Dudley Creek Flood Remediation
Downstream Options Report
Rev 2, 12/6/15
Appendix C

Dudley Creek Flood Remediation:

ECOLOGICAL CONDITION OF LOWER DUDLEY CREEK

EOS Ecology Report No: BEC01-15015-01 | June 2015
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AQUATIC SCIENCE & VISUAL COMMUNICATION


Approved for release by:
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12-06-15

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EXECUTIVE SUMMARY

Dudley Creek is the focus of a flood remediation project, aimed at providing more flood capacity in the lower reaches of Dudley Creek to alleviate flooding in the upper catchment. There are three options currently being considered for the lower reaches of Dudley Creek (Figure 1), which incorporate a combination of pipes to bypass flood flows and widened channels to accommodate larger flood flows. As this programme involves the widening of the channel there are potential effects to the ecology of the stream and its riparian zone (the land immediately adjacent to the stream edge that is integrally linked to the health of the stream). This report summarises the existing ecological condition of Dudley Creek, so that this information can be used to inform the decision-making process regarding the best option for flood remediation, as well to inform the design of the altered channel in a way that will consider the natural values of this system as well as flood remediation goals.

The ecological condition of Dudley Creek was assessed via site walkovers, surveys of trees along the stream, sampling of fish and invertebrate communities, and reviewing existing data on the water and sediment quality of the stream. Dudley Creek is a slow flowing, heavily silted stream, with moderately contaminated stream sediments and reasonable water quality at low flow. The section between the Avon River and the Banks Avenue-North Parade intersection is also tidal. The stream banks are predominantly grassed. The large trees help to shade the stream and would help to keep aquatic plant growth down, but the preponderance of larger exotic trees does pose a risk to the health of this stream during autumn leaf fall, when the accumulation and breakdown of such large amounts of leaves can reduce oxygen levels in the stream. There is a high diversity of native and exotic plants and trees along the stream, with some larger clusters of native vegetation that attract native birds such as fantails/piwakawaka. In general there is an even mix of native and exotic tree species along the Banks Avenue section, while the Stapletons Road section is mainly exotic on the public road-side (i.e., the true-left) and mainly native on the private (true-right) side. However, the majority of large stature trees are exotic, including sycamore and silver birch along Banks Avenue (which are considered ecological risky species or in the case of silver birch, an allergen) and swamp cypress along Stapletons Road (which are used by monarch butterflies as winter roost sites). The native trees tend to be smaller stature and shorter-lived species, such as cabbage tree, ribbonwood, lemonwood and other *Pittisporum* species.

The aquatic invertebrate community was dominated by invertebrate taxa that are typical of heavily urbanised streams with fine bed sediments and slow water velocities, and thus reflective of poor quality habitat. Empty shells of New Zealand's largest freshwater bivalve, the freshwater mussel/kakahi, were found along Banks Avenue. While we cannot be certain if there are any live specimens in Dudley Creek, the presence of empty shells is strong evidence that this stream was once in better condition than it is today. It is possible that the invertebrate community of Dudley Creek was also badly impacted by the large deposits of liquefaction sand that smothered the stream channel following the February 2011 earthquakes.

In contrast to the poor quality invertebrate community, the fish community was found to be diverse, supporting seven native fish species (in order of abundance, common bully, shortfin eel, upland bully, longfin eel, giant bully, bluegill bully, inanga), of which three have a

national threat classification of 'at risk – declining'. Greater densities of fish were found at sites where there was better cover (such as larger instream substrate like rocks, logs and tree roots, overhanging bank vegetation, and gaps in rock edgings or undercuts along earth banks). The discovery of the 'at risk' diminutive bluegill bully at one fast-flowing riffle section along Banks Avenue identifies this section as a high-value habitat that should be protected and if possible, enhanced. Reasonable numbers of large longfin eels, another 'at risk' fish species that is also culturally significant, were found upstream of Petrie Street and always associated with areas of stream with good fish cover. There was a good representation of larger eels, with both large longfin and shortfin eels being regularly fed by residents along Dudley Creek. The future of this large and particularly long-lived species, as well as other fish species such as inanga and giant bully, is certainly dependent on providing sufficient cover (in the form of large coarse substrate in the stream such as rocks and logs, overhanging vegetation, eel holes along the bank, low overhanging vegetation, and trees to provide shade) in and along the stream.

The results of the ecological investigations indicate that the ecological values of the stream are poor in relation to sediment quality and aquatic invertebrates, but moderate in relation to the fish community. On this basis there is great potential to improve these values (especially for fish) through improving habitat quality with some of the proposed options.

In general, design options that look to widen the flood channel to provide for greater flood capacity also provide the opportunity to greatly improve the habitat condition of Dudley Creek and its riparian zone, which will have a long-lasting ecological benefit to the stream and wider environment, and thus secure a greater value natural asset for future generations. This is consistent with the CCC's six values approach (drainage, ecology, landscape, recreation, heritage, culture) and with the philosophies and objectives set out in the CCC's 'Waterways, Wetlands and Drainage Guide' (CCC, 2003a, b) that states that "*drainage is integrated with all other 'values' (ecology, landscape, recreation, heritage and culture) to form the foundation of a philosophy that is multi-disciplinary and sustainable*". Attributes to be included in the design to achieve this would be the removal of fine sediment and replacement with gravels, narrowing of the low flow channel via the creation of a low bank that is planted and regularly inundated, provision of instream and bank cover in the form of larger rocks and logs, the provision of overhanging cover in the form of soft native plants along the stream edge, use of replacement tree species that have an ecological as well as aesthetic function and which are not regarded as problem species from ecological or health perspective, and a good representation of native trees in the wider riparian zone that will help to provide habitat and food for native birds that are currently found in the area.

1 INTRODUCTION

As a consequence of increased flooding in the Flockton area of Christchurch following the 2010 and 2011 earthquakes, the Christchurch City Council (CCC) is looking at options to reduce these flood risks. The initial phase of the works, undertaken in 2013-14 by CCC and its sub-consultants, was to develop solutions for remediating this flood risk. In November 2014 the Council consulted on the project, which included upstream channel widening with a combination of naturalised and engineered banks, and a downstream piped bypass along Warden Street, through Shirley Intermediate and along Banks Avenue. In December 2014 a council decision was made to continue the design and construction work for the upstream portion of works, while continuing to further investigate alternative downstream options. This work is being undertaken on behalf of the CCC by a Beca-Opus consortium.

This report relates to those downstream options being investigated further (as shown in Figure 1 and herewith referred to as the Dudley Creek downstream flood remediation options), to ascertain the most suitable solution that encompasses flood remediation as well as a range of other issues, such as cost, longevity, future-proofing, and ability to meet the CCC's other five values (ecology, landscape, recreation, heritage, culture – as specified in CCC, 2003a, b). The options being considered include a piped diversion at Warden Street combined with channel widening along Banks Avenue (Option A in Figure 1), a piped diversion at Warden Street that discharges directly to the Avon River (with two possible outfall locations, Option B in Figure 1), and channel widening along Stapletons Road prior to a piped diversion at Petrie Street that discharges into the Avon River (Option C in Figure 1).

EOS Ecology, as a sub-contractor to the Beca-Opus team, was commissioned to assess the relative merits of each of the downstream options on ecology, and to provide design input to ensure the protection (and ideally improvement) of the existing ecological values of the stream. However, in order to provide such guidance it is necessary to first understand the ecological condition of Dudley Creek. This report therefore provides an account of the ecological condition of Dudley Creek, between the Avon River and Shirley Stream confluences, and provides the basis for all of our subsequent ecological design and decision-making inputs to the Dudley Creek downstream flood remediation options.

FIGURE 1 ▶
Options proposed to alleviate flooding in the upper Dudley Creek catchment. Map created by the project team on the 3 June 2015.

