Literature Review: Urban River Contaminants

Environment Canterbury
Your regional council

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Report No. U07/100
ISBN : 978-1-86937-765-6

Report Prepared By
URS
Roel Ermens

July 2007

Environment Canterbury
Your regional council

Report U07/100

58 Kilmore Street
PO Box 345
Christchurch
Phone (03) 365 3828
Fax (03) 365 3194

75 Church Street
PO Box 550
Timaru
Phone (03) 688 9069
Fax (03) 688 9067

Website: www.ecan.govt.nz
Customer Services Phone 0800 324 636

F I N A L   R E P O R T

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58 Kilmore Street
Christchurch

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42026924

Project Manager:

…………………………….
Justine Bennett
Snr Environmental Scientist

Project Director:

…………………………….
Sioban Hartwell
Principal

Author:

…………………………….
Roel Ermens
Environmental Chemist

URS New Zealand Limited

Level 6, URS Centre
13-15 College Hill, Auckland
PO Box 821, Auckland
New Zealand
Tel: 64 9 355 1300
Fax: 64 9 355 1333

Date:	20 July 2007
Reference:	42026924
Status:	FINAL

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Executive Summary

The Avon/Ötakaro and Heathcote/Opawaho Rivers run through heavily urbanised parts of Christchurch city and receive stormwater drainage from many different sources. Stormwater from the catchments contain many different contaminants including sediment, heavy metals, nutrients, organic compounds and pathogens. The ultimate receiving environment for the two rivers and all the contaminants they carry is the Avon-Heathcote Estuary/Ihutai. The Styx and Halswell rivers flow on the outskirts of Christchurch city and receive contaminants from a mainly rural catchment.

This report focuses on the collection of relevant information and literature from local, national and international sources. The main objectives of the study were:

- to identify likely sources of contaminants in Canterbury urban rivers and streams;
- to describe the mechanisms and extent of contaminant loads and transport;
- to compare the background concentrations of contaminants in Christchurch urban rivers with rural and non-developed systems elsewhere in New Zealand and internationally; and
- to describe the current known effects of these contaminants on the receiving environment.

This literature study found that in general information was available on all contaminants to a varying degree at local, national and international level. However, methodologies used, location, timescales and extent of studies meant that few were directly comparable. Key contaminants of concern in the Christchurch area are confirmed to be: sediments, heavy metals, nutrients, organic compounds and pathogens. This is consistent with elsewhere in New Zealand and overseas.

The literature identified the following key gaps and areas for possible future research in the Christchurch area:

- The relationship between landuse and contaminant loads and concentrations is poorly researched. Further studies in this area could be useful;
- Information on contaminant levels in sediments is available for the Avon-Heathcote Estuary/Ihutai but very little information is available on levels for the Avon/Ötakaro and Heathcote/Opawaho Rivers;
- Microbacterial contamination information was limited to the Avon-Heathcote Estuary/Ihutai but little supporting information was found on surface waters;
- Minimal studies were found on the effects of contamination from stormwater on macroinvertebrates, invertebrates, and vertebrate communities of Christchurch streams.
- Little information is available on the contaminant levels entering the Avon/Ötakaro and Heathcote/Opawaho Rivers during normal conditions versus storm conditions;
- Identification of point sources of contamination entering into the Avon/Ötakaro and Heathcote/Opawaho Rivers and the associated contaminant levels from these.

Section 1 Introduction

1.1 Overview

URS New Zealand (URS) was commissioned by Environment Canterbury (ECan) to undertake a comprehensive literature search and review of urban river contaminants. The purpose of the project was to use relevant local, national, and international literature to inform ECan about a range of issues regarding urban contaminants and their effects on the local receiving environment. The main focus of the literature review was contaminants associated with stormwater runoff and other discharges to waterways in urban catchments.

The main objectives of the literature review are summarised as follows:

- to identify likely sources of contaminants in Canterbury urban streams;
- to describe the mechanisms and extent of contaminant loads and transport;
- to compare the background concentrations of contaminants in Christchurch urban rivers with rural and non-developed systems elsewhere in New Zealand and internationally; and
- to describe the current known effects of these contaminants on the receiving environment.

The main focus the study was on Canterbury urban areas, predominantly Christchurch and the immediate surrounds. The report concentrates on the Avon/Ötakaro and Heathcote/Opawaho Rivers. Information was sourced regarding the Avon-Heathcote Estuary/Ihutai as this is the initial marine receiving environment for the Avon/Ötakaro - Heathcote/Opawaho Rivers. The Styx and Upper Halswell catchments were studied to a much lesser extent as determined by the amount of available reference material. The information gathered was compared to national and, where possible, international findings.

Local Context

Canterbury is a region of contradicting landscapes with vast flat plains in the east to high mountain ranges in the west. Rivers run extensively through the region, and carry rain water from the mountains to the coast, meandering their way across the plains. The climate can be widely varied. Of the major cities throughout New Zealand, Christchurch has the lowest rainfall and the greatest range of temperatures. The north-western winds that blow across the plains are hot and dry and can cause high temperatures and droughts. In contrast, flooding can occur throughout the Canterbury region during storms. The most severe flood hazard occurs on the flood plains of the Waimakariri River and since Christchurch is built on drained wetland this can cause periodic problems.

Christchurch has a population of approximately 360,000 spread over an area of about 450km^2 (Christchurch City Council Website). The city is divided into two main catchment areas, the Avon/Ötakaro river catchment and the Heathcote/Opawaho river catchment. The Avon/Ötakaro catchment is predominantly residential with some industry and covers an area of approximately 85km^2 (Gilson, 1996). The Heathcote/Opawaho catchment covers an area of approximately 100km^2 and is about 50% developed (Christchurch City Environmental Trends Report 2003). Most of the developed area is medium density residential land use, with the remainder being industrial. Whereas the Avon/Ötakaro catchment is generally flat the Heathcote/Opawaho is about 30% rural hill land use (Port Hills; Christchurch City Environmental Trends Report 2003). It should be noted that both the Avon/Ötakaro and Heathcote/Opawaho Rivers have a number of drains that also enter into them.

