive earth resistance on bank keyed log is ignored for sliding resistance (i.e. full bank scour assumed)
- Angle to flow on weir structures was 90 degrees and (up to) 22.5 degrees for log overhangs

Equations used to estimate the forces acting on the logs (Eqn's 1 and 3) and those resisting movement (Eqn's 2 and 4) are presented below:

$$F_B = \sum_{i=1}^{n} \left(\frac{L \times {D_n}^2}{4} \right) \pi \times P \times g \times (1 - S) \qquad (1)$$

Where: F_B = Buoyancy force on log (N)

n = number of logs

L= Total log length (m)

D_n = Log diameter (m)

P = Density of water (kg/m^3)

g = gravitational acceleration (m/s^2)

S= Specific gravity of "dry" log.

$$W_b = L_a \times W_a \times D_a \times P \times g \times (1 - S_a) \qquad (2)$$

Where: W_b = Weight of ballast anchor (N)

L_a = Anchor length (m)

W_a = Anchor width (m)

D_a = Anchor depth (m)

P = Density of water (kg/m^3)

g = gravitational acceleration (m/s^2)

S_a = Specific gravity of dry log.

$$F_d = \frac{1}{2} v^2 \times L_s \times D \times \sin B \times C_d \times P \qquad (3)$$

Where: F_d = Drag force on log (N)

v = Design velocity (m/s)

L_s = Log length in stream (m)

D = Log diameter (m)

B = Angle between the log and stream banks (degrees)

C_d = Drag coefficient

P = Density of water (kg/m^3).

$$F_r = (W_b - F_b) \times \tan \varphi \qquad (4)$$

Where: Fr = Sliding resistance of log (N)

W_b = Weight of ballast anchor (N)

F_b = Buoyancy force on log (N)

φ = Bed friction angle (°).

Factor of Safety (FoS) against movement were calculated as presented in equations 5 and 6 below.

$$FSb = \frac{W_b}{F_B} \qquad (5)$$

$$FSs = \frac{F_r}{F_d} \qquad (6)$$

The target FoS were adopted based on guidance presented in (Brooks, A. et al. 2006). The adopted FoS against buoyancy was 1.5, the adopted FoS against sliding was 2. Due to the proximity of the Peacockes Road culvert and the potential adverse consequence of partial blockage (based on anecdote of a historical log blockage incident resulting in significant scour and near landslide failure affecting a residence), relatively conservative design assumptions and FoS were adopted.

Assumptions for design of wire rope and ballast anchor fixings included:

- No uplift on log or anchors occurs
- Buoyant and drag forces apply simultaneously and act solely on the upstream anchor connection under tension
- Fc (force on anchor connection) can be calculated as a resultant vector of Fb and Fd.

Connection forces and FoS against movement were calculated as presented in equations 7 and 8 below.

$$F_c = \sqrt{{F_B}^2 + {F_d}^2} \qquad (7)$$

$$F_w = FSc \times F_c \qquad (8)$$

Where: F_c = Force on anchor connection (N)

F_B = Buoyancy force on log (N)

F_d = Drag force on log (N)

F_W = Wire breaking force (N)

FSc = Factor of safety for connection (assumed FSc = 2).

Black wattle was selected for all in-stream log structures as it was considered to be an extremely durable hardwood and was available to the project gratis from tree felling activities within the upper catchment (undertaken as part of the Project D restoration reach development).

Stainless steel fittings and fixings were utilised for durability. Anchors were constructed of 20 MPa concrete. On other projects, T&T have used boulders to anchor woody structures but in this instance boulders are not native to the catchment and concrete blocks were considered to be easier for installation of fixings and to place in live stream conditions. Consideration was given to lifting and placing methods and construction loads on the logs given a single point of lift. A short notch was cut down in the centre of the log weirs to concentrate low flows. Schematic representation of the bank keyed and anchored woody weir is shown in Figure 7 below.