0 40 80 120 160 200m
N
LEGEND
OPTION A
PIPED SECTIONS
SELECTED SECTIONS OF DUDLEY CREEK WIDENED TO IMPROVE STREAM CAPACITY
OPTION B
PIPED SECTIONS
PIPED SECTION ALTERNATIVE ROUTE
OPTION C
PIPED SECTIONS
SELECTED SECTIONS OF DUDLEY CREEK WIDENED TO IMPROVE STREAM CAPACITY
UPSTREAM CREEK MODIFICATION TO IMPROVE STREAM CAPACITY
UPSTREAM CREEK WIDENING AS PREVIOUSLY REPORTED
OPTION A
OPTION B
OPTION C
SHIRLEY STREAM
SHIRLEY ROAD
THE PALMS
DUDLEY CREEK
WARDEN STREET
SHIRLEY INTERMEDIATE SCHOOL
NORTH PARADE
ACHILLES AVE
COOPERS RD
SHIRLEY BOYS' HIGH SCHOOL
MARIAN COLLEGE
BANKS AVE
RICHMOND PARK
BANKS AVENUE SCHOOL
HILLS ROAD
SLATER STREET
CHANCELLOR STREET
STAPLETONS ROAD
PETRIE PARK
PETRIE STREET
GUILD STREET
AVERILL STREET
POULTON AVE
ST ALBANS CREEK
CHRYSTAL STREET
WOODCHESTER AVE
RESIDENTIAL RED ZONE
DUDLEY STREET
ŌTĀKARO / AVON RIVER
MEDWAY STREET
RANDALL STREET
NICHOLLS STREET
FLESHER AVE
RIVER ROAD
NSIDE DRIVE
SULLIVAN PARK

2 METHODS

2.1 LITERATURE/DATA SEARCH

A range of service providers, databases, and report repositories were searched for ecological data on Dudley Creek. From these sources, only limited data was obtained:

- Previous invertebrate data in the project area (i.e., within Dudley Creek through to Aylesford Street) consisted of two sites; one site sampled by Environment Canterbury (ECan) in December 2014 and one CCC site sampled by Boffa Miskell in November 2013. In considering the aquatic invertebrate community of lower Dudley Creek we chose not to include the previous invertebrate data due to concerns over its comparability with subsequent data collected by EOS Ecology in May 2015. Both the CCC and ECan datasets had far lower taxa richness (both had eight taxa compared to 16 and 14 taxa[1] at the EOS Ecology sites), while the CCC data had an unusually low total abundance which was an order of magnitude less than the EOS Ecology samples (i.e., 108 invertebrates at the CCC site compared to 1,154 and 3,056 at the EOS Ecology sites). Differences in sampling protocols, time of year, preceding flow conditions, timing of in-channel maintenance, or processing methods may help explain these differences. Irrespective of the reason, the differences in the data and time of year for sampling compared to the current surveys was such that we did not consider it appropriate to include the data in this report, as its inclusion could result in skewed representations of some sections.
- Previous fish data in the project area (i.e., within Dudley Creek through to Aylesford Street) consisted of one site surveyed by Boffa Miskell in November 2013 (Blakely, 2014) and two historic fish sites (surveyed in 1992) along Banks Avenue found on the New Zealand Freshwater Fish Database (NZFFD). While one fish site surveyed in 2013 was considered recent enough to be of use in this report, the two sites from the NZFFD were considered too old (i.e., from 1992 and so 23 years old) to be relevant in today's post-earthquake environment and so were not included.
- Water quality data from a long-term monitoring site at the North Parade and Averill Street intersection was obtained from the CCC (Bartram, 2014).
- CCC also provided sediment quality data from one site at the North Parade and Averill Street intersection (surveyed by NIWA: Gadd & Sykes, 2014), and biofilm contamination data from one site at the corner of Banks Avenue and North Parade from CCC (surveyed by Golder; Golder, 2012).

[1] Taxa is a term for taxonomic groups (such as phylum, order, family, genus, or species) into which invertebrates were classified.

2.2 ECOLOGICAL SURVEYS TO SUPPLEMENT EXISTING DATA

We undertook extensive site walkovers in April 2015 to characterise the general habitat of Dudley Creek and its wider terrestrial environs. Trees along the stream were also assessed in an arboriculture survey by CCC aborist Laurie Gordon and other staff in April-May 2015, which identified the species, size, condition, and likely remaining lifespan of tree species within the riparian zone of Dudley Creek.

Due to the dearth of information on fish and invertebrates, surveys were undertaken along Dudley Creek between the Avon River and Shirley Stream confluences, including two aquatic invertebrate sites and six fish sites (Figure 2). As fish are migratory, an additional two sites were also fished in Dudley Creek outside of the immediate project area, upstream of the Shirley Stream confluence (Figure 2).

Each invertebrate sample was collected over a 20 m reach, using a conventional kicknet with a 500 micron mesh size. The sample covered an effective area of 0.45m^2 (i.e., a composite of five separate 'kicks'), and covered all the different habitat types within that area (i.e., mid-channel and margin areas, different substrates in the channel, and macrophytes/aquatic plants if present) as per the standard sampling protocols of Stark *et al*., (2001). Each kick involved disturbing the substrate across an approximate 0.3 m × 0.3 m area immediately upstream of a conventional kicknet (500 µm mesh size) (Figure 3). The invertebrate sample was preserved in 70% isopropyl alcohol, and taken to the laboratory for processing following a 'full count with subsample' processing method. This entailed washing the sample through a series of nested sieves (2 mm, 1 mm, and 500 µm) and counting and identifying all invertebrates to the lowest practical level using a binocular microscope and a range of taxonomic identification keys (Figure 3). Sub-sampling was utilised for particularly large samples and the unsorted fraction scanned for taxa not already identified. The invertebrate data was then summarised by the abundance of common taxa, number of Ephemeroptera-Plecoptera-Trichoptera taxa (EPT richness), % EPT, the hard (MCI-hb) or soft-bottomed (MCI-sb) equivalent of the Macroinvertebrate Community Index (MCI), and its quantitative variant (QMCI). The following provides a brief description of these indices:

- EPT taxa are those invertebrates within the orders of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). They are generally regarded as 'clean-water' taxa, meaning they are relatively intolerant of organic enrichment or other pollutants and habitat degradation. The exception to this are the hydroptilid caddisflies (Trichoptera: Hydroptilidae: *Oxyethira*, *Paroxyethira*), which are algal piercers and often found in high numbers in nutrient enriched waters and degraded with high algal content. For this reason, EPT metrics are presented with and without these taxa. EPT richness and % EPT can, therefore, provide a good indication as to the health of a particular site. The disappearance and reappearance of EPT taxa also provides evidence of whether a site is impacted or recovering from a disturbance. EPT taxa are generally diverse in non-impacted, non-urbanised stream systems, although there is a small set of EPT taxa that are also found in urbanised waterways.

- In the mid-1980s, the macroinvertebrate community index (MCI) was developed as an index of community integrity for use in stony riffles in New Zealand streams and rivers, and can be used to determine the level of organic enrichment for these types of streams (Stark, 1985). Although developed to assess nutrient enrichment, the MCI will respond to any disturbance that alters macroinvertebrate community composition (Boothroyd & Stark, 2000), and as such is used widely to evaluate the general health of waterways in New Zealand. Recently a variant for use in streams with a streambed of sand/silt/mud (i.e. soft-bottomed) was developed by Stark & Maxted (2007a), and is referred to as the MCI-sb. Both the hard-bottomed (MCI-hb) and soft-bottomed (MCI-sb) versions calculate an overall score for each sample, which is based on pollution-tolerance values for each invertebrate taxon that range from 1 (very pollution tolerant) to 10 (pollution-sensitive). MCI-sb and MCI-hb are calculated using presence/absence data and a quantitative version has been developed that incorporates abundance data and so gives a more accurate result by differentiating rare taxa from abundant taxa (QMCI-hb, QMCI-sb). MCI (QMCI) scores of ≥120 (≥6.00) are interpreted as 'excellent', 100–119 (5.00–5.99) as 'good', 80–99 (4.00–4.99) as 'fair', and <80 (<4.00) as 'poor' (Stark & Maxted, 2007a, b). Since there were sites with fine sediment and sites with a coarse substrate, both MCI variants were used.

Fish surveys were undertaken via a 'single pass electrofishing' method using a backpack operated Kainga EFM 300 electrofishing machine (Figure 3). Electrofishing passed as low amperage electric current through the water temporarily stuns the fish, allowing them to be caught in a handheld stop net or net. The captured fish are placed in buckets of water and are identified and measured (Figure 3) before returning them live to the stream. Fish data was then summarised by catch per unit effort (CPUE). CPUE refers to the number of fish captured per unit of effort expended, which in this case was the area of stream that was electrofished. One of the key attributes recorded at each fishing site was the amount of fish cover provided by substrate (cobbles, rocks, logs), aquatic plants, undercut banks and overhanging vegetation.