Christchurch is surrounded by two less urbanised river catchments, the Styx and the Halswell Rivers. The Styx River services the northern suburbs of Christchurch City and is predominantly rural. Two natural spring-fed tributaries service the river – Smacks Creek and Kaputone Stream. The Styx River is 21km long and discharges into Brooklands Lagoon. The Halswell River catchment lies to the South of Christchurch and covers an area of approximately 180km^2. 65% is generally flat and supports small scattered areas of urban development and the remaining 35% to the east of the catchment is moderately steep hill country. The Halswell River discharges into Lake Ellesmere (Gilson, 1996).
See Figure 1 for a map of Christchurch.

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Early maps indicate that the preurban Christchurch area was predominantly wet marshy land, with many shallow ponds and bogs, drained by a dense network of small meandering streams and separated from the sea by a belt of low dunes (Scott 1963 in Macpherson, 1979). Settlement by European migrants began in 1850. By 1875 the population was 10,600, rising to 50,000 in 1900 and to 124,000 in 1926 (Nigram 1906, Retter 1977, New Zealand Department of Statistics 1977 *in* Macpherson, 1979). It was not until 1878, that an organised start was made on an underground storm-water and sewage system (Hercus, 1948 *in* Macpherson, 1979). By 1901, 86 km of pipes were laid, increasing to 240 km by 1901 and draining more than 30 percent of the catchment area of the Avon-Heathcote (Macpherson, 1979).

The Avon/Ötakaro and Heathcote/Opawaho Rivers are both spring-fed and are restricted to the city and its immediate surrounding farmland. These rivers, which drain most of Christchurch and flow through residential, commercial, and industrial parts of the city (Environmental Services, 1993), empty into the well-flushed Avon-Heathcote Estuary/Ihutai.

The Avon-Heathcote Estuary/Ihutai is a large, natural ecosystem immediately adjacent to and surrounded by parts of Christchurch. It is roughly triangular in shape and is about 8km^2 in area. The Avon/Ötakaro enters the northern corner and the Heathcote/Opawaho enters the southwest corner (Environmental Services, 1993). Other inputs into the Estuary come from the Christchurch wastewater treatment plant oxidation pond outfall (Christchurch City Environmental Trends Report 2003). All outputs from the oxidation ponds enter the estuary just after high tide.

The Avon-Heathcote Estuary/Ihutai is unparalleled among New Zealand estuaries in supporting a large and varied wildlife population within such a heavily urbanised area. In the last 150 years at least 113 species of bird have been recorded in the Estuary, including 102 species between 1980 and 1992. Between 15,000 and 32,000 wetland birds use the Estuary and oxidation ponds or their margins, with numbers peaking in late summer and autumn. The Estuary is of international importance. A wetland is internationally important if it regularly supports either 20,000 wetland birds or 1 per cent or more of the total world population of a species or sub-species. The Avon-Heathcote Estuary/Ihutai and oxidation ponds regularly support 5-6 per cent of the world populations of South Island pied oystercatcher and New Zealand shoveler, about 3 per cent of New Zealand scaup, close to 1 per cent of Black Cormorant and Little Cormorant and over 1 per cent of the New Zealand populations of at least 13 other species (Christchurch City Environmental Trends Report 2003).

Importance to Maori

Te Ihutai is an area of immense cultural and historical importance to tangata whenua within the Christchurch and wider Canterbury area. The estuary not only provided vital access to waterways stretching from Te Waihora (Lake Ellesmere) to the Kowai River, and to the fishing grounds of Te Tai o Maha-a-nui (Pegasus Bay), but was a place of significant settlement and food gathering for Waitaha, Ngāti Mamoe and Ngāi Tahu for over 600 years. The food and resources taken from the estuary were also part of an important trade and social network between hapū and whānau throughout Te Waipounamu (the South Island) (Christchurch City Libraries 2006; Tau, Goodall, Palmer & Tau 1990 *in* Pauling, 2007).

The first settlers of Te Ihutai were the Waitaha who lived in two principle kaika (villages) around the estuary, located at Raekura (near Redcliffs) and Te Kai o Te Karoro (near Jellicoe Park). This was followed by the Ngāti Māmoe who occupied a settlement near the Estuary on Tauhinu Korokio (Mt Pleasant) during the 1500s. About one hundred years after this, Ngāi Tahu, under the chief Turakautahi, established Kaiapoi pā north of the Waimakariri, along with the settlement of Rāpaki in Whakaraupo, Lyttelton Harbour under, Te Rakiwhakaputa. While Ngāi Tahu did not live alongside the estuary itself, people from both Kaiapoi and Rāpaki visited and used the area extensively as a mahinga kai in a similar way to their predecessors (Christchurch City Libraries 2006; Tau et al 1990 *in* Pauling, 2007).

During these times the estuary was known to support tuna (eels), kanakana (lamprey), inaka (adult whitebait), patiki (flounder) and pipi. Kumara and aruhe (edible fern root) were grown in the sandy soils at the mouth of the Ōtakaro / Avon River. Manuka weirs were built around the mouth of the rivers during the eel migrations and patiki were abundant in the mudflats across the middle of the estuary, an area called Waipatiki (Christchurch City Libraries 2006; Tau et al 1990 *in* Pauling, 2007).

Section 1 Introduction

While the estuary itself provided an abundance of valuable food resources, equally important was the estuary's catchment, which was made up of an extensive network of springs, waterways, swamps, grasslands and lowland podocarp forests (Christchurch City Libraries 2007 *in* Pauling, 2007).

Both the Ōtakaro (Avon River) and Ōpawaho (Heathcote River) were highly regarded as mahinga kai by Waitaha, Ngāti Mamoe and Ngāi Tahu, who maintained a number of settlement and mahinga kai sites along these rivers. These included Puari (Inner city/High Court/Victoria Square area), Pūtarikamotu (Deans Bush), Ōtautahi (Kilmore/Barbados St), Te Oranga (Horseshoe Lake) and Ōpāwaho (Opawa) (Tau et al 1990 *in* Pauling, 2007).