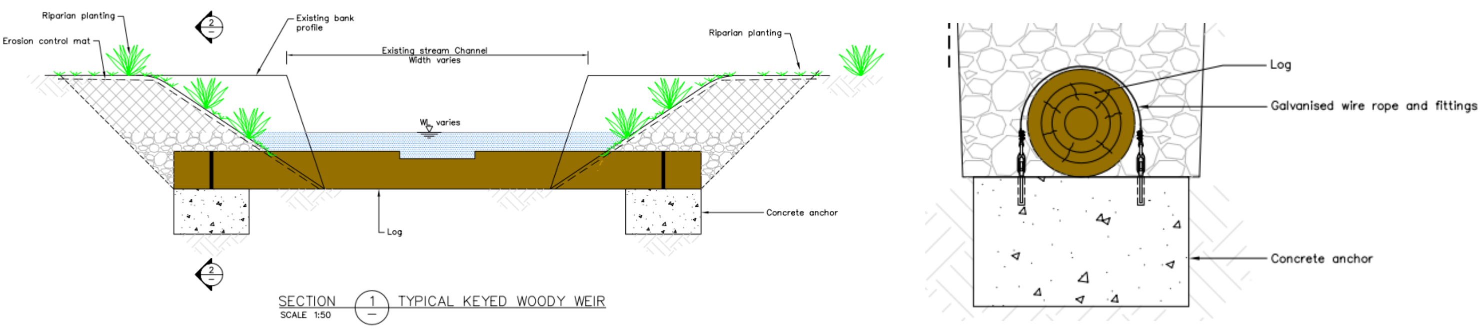

Figure 7. Schematic section of woody weir (left) and anchor (right). Log overhang similar but set above stream bed parallel to flow.

3.1.4.2 FISH REFUGE TUNNELS

The fish refuge tunnel design was developed based on temporary stream installations (by WRC) of short length flexible corrugated pipe fixed by cable ties to hollow concrete block anchors. The design was developed in conjunction with Bruno David of WRC.

Small diameter pipes were selected to provide habitat for juvenile (or adult eel) priority species. Key considerations in design included:

- Separate entry and exit points to enable prey species a means of escape if a predator species entered the tunnel
- Sedimentation
- Hand clearing of pipe if sedimentation occurred
- Variable flow depths
- Placement within a small stream bank footprint
- Visual inspection (by camera) to back of pipe from both ends
- Anchoring
- Pipe materials and ease of construction

Short (approximately 1.2 m long) lengths of u-shaped pipes were selected to allow the duel ends to be exposed to the stream and provide a maximum depth of 600 mm for inspection and cleaning (if required). Multiple layers of pipes were adopted to allow for utilisation under variable flow depths and to provide multiple individual habitats. Flexible and rigid (uPVC) pipes were considered and flexible pipes were adopted based on ease of installation, lack of jointing and availability of slotted pipes to reduce potential flotation issues. Pipe anchoring options considered hollow concrete blocks, placing within gabion baskets, and within open rock. Pipes were eventually anchored by soil containers and incorporated within a terraced bank erosion control feature (BRO2). Given the high density, multi-level habitat provided, this type of feature has been knick named 'Tuna Townhouse' by Bruno David of WRC.

Schematic representation of the tuna townhouse incorporated into BRO2 is shown in Figure 8 below.