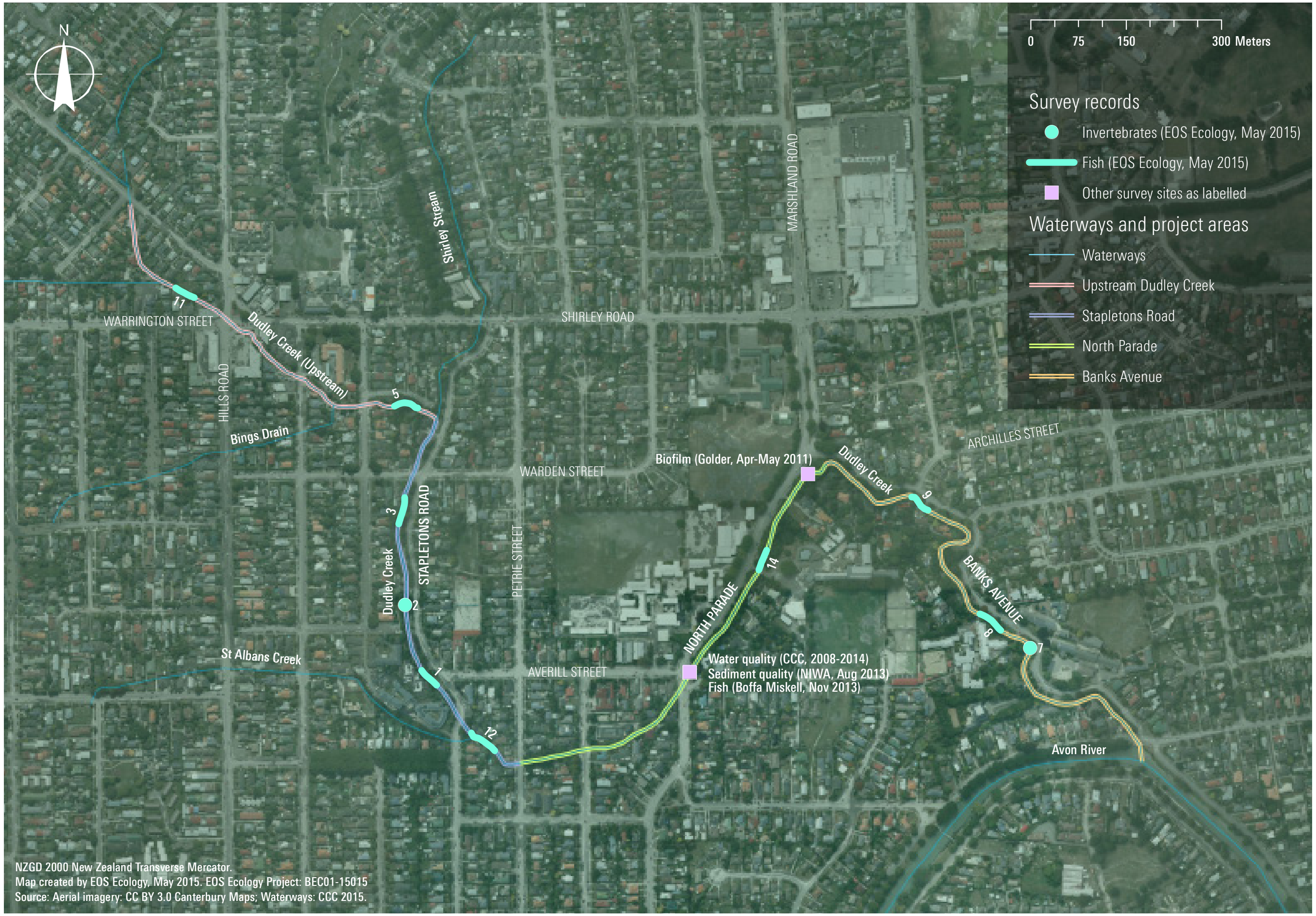


FIGURE 2
Map showing the location where ecological data (either fish or invertebrates) and water/ sediment quality data was obtained for Dudley Creek. EOS Ecology sites were sampled in May 2015, the remaining data was provided by Christchurch Ciy Council, with the dates of sampling as specified on the map. The three project sections for the downstream reach (i.e., Banks Avenue, North Parade, Stapletons Road) are also indicated. Site photographs are provided in Appendix 1.

Kicknet sampling

Processing invertebrate samples

Electrofishing

Measuring and identifying fish (a large longfin eel)

FIGURE 3
Photographs of ecological sampling methods used in May 2015 to assess the health of Dudley Creek between the confluence with the Avon River and the confluence with Shirley Stream.

3 EXISTING ECOLOGICAL CONDITION

3.1 AQUATIC AND RIPARIAN HABITAT

Dudley Creek is a slow flowing, flat gradient stream. The majority of the stream had a silt or sand substrate (Figure 4, 5), which is of poor habitat value. There were some areas of larger rocks overlying this fine substrate providing improved habitat conditions in those locations (Figure 5). Small patches of coarser substrate (gravel and cobbles) were present where the gradient of the stream is steeper (Figure 4, 5), and these were regarded as the better areas of instream habitat. In slow flowing sections with greater numbers of large-leaved exotic deciduous trees, the substrate was covered with a thick layer of leaf litter. In slow flowing sections this litter would likely remain for some time and could result in low oxygen levels in the stream as they break down, reducing the ability of aquatic biota to survive. The lower reaches of Dudley Creek (from the Avon River confluence upstream to near the Banks Avenue-North Parade intersection) is also tidal. In this section the flow reverses (i.e., flowing upstream) during high tide in the Avon River, and there is a tidal fluctuation level of around 0.5 m.

The predominant understory vegetation along the true-left side (i.e. the road reserve side) of the stream along Banks Avenue, North Parade and Stapletons Road, was mainly mown grass (Figure 6), with small patches of recently planted native grasses along the stream edge (i.e., *Carex*). Plants on the true-right (which is predominantly private land) had a greater variety and distribution of species, including native and exotic plants. There were few areas where larger grass species (such as *Carex secta*) and flax/harakeke large enough to provide some vegetative overhang along the stream. A number of plant pest species were also identified growing along the stream banks, including male and female ferns, ivy, tradescantia, and old mans beard (vigorous growth along the true-right side of Dudley Creek along Stapletons Road). The stream banks themselves were made up of a mixture of natural earth, rock walls, iron and timber retaining walls.

The stream was mostly shaded along its length, keeping the growth of aquatic plants to a minimum (although this may also have been a result of regular instream maintenance by CCC). The mix of native and exotic tree species varied throughout the Dudley Creek area, with an even representation of native and exotic trees along the Banks Avenue and Stapletons Road sections and mostly exotic along the North Parade Section (Table 1). For Banks Avenue the mix of native and exotic was roughly balanced on both private and public (street-side) land, while for the Stapletons Road section the majority of native species are on private land (the true-right side), with the road-side being dominated by exotic species. All larger stature trees along Dudley Creek between the Avon River confluence upstream to the Shirley Stream confluence were predominantly exotic; mainly made up of sycamore (*Acer pseudoplatanus*) and silver birch (*Betula pendula*) along Banks Avenue section and swamp cypress (*Taxodium distichum*) along Stapletons Road (Figure 7). The native trees were generally smaller stature species, consisting of mainly cabbage tree (*Cordyline australis*), lemonwood (*Pittosporum eugenioides*), ribbonwood (*Plagianthus regius*) along the Banks Avenue section and *Pittisporum* species (potentially matipo or *Pittosporum tenuifolium* – Laurie Gordon, pers comm.) along Stapletons Road (Figure 7). Native birds (such as fantails/piwakawaka) observed during site visits tended to be associated with areas that had more substantial clusters of native trees and shrubs. The large swamp cypresses along Stapletons Road are also used by monarch butterflies as winter roost sites.

Based on the classification of Howell (2008) sycamore and silver birch are regarded as environmental weeds in New Zealand (as it relates to their status on land managed by the Department of Conservation). Ecan's Regional Pest Management Strategy (RPMS) (Maw, 2011) aims to remove sycamore (along with a range of other species) in 'high-value environmental areas' within the Canterbury region, due to their ability to readily invade natural systems. Waterways within cities usually represent more natural systems within an otherwise heavily modified landscape. As such, the choice of plant and tree species within riparian zones should give consideration to the effect they have on riparian ecosystems and stream functioning, in addition to any aesthetic function. For this reason tree species such as sycamore and silver birch were identified as biosecurity risk species for the riparian zone along the Avon River by McMurtrie *et al*. (2013), due to their prolific viable seed/fruit production, invasive habitat, and thus greater maintenance requirements. Silver birch are also now recognised as a significant allergen source, and have been linked to a range of allergic reactions in some people.