The importance of the Ihutai catchment and the mahinga kai it contained was highlighted by the claims of Hakopa Te Ata o Tu, Pita te Hori and others of Ngāi Tūāhuriri to the Native Land Court in 1868. They attempted to have traditionally significant sites put aside as mahinga kai reserves but were unsuccessful. This action effectively shut Ngāi Tahu out of the development of the city and ultimately, the subsequent management of the Ihutai catchment (Tau et al 1990; Tau 2000; Matunga 2000 *in* Pauling, 2007).

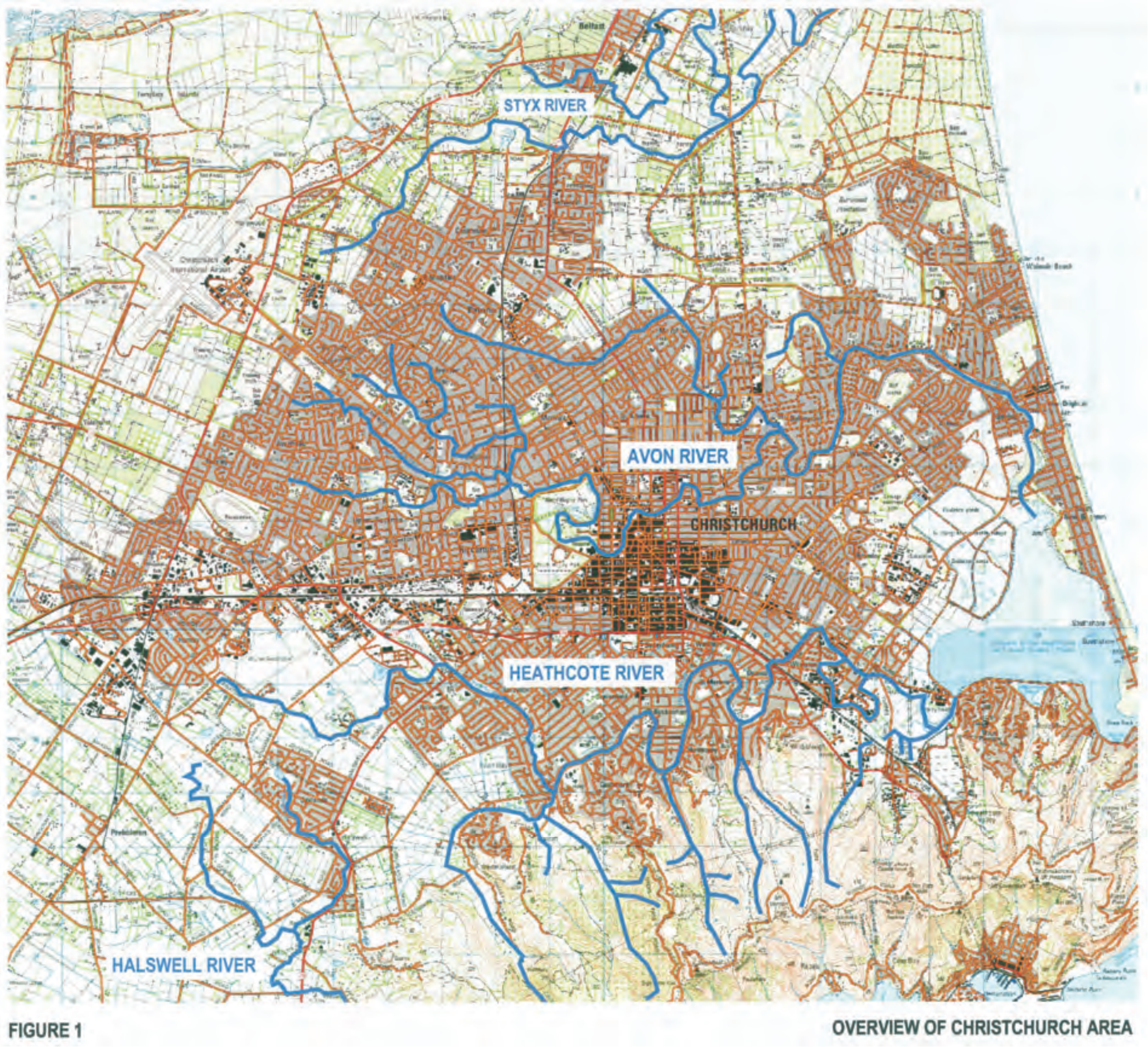
The taking of the Te Ihutai Māori Reserve in 1956 under the Public Works Act as part of the Christchurch sewage works development and the subsequent discharge of human effluent into the estuary further compounded the situation. So important were the sites and the integrity of the mahinga kai found there, that the owners of the reserve would not accept the money offered as compensation, because they believed that only an area of land having similar characteristics to that which was taken would be adequate recompense (Tau et al 1990 *in* Pauling, 2007).

The modern settlement and development of the city of Christchurch has, therefore, had a dramatic impact on the health of the entire catchment, and inturn the values tangata whenua have for the area. Drainage of the original swamplands has lead to extreme sedimentation within both the Avon and Heathcote Rivers and the estuary itself. Industrial and residential development has seen the destruction of extensive areas of native vegetation, the degradation of water quality and the local extinction and/or degradation of native fish and bird species, as well as the depositing of pollution and toxins within the catchment (Bolton-Ritchie, Hayward & Bond 2006; Tau et al 1990 *in* Pauling, 2007).

This has lead to the estuary and its catchment being of little, if any, value as a mahinga kai for tangata whenua, in-turn having serious implications on continuing cultural identity and wellbeing. Future management and restoration would therefore be important in revitalising cultural relationships with Te Ihutai (Pauling, 2007).

Section 1 Introduction

Figure 1 - Overview of Christchurch City



1.2 Report Structure

The report is set out as follows:

- Section 2 – Methodology. This section summarises the main sources of data for the review, including organisations and people who were contacted in the course of the study.
- Section 3 – Urban contaminants. This section describes the key contaminants associated with urban stormwater runoff and categorises data sources into local, national and international. Christchurch data is compared to the national and international contaminant loading rates found, and comment is made on the quality of the data sourced for each contaminant. Background levels of contaminants in Christchurch waterways are compared to the levels identified in stormwater. Background levels are those found outside of storm events. In Christchurch the baseflow for many of the streams and rivers is derived from groundwater and potential for contaminant input from stormwater during rainfall events is high.

