Waterways
Centre for Freshwater Management

UC Campus Waterways Health Monitoring:

A Preliminary Design for an Integrated Monitoring Programme

Summer Scholarship Report

WCFM Report 2018-003

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Executive Summary

This report proposes an integrated water monitoring programme for waterways passing through the University of Canterbury (UC) Ilam campus, Christchurch, New Zealand. The University has previously supported a range of studies related to the health of these waterways, including research on water and sediment quality, heavy metal contamination, stream ecology and cultural health. However, there is no ongoing commitment or programme to monitoring the key indicators of stream health.

This purpose of this study was;

- To collate and review water data previously collected in the course of teaching and postgraduate research projects, and during urban stream monitoring by Christchurch City Council, for campus waterways,
- To propose a simple, efficient integrated monitoring programme for the campus waterways.

Existing data was sourced from the School of Biology and the Civil and Natural Resources Engineering Department and the Christchurch City Council, and is reported here as both raw data and metadata. These data provided insight into specific aspects of water health, at particular sites and times of year (or one-off), and provided a foundation for designing a new long term monitoring programme.

The objectives of this proposed integrated monitoring programme were;

- To assess the health and ecology of campus waterways
- To evaluate the effect of stormwater runoff and campus cooling water (and any other) discharges on waterway health.

The various sites used in previous data collection were assessed for their inclusion in a monitoring programme and 6 were chosen to be representative of upstream, in-campus and downstream environments on the two main waterways; Okeover Stream and the upper Avon River. Parameters have been chosen for monitoring at these sites at a frequency which strikes a balance between data needs and likely resourcing constraints.

Parameter	**Frequency**
Flow	Quarterly
pH, temperature, conductivity, DO and turbidity	Quarterly
Macroinvertebrates: EPT & MCI	Annual (spring)
E coli	Quarterly
Trace elements; Ni, Cu, Pb, Zn, As, Al, Cr & Cd (diss & total) (with likely reduction to 3-4 priority urban contaminants after 3 years)	Quarterly
Sedimentary trace element survey	Biennial (or triennial)

A further 4 supplementary sites on Okeover Stream are proposed for more specific data collection. Other surveys and projects, such as annual fish and riparian vegetation surveys and the assessment of cultural health indicators have been identified for further consideration.

The data would need to be stored in a centralised database, hosted and backed-up by the University of Canterbury, with specific individuals taking responsibility for collating, and entering the data, and undertaking quality control on these data. The database should also include metadata for all one-off research projects providing data of relevance to these waterways.

We also recommend that this programme be incorporated into course teaching as much as practicable, with monitoring sites clearly marked to ensure consistency when being used by different classes and lecturers. Data which cannot be collected as part of the teaching programme should be collected by a single overseeing entity on campus.

Acknowledgements

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Section 1 Introduction

1.1 Urban streams: pressures and impacts

Streams are common in modern urban settings, though changing land use practices globally have greatly altered their appearance and functioning. Changes can include removal of riparian vegetation, increased impermeable surfaces and channelisation. These in turn disrupt natural hydrological regimes through reducing infiltration and therefore increasing surface runoff during rain events (Adams, Mahar & Broad, 2007). This runoff can contain high levels of contaminants, including heavy metals. Heavy metals of particular concern in New Zealand are zinc, copper and lead, though chromium, nickel and aluminium are also fairly common (Charters, 2016). This concern is due to their persistence, prevalence and toxicity to aquatic taxa (Brown & Peake, 2006). The sources of these contaminants are heavily dependent on activities within the catchment.

Traffic is a major cause of contaminants in urban catchments. Brake lining wear produces zinc and copper (Charters, 2016). Abrasion with the road surface produces tyre dust which contains zinc, as well as small amounts of cadmium, copper and lead (Farrant, 2006). Many road markings still contain lead, as well as traces of zinc (Göbel, Dierkes, & Coldewey, 2007). All of this has the potential to make its way into urban waterways through surface runoff during rain events.

Runoff from buildings is another potential source of contaminants. Heavy metals are used quite extensively in roofing design, for example, zinc for galvanisation, copper for roof surfaces and guttering, and lead in older paints (Brown & Peake, 2006; Göbel et al., 2007). Corrosion results in the release of heavy metals from these products. The prevalence of lead, however, has been noted to be decreasing over time due to a shift away from lead-based paints and leaded gasoline, though there are still contributions from legacy accumulation in soil and vehicle tyre weights (Kayhanian et al., 2012).

Alongside increased amounts of heavy metals, the urbanisation of a catchment brings with it many other changes in water chemistry. The removal of riparian vegetation, coupled with the urban “heat island” effect, can dramatically increase water temperatures (Eden, 2016). This tends to result in decreasing dissolved oxygen levels, sometimes to anoxic levels (Paul & Meyer, 2001). Due to the important role riparian vegetation plays in bank stabilisation, its removal can also increase the sediment load of waterways, in turn altering channel morphology and potentially smothering aquatic life (Environment Canterbury, 2007). Suspended sediment also has the potential to accumulate high levels of heavy metals (Beasley & Kneale, 2002).

Changes in the water quality and quantity of urban streams can result in large impacts on aquatic communities. Macroinvertebrate communities are generally less diverse in urban streams, though the number of taxa can often remain quite high (Paul & Meyer, 2001). This

is frequently coupled with a shift in community composition towards more pollution tolerant taxa such as *chironomids* (Paul & Meyer, 2001). More sensitive taxa, particularly *Ephemeroptera*, *Plecoptera*, and *Trichoptera* (EPT), tend to be less common, if they are present at all (Eden, 2016).

While many heavy metals may be important for maintaining aquatic life, such as copper for metabolism, their occurrence in any more than trace amounts can be toxic (Beasley & Kneale, 2002). Copper, for example, has been known to lead to increased mortality, as well as reduced growth and reproductive rates, in aquatic organism while other metals can pose a human health risk when they bioaccumulate (as cited in Charters, 2016).

1.2 The Ōtākaro-Avon River catchment at the UC campus

The University of Canterbury (UC) is located in the upper part of the Ōtākaro-Avon River catchment. Three waterways run through the University of Canterbury campus: Okeover Stream, Ilam Stream and the Avon River. All three stem from springs that are fed primarily by recharge from the Waimakariri River and continue on to the Te Ihutai/Avon-Heathcote Estuary. Extensive modification has occurred along their reaches in the past, leaving current water quality in a degraded state.

Historically, the Christchurch area was predominantly a patchwork of wetlands cut through by winding, spring-fed streams (Dendy, 1900). European settlement resulted in the conversion of much of this to agriculture as early as 1890 to leave little swampland, including the area that was to become the University of Canterbury campus (Dendy, 1900). The Christchurch Drainage Board, established in 1875, sought to remove excess stormwater and sewage from the city, mainly by channelising rivers and removing impeding vegetation (Macpherson, 1979). This practice of considering waterways as waste pipes and drains for the city continued until late last century (Blakely, 2003).

During its development, the current University of Canterbury campus was mostly planted with grasses and exotic trees, as can be seen in Figure 1. Increasing impermeable surfaces from construction, alongside maintenance methods that involved the removal of all riparian margins, led to sedimentation issues and the accumulation of various contaminants. This in turn resulted in a gradual decline in both water quality and biodiversity (O'Brien, Barker, & Weston, 1998). While the stream flow may have been supplemented by a range of artificial inputs, including run-off from carparks, the resulting flows were of a much reduced quality (Sustainability Office, 2015).

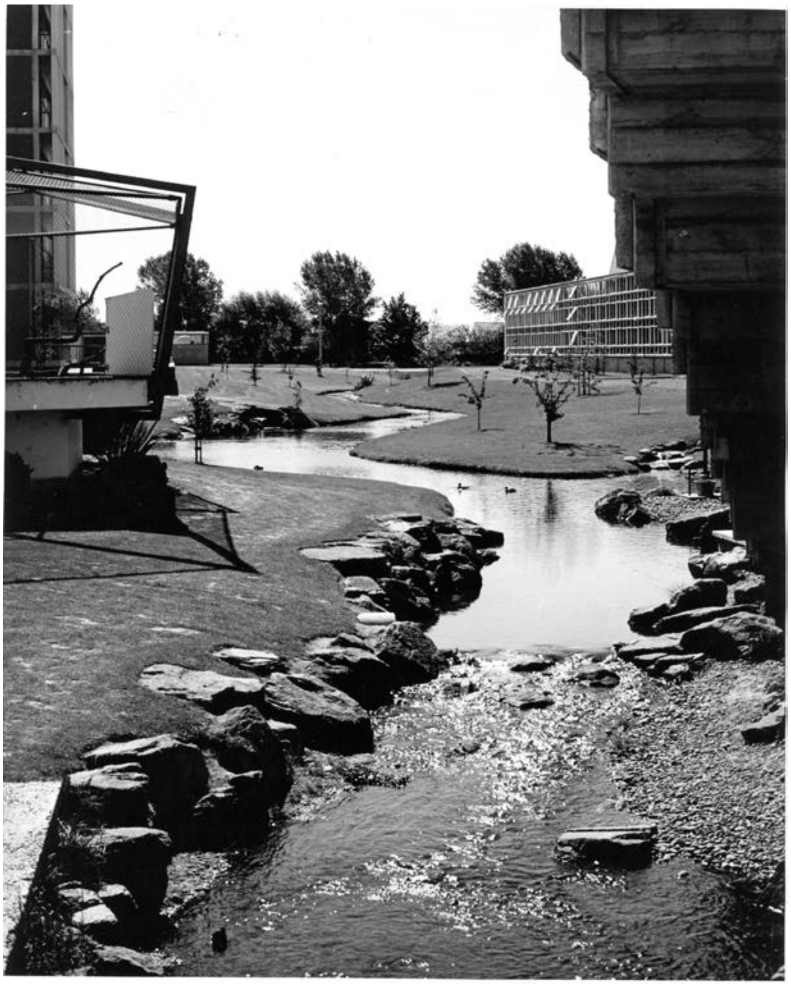

Figure 1. Okeover Stream near the Engineering Block, showing bare stream banks and a few deciduous exotic trees (Photo dated 7/11/69 by David Jones, Geology Department)

From the mid-1970s, the Christchurch City Council began to recognise the importance of waterways beyond being simply drainage channels (Blakely, 2003). It was noted by Marshall (1973) that by this time the Avon River headwaters were only flowing intermittently and inputs from stormwater were introducing a large amount of sediment into the system. This growing concern led to widespread river restoration efforts in Christchurch, including at the University of Canterbury. The Resource Management Act in 1991, and the 1999 republished Christchurch City Plan, represented a dramatic change in direction. The City Plan stated that future waterway management would be undertaken in a way that promoted natural character and sustainable solutions (O'Brien et al., 1998).

Restoration of University of Canterbury waterways began in 1997 and grew into a collaboration between the Christchurch City Council and Kakariki (the University of Canterbury student environment group), focussing almost entirely on Okeover Stream (O'Brien et al., 1998) as shown prior to restoration in Figure 1. Between 1998 and 2005, a

large portion of the riparian margins of Okeover Stream were replanted to provide shading and reduce riparian runoff (Blakely, 2003). In-stream modifications were also undertaken, such as establishing meanders behind the School of Forestry building, to improve habitat heterogeneity and flow (Blakely, 2003). Some riparian planting along the Avon River between Waimairi Road and Ilam Road was also completed during this time (Sustainability Office, 2015). About 250 plants were reported planted by March 2001 (Gundersen, 2012). A sediment trap was installed in Okeover Stream in 2001, to help reduce deposited and suspended sediment moving downstream (Sustainability Office, 2015). Many of the restoration initiatives were driven by the UC Waterways Working Group, officially formed in 2002.

Potential improvements in stream health were noted as a result of these efforts. In 2004, Okeover River was reported to be in better condition than it had been in decades, with larvae of both mayflies and caddisflies, freshwater invertebrates quite sensitive to pollution, showing some increase in abundance (Gundersen, 2012). However, this was not enough to completely restore the degraded ecology, with some finding little significant improvement in the aquatic ecology (Eden, 2016; *Professor J. Harding, pers. comm., December 21, 2017*). There was a legacy of sediment accumulation in the stream despite the plantings and bank maintenance, and stormwater continued to discharge directly into the waterway, resulting in high levels of contaminants (Kainamu, 2013; Sustainability Office, 2015;). Consequently, attempts to introduce endangered *waikākā* (Canterbury mudfish) and endangered *waikōura* (freshwater crayfish) could not be sustained, despite initial success (Sustainability Office, 2015). Canterbury mudfish, which used to be found in campus streams but had previously vanished, were likely predated on by long-finned eel, while freshwater crayfish were probably killed off by successive acute pollution events (Gundersen, 2012).

In 2006, a Draft Waterways Plan was presented by the UC Waterways Group. This set out a number of short and long term milestones for rehabilitation of the three streams on campus, including increased community awareness (Gundersen, 2012). While this plan was never formally ratified by the UC management, sections of it have been addressed by various research projects. Between 2011 and 2017 there were no major waterway modification initiatives, with most available resources redirected into campus restoration after the 2011 earthquakes.

A long-term restoration programme for University waterways is therefore still needed. A revised draft Waterways Plan plan was completed in 2017, parts of which have been incorporated into the 2017 Campus Landscape Plan of the 2017 UC Master Plan (University of Canterbury, 2017).

1.3 Previous research on campus waterways

Since 1999 there has been a wealth of research conducted on the University of Canterbury waterways. This has been undertaken through course fieldwork and laboratories, as well as in undergraduate and postgraduate research projects. The majority of this research has focused on Okeover Stream, due to the replanting of the stream bank by the Forestry Society (their closest waterway) and to the fact that almost the entire reach of the river runs through campus property (O'Brien et al., 1998). Initial objectives for the restoration of Okeover Stream included an increased abundance and diversity of both freshwater invertebrates and fish, alongside trout exclusion from the reach. Research has covered a variety of topics that include heavy metal contamination, stream ecology and cultural indicators. Some of the more pertinent findings are discussed below.