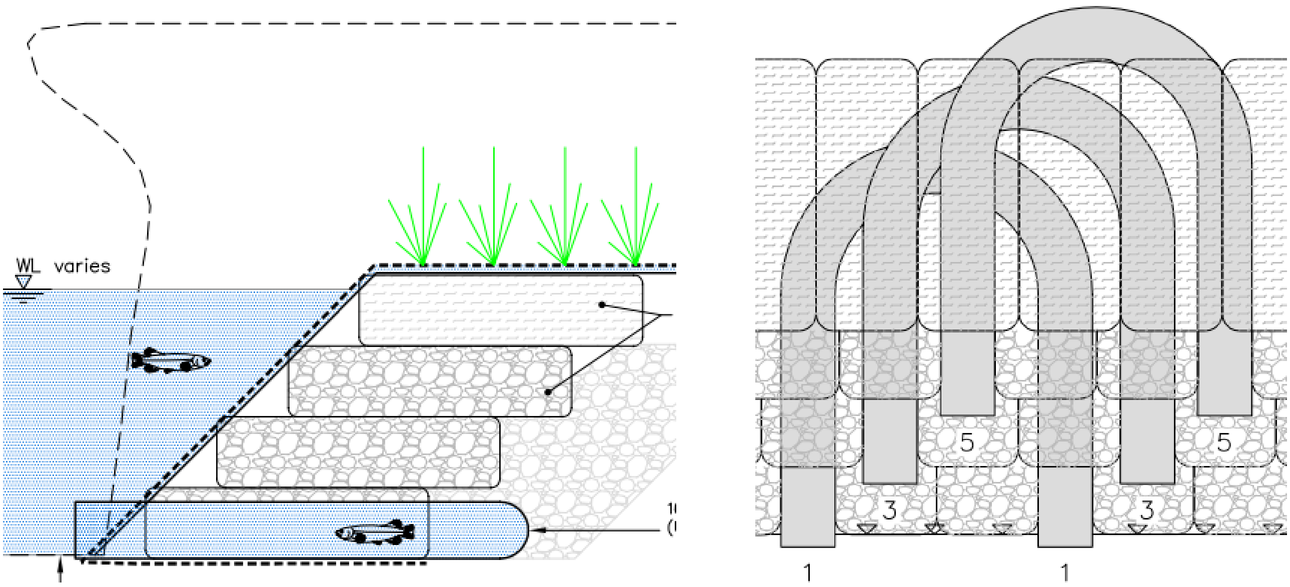

Figure 8. Schematic section of tuna townhouse - lower level pipe only shown (left) and schematic plan– showing three levels of pipes (right).

3.1.4.3 FISH REFUGE CAVERN

Following on from the 'Tuna Townhouse' concept, a large diameter installation was considered to target larger priority species and in particular giant kokopu and again the design was developed in conjunction with Bruno David of WRC.

Key considerations in design included:

- Single entry and exit point therefore pipe must be adequate size to enable manoeuvring (turn around) space for adult giant kokopu
- Provision of a deep, low velocity rest area
- Sedimentation
- Placement within a small stream bank footprint
- Visual inspection (by camera) to back of pipe
- Anchoring
- Pipe materials and ease of construction

In developing the design, the following were also considered:

- Installation would occur within a live stream environment and therefore jointing of pipes would be difficult
- PE or uPVC pipe could be pre-jointed, or 6 m lengths could be purchased, and easily lifted into place
- Ribbed wall PE pipes have significant strength advantages over uPVC pipes and ribs assist anchoring
- A rear chamber could be used to provide; a rest area, additional depth (below pipe obvert), anchoring of the 'land' end, and an inspection point.

A single 6 m length, 450 mm diameter PE pipe at 45 degrees to the flow with a 1.2 m diameter pre-cast concrete manhole rear chamber with invert approximately 400 mm below pipe invert was adopted. The trench was backfilled with aggregate and the stream face was reinstated using soil containers. This type of feature has been knick named 'Kokopu Condo' by Bruno David of WRC.

Schematic representation of the kokopu condo is shown in Figure 9 below.