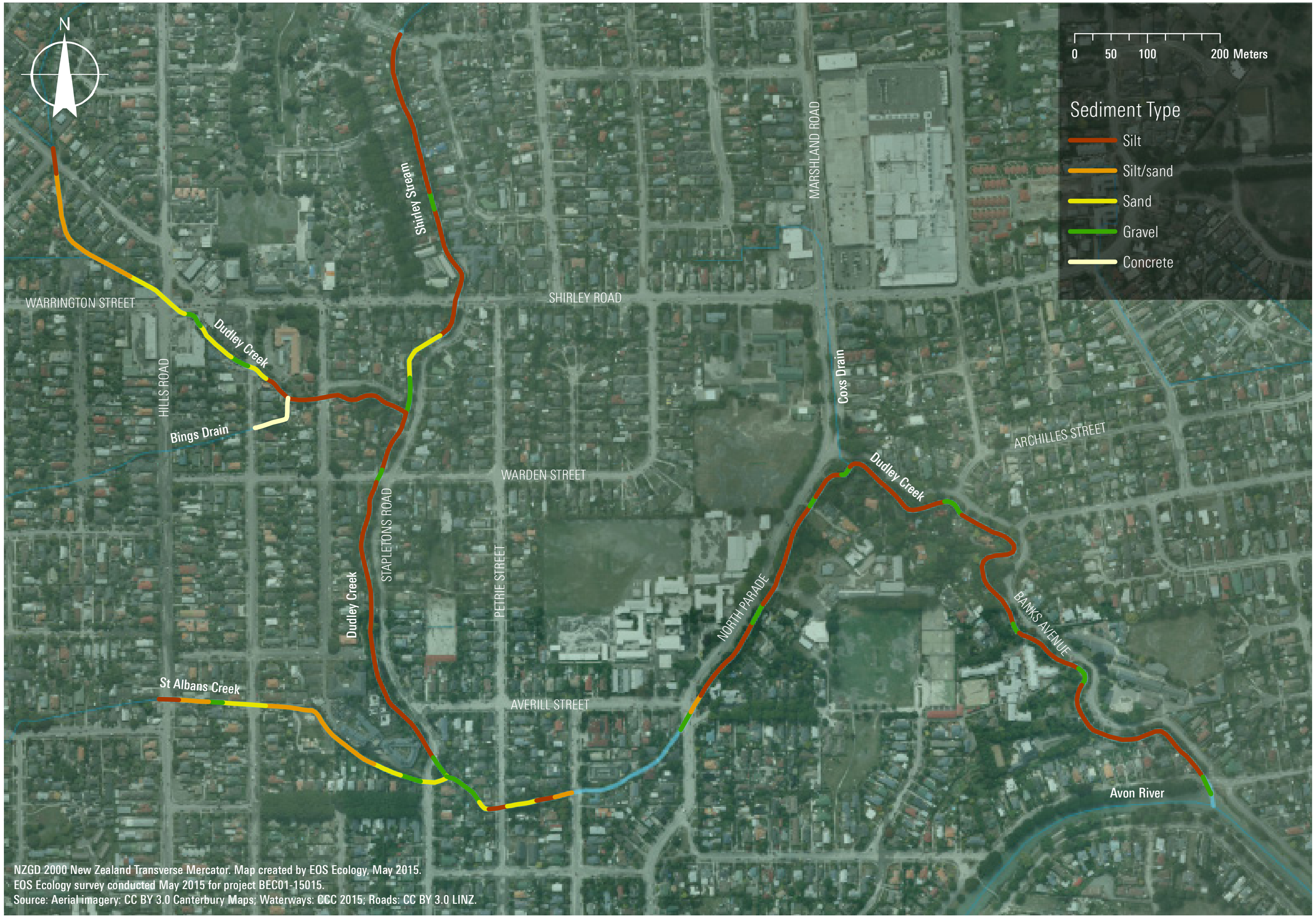


FIGURE 4:
Map describing the general substrate type in Dudley Creek catchment. Based on observations made during site walkovers by EOS Ecology during April 2015. Silt, silt/sand, sand, and concrete substrate categories are generally considered poor substrate for instream biota.

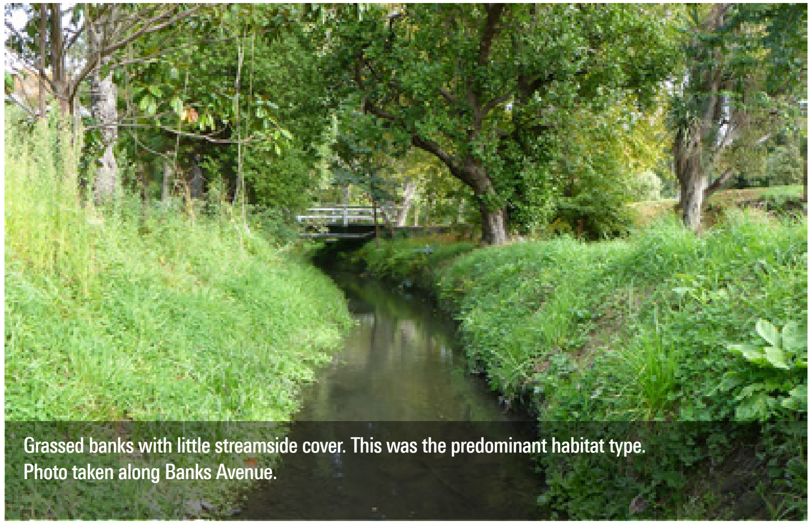
Wide channel with thick layers of silt and little cover. This was the predominant habitat.

Channel with thick layers of sand (possibly liquefaction sand) and no cover. This was a common habitat type.

Narrow channel with fast-flowing gravel/cobble substrate (i.e., riffle habitat). There were few areas like this.

Silted channel with at least some cover provided by larger rocks in the channel or along the bank There were few areas like this.

FIGURE 5
Photographs of the different substrate types found along Dudley Creek between the Avon River and Shirley Stream confluences.



Grassed banks with little streamside cover. This was the predominant habitat type.
Photo taken along Banks Avenue.

Private property generally supported a greater diversity of vegetation (both in structure and species), although low overhanging stream cover was generally lacking throughout.
Photo taken along Banks Avenue.

Large exotic deciduous trees provide good shading of the channel during summer, but in winter the large leaf fall can use problems for small, slow flowing stream habitats.
Photo taken along North Parade.

Some areas of established native planting attract native birds such as fantails/piwakawaka.
Photo taken along Banks Avenue.

FIGURE 6
Photographs of the different riparian vegetation types found along Dudley Creek between the Avon River and Shirley Stream confluences.

EXOTIC: Sycamore (*Acer pseudoplatanus*)

EXOTIC: Silver birch (*Betula pendula*)

EXOTIC: Swamp cypress (*Taxodium distichum*), used as winter roost sites by monarch butterflies along Stapletons Road

NATIVE: Cabbage tree (*Cordyline australis*)

NATIVE: Lemonwood (*Pittosporum eugenioides*)

NATIVE: Ribbonwood (*Plagianthus regius*). Photo: Phil Bendle / www.terrain.net.nz

FIGURE 7 The most common exotic and native mature trees found along Dudley Creek in the Banks Avenue and Stapletons Road sections (sections shown in Figure 2).

TABLE 1 Breakdown of trees recorded in the arborist surveys along Dudley Creek between Avon River confluence and the Shirley Stream confluence.

Tree type and age	Banks Avenue Section	North Parade Section	Stapletons Road Section	TOTAL
Exotic				
Juvenile	31		4	35
Semi-Mature	87	22	17	126
Mature	140	70	61	271
Over Mature	9		8	17
EXOTIC TOTAL	267	92	90	449
Native				
Juvenile	30	3	5	38
Semi-Mature	129	9	56	194
Mature	109	12	45	166
Over Mature	2	1	1	4
NATIVE TOTAL	270	25	107	402
GRAND TOTAL	**537**	**117**	**197**	**851**

3.2 AQUATIC INVERTEBRATES

A total of 17 invertebrate taxa were found in the two sites sampled in Dudley Creek by EOS Ecology in May 2015. The main taxonomic groups present were Mollusca (snails and shellfish: four taxa), Crustacea (four taxa), and Diptera (true flies; four taxa). Trichoptera (caddisflies) and Clitellata (worms and leeches) were each represented by two taxa and Acari (mites) by one taxon. The invertebrate community of both sites were dominated by crustaceans (Ostracoda seed-shrimps at Stapletons Rd and the amphipod *Paracalliope fluviatilis* at Banks Avenue) and the snail *Potamopyrgus antipodarum* (Figure 8). Sphaeriidae pea-clams where also among the five most abundant taxa at both sites. A single "cleanwater" taxa was found, the cased caddisfly *Triplectides*, which was present at both sites albeit in low relative abundances (Figure 8). More of these caddisflies were found in the site with the greater proportion of coarse substrate and faster flowing water, which is also reflective of better habitat conditions for aquatic invertebrates.

MCI-sb and QMCI-sb at the Stapletons Road site (which had 100% mud/silt substratum[1]) were indicative of poor instream conditions, while MCI-hb and QMCI-hb at the Banks Avenue site (which had 50% sand, 30% pebbles, and 20% small cobbles[2]) were indicative of poor and fair conditions, respectively (Table 2). Overall both sites were dominated by invertebrate taxa that are typical of Christchurch's low gradient, urban waterways and are tolerant of or prefer slower water velocities and fine bed sediments. The dominance of the amphipod *Paracalliope* in the Banks Avenue section is most likely related to the tidal nature of the site, as this amphipod is usually abundant in the tidal reaches of lowland springfed streams. It is possible that the invertebrate community of Dudley Creek was also badly impacted by the large deposits of liquefaction sand that smothered the stream channel following the February 2011 earthquakes.