1.3.1. Heavy metal contamination

Waterways at the University of Canterbury are susceptible to inputs from stormwater surface runoff as well as specific discharges from university buildings and activities. The high proportion of impermeable surfaces on the campus results in reduced stormwater infiltration and higher surface runoff flows, carrying heavy metals and sediment into the streams (Good, O'Sullivan, Wicke, & Cochrane, 2012). Okeover Stream is particularly prone to receiving discharges containing high levels of contaminants, with >40 recognised discharge points along its length (Charters, Cochrane, & O'Sullivan, 2014; Wicke, O'Sullivan & Cochrane, 2009).

Okeover Stream

Blakely (2003) reported that sediments of Okeover Stream had significantly higher heavy metals concentrations that those of sediments nearby in the Avon River. Okeover zinc, lead and copper concentrations sometimes exceeded the Interim Sediment Quality Guidelines (ISQG) low threshold for aquatic life protection, as recommended by the Australian and New Zealand Environment and Conservation Council (ANZECC, 2000). This low threshold indicates the level at which toxic effects may occur for sensitive species, while exceedance of the high ISQG threshold would normally result in toxicity to many species present (Long, Macdonald, Smith, & Calder, 1995).

Blakely (2003) attributed this mostly to a discharge occurring directly upstream of the highest metal site. These results were supported by subsequent water measurements by Wicke et al. (2009), who found dissolved copper was consistently elevated in the stream water, even under base flow conditions. Farrant (2006) found similar results when quantifying contaminants in Okeover Stream during storm events; elevated copper, zinc and lead concentrations in the water, while nickel and cadmium concentrations were not significantly affected. During a storm event, copper and zinc remained well above the threshold recommended for the protection of 80% of the aquatic life (ANZECC, 2000) throughout the

event, while lead peaked above the 80% trigger levels, before steadily decreasing, but not dropping below the 90% trigger levels. Farrant (2006) also identified elevated chromium to be of potential concern, with chromium concentrations exceeding 95% trigger levels (ANZECC, 2000). These high levels of contamination were associated with impacted aquatic ecology, a represented by low MCI scores (Winterbourn, Harding, and McIntosh, 2007). Lear, Ancion, Harding, and Lewis (2012) also noted elevated copper in biofilms in Okeover Stream.

It is unusual for copper levels to exceed those of zinc in typical stormwater flows. This and the presence of elevated copper in the stream under baseflow conditions, suggested that copper contamination was also occurring from a source other than surface runoff. Wicke et al. (2009) proposed that the copper was sourced from deteriorating air-conditioning pipes, and entering the stream via cooling water discharges. This was further investigated by O'Sullivan, Wicke, and Cochrane (2012), who measured baseflow water quality in Okeover Stream downstream from three air-conditioning discharge outflows, as well as discharge from a copper alloy roof during a stormflow event. Under baseflow conditions, copper levels regularly exceeded the ANZECC 90% protection threshold by ca. 5 times. During active stormwater discharge, total copper, zinc and lead concentrations, as well as dissolved copper and zinc concentrations, regularly exceeded the ANZECC guidelines. The EMC (Event Mean Concentrations - a way of measuring contaminant levels during stormflow) were 18 times (zinc), 9 times (copper) and 5.7 times (lead) above the 90% species protection guidelines. Discharges from the copper alloy roof during a storm event showed copper concentrations that were up to 5000 times the 90% ANZECC threshold.

As a result of these findings, UC Engineering Services implemented a strategy to gradually replace all copper components in the air-conditioning systems (University of Canterbury, 2017), and to avoid the use of copper cladding and roofing as much as possible in future construction on campus (though recent building activities do not seem to reflect this).

To help identify the exact source of the worst discharges, Charters et al. (2014) looked at contaminant loads from 45 discharge points along Okeover Stream using a previously-developed MEDUSA modelling framework. This allowed particular “hotspots” of contamination to be identified and prioritised for management. For example, copper levels were highest in two sub-catchments that contained copper roofs. In contrast, total suspended solids (TSS) were highest in sub-catchments containing a high proportion of any kind of roofs, compared to other surfaces. Such analysis leads to targeted mitigation measures such as replacing copper roofs with other materials and re-fitting particular roads and carparks with more permeable materials to allow for increased infiltration.

By 2015, a significant improvement in sediment and water quality had been achieved in Okeover Stream, as reported in Eden (2016). Under base flow conditions, dissolved copper concentrations were well below the 99% ANZECC guidelines (although dissolved zinc concentrations still exceeded the 90% guidelines). Zinc, lead and copper concentrations in the sediments were also below the low ISQG thresholds. Similarly, a NIWA (2014) study of

sediment contamination found heavy metal levels in Okeover Stream to be below the ISQG-low threshold values (ANZECC, 2000).

Ilam Stream/Avon River

Under baseflow conditions, the concentrations of both total and dissolved heavy metals in the Avon River, at the downstream margin of the campus, were quite low (Adams et al., 2007). Only zinc (both total and dissolved zinc), exceeded the 99% ANZECC guidelines.

Copper, zinc and lead concentrations in the sediment were normally below the ISQG trigger values, except for one site which exceeded the ISQG-high threshold for lead and zinc (Adams et al., 2017). A NIWA (2014) study of sediment contamination in the Avon River catchment found heavy metal levels in the Avon River to be consistently below the ISQG trigger values. In Ilam Stream, however, both lead and zinc exceeded the ISQG-low threshold, and zinc concentrations approached ISQG-high thresholds (ANZECC, 2000). These levels suggest that Ilam Stream may need to be prioritised for future remediation and further monitoring.

Investigating the potential contribution of the large UC Fine Arts carpark to the Avon River sediment contamination, Adams et al. (2007) found heavy metal concentrations during stormwater runoff from the carpark to be much higher than under baseflow conditions. Zinc, lead and copper concentrations frequently exceeded 80% ANZECC guidelines (nickel concentration were not elevated significantly). Similar results were recorded during a subsequent study at the same location by Hutchison and Funnell (2008), who hoped to use this information to build a relationship model for urban contaminant loading and transport.

Contaminant sources and treatment options.

Some of the heavy metal contamination entering University of Canterbury waterways during rain events is clearly from roof surfaces, particularly copper and galvanised zinc roofs. Wicke, Cochrane, O'Sullivan, Cave & Derksen (2014) looked at whether there were differences stemming from variation in roof type, rainfall pH or roof age. The highest concentrations of heavy metals were recorded from the oldest roofs, due to increased dissolution potential from corrosion as well as the lower pH. In addition, copper and zinc in roof runoff were found to mostly be in a dissolved form, and therefore bioavailable, which means that they were far more likely to have a negative effect on the aquatic ecosystem.

There has also been growing interest in the contribution of aerial deposition to surface runoff. Wicke, Cochrane & O'Sullivan (2010, 2012) proposed a method to quantify this which used concrete and asphalt boards to investigate contaminant accumulation over time and tested this in a University of Canterbury carpark. After 13 days of accumulation, runoff from asphalt had elevated zinc (ca. 4x higher than before the accumulation period) and runoff from

concrete had elevated TSS (ca. 2 x higher). The authors attributed this to pavement surface compositions and roughness. Charters et al. (2014), among others, would later use this data as an input to a contaminant loading model.

A number of stormwater treatment options for the upper Okeover Stream have been recommended, including rock filtering, a detention basin, rain gardens and increased riparian planting. Three rain gardens of varying organic composition were tested to evaluate their respective metal removal efficiency Good et al. (2012). The rain gardens reduced total lead, copper and zinc by more than 50% in all but one case, and were most effective when using a sand-only system. This gave early indications that rain gardens could be a viable option for treatment of stormwater at the University of Canterbury, following further research. A permanent rain garden was subsequently installed in 2016.

1.3.2. Hydrology

Okeover Stream

There have been significant alterations to the hydrology of waterways at the University over time, as a result of urbanisation, campus construction, short and long term climate variability and groundwater extraction for the city’s domestic water supply. These combined factors have reduced the length of Okeover Stream by more than three kilometres (Blakely et al., 2003). Where it once began west of Withells Road, fed by springs, it now begins within the University of Canterbury campus grounds, just east of Ilam Road. The ephemeral upper reach only flows when fed by stormwater (O'Sullivan et al., 2012). In fact, even on the campus grounds, most of the Okeover Stream base flow is due to building cooling waters discharged from pipes. The cooling water is groundwater, extracted from wells on the campus. This is particularly the case in the upper reaches, which dry out when these inputs are stopped (O'Sullivan et al., 2012).

Discharge in Okeover Stream varies from 0.0018 m^3/s at the headwaters to 0.0955 m^3/s just before it meets the Avon River (Blakely, Harding, & McIntosh, 2003). Discharges to the stream cause a sudden and significant increase in flow, which more than triples within a few hundred metres of the Ilam Road bridge (Blakely et al., 2003).

Ilam Stream/Avon River

Barr and Webster-Brown (2016) investigated short term water quantity and quality variability of artesian springs around Christchurch, including those Ilam Garden springs feeding the Ilam Stream. Highly variable flow was recorded in both springs, which ceased to flow in mid-summer (February) 2015, and had not resumed by August 2016, despite having typically resumed flow in previous years in August/September. Barr and Webster-Brown (2016)

attributed most of this to lack of recharge of the urban groundwater system during the dry winters of the (then) drought in Canterbury. Lower groundwater levels resulted in less spring flow, at least in those springs outside of the area recharged by seepage from the Waimakariri River. This supported a growing concern that springs, and therefore headwater streams, in Christchurch were drying up (Setiawan, 2017). Notably the Ilam Garden springs have still not resumed their flow (as at May 2018; *pers comm* Jenny Webster-Brown, June 2018).

1.3.3 General water quality

Okeover Stream

General water quality parameters such as water temperature, turbidity, pH, conductivity and dissolved oxygen levels are important, both for their implications for aquatic life health (Winterbourn et al., 2007) and for understanding the processes affecting the stream environment.

The air-conditioning inputs to Okeover Stream locally raise the temperature of the stream, and could create a temperature gradient downstream. This could potentially have an impact on mortality and growth rates in some aquatic taxa, but the small change of only 1.5^{o}C down Okeover Stream appeared to have a negligible effect on benthic invertebrates (Blakely, 2003). Blakely et al. (2003) found the highest temperatures were measured at a site just below a major discharge of air-conditioning water. Winterbourn et al. (2007) measured in-stream mid-summer temperatures at around 14 or 15 ^{o}C between 2000 and 2005; not high enough to have a detrimental effect on aquatic life. Similar temperatures were recorded in Okeover Stream in 2015, with a maximum of 16.2^{0}C, which is still below the 20^{0}C maximum guideline in Environment Canterbury's Land & Water Regional Plan (LWRP) (Eden, 2016).

During a stormflow event in 2006, Okeover Stream turbidity levels were 9 times higher than the ANZECC 90% aquatic life protection threshold (O'Sullivan et al. ,2012). Even under baseflow conditions, there were indications in 2002 of high turbidity (34.0 NTU ± 11.0 in the ephemeral reach of the headwaters (Blakely et al., 2003). The latter is obvious in the difference between a composite (multiple samples taken to give an average for the event) TSS measurement, and first flush sample TSS values.

Various pH measurements of Okeover Stream between 2000 and 2009 indicate a weakly acidic stream, with pH = 6.1 to 6.8 (O'Sullivan et al., 2012; Winterbourn et al., 2007). These measurements are often outside the recommended range of pH 6.5 – 8.5 for spring-fed plains urban surface water, as specified in Environment Canterbury's LWRP (Canterbury Regional Council, 2015). The mild acidity could potentially enhance metal dissolution, therefore increasing mobility (O'Sullivan et al., 2012). However, these results are close to what might be expected from pure rainwater.

Conductivity measurements for Okeover Stream are moderate, as expected, with the highest measurement in 2002 recorded as 181.2 ± 36.0 µS/cm (Blakely et al., 2003). Conductivity was also found to peak during storm events (Farrant, 2006).

Between 2000 and 2005, dissolved oxygen in Okeover Stream fluctuated between 67% and 95% saturation (Winterbourn et al., 2007). This is somewhat outside the recommended range of 80 to 95% dissolved oxygen to best support aquatic life (ANZECC, 2000), but well above critically low levels. Variation in the dissolved oxygen levels was mostly attributed to the fluctuating balance between photosynthesis and respiration rates. Adams et al. (2007) also measured high levels of oxygen saturation (up to 155% saturation), while Blakely et al. (2003) measured very low dissolved oxygen (1.27 mg/L) in stagnant headwaters in the upper, ephemeral reaches of Okeover Stream.

Ilam Stream/Avon River

The Avon River appears to have a broadly similar water quality to Okeover Stream, but has been subjected to fewer studies. Similar temperatures to those in Okeover Stream were recorded in the Avon River in 2015 (Eden, 2016). Similar levels of turbidity were also found in the Avon River during storm events (Adams et al., 2007), displaying the same "first flush" effect as noted in the Okeover. The Avon River pH was weakly acidic and of moderate conductivity when measured in 2002 (Blakely et al. ,2003).

1.3.4. Stream Ecology

The effects of the degradation of campus waterways on their aquatic ecology has been evident for some time. Using old Drainage Board invertebrate surveys, O'Brien et al. (1998) showed that only 40% of the invertebrate taxa found on campus in 1980 were still present in 1990. With the large investment in stream restoration at the University of Canterbury, it was deemed important to be monitoring the effects through regular biological surveys.

Okeover Stream

Winterbourn et al. (2007) summarised findings of annual biodiversity monitoring of Okeover Stream between 2000 and 2005. They found the invertebrate population to be dominated by *Crustacea, Diptera* and *Oligochaeta*, all of which are indicators of relatively poor water quality. Over the six-year time period, the taxonomic composition of Okeover Stream remained relatively constant everywhere but the headwaters and the calculated MCI scores were quite similar to those recorded in 1980 and 1990. From this study it was concluded that there had been no significant improvement in aquatic diversity and abundance by 2005. This is slightly different from the increase in EPT taxa reported by Gundersen (2012) during the same time period, perhaps due to sampling methods. Percentage EPT (mayfly, stonefly and

caddisfly taxa) is a common indicator of contamination levels in New Zealand as the three taxa are quite sensitive to pollution. This lack of improvement occurred despite the large investment into riparian planting and channel enhancement during the preceding seven years. The authors suggested several potential reasons for these findings, including high in-stream sedimentation, a lack of flushing flows and lack of a source population for recolonization.