- Section 4 – Gap Analysis. This section summarises the main gap found in the literature review and provides suggestions on where further monitoring/research work would be of value.
- Section 5.0 – Glossary. This section explains technical terms used in the report.
- Section 6.0 – References. This section provides a list of all material referenced in the main text.
- Section 7.0 – Bibliography. Provides a brief description of the key documents referenced.

Section 2 Methodology

2.1 Research methodology

A literature search was carried out using the following key data sources:

- Relevant local and regional authority reports from Auckland, Waikato, Otago and Christchurch were sourced and reviewed.
- The University of Canterbury was consulted to source relevant local research information.
- The New Zealand Water and Waste Association Stormwater conference proceedings were searched for relevant papers.
- International technical sources such as the United States Environmental Protection Agency (USEPA) and Stormwater Managers Centre were also searched.
- URS's Portland office was consulted and literature was sourced from Portland City and Oregon State.

In addition relevant regional, national and international information was sought from experienced practitioners in the field of urban contaminant management. These included:

- Dr Mike Timperley (ARC) – contaminant sources and loadings;
- Dr Shane Kelly (ARC) – effects on receiving environment;
- Bill Vant (EW) – Waikato stream information
- Alistair Suren (NIWA) – General information
- Rachel Ozanne (ORC) – Otago Information
- Craig Depree (NIWA) – PAH information
- Shirley Hayward (ECan)- surface water quality
- Aisling Sullivan -University of Canterbury
- Michael Ahrens (NIWA) – PAH coal tar information
- David Price (CCC) – Facts and stats
- Bruce Kelly (CCC) – Vehicle volumes
- Paul Dickson (CCC) – Monitoring data
- Andrew Brough (Pattle Delamore Partners Ltd) – Monitoring data on behalf of CCC

A special thanks goes to the above people, who were contacted during the course of this study and offered their time to help. It is noted that Lincoln University and other relevant Regional Councils were contacted during the course of this study and that relevant personnel were not identified or available over the timescale of this study.

This literature study was carried out over a 6 week period and whilst attempting to gather as much relevant information as possible, it is noted that the literature sourced may not include all relevant papers.

The literature review was categorised into local, national and international information. The information gathered was assessed with regard to relevance and integrity and then summarised as appropriate for inclusion in this report. A tabulated literature analysis is included at the end of each contaminant section.

Section 2 Methodology

Appendix A of this report summarises the most up to date water quality data sourced for urban streams in Christchurch at the time of writing this report. The background levels sections of the report describe the trends and key points derived from Appendix A and is intended to provide an overview of contaminant concentrations currently occurring in the Christchurch area.

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Section 3 Urban Contaminants

3.1 General

One of the most significant sources of urban river contamination is the runoff of rainwater from urban areas. Urban stormwater is produced when rainfall flows over impervious surfaces picking up pollutants, before being channelled into stormwater drainage systems and discharging into receiving water bodies such as streams and estuaries. The exact origins of stormwater-borne pollutants are difficult to trace in any one catchment because of the diverse nature of non point-source pollution. There are, however, many contaminants characteristically associated with urban stormwater, including sediment, nutrients, organic matter, inorganic matter, heavy metals, polycyclic aromatic hydrocarbons, organochlorines, and bacteria (Vincent & Thomas 1997 *in* Botherway & Gardner, 2002). The quality and volume of urban stormwater discharge is known to differ according to catchment size, location, time of day, climate, and season (Pitt *et al*. 1993 *in* Botherway & Gardner, 2002).

In this section of the report the different types and sources of contamination will be identified and typical loadings from different land uses will be discussed. Contaminant levels in the Christchurch area are described in the Background levels section and Appendix A.

3.2 Sediments

Sediments (soil and other fine solid particles) in waterways come from a variety of sources including the erosion of soils, construction sites, urban land uses, airborne particulates, agricultural practices, and the weathering of rock. The major transport mechanism for sediment into waterways comes from the entrainment of solid material from the ground surface in stormwater runoff. In urban areas, heavy rain and increased areas of imperviousness (roofs, roads) can increase both the volume and rate of stormwater entering into waterways and hence the sediment carried with it.

3.2.1 General

The main source of sediment into urban waterways comes from the erosion of soils during urban construction (Williamson, 1993; Pitt, 1995). Stripping of the vegetation and topsoils and recontouring the land greatly increases the chances that large quantities of soils and sub soils will be eroded. The amount of this erosion will depend on the volume and intensity of any rain that falls while the soil is exposed, the catchment slope and size, and the proportion of the catchment undergoing development (Williamson, 1993). Rates of erosion at construction sites can be between 10 and 100 times greater than those in rural areas (Yorke & Davis, 1971;Chen, 1974 *in* Rhoads, 1995). Increased sediment contamination will continue until construction is finished at which point sediment concentrations will gradually decrease (over 20-30 years) to sediment loads more common in mature urban areas (Williamson, 1993).

Another major urban source of sediment is streambank erosion (Williamson, 1993). According to Baird (1992), the natural vegetation on the banks of Avon/Ötakaro and Heathcote/Opawaho catchments have been devastated. Removal of natural vegetation can cause a reduction in the stability of the stream banks and can lead to flood erosion (Parkyn & Wilcock, 2004) which can increase sediment load and cause further damage. Where soils are washed into a stream the supply of eroded soils to the stream far exceeds the stream's transport capacity, and sediments build up in the channel. This process, along with an increase in urban runoff caused by impervious areas, can result in channel widening and very high sediment concentrations (Williamson, 1993).

It should be noted that where urbanisation occurs relatively slowly and involves small proportions of total catchment areas, deposits of urban-derived sediment may never accumulate in streams. However, where urbanisation is rapid, where it involves almost all of a catchment area, and where the conversion to an urban network severely alters pre-existing drainage patterns, initial sediment yields are likely to be high, and rapid deposition downstream may lead to the formation of large urban-derived accumulations (Macpherson, 1979).