Of particular note was the discovery of empty freshwater mussel/kakahi (*Echyridella menziesi*) shells observed in Dudley Creek within the Banks Avenue Section (adjacent to Achilles Street) (Figure 9), indicating they are either present in the catchment or were at least present in the past. *E. menziesi* have a threat classification of "at risk – declining" (Grainger *et al*. 2014). They are our largest freshwater bivalve, growing up to around 10 cm in length, and are useful in regulating water quality due to their filter feeding behaviour. Freshwater mussels/kakahi are declining globally due to pollution, habitat alteration, and sedimentation.

[1] The nature of the streambed substrate (a soft sediment) at this site meant the use of the soft-bottomed variant of the MCI score; referred to as the MCI-sb.

[2] The presence of a more coarse substrate (of cobbles and pebbles) meant the use of the hard bottomed MCI variant (referred to as the MCI-hb) was more appropriate.

TABLE 2 Characteristics of the aquatic invertebrate community at two sites on Dudley Creek sampled by EOS Ecology in May 2015 (sites are shown in Figure 2). For MCI and QMCI the soft-bottomed (sb) and hardbottomed (hb) variants are shown with the most appropriate variant for each site (based on the substrate composition) in bold. Also shown (in brackets) for MCI and QMCI are the interpretive water quality categories of Stark & Maxted (2007).

Section and Site	Stapletons Section (Site 2, opposite 110 Stapletons Rd)	Banks Avenue Section (Site 7, opposite primary school)
Taxa Richness	16	14
EPT Taxa Richness (excl. Hydroptilidae)	1	1
EPT % Abundance (excl. Hydroptilidae)	0.1	1
MCI-hb	68.75 (Poor)	**68.57 (Poor)**
QMCI-hb	3.34 (Poor)	**4.24 (Fair)**
MCI-sb	**60.6 (Poor)**	65.14 (Poor)
QMCI-sb	**2.32 (Poor)**	3.78 (Poor)

FIGURE 8
The five most abundant invertebrate taxa (with relative abundance values shown in brackets) found at two sites in Dudley Creek sampled in May 2015 (sites are shown in Figure 2). Site 2 was opposite 110 Stapletons Rd, Site 7 was opposite the primary school on Banks Avenue.

Site	Five Most Abundant Taxa at Each Site					'Cleanwater' EPT taxa (excl. Hydroptilidae)
Stapletons Section (SITE 2)	Ostracoda (63%)	*Potamopyrgus antipodarum* (12%)	Sphaeriidae (6%)	Copepoda (4%)	Tanypodinae (3%)	*Triplectides* (0.1%)
Banks Avenue Section (SITE 7)	*Paracalliope fluviatilis* (44%)	*Potamopyrgus antipodarum* (36%)	Ostracoda (8%)	Sphaeriidae (4%)	Oligochaeta (2%)	*Triplectides* (1%)

FIGURE 9
Empty freshwater mussel/kakahi shells (left) were found in Dudley Creek along Banks Avenue. No live specimens (right) were found although a specific search for them was not undertaken.

3.3 FISH

Seven species (Figure 10) and 282 individuals were captured during the May 2015 electrofishing surveys of Dudley Creek (sites are shown in Figure 2), which included four additional species to those previously recorded in recent CCC data (i.e., Blakely, 2014). Common bully and shortfin eel were the most common and widely distributed species; accounting for half (common bully) and a quarter (shortfin eel) of all fish captured (Figure 10), and found in all four surveyed sections of Dudley Creek (Table 3). Both are widely distributed throughout New Zealand, and both are known to be tolerant of a range of habitat conditions. Shortfin eels are especially known for their tolerance of soft sediment (sometimes referred to as 'mud eels'), which they will often burrow into in streams with little cover. Upland bullies were generally associated with sites that had a coarse substrate (i.e., gravel, cobbles, or rocks).

While not a threatened species, giant bully (Figure 10) are less encountered in New Zealand than some of the other bully species, and are associated with the lower reaches of streams. They are the largest of the bully species and require good cover (such as undercut banks or rocks/logs) in the stream (Figure 11). It was therefore not surprising they were only found at sites where there was good fish cover.

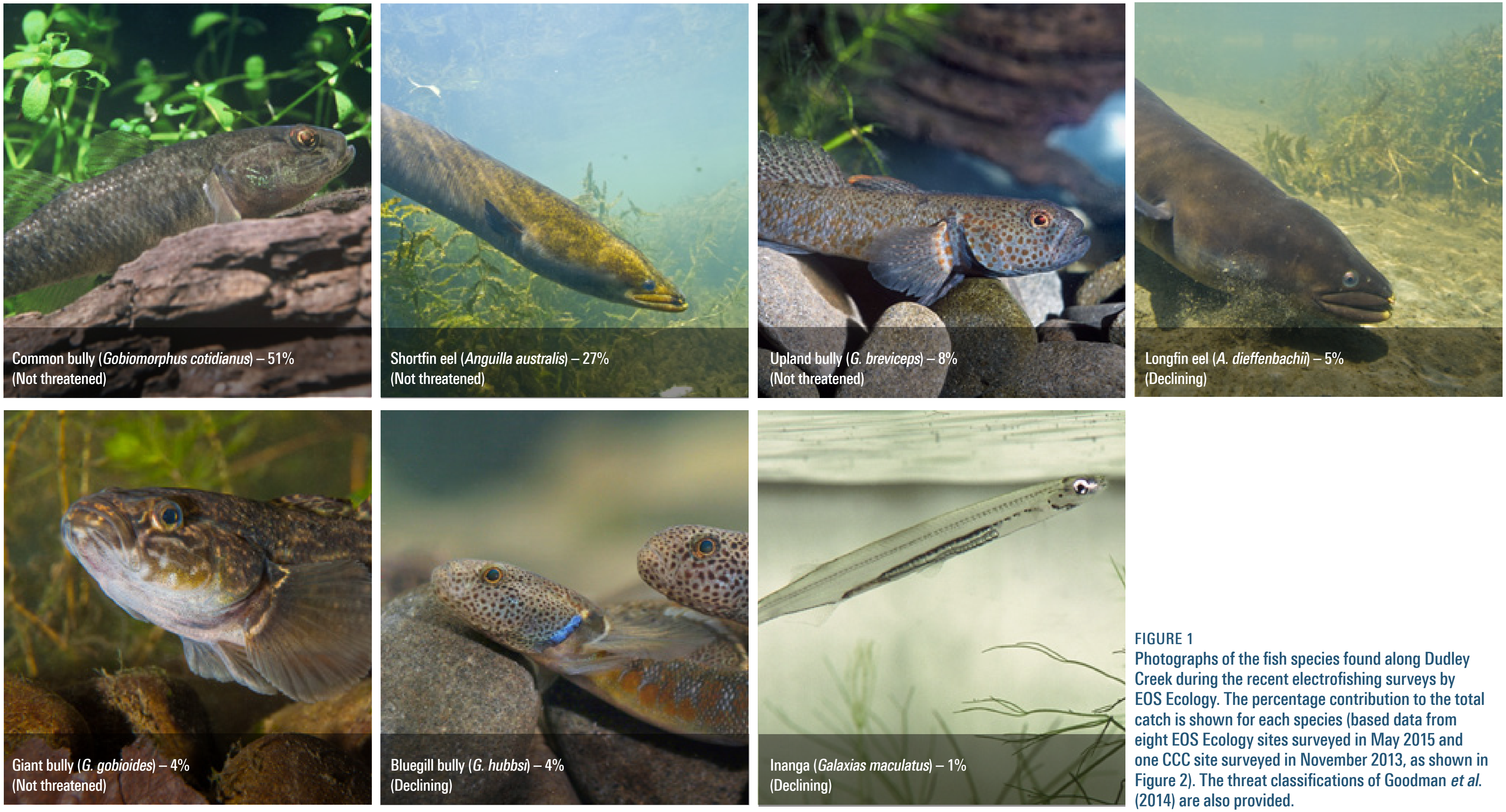
Three species were found in Dudley Creek that have a threat classification of 'at risk - declining': bluegill bully, inanga, and longfin eel (Figure 10, Table 3). The diminutive bluegill bully is the smallest of the bully species and are found in limited areas in Christchurch's waterways. They prefer a cobbled streambed and moderate to swift water velocities, and so were only found in a single riffle section along Banks Avenue (the upstream fish site in the Banks Avenue section) (Figure 11, Table 3).

The discovery of bluegill bullies in Dudley Creek is a new fish record for the stream, and this fast-flowing portion of stream will be an important habitat to protect.