In Blakely (2003), taxonomic richness in Okeover displayed a clear longitudinal pattern, increasing down the length of the stream. While longitudinal patterns are common in rivers, Okeover Stream is only about 1.5 kilometres long (including the substantial ephemeral reach), so any pattern observed is not likely to be natural. The author was unclear why this might be the case, though suggested that heavy metal inputs and the intermittent drying of the upper reaches may play a role. When compared to surveys from 1989, stream composition in 2003 in Okeover Stream was trending towards more pollution sensitive taxa such as caddisflies. This is reflected in the higher MCI score. However, these results are not conclusive as EPT taxa still were in relatively low numbers in 2003 and caddisflies vary greatly in their pollution tolerance. EPT may not therefore have been the best proxy indicator for stream health. In contrast, the Avon River was similar in richness to the highest recorded EPT site in Okeover Stream. Despite all of this, a study comparing Okeover Stream to both the Avon River and the nearby Waimairi Stream, which have had little restoration completed on them, found that there was no significant difference in taxonomic richness or numbers of EPT taxa (Blakely & Harding, 2005). This indicates that the previous restoration efforts along Okeover Stream may not have been as effective as had been hoped, supporting the findings of Winterbourn et al. (2007).

A comparison of benthic invertebrate data between Okeover Stream and the Styx River by Lear et al. (2012) showed much lower benthic invertebrate diversity in the former, with communities mostly made up of non-EPT taxa. One Okeover site sampled contained only a single benthic invertebrate taxon, an amphipod, supporting the conclusions drawn from studies such as Winterbourn et al. (2007). It is evident that caddisfly and mayfly populations are still yet to return to pre-1980 levels, when Robb (1980) described an abundance of the caddisfly *Polyplectropus* and the mayfly *Deleatidium* at that time.

In 2015, Eden (2016) investigated benthic invertebrates across streams in Christchurch, including Okeover Stream, and their response to heavy metals. While Okeover Stream may not have had a high number of taxa (14), it had about 34 % EPT and a high QMCI score (about 4.8) comparative to other urban streams in Christchurch. As the MCI score was about 78, indicative of severe pollution, percentage EPT may not be the most accurate proxy measurement for pollution levels in Okeover Stream. Additionally, these scores are quite similar to those recorded in Blakely (2003), indicating little long term improvement in the health of Okeover Stream. These conclusions are corroborated by both the Freshwater Ecology Research Group (FERG), which has been undertaking annual ecological monitoring of

Okeover Stream since 2000 (*pers comm* Jon Harding, Dec 2017) and two surveys undertaken by Christchurch City Council (Main & Taylor, 2010; Boffa Miskell Ltd, 2014).

To test whether mayflies, in particular, could survive in Okeover at the time or if there was something else limiting their abundance, Blakely (2003) trialled *Deleatidium* species in enclosures along the stream. While there was very high mortality in upstream sites, significantly more *Deleatidium* individuals survived in downstream sites. This was attributed to fewer flatworms (who were potential predators) and reduced suspended sediment levels. However, despite the potential for mayflies to become established in downstream reaches of Okeover, they were not found to be present at the time. To determine why this might be the case, the author looked at availability of oviposition sites (places to lay eggs) and the potential for road culverts (such are common on Okeover Stream) to act as barriers for aerial dispersal of adult caddisflies. An experimental addition of oviposition sites showed a marked increase in adult egg laying. There was also a distinct lack of aquatic adults upstream of road culverts, indicating a barrier to recruitment. The relative lack of natural oviposition sites in Okeover Stream and the multiple road culverts were therefore concluded to be important aspects to address in future restoration work.

Ilam Stream/Avon River

While the Avon River and Ilam Stream have received far less attention than Okeover Stream, they are included as part of the Christchurch City Council's five yearly ecological surveys. In 2008, the Avon River (at that time labelled as Ilam Stream) downstream of Clyde Road was noted to be of "poor" ecological quality, based on calculated MCI and QMCI scores (EOS Ecology, 2009). However, these results were not unusual for the catchment. Ilam Stream was not included this year. A similar survey in 2013 also included Ilam Stream in the list of sites sampled within the Avon River catchment (Boffa Miskell Ltd, 2014). The Avon River at Clyde Road had relatively high taxonomic richness compared to the rest of the catchment, with almost half of the taxa classified as EPT, causing it to be rated the highest according to biotic indices in the Avon River catchment. Ilam Stream, along with another few sites, fell below the LWRP QMCI guidelines for spring-fed urban waterways. Okeover Stream, in comparison, had just reached the point of being in "good" health according its QMCI score, though the MCI still fell under "fair" quality.

Fish Surveys

In addition to benthic invertebrates, fish surveys have been conducted twice in recent years in the Avon River catchment for the Christchurch City Council as part of regular ecological surveys. These included some locations on the University of Canterbury campus. In 2009, Okeover Stream at Forestry Road had upland bullies at a density of approximately 30 per 100m^2 as well as a few recorded short finned eels (Main & Taylor, 2010). This was very similar

to that recorded by Eldon and Kelly (1992). A greater taxonomic richness of fish was observed in November 2013 (Boffa Miskell Ltd, 2014). While no fish were recorded to be present in Ilam Stream (not surprising given the lack of flow), both Okeover Stream and Avon River contained short and long finned eels as well as common bullies, though the Avon River reach also contained brown trout and one individual each of *inanga* and upland bully. However, given the Okeover Stream sample reach in 2013 was some distance closer to the confluence with the Avon River than the Okeover sample in 2009, it is difficult to accurately compare these results.

1.3.5 Cultural health

Though acknowledged in the UC campus Master Plan's Landscape Plan (2017) as an important consideration for stream restoration and management, there has been little research completed into the cultural health of waterways by mana whenua at the University of Canterbury. The 2007 and 2012 State of the Takiwā reports examined the cultural health of a variety of sites across Christchurch, including one site along the Avon River at Athol Tce up-gradient of the University of Canterbury (Lang et al., 2012). This involved a variety of assessments, including a cultural health index (CHI) and a more common water quality assessment. In 2012 the Athol Tce site had 25% of important indigenous species compared to what was once present. It was given a CHI score of 2.3 out of 5, which was slightly higher than the Avon River average of 1.9, and an overall site assessment rating of 1.5 out of 5. This is a poor/moderate score. Mahinga kai harvesting suitability was just 1.5 out of 5, with a 2.2 rating for mahinga kai values. Overall, the State of the Takiwā reports concluded that the moderately modified section of the Avon River by Athol Tce was not very supportive of cultural values.

The potential for mahinga kai development in Okeover Stream has been further investigated (Kainamu, 2013). The author deemed the growing of watercress on campus to be quite unsafe due to its predisposition to high uptake of heavy metals from the water, which, in Okeover Stream, were already considered to be elevated. However, it was suggested that watercress and other mahinga kai species could be considered for phytoremediation of the stream through heavy metal uptake, as well a reduced sedimentation. This idea has yet to be further developed.

1.3.6 Community Perceptions

A community's perceptions and understanding of a waterway play an important role in their behaviour around it. Environment Canterbury and the University of Canterbury jointly ran a project to test engagement and education tools for the Okeover Stream. The original phone survey of local residents, conducted at the start of 2010, indicated the level of understanding about the health of the waterway and how willing they would be to change behaviours in a

way that could improve the health of Okeover Stream (Environment Canterbury, 2010). Just under half of respondents did not think there was anything they could do to improve the health of Okeover Stream, with the Christchurch City Council most commonly cited as responsible for such improvement. However, when given a list of potential actions, about two thirds were prepared to change behaviours around their home to help improve stream health.

Several community initiatives were undertaken in the Okeover Stream catchment over the next two years. These included a car wash event to educate residents on alternative ways for washing their car, seven focus groups, a newsletter and an eel torchlight event (Environment Canterbury, 2012). These aimed to get the community thinking about the waterway and how their actions might have an impact.

A follow-up phone survey in 2012 was undertaken to see whether these initiatives had altered people's perceptions, understanding and behaviours regarding Okeover Stream (Environment Canterbury, 2012). The survey results indicated that residents appeared to have undergone a change in attitude. Most residents surveyed were concerned about the waterway's health and were prepared to transition to behaviours that could improve stream health. However, this shift in behaviour was not as clear in practice. For example, while more respondents cleaned their cars on grass than in 2012, the percentage of people cleaning their roofs with chemicals also increased. The report therefore concluded that people, while willing to help, did not really know what they could do other than eliminating the behaviour completely. This reinforced the need for further promotion of "practical solutions."

1.3.7 Potential externalities

The University waterways operate as part of a larger system, and factors affecting water in other parts of the catchment, or even other parts of the region, can have large impacts on the water which passes through the UC campus. There is therefore a need to consider the effects of these "external" factors. For example, the Canterbury earthquakes affected streamflow and groundwater levels in the urban area for at least the following three years (Mirus, Ebel, Mohr, & Zegre, 2017). Climate change is also expected to further increase the proportion of high intensity storm flow periods to baseflow periods, so reducing the effects of stormwater flow contaminant discharges is particularly important (Mirus et al., 2017).

Potential externalities of note for the University of Canterbury waterways management include:

- Variations in rainfall (total and rainfall intensity) and evapotranspiration
- Groundwater levels
- Diffuse pollution from surfaces outside the campus (e.g., road runoff, domestic discharges)
- Consents for water extraction and discharge to water

- Upper catchment urbanization and population density

Changes in some or all of these factors could be constraining the full effect of stream improvements within the campus grounds. For example, the current shift towards a reduction in drinking water takes from shallow aquifers could improve stream flow in urban areas (Christchurch City Council, 2017). Recording such factors for analysis alongside stream health indices will provide an opportunity to better understand the state and trends in stream environment quality.

1.4 Research aims

The primary aim of this research was to develop a design for an ongoing water monitoring programme for the University of Canterbury's campus waterways, optimising the value of past data collection while ensuring robust monitoring data for future waterways management needs.

There were three main objectives for this research;

- To collate and review data already collected on campus waterways
- To propose a design for an integrated monitoring programme to enable estimation and evaluation of UC baseflow and storm flow contaminant discharges to waterways, and to assess stream health.
- To recommend possible options for resourcing the monitoring programme, maximising student involvement through teaching courses but also ensuring quality control and full coverage or requirements.

Section 2 Compilation of existing information

2.1 Data sources

Existing data for the campus waterways is currently held in multiple places and multiple formats. An audit of current data was undertaken by interviewing key personnel in the Civil and Natural Resources Engineering Department (CNRE) and the School of Biology at UC. CNRE holds much of the data from research projects undertaken from within their department, while Biology holds annual biodiversity monitoring undertaken during teaching curses since 2000. Both groups also have thesis research data of relevance. The Christchurch City Council is the other main source of data for the waterways, through their five-yearly monitoring of the catchment. This includes ecological and sediment surveys.

Metadata for this information in shown in Appendix 1. This identifies all the sources for campus waterway data and indicates the parameters measured, providing a useful resource for future research projects. While the data from some sources is incomplete and there are likely to be projects that have been missed, it still provides a good overview of what has already been done on the University of Canterbury waterways.

2.2 Data compilations, treatment and quality control

The data collected have been collated into MS Excel spreadsheets, and are summarised in Appendix 2. Continuous measurements, such as of stream flow, were excluded from this database as incorporating them in a meaningful way would have been difficult. However, stream flow could be stored with other regular time series data (such as the parameters previously mentioned as external factors) in a parallel database with key summary information accessible from the integrated database.

Note that this data compilation is simply designed to indicate data gaps and overall water and sediment conditions. The data has been taken directly from its source. During data extraction, accuracy has been prioritised, involving multiple checks of the data, often against different data sources. However, there are potential methodological or calculation errors arising from the data sources. This is made more likely by the fact that some of the data was collected by students who may have been practicing new skills at the time. In addition, some of the data collected needed to be converted as the units were not consistent, in particular total and dissolved heavy metals. Anyone seeking to use this data should therefore consult the original documents, where these are referred to and available.

Section 3 Design for a Future Monitoring Programme

3.1 Designing a monitoring programme

In recent years there has been growing awareness for a need to reliably and comprehensively assess the current state of a waterbody and observe trends, in order to make recommendations for future management through monitoring and evaluation. Monitoring is the process of collecting data regularly, with careful and recurrent assessment against the programme's objectives (Behmel, Damour, Ludwig, & Rodriguez, 2016). The integration of various monitoring activities into a single comprehensive programme allows managers and users to have relevant and consistent information in addition to avoiding unnecessary duplication of data (Bartram & Ballance, 1996).

However, it is unlikely that a single holistic water monitoring design will be suitable for all contexts. Monitoring programmes are normally required to be able to track a range of complex processes (Wilkinson, Souter, & Fairweather, 2007) and to encapsulate a broad range of ecosystem components. However, there are a number of key elements that are acknowledged to be important in the construction of a robust monitoring programme, such as those proposed by Chapman (1996) and outlined below.

The first consideration in establishing a monitoring programme should always be deciding the objectives of the study. These will in turn determine the type, intensity and frequency of monitoring that will be undertaken. The objectives of a monitoring programme can vary greatly depending on the information needs of the users. For example, a monitoring programme may be commenced for long term trend and process modelling or to evaluate the impact of a particular pollutant source (Fölster, Johnson, Futter, & Wilander, 2014; Hill & Price, 1983). To date, there seems to be no methodical way of setting out objectives, so they are likely to reflect information needs and expert opinion (Behmel et al., 2016). While it may be desirable to have in-depth knowledge of all components of a system, there are constraints imposed by human, technical and financial resources. As such, there is a need to prioritise objectives to determine what information is important and what would just be nice to know.

After the objectives of a monitoring programme are set, preliminary surveys are often carried out. It can be helpful to test assumptions about a waterway before applying them to the whole target area. Preliminary surveys can include investigating ideas about the waterbody, such as how many samples may be necessary, as well as testing logistical aspects that include site accessibility (Bartram & Ballance, 1996). In an area with previous monitoring this will also involve collating and comparing past data to programme objectives, thus determining how well it met its purpose and how the existing programme might be improved (Ward, Loftis, & McBride, 1990).