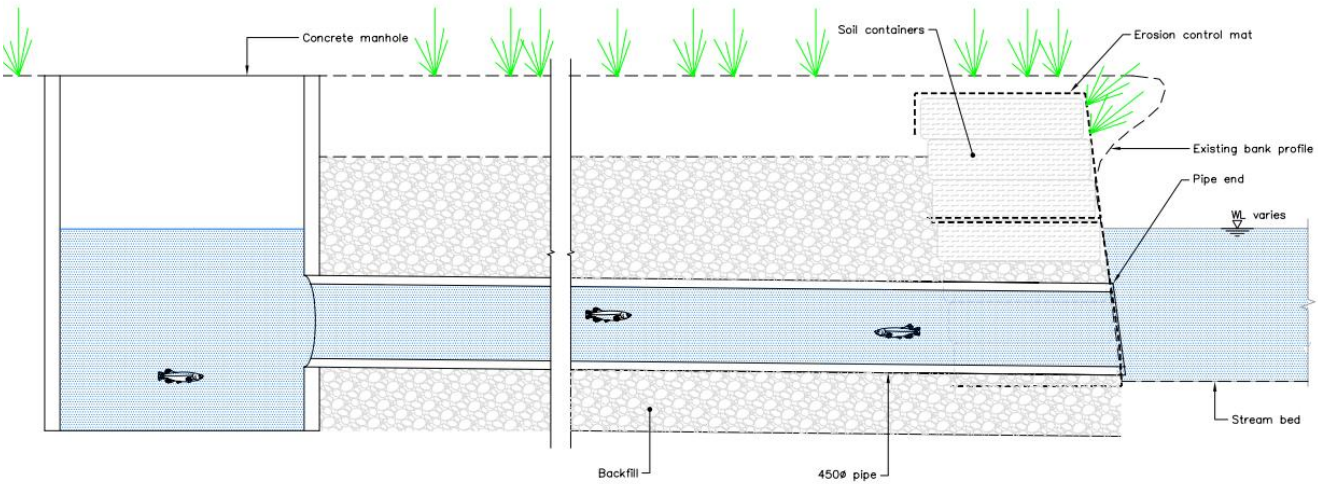

Figure 9. Schematic section of kokopu condo.

3.2 MINI WETLAND

3.2.1 SITE OBSERVATIONS

An existing degraded, neglected and damp corner of Sandford Park was identified as a potential site for the creation of a mini wetland providing landscape enhancement and provision for native mudfish habitat. An existing spring of unknown origin discharging to the Peacockes road kerb and channel some 100m from the proposed wetland was identified as a perennial source of freshwater. An existing culvert under the park access track provided a discharge point for local overland flows to the Mangakotukutuku Stream. The culvert outlet was generally perched above normal water levels but is regularly inundated in the winter months.

3.2.2 KEY HABITAT FEATURES

The key forms of habitat identified for native mudfish include:

- Areas of low water velocity (< 0.1 m/s) in shallow pool areas (<0.5m deep)
- Features (plants and hard substrates) that provide shade cover
- Soft bottom sediments suitable for burrowing
- Variable water depth with periodic drainage
- Overhead riparian cover and shade

3.2.3 DETAILED DESIGN

The design approach to the mini wetland included consideration of:

- Maximum pool depth of 450mm
- Dense wetland and riparian margin plantings
- Provision of wetland liner to maintain standing water
- Provision of topsoil for planting and as a soft substrate to facilitate burrowing
- Provision of woody log features for cover and burrowing areas
- Adjustable stop-logs within the outlet structure to facilitate control of standing water levels and ability to fully drain wetland
- Distribution of freshwater spring inflows across wetland
- Fish barrier outlet to reduce predator (mainly eel) invasion of wetland

The design included an imported low permeability clay liner over natural ground. The spring was tapped into at the existing pipe connection to the kerb and channel. The inflow pipe was located above ground and slotted flexible pipe was utilised to distribute flows at low velocity over a 20m length. Timber baffles were used within the outlet structure and sealed using silicone. The wetland outlet pipe utilised was solid wall flexible pipe to outside the wetland footprint and then utilised slotted pipe to distribute flows over approximately 20m of re-shaped drain. The capped end slotted wall pipe was used to disperse flows to minimise attractant flow for predators such as eels. The slots are sufficiently small to create a barrier to eels so as to eliminate entry into the wetland via the outlet pipe.