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Land elevation and slope can also have an effect on sediment levels (Galbraith & Burns, 2007), and this is of particular relevance in the Heathcote/Opawaho and Halswell River catchments which are semi-surrounded and influenced by the Port Hills.

To a lesser extent airborne particulates can contribute sediment to urban rivers and streams especially from industry situated near waterways and in residential areas from domestic housefires, although this is not a problem year round.

Agricultural practices/rural land use can also contribute sediment to waterways (Elliot, 1998). The removal of natural forests and vegetation from rural areas to provide pastoral and agricultural land has large effects on the surrounding waterways. Pastoral streams have higher amounts of sediments than native forest streams (Dons, 1987; Smith *et al*., 1993; Quinn *et al*., 1997; Quinn and Stroud, 2002 *in* Parkyn & Wilcock, 2004) because of increased runoff, hillside erosion and bank instability caused by grazing (Trimble and Mendel, 1995 *in* Parkyn & Wilcock, 2004).

Estuaries (such as the Avon-Heathcote Estuary/Ihutai) and shallow coastal seas are the eventual sinks for much of this particulate material (Meade 1972, Roberts and Pierce 1974 in Macpherson, 1979) and, as a result, may be significantly enriched in a wide variety of potentially harmful substances (Ahr 1973, Clifton and Vivian 1975, Craig and Morten 1976 in Macpherson, 1979).

One of the main problems with sediments is often not the sediments themselves but the contaminants, such as heavy metals, Polycyclic Aromatic Hydrocarbons (PAHs) and pathogens that they carry with them (Pitt, 1995). These contaminants will be discussed in detail further on in this report.

3.2.2 Local Information

Large amounts of sediment exit the Avon/Ötakaro and Heathcote/Opawaho Rivers and deposit into the Avon-Heathcote Estuary/Ihutai. The average sediment yields of the Avon/Ötakaro and Heathcote/Opawaho catchments have been found to be 350 and 430 kg/ha/yr respectively, values typical of mature urban catchments. Doyle (2005) states that established residential land use has a typical sediment yield of 500 kg/ha/yr. Generally, the Avon/Ötakaro river's suspended load during storm runoff averages about 22% organic material, which is almost twice that of the Heathcote/Opawaho River which is greatly impacted by the large amount of inorganic material sourced from the Port Hills. During minor storm events the Avon/Ötakaro and Heathcote/Opawaho sediment yields are similar but during larger storm events the yield of the Heathcote/Opawaho is considerably more than that of the Avon/Ötakaro. This pattern reflects increasing sediment production from the Port Hills tributaries with heavier rain, and limited sediment supplies in most of the flat tributaries of the Avon/Ötakaro River (Environmental Services, 1993).

A study carried out by Ray *et al*. (2000) on the effects of stormwater on Lake Ellesmere noted that the specific yield of the Halswell River is 11 kg/ha/yr, however during major storm events this may increase with sediment runoff from the Port Hills.

It is well known that during winter months in Christchurch, the city experiences a large 'smog' effect over the city. This is caused in large by domestic fires and the sediment/particulate fallout from this can contribute to the waterways. Years of testing in Christchurch has shown that 90% of the suspended particulate pollution in winter is produced by domestic solid fuel burning (wood and coal fires). Motor vehicles produce around 3% and industrial burning the remaining 7% (Ecan website accessed 21st June 2007). The effect from this on total sediment loads is thought to be minor.

Agricultural practices/rural land use, although not much of an issue on the Avon/Ötakaro River, could contribute sediment in to the Heathcote/Opawaho River since 40% of the catchment is described as rural land use (Christchurch City Environmental Trends Report 2003). The Styx River catchment is largely rural (over 70%; Christchurch City Environmental Trends Report 2003) and horticultural practices such as the large degree of market gardening found within the Styx catchment can greatly increase the sediment loading on the river, though little evidence in literature was found to support this.

As mentioned in Section 3.2.1 erosion of soils during construction can have a major impact on suspended sediment levels. A study carried out by Pattle Delamore Partners Ltd (2007a) looked at stormwater quality from Kirkwood subdivision located in Halswell. Part of the study looked at comparing levels of suspended sediment from the Kirkwood subdivision with that of the existing Halswell township. This found that average levels of sediment were much higher from the recently constructed Kirkwood subdivision (67 g/m^3) than from the existing Halswell Township (11 g/m^3). The higher levels found in the new subdivision are likely to be influenced by the presence of less established vegetation compared to that found in the existing Halswell township.

The eventual sink for the Avon/Ötakaro and Heathcote/Opawaho Rivers is the Avon-Heathcote Estuary/Ihutai. Along with input of freshwater sediment from both the Avon/Ötakaro and Heathcote/Opawaho Rivers, the Christchurch wastewater oxidation ponds provide another source of sediment entering the estuary. The amount of sediment from the oxidation ponds, relative to the Avon/Ötakaro and Heathcote/Opawaho River inputs are reported as negligible (Environmental Services, 1993). During the tidal cycle most of the inputs are drained into the Pacific Ocean through the mouth of the Estuary. However 44% of the freshwater drained returns on the next high tide (Knox & Kilner, 1973; Robertson *et al*., 2002 *in* Burge, 2007).

Christchurch City Environmental Trends Report (2003) states that studies of the Avon-Heathcote Estuary/Ihutai note that there was a large influx of muddy sediment into the Estuary associated with the development of Christchurch. It is thought that there was a phase of high sediment input that probably began in the late 1800s and extended through until the 1950s. Over the last 30 years the bed of the Estuary has become less muddy overall and is currently composed of muddy sand. Rapid sedimentation of the Estuary, as interpreted for the early part of this century, is no longer an issue. Current sedimentation is relatively minor and local in its effects (Christchurch City Environmental Trends Report 2003). It is noted that both the Environmental (1993) and Christchurch City Environmental Trends Report (2003) literature are predominantly discussion style documents with limited data presented. Further study in this area would be beneficial.