From here an initial monitoring design can be developed. There are many guidebooks that lay out how this might be accomplished, including statistical techniques to do so (Altenburger et al., 2015; Fölster et al., 2014; Ward et al., 1990). However, to develop a robust water monitoring programme, four areas must be considered (Chapman, 1996);

- The selection of suitable water parameters to sample
- Determination of natural water variation as seen in preliminary surveys
- The combination of water quantity and quality monitoring
- How the design could be regularly reviewed

It may involve sampling any combination of water, biological and particulate matter depending on the objectives of the programme as well as existing and projected water uses (Bartram & Ballance, 1996). Choice of sampling frequency and locations will stem from a combination of the desired objectives, knowledge from previous monitoring and preliminary surveys as well as the available resources. These will be highly dependent on the nature of the waterbody in question, specifically the degree of spatial variation and mixing (Ward et al., 1990). Field observations of water quality will need to be supported by hydrological information. This allows a better understanding of how a waterbody operates and can give an indication of potential relationships between different components. This will also need to take into account both temporal and spatial variability (Chapman, 1996). Finally, periodic review of the water monitoring programme needs to be built into the design (Chapman, 1996). This allows regular reflection on whether a programme is achieving its objectives and whether any changes might need to be made.

At this point the water monitoring programme can be put into practice. Logistics, including human resources and necessary training, should be considered here. Some parameter measurements will invariably need to be conducted in the field, such as *in situ* measures on conductivity and discharge. Others, including detailed contaminant analysis, require laboratory facilities. Protocols for these are outlined in guidebooks such as Bartram and Ballance (1996).

There are several considerations that need to be considered after data collection. Data quality control, while often complicated and time consuming, is necessary to ensure that data is meaningful and comparable. This normally depends on strict adherence to monitoring protocols, such as those outlined in Bartram and Ballance (1996), as well as clear recording of procedures followed. The data should be stored and treated in a way that prevents errors in data collation or loss of data (Behmel et al., 2016). Some form of centralised database can be a valuable tool for this. Finally, the data needs to be interpreted before it is communicated to decision makers and the wider public. Data is of limited use by itself unless it is reported in a way that can easily be understood by a variety of people.

3.2 Monitoring programme objectives

During preliminary discussions with involved academic staff at UC, it became clear that the overall purpose of an integrated monitoring programme must be to "report on the long-term health of campus streams, and to complement CCC data collection downstream of the campus." (*Dr. Matt Morris, pers. comm.,* November 29, 2017). There was also a collective feeling that having set locations for undertaking data collection to support teaching or research projects at UC, would allow for better sharing of information and greater consistency over different space and time scales (*Dr Matt Morris, pers. comm*., November 29, 2017).

There were two more specific objectives voiced also;

- From an ecological perspective, interest focussed on whether Okeover Stream is recovering with time through the establishment of new species (*Professor J. Harding, pers. comm*., December 21, 2017).
- Civil and Natural Resources Engineering staff were most interested in developing more efficient water monitoring of stormwater runoff effects, and ways to regularly collect and reliably store data (*Dr F. Charters & Associate Professor T. Cochrane, pers. comm*., December 12, 2017).

Consequently, the proposed monitoring programme embodies two main objectives (as noted previously):

i) The assessment of UC stream health and ecology

ii) The estimation and evaluation over time of baseflow conditions and UC stormwater contaminant discharges to the waterways

3.3 Site selection

Six sites across the University of Canterbury have been identified as important for a robust monitoring programme: three on Okeover Stream and three on the Avon River. Figures 2 and 3 show the details of each site. The criteria used to select sites included:

- Accessibility
- Historical monitoring data available for that site
- Sufficient distance from piped discharges to allow for full mixing
- The need to have (for each stream) one site upstream of all inputs, and one site downstream of all inputs.

The main 6 sites provide a holistic overview of campus stream conditions from where water enters university grounds as the upper Avon River (A1) or the upper reaches of Okeover Stream (O1), to the where it exits the campus near Clyde Road (A3 & O3) . A site central to

the campus, on both waterways, was also chosen (A2 & O2). These are principal sites envisaged for long term, ongoing monitoring and will indicate the state of the waterways as well as the contribution of the University to this.

Two of the Okeover Stream sites (O2 & O3) are currently monitored annually for their ecological health and have been included in other research, providing some historical data for these sites and thereby extending time trends. There is currently no regular monitoring of the Avon River undertaken by the University of Canterbury, but the central site (A2) was mentioned independently by both the Civil and Natural Resources Engineering Department and the Biology Department as an ideal site for monitoring, and has been used in past projects (*Dr F. Charters & Associate Professor T. Cochrane, pers. comm., December 12, 2017; Professor J. Harding, pers. comm., December 21, 2017*). When sampling the Avon River it will be important to note whether Ilam Stream is overflowing the culvert beside the Staff Club. In a similar way, when sampling Okeover Stream it will be important to estimate the flow upstream of the campus, as this is an ephemeral reach.

A number of supplementary sites are also proposed for Okeover Stream. These include O4a (by Ilam Road, Figure 2), which marks the top of the ephemeral reaches of Okeover Stream, is useful for storm-flow modelling but does not have the consistent flow required for regular monitoring (Farrant, 2006). There are no major inputs between this site and site O1, except for a few runoff pipes from neighbouring residential properties. This supplementary site could be used to assess storm flow and quality during rain events.

Site O4b (near the University Crèche and community gardens, Figure 2) is currently used for annual macro-invertebrate monitoring, and is likely to continue to be used for this purpose. It was initially considered as a principal monitoring site. However, it is downstream of a significant cooling water input, as well as at least three other (probably stormwater runoff) discharge pipes. As a result, it doesn't provide an accurate indication of general water quality in Okeover Stream.

Site O4c (by the Electrical Engineering Bridge/Zoology carpark, Figure 2) is also used for biodiversity monitoring by FERG, and has been the subject of storm- and base-flow water research in the past. While such activities may continue at this site, it is a less useful indication of overall stream health than the three principal monitoring sites identified along Okeover Stream. As such, while continued research there may be useful, it is not an essential part of an integrated UC waterways monitoring programme.

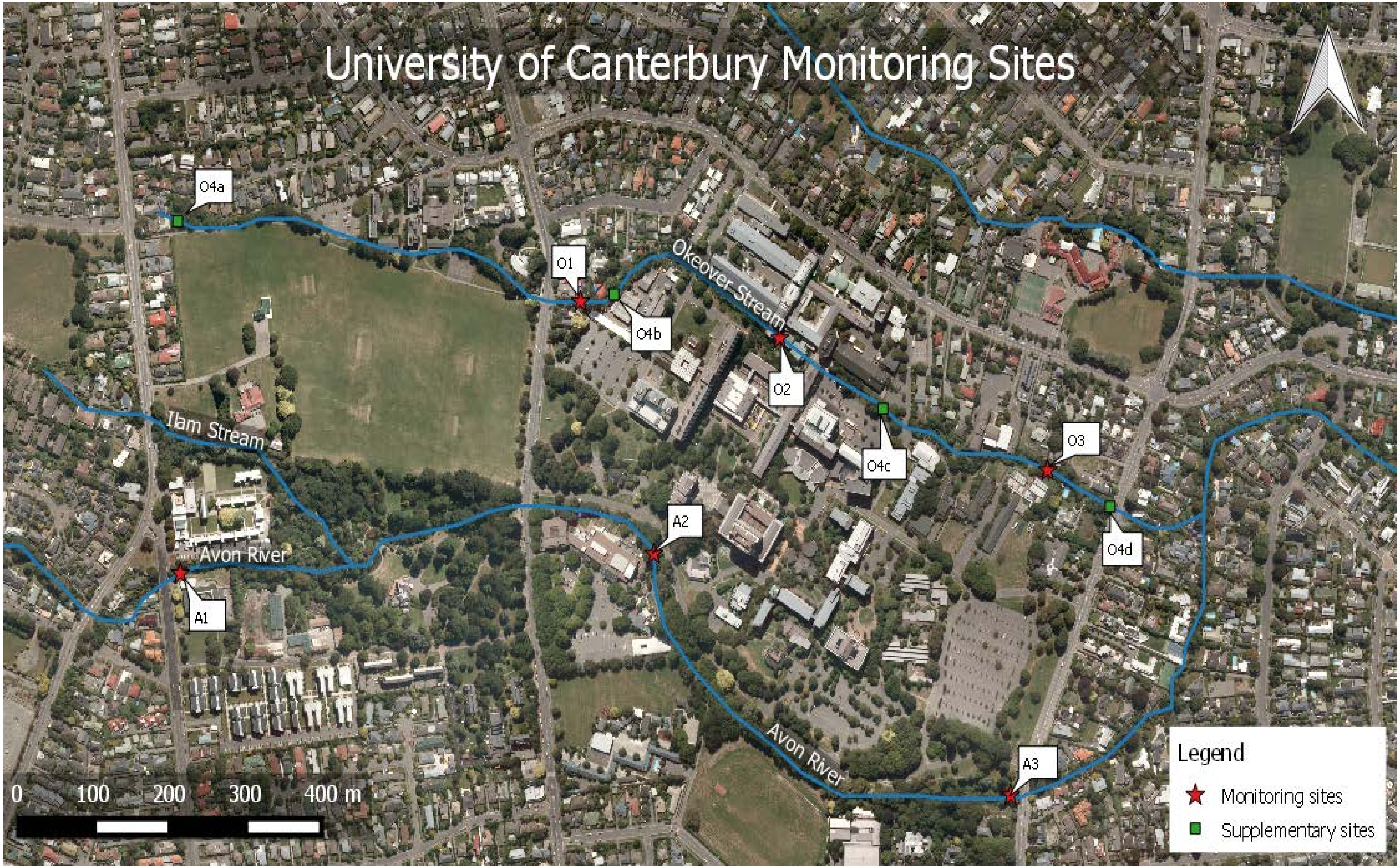

Figure 2. Map of main monitoring sites located along Okeover Stream (O1-3) and the Avon River (A1-3), together with proposed supplementary sites on Okeover Stream (O4a-d)

Site A1: 13m downstream of Waimari Road

8m upstream of Waimari Village runoff

By Bishop Julius Hall of Residence

No permanent water level marker

Easy access

-43.52421, 172.57348

Site A2: 10m upstream of UCSA Bridge

Road runoff about 8m upstream

No permanent water level marker

Easy access

-43.52404, 172.58124

Site A3: 8m upstream of Clyde Road

Permanent water level marker

Easy access

-43.52671, 172.58698

Figure 3a Monitoring sites located along the Avon River. GPS coordinates are accurate to approximately 5m.

Site O1: 12m downstream of the Crèche Bridge, below Ilam Road

3m upstream of first cooling water input

No permanent water level marker

Relatively difficult access

-43.52143, 172.57988

Site O2: at Engineering Bridge

Permanent water level marker

Easy access

-43.52189, 172.58327

Site O3: behind second collection of glasshouses

No permanent water level marker

Easy access

-43.52317, 172.58764

Figure 3b. Monitoring sites located along Okeover Stream. GPS coordinates are accurate to approximately 5m.

Site O4d (Okeover Stream at Clyde Road, Figure 2) is technically the best site for assessing the state of water exiting the campus. However, it is quite difficult to access. In contrast, site O3 behind the glasshouses (Figure 2) has some of the best aquatic biodiversity on campus *(Professor J. Harding, pers. comm., December 21, 2017),* and has very easy access, which makes it a better long term monitoring site. There appears to be only one runoff pipe discharging to the stream between O3 and O4d, but some monitoring of site O4d is required to ensure this discharge does not affect water quality.

No supplementary sites were identified on the Avon River, or on Ilam Stream. Little research has been conducted along Ilam Stream, other than its inclusion in two Christchurch City Council surveys, and there is typically very little flow, making establishing useful monitoring sites difficult at this stage (Mitchell, 2016; Barr & Webster-Brown, 2016). If there was to be a monitoring site established at some point along Ilam Stream, then a site near to Waimari Road is recommended. This site would be at the edge of University grounds and is the location used in the past by the Christchurch City Council for catchment monitoring (Boffa Miskell Ltd, 2014; NIWA, 2014).

3.4 Parameters and frequency

The choice of parameters to be measured, as for site choice, is partially guided by past data collection as well as the objectives of the proposed monitoring programme (Table 1). Annual macro-invertebrate surveys for taxonomic and EPT richness are currently undertaken by FERG at some of the sites, for example, usually in September. These data can be used to calculate MCI and SQMCI, indices that are commonly used to assess the state of ecosystem health in waterways. This should clearly continue, and could be extended to include annual fish and aquatic vegetation surveys.

Contaminant monitoring should be limited to those contaminants known to be present in urban stormwater run-off and in cooling water discharges. This includes nutrients, sewage-bacteria, heavy metals and suspended sediment. Nutrients nitrate (NO_3-N) and phosphate (PO_4 or DRP) are sourced from the use of fertilisers on grass and gardens, or from sewage leaks, and should be monitored routinely as they can disrupt aquatic ecosystem function. The presence of sewage, and the microorganisms contained therein, is detected using an indicator bacteria; *E coli.* A variety of trace elements can be present in stormwater depending on the nature of the catchment ... and in cooling water depending on the nature of the cooling system. It is recommended that a wider range of both dissolved (filtered through 0.45um) and total Ni, Cu, Pb, Zn, As, Al, Cr & Cd concentrations be measured initially, and the list reduced to just those shown to be elevated after an initial period (suggested as 3 years).

The concentrations of suspended sediment can be assessed from the (much easier) measurements of turbidity, but only after a period of calibration between these two

parameters. A period of quarterly ***and*** high rainfall event monitoring, at the central campus sites on each waterway (O2 and A2) is recommended to provide this calibration data, before only turbidity is monitored.

In addition, the measurement of water discharge (flow) and general water quality measurements such as temperature, conductivity, dissolved oxygen and pH needs to be made in order to inform the interpretation of ecological and contaminant data. Discharge could be calculated from water level, once the sites have been properly gauged (their cross sectional area and hydrograph established).