4 CONSTRUCTION

4.1 GENERAL

Construction occurred from March 2013 to June 2013. The stream was not diverted during the works and all works occurred 'in the wet'. Stream flows varied from 200 to 400mm above nominal bed level but were typically lower than normal, with the region being in a drought at the time. Notwithstanding, some significant flows occurred and are discussed below.

4.2 EROSION CONTROL FEATURES

BRO4 was constructed first and a significant depth (0.5-1.0m) scour hole had formed at the lower end of BRO4 since measurements were undertaken for design purposes. The scour hole was backfilled with approximately 4 m^3 of drainage metal prior to starting placement of soil containers.

For all BROs the bank was re-graded to the design batter by excavator and materials stockpiled on-site. The contractor initially utilised a metal filling frame whereby four to six containers were fixed to the frame and filled by excavator bucket prior to lifting off and placing. The contractor abandoned this method in favour of filling individual bags by shovel. The contractor initially filled the bags to near full before securing closed but this resulted in container mass of up to 40kg. The contractor subsequently revised his filling regime to effectively half fill the containers to reduce the mass to approximately 20kg. Each container was filled in an upright position, 'bounced' to consolidate and the ends rolled closed as tight as possible before securing with cable ties. A sharp point was used to penetrate the containers to thread cable ties.

Erosion matting was anchored at the toe by placing soil containers over the mat. Containers were placed flat on their side with the rolled end facing the bank and moulded in placed. The roll was then left in the stream whilst the soil containers were placed up to four containers high before the mat was raised into position and anchored by either additional soil containers or steel pins. Native soils were spread over the containers and erosion mat and grass seed applied.

4.3 HABITAT FEATURES

The mini wetland was constructed first in the programme. The site was cleared and excavated to foundation level. The foundation was very soft and two layers of geotextile placed perpendicular to each other was used to improve foundation strength. No other issues were encountered. The wetland was planted without the outlet timber baffles in place to prevent flotation of plants during the root development stage. Baffles were placed and sealed to raise the water depth to approximately 300mm some three months after planting. Four short length macrocarpa and kanuka logs were placed around the wetland by the contractor.

The kokopu condo was the first in-stream feature constructed and no significant problems were encountered. The manhole chamber was constructed 'in the dry' ahead of the pipe installation. The pipe trenching was initially half completed (chamber end only) allowing the pipe penetration in the manhole to be formed before breaking through to the stream and flooding the trench. Tracking aerials for future monitoring were incorporated into the stream and land ends of the pipe during installation under supervision of WRC. An existing log keyed into the bank immediately upstream of the pipe was left in-situ and soil containers moulded around to suit.

The woody weir installations proved difficult given the live stream conditions, access and plant used by the contractor. Access was only available via the true left bank and the contractors 12 t excavator had limited reach. To enable the far side to be prepared to site the log and anchor block, the contractor cut down the near bank to a low level to gain reach. The log and anchor blocks were fixed together on the flat and lifted into place as a single unit to avoid fixing the log to the placed anchors (underwater) in the live stream. The weir units were lifted in place using the excavator and a truck mounted 'palfinger' lifting unit. Chain strops were used under the log adjacent to each anchor block. The weir unit had to be lifted in place, the 'fit' with the stream bed checked and the unit lifted out again to cut down to anchor foundation level as required. This process was repeated a number of times to avoid over-excavation of anchor trench foundations before the right levels were obtained. The stream bank and channel materials at KW2 were very weak compared to KW1 and added to access and placement issues. The trimmed banks were covered with erosion mat and native soils and grass seed applied.

The log overhang installations were less difficult than the woody weir installations as the smaller log and anchor size, placement on the near side of the stream channel and lesser importance of the log being horizontally level meant that the contractor's plant was better suited.

4.4 NATURE'S TEST

In late April 2013, approximately 80% through construction of all works, a significant rain event occurred and the stream broke its banks inundating all of the works and the flood plain (Sandford Park) by up to 1 m over the site reach. Silt and debris were observed deposited across the park. It is roughly estimated that this was a 20 to 10% AEP event.