3.2.3 National Information

This section presents national information with regard to sediments and discusses it's relevance to Christchurch. Typical sediment loads related to various types of landuse found during extensive studies done by the Auckland Regional Council (ARC; 2005), have been used in their contaminant load model and those of significance are provided in Table 1. Whilst it is likely that contaminant loadings will be related to landuse, literature from similar studies was not found for the Christchurch area.

Section 3 Urban Contaminants

Table 1 - Urban Sediment Loads (g m^{-2} a^{-1})

Parameter			Sediment
Urban Grass Lands	Slope	<10 0-20 >20	35 80 160
Construction Site Open for 2 months/year	Slope	<10 10-20 >20	400 2500 7000
Construction Site Open for 6 months/year	Slope	<10 10-20 >20	1300 7500 20000
Construction Site Open for 12 months/year	Slope	<10 10-20 >20	2500 15000 40000
Stable Bush	Slope	<10 10-20 20-30 >30	5 30 100 250
Farmed Pasture	Slope	<10 10-20 20-30 >30	50 100 500 1000
Roofs			**Sediment**
All Roof Types			5-10
Paved Surfaces			**Sediment**
Residential			20
Industrial			50
Commercial			100
Vehicles/Day			**Sediment**
<1000			4
1000-5000			30
5000-20000			150
20000-50000			299
50000-100000			300

Source: ARC, 2006

Sediment loadings from roofs are relatively low per m^2 and will generally be a minor contributor to the overall sediment load, but precisely how much they will contribute will depend on the amount of catchment that has been developed.

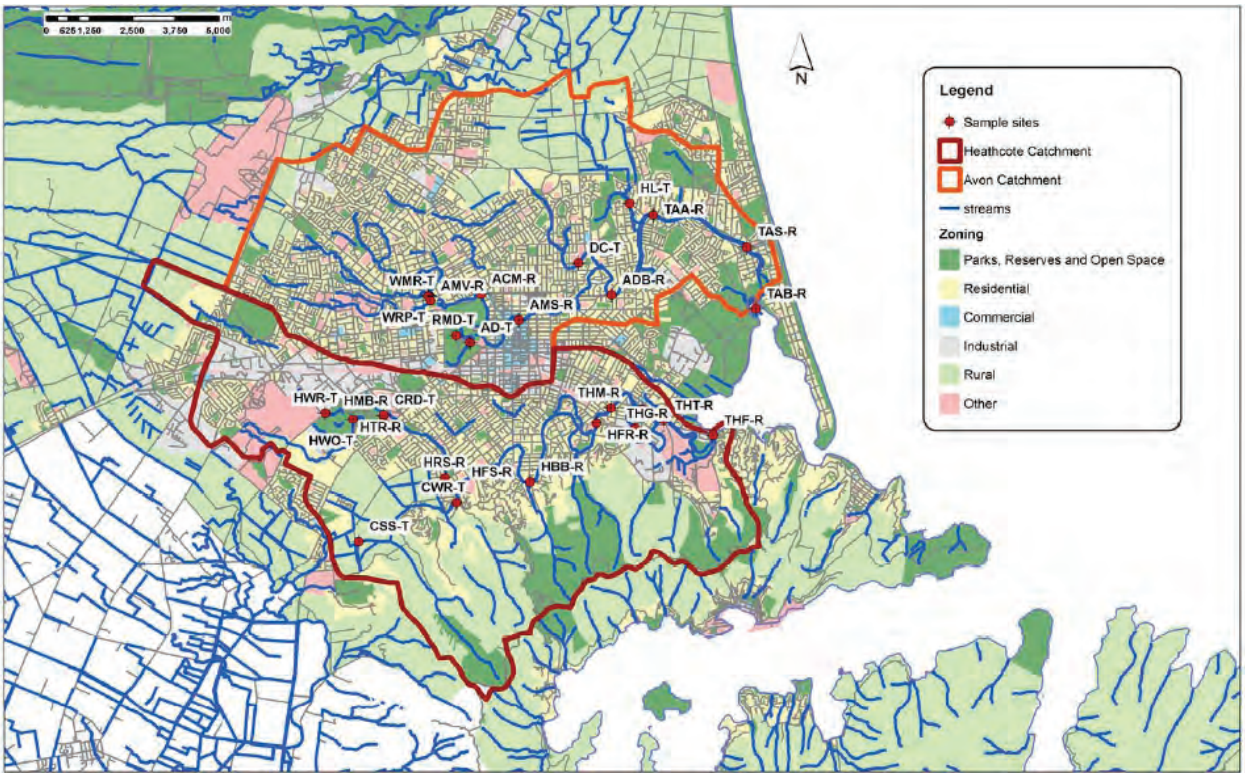
Roads contribute sediment dependant on the number of highly trafficked roads running through the catchment as can be seen in Table 1 based on the Auckland data (ARC, 2005).

The largest road in Christchurch on a vehicle/day basis is Moorhouse Avenue with approximately 40,000. Other large roads throughout Christchurch were found to be between 25,000 and 35,000 vehicles per day (Bruce Kelly *per comms.*, Christchurch City Council, 25th June 2007).

Section 3 Urban Contaminants

Paved surfaces (excluding roads) show that contaminant loads will be dependant on land use of the catchment. Based on landuse zonings from Christchurch District Plan this will predominantly be residential throughout the Avon/Ötakaro catchment, and residential, with sporadic industrial throughout the Heathcote/Opawaho catchment (refer Figure 2).

Figure 2 - Landuse within Christchurch



Source: Pattle Delamore Partners Ltd (PDP), 2007b

Construction sites, especially those that run year round were found to be by far the greatest contributor of sediment contamination. In respect to Christchurch, sediment contamination from construction sites will be minimal in mature urban areas such as the Avon/Ötakaro catchment and areas of the Heathcote/Opawaho River around the estuary inlet. Elliot (1998) and Christchurch City Environmental Trends Report (2003) show that a 10% increase in developed land was noted for the Heathcote/Opawaho catchment over the period of 1998 to 2003. Development in rural areas throughout the Heathcote/Opawaho catchment is likely to have increased sediment, however recent data is not available to confirm this.