Table 1. Proposed parameters to be measured, and their frequency.

Parameter	Units	Frequency
Discharge (flow)	L/sec	Quarterly
Temperature	^oC	Quarterly
pH	pH units	Quarterly
Conductivity	µS/cm	Quarterly
DO	mg/L & %sat	Quarterly
TSS or Turbidity	mg/L or NTU	Quarterly
NO_3-N and DRP	mg/L	Quarterly
E coli	CFU/ml	Quarterly (seasonal)
Trace elements; Ni, Cu, Pb, Zn, As, Al, Cr & Cd (dissolved and total) (with reduction to fewer priority urban contaminants after 3 years)	µg/L	Quarterly (seasonal)
Macroinvertebrates	MCI & EPT	Annual (spring)
Sediment trace element survey		Biennial (or triennial)

A comprehensive sediment trace element survey need only occur every two or three years. Trace element levels in sediment do not fluctuate greatly over short periods, but do integrate the effects of regular discharges of contaminants (*Professor J. Webster-Brown, pers. comm., January 31, 2018).* They can therefore provide useful information on long term trends, compared to measurements of total and dissolved contaminant concentrations, which are expensive to determine frequently, and can fluctuate greatly depending on the presence of active discharges and storm events (Environment Canterbury, 2007). Consequently, it is

recommended that trace elements in sediment be measured only biennially or even less frequently. It could be useful to run a 3 or 4 year survey to compare mid-summer (when cooling water inputs are the highest relative to base flow) and mid-winter trace element concentrations, before deciding on the best time of year to collect this data. As for dissolved trace element concentrations, it would be preferable to test for a range of trace elements initially (e.g., nickel, copper, lead, zinc, arsenic, aluminium, chromium and cadmium), before reducing to those shown to be elevated in these waterways.

Methods and protocols for sample collection and analysis are not included in this report, as the focus is on monitoring programme design. However, it should be noted that once chosen, methods need to stay consistent over time, and if possible similar to those used previously so historical comparisons are possible (*Dr F. Charters & Associate Professor T. Cochrane, pers. comm., December 12, 2017; Professor J. Harding, pers. comm., December 21, 2017*). Samples should generally be analysed according to existing sampling and analysis protocols, as taught in the School of Biology, CNRE and Waterways Centre for Freshwater Management. Where differences in methods exist between these groups, an agreement must be reached (and adhered to) regarding the methodology to be used in this monitoring programme.

3.5 Data storage & analysis

Once a monitoring programme is running there would need to be a centralised database for all of the data, both the historical and ongoing monitoring data. The database designed to collate the historical data (Appendix 2) for this study, may provide a template, although a simplified version only including those parameters that are to be regularly monitored would need to be the interface. In addition, the departments involved may of course wish to keep their own copy of the data.

Access would be a key consideration, for both academics who contribute to it as well as researchers who would like to use the data. Data entry (and change) needs to be carefully controlled, with consideration given to quality control procedures. This would necessarily limit those allowed to enter and edit data. Such databases are already in use by other organisations (e.g., NIWA, Regional Councils), and so the design of this should not be an obstacle.

Data review at regular intervals by a suitably qualified person is also recommended, perhaps once every 3 years. The review could include an analysis of state and trends, comparing data trend with time, and with respect to set target values for each of the parameters, such as ANZECC trigger values to protect aquatic ecosystem health (ANZECC, 2000).

3.6 Programme review

Finally, a monitoring programme such as this requires a built-in process for regular review, particularly during the establishment phase. However, any refinements, including adding or moving site locations, would need to be undertaken with caution so that data continuity is not lost.

Section 4 Recommendations for Implementation

4.1 Making it happen

With all of the changes projected to take place on campus over the next few decades, it is clear that there is a need to establish an integrated water monitoring programme for the University of Canterbury, to assess the status and trends of campus water quantity and quality and ecosystem health. The proposed programme specifies monitoring at three sites on the Avon River and three on Okeover Stream, where they flow through the university campus. Useful information to support the monitoring programme can be collected at a further four supplementary sites on Okeover Stream. These are sites at which data has been collected in the past and is anticipated for the future, to address particular issues or to meet particular teaching needs. Recommended frequency for monitoring ranges from quarterly for most parameters, to annually for ecological data, to once every few years for sediment contamination. A centralised database would need to be developed to collate results in a way that is readily accessible.

For such a monitoring programme to be successful, there will need to be recognition of the importance of this monitoring programme, from relevant departments or schools, UC Facilities Management, UC Sustainability Office and other university management systems (*Professor J. Harding, pers. comm., December 21, 2017; Dr F. Charters & Associate Professor T. Cochrane, pers. comm., December 12, 2017*). The 3 departments/schools with the strongest connection to these waterways are the School of Biology, the Civil and Natural Resources Engineering Department and the Waterways Centre. These entities use the waterways in teaching programmes, and in research projects, as well as having an abiding interest in their health and character as typical urban stream environments.

Support from UC Facilities Management and the UC Sustainability Office will also be very important. Despite the best intentions, it is difficult for a monitoring programme to be successful without proper resourcing, and there is currently no budget allocated for implementing such a monitoring programme (*Dr M. Morris, pers. comm., November 29, 2017*), despite the interest expressed in the 2017 Landscape Plan (University of Canterbury, 2017). There is interest in incorporating conclusions from a campus waterways monitoring programme into the annual UC Sustainability report (*Dr M. Morris, pers. comm., November 29, 2017*).

Some of the data required for the monitoring programme could be collected during teaching progammes. If course coordinators are made aware that the data collected by the class could be an important component of the monitoring, they could (hopefully) make minor adjustments to their data collection and site choice, as required to fit the monitoring programme. This would have the dual benefit of contributing to the waterway database in a meaningful way and increasing student engagement with the waterways. It aligns with the

University's promotion of the campus as a "living laboratory", where students are able to use stream restoration projects to apply their learning (University of Canterbury, 2017).

Programme leadership and overview from a single agency will be important; this agency could be the UC Sustainability Office or the Waterways Centre for Freshwater Management. The agency would be ultimately responsible for ensuring that monitoring is completed when required, and augmenting data collected in various teaching programmes when needed.

4.2 Additional surveys

Annual fish survey

One potentially important environmental quality indicator that is not yet incorporated into the proposed monitoring programme is an annual fish survey. While fish surveys may be part of the Christchurch City Council's five-yearly surveys of the city's waterways, this is not regular enough to provide useful information about fish species, particularly about the occurrence of pest species (Boffa Miskell Ltd, 2014). Annual fish surveys are a parameter that will likely be important for a thorough monitoring programme (*Professor J. Harding, pers. comm., December 21, 2017*).

Riparian vegetation

The Landscape Master Plan proposes a number of projects focused on plantings, including developing wetlands and using endemic and *taonga* plant species for riparian margins (University of Canterbury, 2017). As the improvement of riparian margins does have an impact on water quality (e.g., Environment Canterbury, 2007), it may be a good idea to incorporate data on changes in riparian vegetation. This could be as simple as annual cover assessments or a general site assessment (including vegetation cover) for each site monitored annually. This would provide important context for other data collected at the time.

Cultural health

There is a need for the determination of cultural health indicators, as advised by Te Ngāi Tūāhuriri. The Landscape Master Plan and other university strategic documents acknowledge Ngāi Tahu as having mana whenua over the University grounds, and playing an important role in relevant decision making. However, there is yet to be significant progress in the integration of cultural priorities into waterways management (University of Canterbury, 2017). There is the potential to incorporate similar indicators to those used in the State of the Takiwā reports, particularly a cultural health index (Lang et al., 2012).

A "Relevant research" register

Another important initiative is a permanent process for registering research on campus waterways (*Professor J. Harding, pers. comm., December 21, 2017*). A way to formally register research projects, such as postgraduate theses, hons projects and summer scholarship

reports, would make it easier to track what has been studied and identify ongoing gaps in knowledge. This could be linked to the monitoring data collation and storage process in some way. Capturing all of the relevant research projects, and keeping the information up to date would be an ongoing challenge.

4.3 Conclusion

An integrated water monitoring programme for the University of Canterbury's campus waterways is proposed, and supplementary information needs are identified. There are likely to be feasibility challenges to implementing such a programme, including resourcing the programme, sharing the responsibility for monitoring in a way that doesn't generate data gaps, and collating and storing data securely while making it widely accessible.

The monitoring programme may take some time to establish and may need to be reviewed and revised in its early years. However, there is a clear need to gather and record accurate and up-to-date information on the health of University waterways, particularly with all of the development expected to occur on campus in the near future.

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Appendix 1. Metadata for water flow and water quality

						Water Quantity			Water Quality															
Year	Data Dates	Key Person or Reference	Description	Location	Details	Water Level (mm)	Height over weir (mm)	Velocity/Discharge	TSS	Turbidity	Conductivity	Specific Conductivity	DO (mg/L)	DO (% sat)	Temperature	pH	ORP	Alkalinity	Total Metals	Dissolved Metals	PAHs	Nitrates	Phosphates	Other ions
2009/10	18 Nov 09 - 9 Jun 10	CNRE	Water level and flow logging	E9 Engineering Bridge	1 location, 10-min intervals	x		x																
2009	14 May 09 - 21 Sep 09	CNRE	Water level and flow logging	Weir near Waimairi Road	1 location, 10-min intervals																			
2010/11	23 Mar 10 - 7 Feb 11	CNRE	Water level and flow logging	Weir near Waimairi Road	1 location, 10-min intervals																			
2009-12	11 Dec 09 - 20 Apr 10, 26 Aug 10 - 7 Feb 12	CNRE	Water level and flow logging	Forestry Road Bridge	1 location, 10-min intervals	x		x																
2012	11 Dec 09 - 7 Feb 12	CNRE	Water level and flow logging	Engineering Road crossing	1 location, 10-min intervals																			
2006	11 May 06 - 12 May 06	Stu Farrant, CNRE	Stormflow water sampling	Okeover in-stream	1 location (ephemeral weir), 14 time-series points		x	x	x		x	x	x	x	x	x			Cu, Pb, Zn, Ni, Cd, Cr	Cu, Pb, Zn, Ni, Cd, Cr				
2006	24 May 06	Stu Farrant, CNRE	Stormflow water sampling	Okeover in-stream	1 location (ephemeral weir), 16 time-series points		x	x	x	x						x			Cu, Pb, Zn, Ni, Cd, Cr	Cu, Pb, Zn, Ni, Cd, Cr				
2006	7 June 06	Stu Farrant, CNRE	Sediment sampling	Okeover in-stream	5 locations (between weir and child centre bridge)																			
2007	5 Dec 06	Ellie Taffs, CNRE	Baseflow water sampling; sediment sampling	Okeover in-stream	5 transects between Clyde Road and Ilam Road			x	x	x	x	x	x	x	x	x	x		Cd, Cu, Pb, Zn	Cd, Cu, Pb, Zn		x		x
2007	20 Dec 06	Ellie Taffs, CNRE	Stormflow water sampling; sediment sampling	Okeover in-stream	Ilam Road, 11 time-series grab samples			x	x	x	x	x	x	x	x	x	x		Cd, Cu, Pb, Zn, Ni	Cd, Cu, Pb, Zn, Ni				x
2009		Lilley and Platts, CNRE	Carpark Board experiments																					
2009	30 Jan 09, 3 Feb 09	Daniel Wicke (Postdoc researcher) CNRE	Concrete, asphalt, rubber board runoff quality		2 boards, 5 time-series samples																			
2009	Dec 09, Jan 10	Daniel Wicke (Postdoc researcher) CNRE	Copper roof runoff quality	E9 roof	Runoff during 6 rain events							x				x				Cu, Zn				
2007	11 June 07, 16 Aug 07	Adams et al 3rd Pro, CNRE	Baseflow water quality and sediment	Avon River	Baseflow and around outlet pipe			x	x	x	x	x	x	x	x	x		x	Zn, Cu, Pb, Ni	Zn, Cu, Pb		x		x
2007	28 Mar 07 - 4 Sept 07	Adams et al 3rd Pro, CNRE	Carpark runoff quality	Arts Carpark	Stormflow, 5 storm events				x	x	x	x	x	x	x	x		x	Cu, Pb, Zn, Ni	Cu, Pb, Zn, Ni		x		x
2008	24 Aug 08 - 18 Sept 08	Hutchison and Funnell 3rd Pro, CNRE	Carpark runoff quality	Arts Carpark	3 storm events				x										Cu, Pb, Zn	Cu, Pb, Zn				

Appendix 1 cont…

2009	17 Dec 09 - 1 Jan 10	Daniel Wicke (Postdoc researcher) CNRE	Conductivity	Okeover	Continuous						x													
2014	16 April 14 - 1 Oct 14	James and Amanda 3rd Pro, CNRE	Water level	Electrical Bridge, E9 Bridge	Continuous, rating curves	x		x																
2014	24 July 14 - 30 Sept 14	James and Amanda 3rd Pro, CNRE	Water level	Electrical bridge	Stream gauging	x		x																
2014	2 July 14 - 25 Sept 14	James and Amanda 3rd Pro, CNRE	Baseflow and stormflow water quality	E9 bridge	Continuous and in situ	x			x	x	x	x	x	x	x	x			**Al, Cr, Ni, Cu, Zn, As, Cd, Pb**	**Al, Cr, Ni, Cu, Zn, As, Cd, Pb**				
2016	2014/15	Frances Charters, CNRE	At-source stormwater quality in Okeover catchment	Runoff from: Galvanised roof, copper roof, concrete roof, asphalt road	TSS, heavy metals																			
2009	24 Nov 09 - 3 Dec 09	Daniel Wicke (Postdoc researcher) CNRE	Rating curves	Engineering Road culvert, E9 bridge, Geology	Rating curves for Okeover			x																
2015/16		Salina Poudyal, CNRE	At-source stormwater quality in Avon catchment	Runoff of from: Carpark, Coloursteel roof	TSS, heavy metals, E coli																			
2016	1 Apr 15 - 11 June 15	Stephen Stern and Liam Broughton (Honours), CNRE	Water level	E9 Bridge	Continuous	x																		
2016	21 Mar 16 - 13 July 16	Stephen Stern and Liam Broughton (Honours), CNRE	Water level	E9 Bridge	Continuous	x																		
2016	1 Oct 14 - 15 May 15	Stephen Stern and Liam Broughton (Honours), CNRE	Water level	Electrical Bridge	Continuous	x																		
2016	21 Mar 16 - 8 Aug 16	Stephen Stern and Liam Broughton (Honours), CNRE	Water level	Electrical Bridge	Continuous, cross section	x		x																
2016	17 Feb 14 - 3 Oct 14	Stephen Stern and Liam Broughton (Honours), CNRE	Water level	Okeover Stream	Continuous	x																		
2016	13 May 16 - 17 July 16	Stephen Stern and Liam Broughton (Honours), CNRE	Water level	Okeover Stream	Continuous	x																		
2008	18 Feb 08 - 30 Apr 08	Jon Harding, Bio	unpublished data obtained from EOS Ecology	Avon River	5 dates						x				x	x								
2005	Nov/Dec 02, May 03	Tanya Blakely and Jon Harding, Bio	Inter- and intra-stream WQ and sediment comparisons	Avon River, Okeover Stream	Baseflow sampling, Avon downstream of Clyde Road, Okeover was average of 5 sites					x	x		x		x	x		x					x	
2007	1992-2006	ECan/Pattle Delamore	Avon/Otakaro Heathcote/Opawaho catchement sites assessement	Avon River	Mean, Avon River on Mona Vale grounds, 20m u/s Wairarapa confluence				x		x		x		x	x						x		