All BRO's were constructed as were three of the four log structures and the mini-wetland. The erosion mat on all features faired reasonably well with the exception of BRO2 where the mat was lost entirely. The contractor had chosen to install temporary pins on all erosion mats and had not completely finished anchoring the erosion mat at the ends. In many cases the temporary (standard 200mm long staples) were observed to have lifted, either caused by or allowing, the erosion mat to oscillate (lift and fall) under stream flow pressures. The downstream end of all bank features appeared to have suffered more than the upstream end. Subsequent observations under varied flow conditions suggests that turbulence and back eddies at the downstream transition from the new bank profile to the existing (near vertical) bank profile tended to exacerbate pressure waves and encourage the mat and pins to oscillate and lift.

The mini-wetland was finished with topsoil and grass but had not been planted. The wetland was submerged during the flood event but little to no damage was caused other than the saturated topsoil slumping off the top of the perimeter bunds as waters receded.

The three installed log structures and the kokopu condo did not appear to be affected. It should be noted that the log for woody weir structure KW2 was sitting above the stream bank, was submerged by flood flows and, despite being in a 'dry' condition and without concrete anchors, did not appear to have moved at all, suggesting that the bank keyed and anchor design is quite conservative.

5 MONITORING

5.1 MINI-WETLAND

Post-construction observation of the wetland has shown that the dispersed spring inlet arrangement, clay liner, baffle outlet, and slotted outlet pipe systems are functioning well and a permanent pool was maintained through the dry summer period. The selected plants have established very well and algal growth is quite limited. Weed growth is also rapid and the wetland and surrounds are being managed by MSCG.

At the time of writing no native mudfish have been transferred to the wetland but a transfer permit application is being prepared.

Temperature monitoring of the water within the wetland (near the outlet), stream (near the kokopu condo) and within the kokopu condo (manhole chamber) has been undertaken using 'tidbit' temperature loggers. Temperature monitoring has been undertaken from 31 October 2013, data retrieved to 28 February 2014 and results are summarized in Table 3. Air temperature data was obtained from the 'Hamilton Ruakura 2 EWS' weather station using the online National Climate Database administered by NIWA.

Table 3. Temperature Monitoring Summary

	Stream	Wetland	Kokopu Condo	Air
Maximum	21.9	26.2	20	28.5
Average	17.1	17.6	16.9	17.3
Minimum	13.1	11.7	14.4	5.5

Maximum and average wetland water temperatures recorded are elevated above recorded stream temperatures. Recorded minimum temperature is lower within the wetland compared to the stream. It is inferred that the wetland is more significantly affected by air temperature than the stream. The range of recorded wetland temperatures are within the range tolerable to native mud fish with the recorded maximum being at the extreme end of the recorded survivable range (O'Brien & Dunn, 2007). Additional shading plant species in and around the wetland may be required to reduce peak daily temperatures. Mudfish are likely to be compelled to aestivate (hibernate in the mud) as temperatures rise and dissolved oxygen falls (Barrier & Hicks, 1996).

5.2 IN-STREAM HABITAT STRUCTURES

Visual and probe inspections have been undertaken on a number of occasions since completion of physical works. In addition, visual inspection utilizing an underwater camera was undertaken by T&T in October 2013.

Visual, probe and camera inspections of the two log overhangs generally show variable levels of sedimentation with the stream bed undulating over the log length. Average void depth under the logs varies from 0 to 300 mm with very good habitat potential. LO1 generally has better void space whilst significant sediment accumulation between LO2 and the near bank was found to be limiting the void space and thus habitat potential under that log. The stream bank in the area of LO2 is very soft and unstable and bank slumping appears to be the source of most sediment.