Farmed pasture lands tend to contribute much higher amounts of sediments than urban grass lands (Dons, 1987; Smith *et al*., 1993; Quinn *et al*., 1997; Quinn & Stroud, 2002 *in* Parkyn & Wilcock, 2004) and this tends to be caused by the presence of ploughed, exposed grounds, grass cover and cattle. Large areas of the Styx River catchment are rural, and areas such as the market gardens found within the area, have potential to add to the sediment loads during times of harvest. At the time of writing, no written material was available to support this theory.

3.2.4 International Information

Consistently large concentrations of suspended sediment are found on the High Plains of South Dakota, Colorado, Oklahoma, Texas, and New Mexico, and are the result of a combination of easily eroded sedimentary rock and relatively little protective vegetation. Although intense rainfall events on the High Plains are frequent enough to cause significant erosion, the total amount of precipitation is too small to allow the development of the kind of vegetation that would protect the soil from erosion (USGS website).

This international study provides an example of the effect on sediment loads of limited vegetation as can be seen in parts of the Avon/Ötakaro and Heathcote/Opawaho Rivers throughout Christchurch.

A study on the Köppernitz river in the city of Wismar, Germany showed a relatively low range (2-19 g/m^3) of suspended sediment throughout three sampling locations, studied over four separate dates (Doyle, 2005). The catchment was flat (similar to that of the Avon/Ötakaro catchment) and therefore the results may tend to show similar trends to those found throughout the Avon/Ötakaro River.

Hornsby Shire Council in Australia has an extensive sampling regime throughout their district and data from the 2001 Annual Report gives levels of suspended sediment in different landuse areas. Concentrations of suspended sediment in the urban zones had a mean range of 1.67-29.5 g/m^3 while concentrations in the rural zones had a mean range of 2.58-10 g/m^3 (CRC, 2004). Concentrations in Christchurch from both the urban and rural zones show similar mean ranges (refer Appendix A).

In another study, Hollinger *et al*. (2001 *in* CRC, 2004) looked at the runoff collected from a market garden from 13 storm events over a two year period. The average load coming off the site over the two year period was 6102 g/m^3 during the storm period. There was no mention of loads from the site during dry conditions, but the levels mentioned above, suggest that horticultural landuses have the potential to significantly affect suspended sediment levels under wet conditions. This may be relevant to the Styx catchment.

3.2.5 Background Levels

Sediment derived from the land is usually measured as total suspended solids (TSS) once mixed with water flowing in streams.

Generally the range of TSS found throughout the Avon/Ötakaro River is extremely low ranging from 1-3 g/m^3 (Gilson, 1996), however higher levels (12 g/m^3; Gilson, 1996) were found near Bridge Street in Christchurch. This can be explained by the influence of the Estuary with respect to the incoming tide, which tends to disrupt any sediment that has recently deposited in the estuary. The levels provided by Gilson are based on concentrations for a period of 1991-1995 and may be somewhat conservative. Average concentrations for a much larger data set (CCC monitoring from 1996-2006) for the same sampling sites showed slightly higher concentrations ranging from 4 -14 g/m^3.

TSS levels in the Heathcote/Opawaho catchment are significantly higher than those of the Avon/Ötakaro catchment and range from 2-62 g/m^3 (Gilson, 1996). This is likely to be due to soil wash off from the Port Hills where increased gradient can result in an increase in soil pick up and transport due to higher runoff velocity (Galbraith & Burns, 2007). These levels are similar to those found in the larger data set, Christchurch City Council 1996-2006.

Analysis of monitoring results from the Avon/Ötakaro and Heathcote/Opawaho Rivers was carried out by PDP (2007b) and was compared against relevant guidelines. Two guidelines were identified. The lower total suspended solids guideline value of 10 g/m^3 (Ryan, 1991 *in* PDP 2007b)relates to aesthetic effects, where a change of colouration is detected, and a higher guideline value of 25 g/m^3 (Richardson *et al*., 2001 *in* PDP, 2007b) which relates to levels where the behaviour of fish is impaired. Analysis showed that median concentrations on the Avon/Ötakaro River were all, with the exception of Bridge Street below the lower guideline. The median concentration at Bridge Street was below the higher guideline and was thought to be influenced by the tide. Median concentrations were generally higher on the Heathcote/Opawaho River. Most sites showed at least one exceedance of the higher guideline value and all sites showed exceedances of the lower guideline.

Levels of sediment throughout the Styx catchment were found to be relatively low ranging from 1-6 g/m^3 (Styx website: unpublished data). Sediment levels throughout the Halswell catchment were found to range between 2-15 g/m^3 which could again suggest influences caused by the Port Hills. Concentrations of TSS reported from both the Styx and Halswell catchments are comparable to other rural streams found throughout New Zealand (see Appendix A), though data is based on a smaller data set.

Levels of TSS in residential areas throughout the Christchurch area were in most parts higher than those found in rural areas. This is not to say that residential areas contribute more sediment than rural areas in

Christchurch, but rather that where samples were taken in residential areas, local factors such as the influence of the Port Hills, extent of vegetation and the Estuary may come into play.

During long, dry periods, such as the dry Canterbury summer, there is a greater chance of pollutant build-up. This build-up of contaminants will be a major contributor to the pollution load during the initial period of a major storm or rain event. This phenomenon is better known as 'first flush', and can occur following any extended period of dry weather (Soller *et al*., 2005, Lee at al., 2004). This phenomenon has been shown in a study carried out by the Otago Regional Council (2005) which investigated the water quality of 18 selected stormwater outfalls after two storm events. Levels of TSS were found to be elevated (>100mg/l) in all catchments. Similar data is available (Chiew *et al*, 1997) for two Sydney urban catchments which shows the effect of rain on suspended sediment loads and can be seen in Table 2.