Appendix 1 cont…

1959	1955-56	Hogan and Wilkinson, CNRE	Annual range of Avon River	Avon River	Annual range								x		x	x								
1980	Aug 79	Robb, Bio	Sediment composition, unpublished data obtained from EOS Ecology, 2005	Avon River	Kahu/Kotare Road, near Clyde Road											x		x	**Cd**					x
2007	2000-2005	Winterbourn, Bio	Annual river data	Okeover Stream	Average of four reaches						x		x		x	x								
2008	16 Aug 2007	ENNR305 reports, CNRE	Class sampling	Avon River	Baseflow				x	x		x	x		x	x			**Zn, Cu, Pb**					x
2017	2006-2017	FERG teaching , Bio	Ecology surveys	Okeover	Four sites, undertaken annually																			
2016	Jan - Dec 15	Jason Eden thesis (2016) Bio/WCFM	Metal and ecological surveys	Avon, Okeover	UCSA footbridge, glasshouses	x		x			x		x	x	x	x				**Al, Cr, Ni, Cu, Zn, As, Cd, Pb**				x
2014	5-8 Aug 13	CCC: Avon River Sediment Quality 2014	Avon River sediment survey	Ilam, Okeover, Avon	Waimari Road (Ilam) and Clyde Road (Avon, Okeover)																x			
2009	March 09	CCC: 5 Yearly Avon River Invertebrates and Fish (2009, 2014)	Long-term monitoring of aquatic invertebrates	Avon River, Okeover Stream	Okeover (Clyde Road), Avon (d/s Clyde Road)	x		x																
2010	Ap 09	CCC: 5 Yearly Avon River Fish (2010)	5 yearly fish survey	Okeover Stream	Forestry Road																			
2014	22 Oct 13- 7 Nov 13	CCC: 5 Yearly Avon River Invertebrates and Fish (2014)	Ecological survey	Ilam, Okeover, Avon	Waimari Road (Ilam), glasshouses (Okeover), d/s Clyde Road (Avon)	x		x				x			x	x								

Appendix 2. Meta data for sediment quality and ecology

						Sediment			Ecology							
Year	**Data Dates**	**Key Person or Reference**	**Description**	**Location**	**Details**	**Total Metals**	**Inorganic / organic sediment, size distribution**	**Periphyton**	**E coli / FC**	**MCI**	**SQMCI**	**QMCI**	**BOD5**	**Total taxa**	**EPT taxa**	**Fish**
2006	7 June 06	Stu Farrant, CNRE	Sediment sampling	Okeover in-stream	5 locations (between weir and child centre bridge)	**Zn, Cu, Pb, Ni, Cd**										
2007	5 Dec 06	Ellie Taffs, CNRE	Baseflow water sampling; sediment sampling	Okeover in-stream	5 transects between Clyde Road and Ilam Road	**Cu, Zn, Ni, As**										
2007	11 June 07, 16 Aug 07	Adams et al 3rd Pro, CNRE	Baseflow water quality and sediment	Avon River	Baseflow and around outlet pipe	**Zn, Cu, Pb**										
2007	28 Mar 07 - 4 Sept 07	Adams et al 3rd Pro, CNRE	Carpark runoff quality	Arts Carpark	Stormflow, 5 storm events				**x**							
2005	Nov/Dec 02, May 03	Tanya Blakely and Jon Harding, Bio	Inter- and intra-stream WQ and sediment comparisons	Avon River, Okeover Stream	Baseflow sampling, Avon downstream of Clyde Road, Okeover was average of 5 sites	**Cd, Cu, Pb, Zn**	**x**	**x**								
2007	1992-2006	ECan/Pattle Delamore	Avon/Otakaro Heathcote/Opawaho catchement sites assessement	Avon River	Mean, Avon River on Mona Vale grounds, 20m u/s Wairarapa confluence				**x**				**x**			
1980	Aug 79	Robb, Bio	Sediment composition, unpublished data obtained from EOS Ecology, 2005	Avon River	Kahu/Kotare Road, near Clyde Road		**x**									
2017	2006-2017	FERG teaching , Bio	Ecology surveys	Okeover	Four sites, undertaken annually					**x**	**x**			**x**	**x**	
2016	Jan - Dec 15	Jason Eden thesis (2016) Bio/WCFM	Metal and ecological surveys	Avon, Okeover	UCSA footbridge, glasshouses	**Al, Cr, Ni, Cu, Zn, As, Cd, Pb**				**x**		**x**		**x**	**x**	
2014	5-8 Aug 13	CCC: Avon River Sediment Quality 2014	Avon River sediment survey	Ilam, Okeover, Avon	Waimari Road (Ilam) and Clyde Road (Avon.	**As, Cd, Cr, Cu, Pb, Ni, Zn**	**x**									
2009	March 09	CCC: 5 Yearly Avon River Invertebrates and Fish (2009, 2014)	Long-term monitoring of aquatic invertebrates	Avon River, Okeover Stream	Okeover (Clyde Road), Avon (d/s Clyde Road)					**x**		**x**		**x**	**x**	
2010	Ap 09	CCC: 5 Yearly Avon River Fish (2010)	5 yearly fish survey	Okeover Stream	Forestry Road											**x**
2014	22 Oct 13- 7 Nov 13	CCC: 5 Yearly Avon River Invertebrates and Fish (2014)	Ecological survey	Ilam, Okeover, Avon	Waimari Road (Ilam), glasshouses (Okeover), d/s Clyde Road (Avon)					**x**		**x**		**x**	**x**	**x**

Appendix 3. Raw data for UC campus waterways (Okeover & Ilam streams and upper Avon)

Okeover: basic water quality				Water Quantity				Water Quality								
Collector (Source), desc	Date(s)	Location	Further details	Water Level (mm)	Height over weir (mm)	Discharge (m3/s)	Velocity (m/s)	TSS (mg/L)	Turbidity (NTU)	Conductivity (µS/cm)	Specific Conductivity (µS/cm)	DO (mg/L)	DO (% sat)	Temperature (°C)	pH	ORP
T. Blakely and J. Harding	Nov/Dec 2002		Alkalinity = 41.5						1.9	167.3		9		14	6.1-6.2	
	May 2003															
E. Taffs	Dec 2006	T1: Clyde Road				0.0630		< 3	1.25	137.5	172.82	10.04	98.2	14.4	6.77	135
		T2: Maori Dept				0.0300		< 3	0.63	139.5	112.06	9.41	93.0	14.8	6.69	137
		T3: Engineering Road				0.0050		< 3	0.35	141.7	177.25	9.37	92.0	14.6	6.67	173
		T4: Just d/s of air con discharge from FM				0.0140		< 3	0.22	132.5	167.74	10.68	104.1	14.1	6.65	207
		T5: Ilam Road				0.0010		46	5.26	160.7	200.53	2.16	21.3	14.7	6.44	134
Storm event	20/12/2006	Ilam Road	14:26					41	42.9	155.5	194.97	5.13	50.2	14.5	6.53	134
			15:00			0.001		41							6.7	
			15:10					8							6.7	
			15:20					412							6.2	
			15:25			0.0759										
			15:29						110	52.5	45.38	8.63	88.6	16.8	6.65	111
			15:35					284							6.1	
			15:40			0.1374										
			15:50					137							5.8	
			16:00					112	26.3	25.6	27.95	9.49	96.6	15.6	6.66	135
			16:20					64							6.1	
James and Amanda 3rd Pr	2 July 2014	Engineering Bridge	15:45					3.5	1.34	140.5	182.4		88.7	13.0	7.65	
	11 July 2014		11:00					1.1	0.25	148.2		8.51		13.6	7.7	
	18 July 2014		9:10	380					1.51	138.9	182.6	9.15	86.1	12.5	6.76	
			12:00	450				53.3	47.62	69.3	101	11.17	96.1	8.7	6.84	
			16:30	380				8.3	5.22	137.2	180.5	9.04	84.9	12.4	6.84	
	5 Aug 2014		15:36	370				4.4	0.86	150.3	194.3	8.63	82.5	13.2	6.66	
	22 Sept 2014		8:10					6.8	4.88	137.1	186.8	8.2	74.5	11.1	6.52	
			10:30	400				48.8	39.67	89.4	131.7	11.25	96.1	8.4	6.57	
			13:35	340				6.0	7.08	137.9	187.6	8.67	78.8	11.1	6.57	
	24 Sept 2014		9:51	360				1.1	0.54	150.2	193.2	8.75	83.9	13.4	6.99	
			13:25	360				1.3	1.05	148.9	189.1	8.82	85.5	13.9	7.03	
			16:23	360				1.2	0.56	149.5	191.3	8.81	85.3	13.6	7.03	
			19:05	360				1.6	0.53	147.4	190.1	8.82	84.0	13.3	6.99	
Continuous data																
Winterbourn et al	2000		Average of four reaches							140		9.8			7	
	2001									172				15.8	6.5	
	2002											9.9		14	6.6	
	2003									159		8.2		14.4	6.8	
	2004									168		7.0		13.6	7	
	2005									167		8.7		14.3	7.2	
Storm events	11 - 12 May 2006	Ephemeral weir	begin sampling 23:40, after 7 dry days		20	0.0001		237		129.1	167.9	2.32	20	12.9	6.36	
			23:50		80	0.0028		3		105.8	137.6	3.82		12.9	6.33	
			0:00		120	0.0078		20		104.8	137.0	7.12		12.7	6.39	
			first flush (peak) [~00:10]		170	0.0187		26		93.2	122.7	8.1	90	12.4	6.41	
			0:20		260	0.0540		35		48.7	66.0	9.47		11.3	6.39	
			0:30		260	0.0540		27		55.9	75.7	9.67		11.3	6.4	
			0:40		220	0.0356		27		50.7	68.8	9.81		11.2	6.45	
			0:50		150	0.0136		20		43.8	59.5	9.77		11.2	6.55	
			1:00		120	0.0078		17		42.5	57.9	9.55		11.1	6.5	
			1:10		100	0.0050		13		40.2	54.6	9.36		11.2	6.54	
			1:20		90	0.0038		18		39.8	54.0	9.05		11.2	6.58	
			1:30		70	0.0020		17		39	53.0	9.28		11.2	6.54	
			1:40		60	0.0014		21		38.7	52.6	9.83		11.2	6.55	
			sample at end [1:50]		50	0.0009		17		38.5	52.1	8.55	90	11.3	6.6	
			background sample 9:45am		240	0.0442				26.8	37.9	10.84	95	9.7	6.49	
	24 May 2006	Ephemeral weir						18								
								13								
								13								
								11								
								8								
								10								
								13								
			beginning of main storm (16:10), after 5-8 dry days		300	0.0772		31	24.1						6.4	
			16:20		390	0.1488		55	55.1						6.4	
			first flush (peak) [~16:25]		400	0.1585		114	78.4						6.4	
			16:30		410	0.1686		31	37.6						6.3	
			16:40		400	0.1585		59	44						6.3	
			after peak [16:50]		350	0.1135		36	39.6						6.3	
								39								
								46								
								24								
D. Wicke	2 Dec 2009	E9 roof	4:51													
			5:03								188				6.4	
			6:03								38				6.3	
			7:03								47				6.4	
			8:03								15				6.3	
			9:03								10				6.3	
			10:03								10				6.3	
	14 Dec 2009		13:58													
			14:13													
			14:43													
			16:11													
			16:26													
			16:41													
			17:11													
			17:26													
	19 Dec 2009		1:22								137				5.7	
			1:36								80				5.8	
			1:51								67				5.9	
	20 Dec 2009		14:41								249				6.1	
			14:56								86				6	
			18:01								87				6	
			18:16								37				6.1	
			18:31								28				6.1	
	8 Jan 2010		16:09								181				5.5	
			16:23								131				5.4	
			16:38								136				5.5	
			18:57								170				5.6	
			19:12								133				5.6	
			20:31								179				5.7	
			20:46								169				5.7	
			23:11								227				5.8	
			23:26								201				5.9	
			23:41								191				5.9	
	7 Feb 2010		19:41								389				5.9	
			19:48								380				6	
			20:01								362				6	
			20:38								346				6.2	
			20:44								314				6.2	
			20:51								284				6.2	
			21:06								273				6.2	
			22:10								273				6.2	
Eden 2016	Jan - March 2015	Glasshouses		80			0.26			170		9.3	96.0	16.2	6.6	
EOS Ecology (CCC)	March 2009	Clyde Road		100			0.30									
Boffa Miskell Limited (CCC	22 Oct - 7 Nov 20	Glasshouses		150												