Visual, probe and camera inspections of the two woody weirs has shown quite different results. The stream adjacent KW1 has an average bed level differential across the log of approximately 100 to 200mm with variability across the stream width from 0 – 300mm. The top of the log sits at least 100 mm proud of the stream bed. The log is not quite level and the greater differential was observed on the 'high' (true right) side where a deeper scour hole (600 mm below log level) was observed immediately downstream. The KW2 log has experienced on ongoing sedimentation since construction and at the time of writing is effectively buried over the full stream width. The feature weir has been rendered ineffective and does not appear to have been able to maintain a bed differential across the log or a scour hole on the downstream side.

The kokopu condo has experienced ongoing sedimentation since construction and at the time of writing sediment accumulation approximately 500mm in from the stream end is approximately half the pipe diameter. A probe has been extended into the pipe a number of times and it is inferred that the sediment does not get significantly higher than half the pipe height and appears to taper off further in to the pipe. Sediment accumulation at the rear manhole chamber and manhole end of the pipe has been less than 100mm and confirms inferred ‘tapering’ of sediment within the pipe. Camera inspection from the stream end proved ineffective as the poor water clarity is made significantly worse by disturbance of algal growth on the pipe walls and overall visibility is too poor to make any definitive observations. Overall some void space, and thus access and habitat, remains available near the pipe obvert and all habitat is available within the rear chamber. Some filmy water observed within the rear chamber suggests some lack of water exchange between the stream and the chamber. Temperature monitoring has been undertaken within the rear chamber and results are summarised in table 3 above. In general it appears that the rear chamber water temperature is similar to the stream but has a more narrow range and lower average temperature. The more narrow range and lower average temperatures is inferred to be due to the lack of direct sunlight and possibly due to low levels of water exchange.

All six fish refuge tunnels that make up the tuna townhouse are partially blocked with deposits increasing in depth from nil at the stream openings to 80-100% at the rear. The lower level pipes generally have less sediment accumulation than the top level which is partially above low water levels during summer. Overall the void space and habitat potential remains available near the pipe obvert but the tunnels are tending to be more like small caverns due to lack of thoroughfare at the rear. On two occasions these pipes have been cleaned out using a flexible foam rod (pool noodle) and re-sedimentation has occurred within a month. The pipes have been left untouched for periods of over six months and the sediment accumulation has not been observed greater than after one month. Camera inspection from the stream ends proved ineffective as the poor water clarity is made significantly worse by disturbance of algal growth on the pipe walls and overall visibility is too poor to make any definitive observations.

5.3 EROSION CONTROL FEATURES

Visual inspections of the four BROs and the erosion control matting placed on disturbed areas associated with the kokopu condo and the two woody weirs have been undertaken semi-regularly since the completion of construction.

The erosion mat on all features (except BRO4) has faired reasonably well where grass strike was rapidly achieved. The matting used appeared to provide a reasonable growing medium for seeds to germinate in and the grass roots were capable of penetrating to the underlying soils. In these cases the erosion mat has done a good job at temporarily protecting the bare ground before breaking down and providing mulch for continued grass growth.

Where grass strike was not achieved rapidly (isolated areas of some features, all of BRO4 and the far bank at KW1 and KW2) the erosion mat did not perform well. It is generally considered that grass strike was not achieved in some locations due to seeded areas being constantly inundated and/or continually washed out by stream flows as the contractor re-seeded a number of areas to no avail. Where grass did not strike quickly into the erosion mat, the matting rapidly deteriorated, becoming so weak (similar to wet cardboard) within two months that nominal finger pressure would push through the matting and oscillations of the mat caused by stream flow pressures would tear the matting around the fixing pins. BRO4 was particularly bad and local high velocities, eddies and vandalism all appeared to be contributing factors at this location. It should be noted that BRO3 and BRO4 are the same erosion control option types, used the same materials and BRO3 had great grass strike and no problems. The erosion mat has disintegrated on all features just above the normal water line.

The soil containers on most features remain covered except at or below the normal water line. The soil containers in those areas are exposed and have variable silt cover and appear to be in fair condition. The soil containers forming the mid-slope bench on BRO2 are generally covered with 100mm of sediment and weed species have fully established on the bench during summer 2013/2014. Soil containers higher up on BRO4 have been exposed to sunlight for some six months due to problems with the erosion matting. The material has become brittle and is showing signs of deterioration, for example, if reasonable pressure (like foot fall) is placed on the containers they tend to split. The containers with penetrations from fixing pins appear to be in the same condition as other containers i.e. no additional tearing has occurred.