Inanga are a member of the group of fish known as whitebait, and are a culturally significant species. A few specimens were found in the 'North Parade' section during the electrofishing surveys, but schools of them were also observed in the area, indicating this species is probably more abundant and widespread than indicated by the electrofishing results. Such schools of inanga may regularly move up and down Dudley Creek to and from the Avon River. Inanga require overhanging or emergent vegetation (Figure 11), and instream debris to provide cover that helps them avoid predation by birds and other fish. There is little of this cover currently found in Dudley Creek, and so their numbers are likely to be limited by predation. While the lower reaches of Dudley Creek are tidally influenced, the saltwater wedge does not penetrate this far upstream and thus the area is outside of the spawning zone for inanga. The value of Dudley Creek is therefore to provide habitat for inanga to grow to adults, which will then migrate downstream to the Avon River to spawn.

Longfin eel were only found at the two upstream sections, where cover for large longfin eels (in for the form or large rock walls with deep crevices, or undercut banks) was sufficient for them. The size range of longfin eels indicated a reasonable age population structure, and included a particularly large specimen just over 1 m long (Table 4, Figure 12). As eels are so slow growing, the larger specimen could be over 60 years old. Both longfin and shortfin eels migrate to sea after decades living in freshwater streams, travelling to the warm seas of the Pacific Ocean to spawn and die. The juveniles then migrate back into our streams as semi-transparent 'glass eels'. Juvenile longfin eels prefer coarse substrates, and adult longfin eels require good stream cover (overhanging vegetation or undercut banks), meaning their survival in Dudley Creek is certainly directly related to the provision of good habitat and cover.

There are a number of locations along Dudley Creek where eels (including both shortfin eels and longfin eels) are fed by adjacent landowners (Figure 12). Provided there is sufficient cover for these fish, they will tend to remain in the general area where they are regularly fed. For a small stream like Dudley Creek with a limited invertebrate fauna, the regular feeding of eels would help to maintain a larger number of eels than might be found there naturally. Provided these large fish are fed meat and not bread (which is not a nutritious food item) the feeding of eels should not cause any water quality issues that is sometimes associated with the large numbers of mallard ducks that can be attracted to an area via regular feeding with bread.



Common bully (*Gobiomorphus cotidianus*) – 51% (Not threatened)

Shortfin eel (*Anguilla australis*) – 27% (Not threatened)

Upland bully (*G. breviceps*) – 8% (Not threatened)

Longfin eel (*A. dieffenbachii*) – 5% (Declining)

Giant bully (*G. gobioides*) – 4% (Not threatened)

Bluegill bully (*G. hubbsi*) – 4% (Declining)

Inanga (*Galaxias maculatus*) – 1% (Declining)

FIGURE 1
Photographs of the fish species found along Dudley Creek during the recent electrofishing surveys by EOS Ecology. The percentage contribution to the total catch is shown for each species (based data from eight EOS Ecology sites surveyed in May 2015 and one CCC site surveyed in November 2013, as shown in Figure 2). The threat classifications of Goodman *et al.* (2014) are also provided.

The fast-flowing riffle habitat in Dudley Creek along Banks Avenue (Site 9, opposite Achilles Street) is the only location to support bluegill bullies.

Longfin eels were only found where there were good areas of undercut banks or holes created by the rock edging along the bank. Photo taken in the Avon River.

Giant bullies were found at sites with larger rocks along the stream edge that provided them with good habitat and cover.

Inanga need overhanging and emergent vegetation to hide amongst and avoid predation by birds and fish. Photo not taken in the Dudley Creek catchment.

A coarse stream substrate is great habitat for upland bullies, giant bullies, juvenile longfin eels, and many other small fish species. Coarse substrate in Dudley Creek is still silted due to fine sediment in the system.

Any type of structure in the channel (such as this log) that creates a range of microhabitats (i.e., different water depth, velocity and substrate) will naturally support more fish and invertebrate species.

FIGURE 11 **Photographs of key habitat types associated with different fish species**

TABLE 3 The number of each fish species captured in Dudley Creek via electrofishing. The threat classifications of Goodman *et al.* (2014) are also provided.

FISH SPECIES	THREAT CLASSIFICATION	DUDLEY CREEK – UPSTREAM SECTION	DUDLEY CREEK – PROJECT SECTIONS		
		Upstream of Shirley Stream Confluence (2 Sites)	Stapletons Section (3 sites) (Shirley Stream to Petrie St)	North Parade Section (2 sites [1]) (Petrie St to Banks Avenue)	Banks Avenue Section (2 sites) (Banks Avenue to Avon River)
Common bully	Not threatened	11	71	21	48
Shortfin eel	Not threatened	15	22 [2]	17	25
Upland bully	Not threatened	16	7		1
Longfin eel	Declining	2	13		
Giant bully	Not threatened	5	7		
Bluegill bully	Declining				12
Inanga	Declining		1	2 [3]	
ALL FISH SPECIES		**49**	**121**	**40**	**86**

1 Includes one CCC site surveyed by Boffa Miskell in 2013.

2 In this section, along Stapletons Rd, upstream of Warden St 13 large shortfin eels were also observed during a site visit. Adjacent landowners regularly feed these eels.

3 A school of ~30 inanga was also observed at the corner of North Parade and Averill St in this section during a site visit.


The largest eel (a longfin eel) caught in the fish surveys was 1.02 m long and found in an undercut bank under large trees at Site 5 (Dudley Creek, upstream of Shirley Stream confluence).


Eels are fed by locals in the Dudley Creek catchment, including this site upstream of Warden Street. It appeared that these eels came from under logs or cracks in rock edging along the banks.

FIGURE 12 **Particularly large eels caught or observed in Dudley Creek.**

Fish species richness was higher further upstream with the surveyed sections upstream of Petrie St having 5–6 fish species and those downstream having 3–4 fish species (Table 3; Figure 13). The catch per unit effort (CPUE) was greatest in the Banks Avenue section (at around 40 fish per 100 m^2 of area fished. This was driven by the large number of fish found at the riffle site (Site 9). The upstream-most section (upstream of the Shirley Stream confluence) and the North Parade Section had the lowest CPUE, being around half that of the other sections (Figure 13). Fish cover (i.e., larger rock substratum, woody debris, overhanging vegetation, undercut banks) played an important role in the abundance of fish, with sites having higher total fish cover tending to have a greater CPUE (Figure 14). In a highly modified stream like Dudley Creek, it is vital to ensure there is sufficient cover available to support all the fish species found in this catchment.

TABLE 4 **Length data for fish caught in Dudley Creek (including the four surveyed sections indicated in Figure 2). Includes eight EOS Ecology sites surveyed in May 2015 and one CCC site surveyed in November 2013 (Blakely, 2014).**

FISH SPECIES	LENGTH (mm)		
	Maximum	Minimum	Average
Longfin eel	840	212	582
Shortfin eel	720	120	262
Common bully	110	28	67
Giant bully	125	74	96
Upland bully	75	32	49
Bluegill bully	53	35	44
Inanga	101	65	83

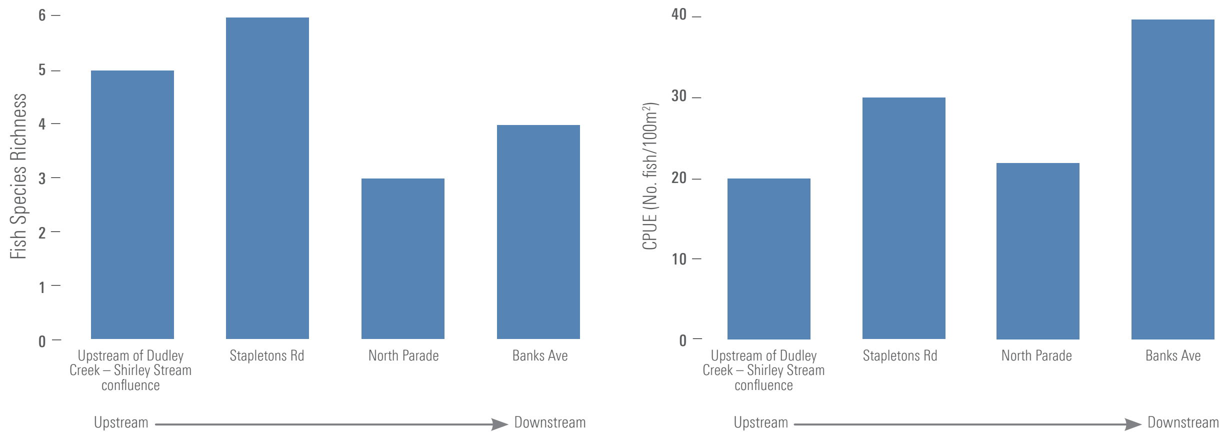


FIGURE 13 Fish species richness and catch per unit effort (CPUE) for four sections of Dudley Creek based on an electrofishing survey by EOS Ecology in May 2015.