Okeover: Nutrients and Contaminants

Collector (Source), descri	Date(s)	Location	Further details	Nutrients		Major ions (mg/L)						Total Metals (mg/L)								Dissolved Metals (mg/L)					
				NO3	NO2	Ca	Mg	Na	K	Cl	SO4	Al	Cr	Ni	Cu	Zn	As	Cd	Pb	Cr	Ni	Cu	Zn	As	Pb
T. Blakely and J. Harding	Nov/Dec 2002		PO4-P <DL																						
E. Taffs	Dec 2006	T1: Clyde Road		2.84	<0.002	21.4	2.63	7.86	1.06	9.5	9				0.0036	0.0080		< DL	0.0003			0.0015	0.0080		< DL
		T2: Maori Dept		3.22	0.004	23.7	2.97	8.66	1.11	11.9	11.7				0.0047	0.0110		0.0030	0.0005			0.0026	0.0130		< DL
		T3: Engineering Road		2.94	0.002	21.5	2.79	8.16	1.08	9.8	9.7				0.0073	0.0100		< DL	0.0002			0.0047	0.0090		< DL
		T4: Just d/s of air con discharge from		2.78	<0.002	20.8	2.55	7.52	1.04	8.9	8.2				0.0117	0.0020		< DL	<0.0001			0.0112	0.0030		< DL
		T5: Ilam Road		1.79	0.028	23.2	3.18	10.2	1.7	14.5	13.7				0.0093	0.1240		< DL	0.0077			0.0029	0.1020		0.0004
Storm event	20/12/2006	Ilam Road	14:26																						
			15:00	1.07	0.16	22.8	3.3	10.3	1.7	14.9	14.4			0.0030	0.0279	0.2000		0.0001	0.0095			0.0041	0.0680		0.0004
diss Cd < DL in all samples			15:10	1.91	0.03	18.0	2.8	9.3	1.9	13.5	13.0			0.0016	0.0246	0.1400		<DL	0.0084		0.0007	0.0087	0.1040		0.0005
			15:20	0.24	0.00	4.0	0.6	3.2	2.0	5.7	4.3			0.0046	0.0525	0.5210		0.0003	0.0653		0.0006	0.0081	0.1950		0.0013
			15:35	0.28	0.01	3.4	0.5	3.1	2.0	6.1	3.6			0.0039	0.0497	0.5160		0.0002	0.0734			0.0052	0.1450		0.0012
			15:50	0.19	0.01	2.1	0.3	2.1	1.7	3.8	2.2			0.0016	0.0164	0.2200		0.0001	0.0275			0.0044	0.1130		0.0010
			16:20	0.14	0.01	1.7	0.3	1.7	1.6	2.8	1.6			0.0008	0.0096	0.1260		<DL	0.0105			0.0040	0.0890		0.0008
James and Amanda 3rd Pro	2 July 2014	Engineering Bri	15:45									0.0889	0.0126	0.0014	0.0032	0.0207	0.0004	0.0001	0.0008	0.0007	0.0019	0.0006	0.0168	0.0003	0.0002
	11 July 2014		11:00									0.0290	0.0119	0.0012	0.0026	0.0191	0.0003	0.0000	0.0003	0.0005	0.0014	0.0004	0.0098	0.0003	0.0001
	18 July 2014		9:10									0.2386	0.0397	0.1126	0.0081	0.0371	0.0005	0.0000	0.0017	0.0008	0.0021	0.0021	0.0310	0.0004	0.0002
			12:00									1.9156	0.0159	0.0037	0.0219	0.1371	0.0025	0.0001	0.0113	0.0007	0.0015	0.0018	0.0858	0.0014	0.0001
			16:30									0.2549	0.0141	0.0022	0.0054	0.0342	0.0007	0.0001	0.0020	0.0007	0.0011	0.0008	0.0253	0.0005	0.0001
diss Al & Cd <DL in all samp	5 Aug 2014		15:36									0.1083	0.0126	0.0015	0.0048	0.0135	0.0003	0.0000	0.0009	0.0005	0.0014	0.0008	0.0102	0.0003	0.0001
	22 Sept 2014		8:10									0.3571	0.1669	0.5431	0.0144	0.0995	0.0009	0.0001	0.0020	0.0008	0.0012	0.0046	0.1040	0.0007	0.0001
			10:30									2.7512	0.0334	0.0497	0.1372	0.2579	0.0040	0.0001	0.0211	0.0010	0.0014	0.0038	0.1504	0.0026	0.0001
			13:35									0.3598	0.0218	0.0140	0.0085	0.0985	0.0010	0.0000	0.0019	0.0008	0.0013	0.0024	0.0921	0.0009	0.0001
	24 Sept 2014		9:51									0.0671	0.0218	0.0089	0.0044	0.0212	0.0004	0.0000	0.0003	0.0006	0.0013	0.0014	0.0163	0.0003	0.0001
			13:25									0.1054	0.0185	0.0073	0.0050	0.0279	0.0003	0.0000	0.0006	0.0005	0.0010	0.0011	0.0114	0.0002	0.0001
			16:23									0.0645	0.0182	0.0078	0.0044	0.0269	0.0003	0.0001	0.0003	0.0005	0.0011	0.0012	0.0106	0.0003	0.0001
			19:05									0.0868	0.0190	0.0072	0.0041	0.0179	0.0003	0.0000	0.0004	0.0005	0.0012	0.0013	0.0099	0.0003	0.0001
S Farrant	11 - 12 May 200	Ephemeral weir	23:40										0.0015	0.0014	0.0100	0.1800		0.00011	0.1200	< 0.0005	< 0.0005	0.0015	0.0550		0.0034
	Storm event		23:50										0.0009	0.0007	0.0041	0.1170		< 0.00005	0.0071	< 0.0005	< 0.0005	0.0016	0.0600		0.0013
			0:00										0.0027	0.0013	0.0109	0.2060		< 0.00005	0.0148	0.0006	0.0007	0.0066	0.1750		0.0012
			first flush (peak) [~00:10]										0.0028	0.0017	0.0156	0.4710		0.00008	0.0173	0.0006	0.0009	0.0105	0.2250		0.0012
			0:20										0.003	0.0016	0.0127	0.4710		0.00008	0.0180						
			0:30										0.0022	0.0012	0.0097	0.4120		0.00006	0.0112	0.0005	0.0006	0.0063	0.3600		0.0009
			0:40										0.0023	0.0012	0.0083	0.3710		< 0.00005	0.0120						
			0:50										0.0018	0.0009	0.0067	0.3320		< 0.00005	0.0092	< 0.0005	< 0.0005	0.0045	0.3070		0.0007
			1:00										0.0015	0.0008	0.0060	0.2920		< 0.00005	0.0082						
diss Cd <DL in all samples			1:10										0.0025	0.0007	0.0053	0.2690		< 0.00005	0.0078	< 0.0005	< 0.0005	0.0038	0.2550		0.0005
			1:20										0.0014	0.0009	0.0054	0.2700		< 0.00005	0.0067						
			1:30										0.0013	0.0008	0.0053	0.2740		< 0.00005	0.0066	< 0.0005	< 0.0005	0.0037	0.2480		0.0005
			1:40										0.0012	0.0008	0.0052	0.2640		< 0.00005	0.0067						
			sample at end [1:50]										0.0013	0.0007	0.0047	0.2530		< 0.00005	0.0061			0.0037	0.2480		0.0005
			background sample 9:45am										0.0028	0.0008	0.0063	0.1340		<0.00005	0.0075			0.0047	0.1340		0.0034
	24 May 2006	Ephemeral weir											0.0022	0.0014	0.009	0.367		0.00006	0.0206	0.001	0.0006	0.0054	0.301		0.0037
													0.0017	0.0011	0.0076	0.376		< 0.00005	0.0111	0.0009	0.0007	0.0053	0.341		0.0033
													0.002	0.001	0.0071	0.375		0.00006	0.0098	0.0007	0.0005	0.0049	0.333		0.0035
													0.0014	0.001	0.0062	0.402		< 0.00005	0.0086						
													0.0012	0.0009	0.0063	0.305		< 0.00005	0.0077						
													0.0022	0.0009	0.0066	0.333		< 0.00005	0.0081	0.0006	0.0005	0.0044	0.303		0.0023
													0.0016	0.0009	0.0071	0.333		< 0.00005	0.009						
			beginning of main storm (16:10)										0.0014	0.0007	0.0051	0.2660		< 0.00005	0.0087	0.0005	< 0.0005	0.0025	0.199		0.001
			16:20											0.002	0.0157	0.2590		0.00009	0.0406						
			first flush (peak) [~16:25]										0.0085	0.003	0.0203	0.3120		0.00011	0.0532						
			16:30										0.0038	0.0019	0.0098	0.2310		0.00007	0.0294	0.0006	< 0.0005	0.001	0.094		0.0005
			16:40										0.0031	0.0014	0.0079	0.1710		< 0.00005	0.0196	0.0005	< 0.0005	0.0011	0.083		0.0004
			after peak [16:50]										0.0019	0.001	0.0056	0.1200		< 0.00005	0.0125						
													0.0022	0.0009	0.0055	0.117		< 0.00005	0.0123						
													0.002	0.0009	0.0052	0.119		< 0.00005	0.0104						
													0.0022	0.001	0.0053	0.116		< 0.00005	0.0104						
D. Wicke	2 Dec 2009	E9 roof	4:51																			0.9330	0.0796		
		run-off	5:03																			0.8430	0.0605		
			6:03																			1.0330	0.0211		
			7:03																			1.2050	0.0247		
			8:03																			0.7410	0.0113		
			9:03																			0.5260	0.0104		
			10:03																			0.7180	0.0115		
	14 Dec 2009		13:58																			5.8790	0.1825		
			14:13																			5.1750	0.1222		
			14:43																			3.0380	0.0839		
			16:11																			2.5000	0.0899		
			16:26																			0.7320	0.0302		
			16:41																			0.6510	0.0158		
			17:11																			0.4940	0.0182		
			17:26																			0.6920	0.0168		
	19 Dec 2009		1:22																			3.9070	0.1641		
			1:36																			3.3590	0.0593		
d			1:51																			2.4840	0.0965		
	20 Dec 2009		14:41																			4.1140	0.1233		
			14:56																			2.8400	0.0511		
			18:01																			1.9180	0.0431		
			18:16																			1.3740	0.0245		
			18:31																			1.2920	0.0296		
	8 Jan 2010		16:09																			2.9050	0.1173		
			16:23																			3.0260	0.0593		
			16:38																			3.0840	0.0553		
			18:57																			2.9960	0.0808		
			19:12																			2.2450	0.0504		
			20:31																			3.0610	0.0897		
			20:46																			2.7160	0.0709		
			23:11																			2.3890	0.0677		
			23:26																			2.4270	0.0904		
			23:41																			2.3640	0.0469		
	7 Feb 2010		19:41																			8.6176	0.2688		
			19:48																			9.3987	0.2449		
			20:01																			9.4976	0.2171		
			20:38																			8.8436	0.1996		
			20:44																			8.7809	0.1928		
			20:51																			8.6244	0.1840		
			21:06																			8.4074	0.1832		
			22:10																			8.2206	0.1844		
Eden 2016	Jan - March 201	Glasshouses				21	2.5		1.0											0.0001		0.0001	0.0180	<0.001	<0.001
Diss Sb, Al, Ni, As < Dl in all samples		Diss Cd = 0.0003																							
		Tot V = 0.0002																							
		Tot Mn = 0.0004																							
		Tot Fe = 0.01																							
		Tot Co <DL																							
		Tot Cr = 0.0001																							

Okeover: Sediments and ecology

Collector (Source), description	Date(s)	Location	Further details	Cr	Ni	Cu	Zn	As	Cd	Pb	Total taxa	EPT taxa	EPT (%)	MCI	SQMCI	QMCI
				Sediment Metal							**Ecology**					
T. Blakely and J. Harding	Nov/Dec 2002		Periphyton 0.48 ug chlor a/cm2													
	May 2003		Inorganic sediment 1.82 mg/cm2			32.3	110		0.06	86.9						
			organis sediment 1.38 mg/cm2													
E. Taffs	Dec 2006	T1: Clyde Road			8	27	121	3								
		T2: Maori Dept			10	336	441	5								
		T3: Engineering Road			17	14	297	3								
		T4: Just d/s of air con discharge from FM			9	146	364	5								
		T5: Ilam Road			10	51	522	4								
S.Farrant	2006	Site 1: immediately above weir			13.1	87.7	955		0.63	1120						
		S2: culvert entrance prior to drain flowing beneath residences			12.6	32.4	620		0.33	201						
		S3: Top section of box drain			10.3	81.8	677		0.25	199						
		S4: Bottom section of box drain above Ilam Road			8.1	17.8	406		0.19	36						
		S5: Beneath the bridge to child care centre			11.8	170	691		0.34	134						
FERG	2000	Okeover Stream	Summary								19			76	3.5	
Normally undertaken in Nov/Dec	2001		Summary								16			74	4.6	
	2002		Summary								17			84	4.4	
	2003		Summary								20			84	4.2	
	2004		Summary								18			80	4.8	
	2005		Summary								13			69	3.8	
	2006	Creche									8			62	4.7	
		Engineering Road									8			62	4.4	
		Zoology carpark									13			80	4.4	
		Glasshouses									11			72	4.5	
			Summary								18			69	4.5	
	2007	Creche									8			67	5	
		Engineering Road									13			71	4.2	
		Zoology carpark									12			72	4.4	
		Glasshouses									14			94	2.8	
			Summary								25			76	4.1	
	2008	Creche									6	0		83	4.9	
		Engineering Road									10	2		80	4.4	
		Zoology carpark									11	4		85	2	
		Glasshouses									14	4		89	4	
			Summary								22			84	3.8	
	2009	Creche									5	0		64	4.9	
		Engineering Road									9	0		76	4.6	
		Zoology carpark									13	4		91	4.5	
		Glasshouses									11	4		91	4.4	
			Summary								18			80	4.6	
	2010	Creche									12	0		73	3.9	
		Engineering Road									9	0		71	4.7	
		Zoology carpark									21	5		88	4	
		Glasshouses									22	8		94	4.6	
			Summary								27			81.5	4.3	
	2011	Creche									9	1		71	4.3	
		Engineering Road									20	3		84	4.2	
		Zoology carpark									16	6		85	4.7	
		Glasshouses									19	6		96	5	
			Summary								25			84	4.6	
	2012	Creche									11	2		80	4.5	
		Engineering Road									11	1		67	3.9	
		Zoology carpark									16	5		81	4.2	
		Glasshouses									20	8		95	4.7	
			Summary								22			81	4.3	
	2013	Creche									8	2		88	4.9	
		Engineering Road									8	0		65	4.6	
		Zoology carpark									11	4		89	4.9	
		Glasshouses									11	3		78	4.9	
			Summary								17			80	4.8	
	2014	Creche									10	1		74	4.9	
		Engineering Road									9	1		76	4.5	
		Zoology carpark									12	5		88	3.9	
		Glasshouses									13	4		88	5	
			Summary								19			81.5	4.5	
	2015	Creche									0	0		0	0	
		Engineering Road									0	0		0	0	
		Zoology carpark									14	3		73	4.7	
		Glasshouses									15	4		86	3.3	
			Summary								21			80	4	
Site moved from Engineering Road to	2016	Creche									11	2		85.5	4.17	
E8 due to construction work		E8									10	2		102	4.19	
		Zoology carpark									11	3		81	4.27	
		Glasshouses									14	4		91	5.24	
			Summary								19			90	4.5	
	2017	Creche									6	0		63	4.2	
		E8									7	1		74	4.2	
		Zoology carpark									11	5		92	4.3	
		Glasshouses									11	5		105	5.2	
			Summary													
Eden 2016	Jan - March 2015	Glasshouses	sed Al = 2800 mg/L	4.70	3.50	22.30	72.00	1.60	<0.1	37.10	14					
CCC 2014	6 Aug 2013	30m downstream of Clyde Road		9.20	6.60	17.80	73.00	2.80	0.03	41.00						
		Sediment composition = 100% gravel size														
EOS Ecology (CCC)	March 2009	Clyde Road									20	8	40	88.4		4.5
Boffa Miskell Limited (CCC)	22 Oct - 7 Nov 20	Glasshouses									12	3	25	85		5.1