The exposed soil containers on BRO4 have provided an opportunity to inspect soil condition within the containers and observe regeneration without the erosion mat. Small penetrations were made into two separate containers in order to inspect the contained soils. The soil appeared very firm compared to in-situ stream bank soils and had a reasonably cover of small vegetation (mosses and grasses). Similarly to the erosion mat, we can infer from these limited observations that the act of containing the native soils has provided short term resistance to erosion whilst allowed vegetative cover to establish. Stream sediments have been deposited on the soil container face, mainly at the small step between container layers and particularly at the small depression between containers. Grasses and weed plants have seized this small opportunity and have established disparate pockets of growth up and down the length and full bank height, meaning that not all of BRO4 is fully exposed.

Consolidation of soil containers and consequential effects on the re-graded stream banks was considered a key design risk but has not been a significant issue post-construction. All erosion control features appear stable with the exception of some local scouring caused by concentrated overland flows from the park area affecting BRO1.

5.4 FISH MONITORING

NIWA and WRC have installed tracking aerials within the project reach (approximately 10m downstream of the kokopu condo) and within the kokopu condo (each end of pipe) respectively. In late 2013 five giant kokopu, sixteen longfin eels and two short fin eels were netted, measured and tagged on the Mangakotukutuku Stream. Only two giant kokopu and eight longfin eels were netted and tagged within the project reach. Pit tags with individual numerical identification were attached to each fish netted to enable tracking. Each time a tagged fish passes through an aerial, the time, date and tag number is recorded.

NIWA has retrieved raw data for the period from 14 November 2013 to 15 January 2014. The data has not been fully analysed but a signal count, how many times a fish has been recorded on the system, has been undertaken. NIWA (pers. comm Cindy Baker) has advised that only fish netted within the project reach have been recorded and that six out of the ten fish recorded in the reach (one giant kokopu and five longfin eels) have had signals tracked that indicate movement across the aerial within the reach.

WRC has retrieved raw data for the period from 14 November 2013 to 7 December 2013). WRC have advised (pers. comm Bruno David) that one longfin eel tagged within the reach is utilising the kokopu condo. The signals also indicate that this fish has explored at least the entire pipe length and more than likely entered the rear chamber. Further analysis is required to assess the length of occupancy and any movement patterns. WRC have also advised that on 30 August 2013 (prior to pit tagging) they visually identified (using underwater camera) one longfin eel sitting within the kokopu condo pipe, it is not known if this is or is not the tagged longfin identified by later signal records. In summary we can say that from August to December 2013 the kokopu condo has been ‘occupied’ and in the later part of this period at least one particular individual longfin has frequently occupied this artificial habitat feature.

6 CONCLUSIONS

This paper has discussed restoration initiatives implemented along a short reach of the Mangakotukutuku Stream in Hamilton.

This paper showcases the work involved in creating demonstration restoration sites on the Mangakotukutuku Stream in Hamilton City. The paper has openly discussed design development, construction and monitoring associated with erosion control and habitat enhancement features. A design calculation method for anchored woody in-stream structures was used and appears conservative.

Independent fish movement monitoring and preliminary data review by NIWA and WRC indicates that one (longfin eel) out of the ten fish tagged within the project reach has been frequently occupying the kokopu condo as habitat and has at least explored the entire pipe and more than likely the rear chamber.

With respect to the potential for community based construction initiatives we consider that with appropriate design, guidance and supervision, a community group could successfully implement erosion control features, including the tuna townhouse habitat enhancement or similar features as discussed within this paper. We consider that features such as, the mini wetland, kokopu condo and woody in-stream structures require professional construction contractors.

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- John Carter Constructors Ltd

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