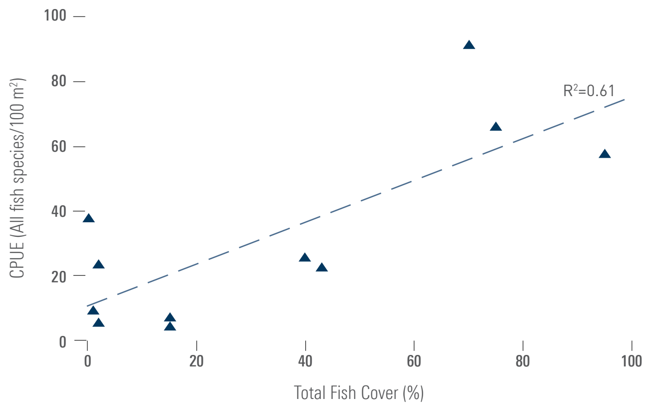


FIGURE 14 The relationship of catch per unit effort (CPUE) with total fish cover based on electrofishing surveys by EOS Ecology in May 2015. Greater fish cover was positively correlated with a greater density of fish.

3.4 WATER AND SEDIMENT QUALITY

The water quality of Dudley Creek at the CCC's monitoring site was generally good during times of normal flow and did not exceed the guidelines or trigger values of the Canterbury Land and Water Regional Plan (CLWRP) (Environment Canterbury, 2014) or ANZECC (2000) for most measured parameters (Table 5). Median turbidity was marginally above the ANZECC (2000) guideline level. Median *Escherichia coli* and dissolved reactive phosphorus were also above CLWRP guidelines (Table 5). Dissolved lead and copper were regularly at concentrations below laboratory detection levels (Table 5). A study by Bartram (2014) found for the period July 2008 to December 2012 (after adjusting data to remove the atypical results that occurred as a result of the 2010-2011 Canterbury earthquakes) there were increasing trends in *E. coli*, faecal coliforms, ammonia, pH, total suspended solids, and total nitrogen, and a decreasing trend in conductivity. Thus it would appear water quality in Dudley Creek is declining. Of most concern to instream ecology are the increases in ammonia (as it is toxic above a certain level which depends on pH) and total suspended solids (the deposition of which add to the sediment issues already faced by much of Dudley Creek). It is unknown what the water quality of Dudley Creek is during rain events as most of the long-term water quality monitoring undertaken by CCC is generally during baseflow conditions (or does not specify flow).

Sediment quality in Dudley Creek in terms of metals and metalloids was relatively good compared to the ANZECC (2000) guidelines, with only lead being found to be above the ISQG-low guideline by Gadd & Sykes (2014) (Table 6). However, a biofilm sample taken by Golder (2012) showed lead, nickel, and mercury to be above the ISQG-low and zinc to be nearly double the ISQG-high value (Table 6). This is of concern as these biofilms form part of the base of the stream food web, and so are eaten by numerous aquatic invertebrates. Total polycyclic aromatic hydrocarbons (PAHs) were elevated in Dudley Creek sediments and this has at least partly been attributed to the historic use of coal tar in road construction in the catchment (Gadd & Sykes, 2014). The initial sample of Gadd & Sykes (2014) contained extremely high total PAH concentrations (i.e., 693 mg/kg compared to a ISQG-high value of 45 mg/kg) (Table 6). A reanalysis of the sample found a much lower concentration, with the anomalous high level in the initial sample possibly resulting from a small fragment of coal tar material being present in the sample (Table 6) (Gadd & Sykes, 2014).

Coal tar, a by-product of goal gasification (in gas works) and coal coaking (in the steel industry), was used in Christchurch as binders (a primer and first coat seal) for bitumen roads. The use of coal tar in New Zealand was phased out in the 1970s, thus any street constructed in Christchurch prior to 1970 will still have coal tar in the road subsurface and soils along the road shoulder (Depree & Fröbel, 2009). Coal tar is an environmentally dangerous compound. It has 5,000-10,000 times the amount of PAHs that are potentially carcinogenic, and that have carcinogenic, mutagenic, and teratogenic effects on animals (Depree & Fröbel, 2009). The presence of coal tar fragments in a sediment sample collected from Dudley Creek by Gadd & Sykes (2014) implies there may be fragments of coal tar material within the Dudley Creek sediments. This may explain the poor health of the invertebrate community and should be taken into account for the works programme (i.e., removing potentially contaminated fine sediment where works along the stream are designed to improve the natural values of the stream). The likely presence of coal tar in the road subsurface and soils of the road shoulder should also be considered for any works that result in excavation of the roads/under roads (i.e., Option A-C in Figure 1) or roadside grassed verges (i.e., Option A-B in Figure 1) in the project area.

TABLE 5 **Selected water quality parameters from the Christchurch City Council Dudley Creek monitoring site (2008–2014) (see Figure 2). CLWRP = Canterbury Land and Water Regional Plan (Environment Canterbury, 2014); HMTV=hardness modified trigger value; NA=not applicable. Median values that exceed the guideline/trigger values are shaded. Samples were predominantly taken during normal flow conditions. Where results for the sampled parameters were below laboratory detection rates, these were assigned a value of 0.5 × the detection rate for the purposes of calculating minimum, maximum, and median values presented in the table below.**

PARAMETER	GUIDELINE/TRIGGER VALUES	*N*	MIN	MAX	MEDIAN	NUMBER OF SAMPLES BELOW LABORATORY DETECTION LEVEL
Conductivity (mg/l)	None	75	88	341	164.1	NA
Water temperature (°C)	<20 (CLWRP)	74	4.5	20	12	NA
pH	6.5–8.5 (CLWRP)	75	6.9	8.1	7.5	NA
Dissolved oxygen (%)	>70% (CLWRP)	74	15	130	79	NA
Dissolved oxygen (mg/l)	None	74	1.4	14.7	8.6	NA
Total Suspended Solids (mg/l)	None	75	1	310	7	22
Turbidity (NTU)	<5.6 (ANZECC, 2000)	75	1.4	130	**5.9**	NA
Escherichia coli (CFU/100 ml)	<550 (CLWRP)	75	160	250,000	**960**	0
Dissolved Copper (mg/l)	0.003 (HMTV from ANZECC, 2000)	43	0.001	0.005	0.001	37
Dissolved Lead (mg/l)	0.012 (HMTV from ANZECC, 2000)	42	0.0005	0.004	0.001	27
Dissolved Zinc (mg/l)	0.025 (HMTV from ANZECC, 2000)	42	0.002	0.084	0.016	2
Total Ammonia (mg/l)	<1.6 at pH of 7.5 (CLWRP)	75	0.005	11	0.150	2
Nitrate-Nitrite (mg/l)	<0.444 (ANZECC, 2000)	75	0.036	1.7	0.370	0
Dissolved Inorganic Nitrogen (DIN) (mg/l)	<1.5 (CLWRP)	75	0.202	11.61	0.540	0
Dissolved Reactive Phosphorus (DRP) (mg/l)	<0.016 (CLWRP)	75	0.018	1.1	**0.05**	0

TABLE 6 Total recoverable metals and metalloids and total polycyclic aromatic hydrocarbons (PAHs) in sediment (mg/kg dry weight) from Dudley Creek sites sampled by Gadd & Sykes (2014) and Golder (2012) (see Figure 2). Also shown are concentrations in biofilms, which were measured by Golder (2012). Total PAHs have been normalised to 1% total organic carbon (TOC) as recommended by ANZECC (2000). Values in light grey and dark grey cells exceed the low and high Interim Sediment Quality Guideline (ISQG), respectively. Note that Gadd & Sykes (2014) recorded an exceptionally high value in their original sample, prompting reanalysis of the sample. The high value was not a lab error and likely the result of a piece of coal tar material being present in the sample (Jennifer Gadd, NIWA, pers. comm.).