Ilam Stream: All available data					Sediment metals									Ecology				
Collector (Source), description	Date(s)	Location	Further details	Water Level (mm)	Fe	Mn	Cr	Ni	Cu	Zn	As	Cd	Pb	Total taxa	EPT taxa	EPT (%)	MCI	QMCI
NIWA (CCC) 2014	6/08/2013	Waimari Road	PAH = 0.6 mg/kg				14.2	8.4	13.1	380	4.9	0.147	61					
		Composition:	30% Clay/silt															
			0 % Sand															
			10% Gravel															
			0% Cobble															
			60% Leaves/veg															
Boffa Miskell Limited (CCC)	22 Oct - 7 Nov 2013	Waimari Road		90										12	1	8	66.7	3
Clunies-Ross (2014)	Dec-13	Waimari rd	coarse fraction		7200	157	12.3	8.65	11.63	361	3.08	0.13	53.8					
			<67um		7700	159	15.8	9.63	20.54	437	4.57	0.15	80.34					
		Also analysed;	V, Co, Ag, Sb, Pt, Pd, Ru															

Avon River: Water flow and quality				Water Quantity										
Collector (Source), description	Date(s)	Location	Further details	Water Level (mm)	Velocity (m/s)	TSS (mg/L)	Turbidity (NTU)	Conductivity (µS/cm)	Specific Conductivity (µS/cm)	DO (mg/L)	DO (% sat)	Temperature (°C)	pH	Alkalinity
J. Harding 2008	18/02/08							179				13.6	6.74	
	6/03/08							119				14.1	7.16	
	2/04/08							175				13.3	6.62	
	16/04/08							179				14.4	6.69	
	30/04/08							175				14.2	6.77	
T. Blakely and J. Harding 2005	Nov/Dec 2002	d/s of Clyde Rd					1.8	173		9.1		14.0	5.8-6.0	41.5
Hogan and Wilkinson 1959	1955-56		Annual range							8.9 -		11.0 - 16.0	6.9 -	
Robb 1980	August 1979	Kahu/Kotare Road, near Clyde Road											7.0	45
Adams et al. 2007	11/06/2007	Avon River	Baseflow Sampling site discharge = 0.124 m3/sec			1.5	0.4	155	194	10.1	101.5	15.9	6.6	69
Run-off surface water quality parameters measured during storm events - Fine Arts Carpark														
	28-Mar	9 preceding dry days	first flush (ff) - sump			38		69	80				5.9	5
			ff - trap			52		108	126				6.4	13
			composite sample - Sigma				9.5			9		18.4	6.4	
			composite sample - sump			12		60	70				6.2	6
			composite sample - trap			14		60	70				6.4	7
			Sump (carpark)			20.3								
			Main stormwater drain			16.3								
	2-May	<1 preceding dry da	first flush (ff) - Max				10.6	221	268	12.1	121.4	16.4	6.5	
			ff - Sigma				11	340	407	11.2	115.4	17.2	5.5	
			ff - sump			18		260	300				6.3	4
			ff - trap			11		390	450				6.3	7
			composite sample - Max				7.8	136	162	11.6	120.2	17.2	6.6	
			composite sample - Sigma				9.4	224	269	11.7	118.9	17.1	6.4	
			composite sample - sump			12		150	170				6.2	3
			composite sample - trap			12		260	300				6.4	6
	29-Jun	3 preceding dry days	first flush - Sigma				12.8	-	-	12.1	113.5	14.9	6.9	
			ff - sump			19								
			ff -trap			15								
			composite sample - Max				5.8	-	-	12.6	120.5	16	7	
			composite sample - Sigma				5.1	-	-	12.9	120	14.3	7	
			composite sample - sump			5								
			composite sample - trap			6								
			Sump (carpark)			7.3								
			Main stormwater drain			7.5								
	29-Jul	6 preceding dry days	first flush - Max					400	489	10.3	106	16.4	7.1	
			first flush - Sigma					693	901	12.7	139	13.8	7	
			ff - sump			26								
			ff - trap			55								
			composite sample - Sigma					247	322	11.5	115.1	14.5	7.2	
			composite sample - sump			11								
			composite sample - trap			42								
	4-Sep	4 preceding dry days	first flush - Max				29.4	665	1024	14.8	155	15.3	5.7	
			first flush - Sigma				53.8	1100	1502	13.9	148.5	14.7	5.4	
			ff - sump			29								
			ff - trap			59								
			composite sample - sump			18								
			composite sample - trap			11								
			Sump (carpark)			19.8								
			Main stormwater drain			19.8								
Hutchinson and Funnell 2008	24/08/08	Fine Arts Carpark	Preceding dry days:			29.2								
	04/09/08		8			21.1								
	18/09/08		9			29.4								
ENNR305 2008	16/08/2007	Avon River	Baseflow			< 3	1.8		189	10.2		12.2	6.7	
Eden 2016	Jan - March 2015	At UCSA bridge		140	0.46			166		7.5	74.8	13.8	6.2	
EOS Ecology (CCC)	March 2009	d/s Clyde Road		200	0.45									
Boffa Miskell Limited (CCC)	22 Oct - 7 Nov 2013	d/s Clyde Road		280	0.38									

Avon: Nutrients, ions and contaminants

Collector (Source), description	Date(s)	Location	Further details	Nutrients (mg/L)				Major ions (mg/L)						Total metals (mg/L)				Dissolved metals (mg/L)			
				NOx-N	NO3	NO2	PO4-P	Ca	Mg	Na	K	Cl	SO4	Ni	Cu	Zn	Pb	Ni	Cu	Zn	Pb
T. Blakely and J. Harding	Nov/Dec 2002	Avon					0.1														
	May 2003																				
Hogan and Wilkinson 1959	1955-56		Annual range																		
Robb 1980	August 1979	Kahu/Kotare						10	2.6												
Adams et al. 2007	11/06/2007	Avon River	Baseflow Sampling	3.41	3.4	0.01		21.8	2.8	9	1.2	11.5	11.5	<DL	0.0010	0.0060	0.0002		0.0008	0.0060	0.0001
			Outlet pipe site 1 ;																		
			Outlet pipe site 1;																		
			Downstream of																		
Run-off surface water quality	28-Mar	Fine Arts Carpark	first flush (ff) -	0.211					0.96					0.0036	0.0165	0.0750	0.0054	0.0023	0.0115	0.0500	0.0007
			ff - trap	0.34										0.0031	0.0199	0.2170	0.0096	0.0018	0.0123	0.1700	0.0020
			composite sample -																		
			composite sample -	0.208										0.0014	0.0110	0.0410	0.0020	0.0013	0.0095	0.0390	0.0008
			composite sample -	0.009										0.0017	0.0152	0.1770	0.0048	0.0012	0.0118	0.1590	0.0014
			Sump (carpark)												0.0119	0.0467	0.0026		0.0098	0.0408	0.0008
			Main stormwater												0.0160	0.1837	0.0056		0.0119	0.1608	0.0015
	2-May		first flush (ff) - Max																		
			ff - Sigma																		
			ff - sump	0.127					0.51					0.0009	0.0062	0.0390	0.0021	0.0005	0.0044	0.0310	0.0004
			ff - trap	0.121					0.71					0.0009	0.0077	0.1090	0.0023	0.0007	0.0063	0.1080	0.0011
			composite sample -																		
			composite sample -																		
			composite sample -	0.073					0.29					<0.00	0.0053	0.0250	0.0015	<0.00	0.0028	0.0210	0.0004
			composite sample -	0.061					0.47					0.0008	0.0056	0.0710	0.0022	0.0005	0.0041	0.0670	0.0008
	29-Jun		first flush - Sigma																		
			ff - sump												0.0118	0.0960	0.0023		0.0107	0.0980	0.0006
			ff -trap												0.0088	0.2260	0.0032		0.0069	0.2410	0.0012
			composite sample -												0.0075	0.0460	0.0025		0.0057	0.0360	0.0003
			composite sample -												0.0059	0.1020	0.0018		0.0052	0.1090	0.0008
			Sump (carpark)												0.0077	0.0493	0.0019		0.0065	0.0463	0.0004
			Main stormwater drain												0.0064	0.1227	0.0032		0.0055	0.1310	0.0009
	29-Jul		ff - sump												0.0066	0.0690	0.0038		0.0044	0.0460	0.0004
			ff - trap												0.0139	0.2270	0.0123		0.0060	0.1610	0.0008
			composite sample -												0.0047	0.0028	0.0017		0.0041	0.0240	0.0002
			composite sample -												0.0077	0.0720	0.0073		0.0034	0.0530	0.0004
			ff - sump												0.0173	0.0860	0.0010		0.0139	0.0760	0.0004
			ff - trap												0.0201	0.2820	0.0049		0.0125	0.2310	0.0011
			composite sample -												0.0109	0.0510	0.0022		0.0075	0.0340	0.0002
			composite sample -												0.0109	0.1320	0.0024		0.0081	0.1100	0.0007
			Sump (carpark)												0.0119	0.0565	0.0020		0.0086	0.0410	0.0002
			Main stormwater												0.0124	0.1570	0.0049		0.0088	0.1302	0.0008
Hutchinson and Funnell 2008	24/08/08	Fine Arts Carpark													0.0107	0.0400	0.0102		0.0040	0.0133	0.0005
	04/09/08														0.0080	0.0335	0.0028		0.0049	0.0215	0.0001
	18/09/08														0.0142	0.1208	0.0055		0.0064	0.0917	0.0013
ENNR305 2008	16/08/2007	Avon River	Baseflow		4.3			23.3	3	9.6	1.2				< DL	0.0110	0.0003				
Eden 2016	Jan - March	Avon River,	Also analysed:					23	2.9	9.3	1.1							0.0001	0.0001	0.0220	<0.00
			Tot V 0.0002																		
			Tot Mn 0.003																		
			Tot Fe 0.01																		
			Tot Co <DL																		
			Diss Al <DL																		
			Diss Cr 0.0001																		
			Diss As <DL																		
			Diss Cd 0.0002																		

Avon: Sediment Quality and Ecology

Collector (Source), description	Date(s)	Location	Further details		Sediment metals (mg/kg) Cr	Ni	Cu	Zn	As	Cd	Pb	Inorganic sediment (mg/cm2)	Organic sediment (mg/cm2)	Sediment size distribution (%)	Ecology E coli (CFU/100ml)	Total taxa	EPT taxa	EPT (%)	MCI	QMCI
T. Blakely and J. Harding 2005	Nov/Dec 2002	Avon downstream of	Periphyton = 3.32									3.39	1.39							
	May 2003						9.5	113.5		0.06	27.3									
Robb 1980	August 1979	Kahu/Kotare Road, near Clyde											1.25%							
			Composition (%)	Silt/clay										43.61						
				Fine sand										37.32						
				Medium sand										6.46						
				Coarse sand										6.48						
				Gravel/pebble										6.13						
Adams et al. 2007	11/06/2007	Avon River	Baseflow Sampling site																	
			Outlet pipe site 1 ; shallow				7.5	44.8			14.6									
			Outlet pipe site 1; deep				8	41.9			14.7									
			Downstream of outlet pipe site 2: shallow				15.3	125			66.1									
Run-off surface water quality	parameters measured during storm e		ff - Sigma												270					
	2-May		ff - sump												1300					
ENNR305 2008	16/08/2007	Avon River	Baseflow																	
Eden 2016	Jan - March 2015	at UCSA bridge		Al = 3980 mg/kg	7.30	5.30	12.70	98.00	1.00	<0.1	22.30					20				
NIWA (CCC) 2014	7/8/2013	at Clyde Road		PAH = 3.10	10.70	7.90	11.80	187.00	1.70	0.13	29.00									
Sediment survey			Composition (%)	Clay/silt										20						
				Sand										30						
				Gravel										40						
				Cobble										10						
				Leaves/veg										0						
EOS Ecology (CCC)	March 2009	d/s Clyde Road														16.3	4.3	26.3	74.8	3.9
Boffa Miskell Limited (CCC)	22 Oct - 7 Nov 2013	d/s Clyde Road														16	7	43.8	86.2	4.1

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