PARAMETER	ANZECC (2000) ISQG VALUES		DUDLEY CREEK		
			NORTH PARADE BY FORMER MARIAN COLLEGE SITE (SITE 18 IN GADD & SYKES, 2014)	BANKS AVENUE OPPOSITE SHIRLEY INTERMEDIATE (SITE 14 IN GOLDER, 2012)	
	Low ISQG	High ISQG	Sediment	Sediment	Biofilms
Arsenic	20	70	7.3	21	24
Cadmium	1.5	10	0.181	0.24	0.61
Chromium	80	370	14.5	16	41
Copper	65	270	14.2	16	62
Lead	50	220	111	39	129
Nickel	21	52	11.7	10	29
Mercury	0.15	1	Not measured	0.086	0.21
Zinc	200	410	172	61	780
Total PAHs	4	45	Initial sample: 693 Reanalysed sample: 29.8	9.3	Not measured

4 OPPORTUNITIES FOR DUDLEY CREEK WITH FLOOD REMEDIATION WORKS

In general, design options that look to widen the flood channel to provide for greater flood capacity also provide the opportunity to greatly improve the habitat condition of Dudley Creek and its riparian zone, which will have a long-lasting ecological benefit to the stream and wider environment, and thus secure a greater value natural asset for future generations. This is consistent with the CCC's six values approach (drainage, ecology, landscape, recreation, heritage, culture) and with the philosophies and objectives set out in the CCC's 'Waterways, Wetlands and Drainage Guide' (CCC, 2003a, b) that states that "*drainage is integrated with all other 'values' (ecology, landscape, recreation, heritage and culture) to form the foundation of a philosophy that is multi-disciplinary and sustainable*". Attributes to be included in the design to achieve this would be as follows:

- Removal of fine sediment and the addition of clean gravels.
- Narrowing of the low flow channel via the creation of a low bank that is planted.
- Provision of instream and bank cover in the form of larger rocks and logs.
- Provision of overhanging cover in the form of soft native groundcover plants along the stream edge.
- A good representation of native trees in the wider riparian zone that will help to provide habitat and food for native birds that are currently found in the area.
- The selection of replacement plants (trees, shrubs and groundcover) along Dudley Creek that have an ecological as well as an aesthetic function. To that end, trees being removed that are considered a potential health risk (such as silver birch) or listed in the RPMS (such as sycamore and ash) should be replaced with other species that can provide a similar structure or longevity, but which provide additional ecosystem services to the Dudley Creek environment. This includes a good representation of native trees in the wider riparian zone that will help to provide habitat and food for native birds currently found in the area, and the consideration of the detrimental impact that an overabundance of large exotic deciduous trees has in the addition of significant leaf litter to the stream during autumnal leaf fall.
- Protect and enhance those areas of the stream that have existing faster flow and a coarser substrate as a result of a narrow low flow channel and relatively steeper gradient than other sections of stream. These sections are generally identified as the 'gravel' habitat in Figure 4, and especially the section where bluegill bullies were found along Banks Avenue (i.e., Site 9), and the upstream of Petrie Street (i.e., Site 12) where the largest number of longfin eels were caught.

The loss of trees as part of flood channel widening either along Banks Avenue or Stapletons Road will have a short-term effect on terrestrial ecology. However, this is generally offset by the future ecological benefits, i.e., the replacement of lost trees (some of which were in poor condition) with a mix of native and exotic species, and with additional native planting along the stream edge. Existing areas of larger native tree clusters are also being retained, meaning that disturbance of roosting, nesting, and feeding habitat for native birds should be minimised.

In general the piped option (i.e., Option B) offers little in the way of environmental advantages, as the works will involve no changes along Dudley Creek itself, and thus provide no opportunity to improve the ecological state of the stream. It also represents the least environmental risk to Dudley Creek during the construction phase, as there are few works being undertaken within the stream or stream corridor (with the exception of piping under Dudley Creek. However, the long-term ecological benefits of the other options outweigh their short-term risks.

5 ACKNOWLEDGEMENTS

Thank you to the CCC and ECan for providing copies of their ecology and water/sediment quality data for use in this report. Thank you to Kirsty Brennan (EOS Ecology) and Alex Jenkins (Beca) for editing the report.

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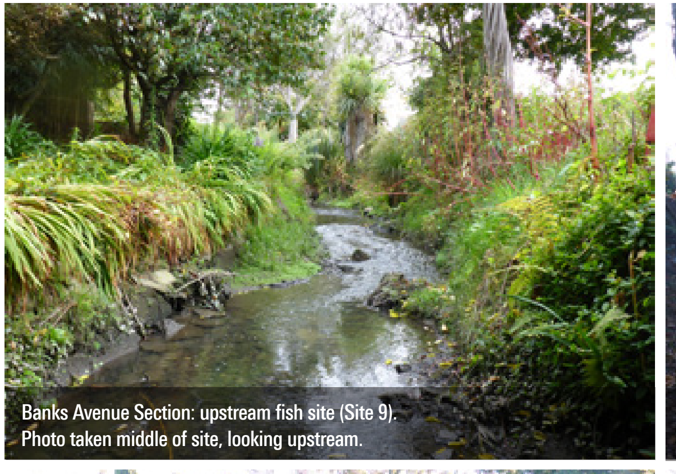
7 APPENDICES

7.1 APPENDIX 1: FISH SAMPLING SITE PHOTOGRAPHS

Site photographs of fish sites along Dudley Creek between the confluence with the Avon River and the confluence with Shirley Stream. Photographs were taken at the time of the May 2015 ecological surveys, unless otherwise stated.


Banks Avenue Section: downstream fish site (Site 8).
Photo taken middle of site, looking downstream.


Banks Avenue Section: upstream fish site (Site 9).
Photo taken middle of site, looking upstream.


North Parade Section: downstream fish site (Site 14).
Photo taken middle of site, looking downstream.


North Parade Section: upstream fish site (sampled by Boffa Miskell, 2013). Photo taken in general vicinity during the April 2015 site walkovers, looking upstream.


Stapletons Section: downstream fish site (Site 12).
Photo taken middle of site, looking upstream.


Stapletons Section: middle fish site (Site 1).
Photo taken middle of site, looking upstream.


Stapletons Section: upstream fish site (Site 3).
Photo taken middle of site, looking downstream.

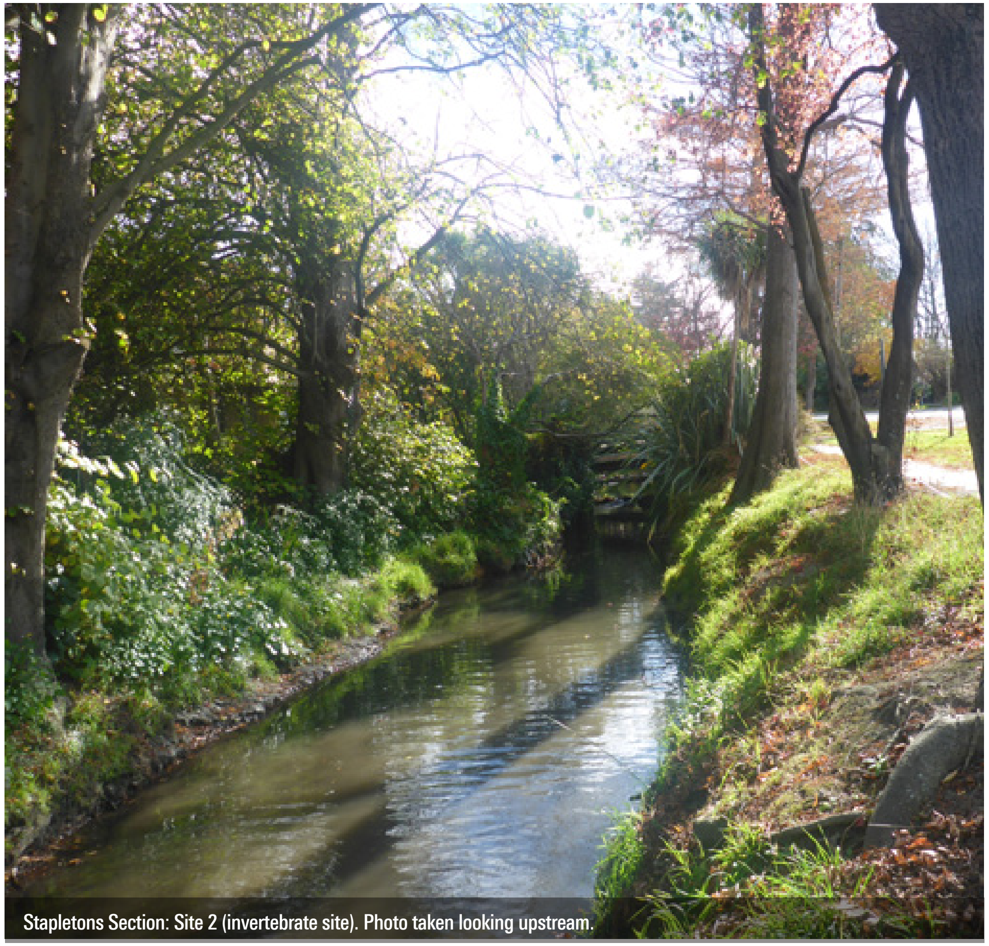

Upstream Section: downstream fish site (Site 5).
Photo taken middle of site, looking downstream.


Upstream Section: upstream fish site (Site 11).
Photo taken middle of site, looking downstream.

7.2 APPENDIX 2: INVERTEBRATE SAMPLING SITE PHOTOGRAPHS

Site photographs of invertebrate sampling sites. Photographs were taken at the time of the May 2015 ecological surveys.

Banks Avenue Section: Site 7 (invertebrate site). Photo taken looking upstream.



Stapletons Section: Site 2 (invertebrate site). Photo taken looking upstream.

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