Table 2 - Rainfall vs. Suspended Sediment

Catchment Area (ha)	Runoff (ml)		Suspended Sediment (tonnes)	
	dry weather	wet weather	dry weather	wet weather
670	190	1100	5	130
6000	1400	2400	16	320

Source: Chiew *et al*., 1997.

3.2.6 Effects of Sediment

Erosion and movement of sediment has enormous impacts directly downstream of new developments. Dumped sediment greatly alters the stream morphology, smothers insect life and aquatic habitats and water draining these catchments can become very unclear. High sediment levels can affect fish feeding and behaviour (Rowe and Dean, 1998 *in* Rowe, 2004) and reduce instream algal productivity by increasing light scatter (Davies-Colley *et al*. 1992 *in* Rowe, 2004). Sediment that settles in the lower reaches of a stream network can raise the stream bed, reducing the flood capacity of the stream (Rowe, 2004).

Sediments will ultimately drain to the coast, or in the case of Christchurch City into the Avon-Heathcote Estuary/Ihutai where sediment may build up and smother estuarine organisms. Avon-Heathcote Estuary/Ihutai has an intertidal nature, where a large proportion of the estuary is exposed at low tide. Sediments that enter the estuary will be subject to dispersion by water currents, flocculated, settled, and resuspended by waves, tidal, or riverine currents (Williamson & Morrisey, 2000). Generally the input of sediment into the estuary will result in some settling of coarser sediment, partial flocculation of finer particles and some dispersion by currents to other parts of the estuary or beyond. When fresh water enters an estuary from a stream or stormwater drain, all except the finest transported particles settle within a short distance, because of reductions in current velocity and differences in pH and ionic composition of sea water (Knox 1986 *in* Botherway & Gardner, 2002).

Sediments that enter into the Estuary can clog fish gills and feeding mechanisms on filter feeders, reduce the visual range of aquatic animals and limit photosynthetic productivity (Doyle, 2005).

Limited information was sourced with respect to specific sediment effects on the Avon/Ötakaro and Heathcote/Opawaho Rivers or the Avon-Heathcote Estuary/Ihutai.

3.2.7 Outline Analysis of Key Literature

Table 3 below summarises the literature cited in this section of this report and comments on validity and relevance of the information provided.

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Table 3 - Summary of Literature in Section 3.2

Reference	Year	Comments
		Local
Doyle	2005	A New Zealand masters thesis based on a single case study. Used for comparison only and thought to be accurate based on the age of the paper and sample regime.
Environmental Services	1993	Overview paper relevant to the Avon-Heathcote area. Descriptive text rather than technical detail and scientific data. Relatively old, may no longer be accurate.
Ray *et al.*	2000	Scientific paper on Lake Ellesmere. Data mentioned in report is thought to be reasonable given the degree of urban development in the Halswell catchment at the time of writing.
Christchurch City Environmental Trends Report	2003	Overview of the environmental issues within Christchurch City. Lots of facts and figures but minimal references. General information still relevant, some statistics out of date.
Burge	2007	Literature review on sedimentation. Limited to the Avon-Heathcote Estuary/Ihutai only. Older literature is backed up with more recent studies. Useful and relevant.
Pattle Delamore Partners Ltd (PDP)	2007a	Small case study done for Christchurch City Council on a subdivision. The numbers used in section 3.2.2. of our report thought to be relevant based on age of the report and the number of samples taken. Study uses data from 2005-2007
Pattle Delamore Partners Ltd (PDP)	2007b	Analysis of monitoring data for 1992-2006. Very relevant based on local information and age of data. Compares results to national guidelines.
Gilson	1996	Analysis of water quality results based on Christchurch City Council monitoring. Based on a small data set (1991-1995). Data is old. Appendix A of this report cites more recent data source (1996-2006).
		National
Otago Regional Council	2005	Small study looking at effects of first flush on storm water quality. Relevant based on age and number of samples and limited availability of Christchurch information with respect to stormwater. Based on information from November 2004 to February 2005.
Rowe	2004	Scientific paper on Lake restoration. Relevant as used for general context and comment only.
Williamson and Morrisey	2000	Scientific paper on stormwater contamination of urban estuaries. Relevant as used for general context and comment only.
Botherway and Gardner	2002	Scientific paper on storm drain discharge. Relevant as used for general context and comment only.
ARC	2005	Significant study by Auckland Regional Council. Study limited to one catchment of each type. Levels of contaminants in similar catchments assumed to have similar concentrations and loadings. This assumption is a simplification of actual conditions. Most accurate and up to date data available nationally. Based on studies from 2000-2002.
		International
Chiew *et al.*	1997	Basic industry report on urban stormwater. Relevant examples used.
CRC	2004	Literature review on contaminant levels in Australia. Extensive amount of data. Relevant examples used. Age of data relevant.

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Literature found for sedimentation during this study, that had direct relevance to the Avon/Ötakaro and Heathcote/Opawaho Rivers was extremely limited. Since the Avon-Heathcote Estuary/Ihutai is the final sink for much of the sediment derived from the Avon/Ötakaro and Heathcote/Opawaho Rivers a lot of literature and studies have focused on the effects of sediment on this waterbody rather than the rivers themselves. Average concentrations of sediment (suspended solids) for the Avon/Ötakaro and Heathcote/Opawaho Rivers are included in Appendix A. These have been derived from Gilson (1996) and from monitoring done by Christchurch City Council over the period 1991 to 1995. Interpretation of this data with respect the sources or effects that these concentrations have on the environment is not currently available. Further studies such as the PDP (2007a) for the Avon/Ötakaro and Heathcote/Opawaho Rivers to gauge the amount of sediment derived from construction may be beneficial in determining sources. Further studies into the determination of concentrations and loadings for catchment type as per ARC (2005) would be useful.

3.3 Heavy Metals

3.3.1 General

Metals can be derived from many natural locations such as from rock, soils, and geothermal areas. However with the introduction of urbanisation the source of metals increases greatly specifically from impervious sources such as roofs, pavements and roads. Although nearly all metals will be present in some form in most waterways, the main type of metal contaminants in waterways are copper, zinc, and lead. Other metals of interest include nickel, arsenic, cadmium, chromium and mercury but these have been measured in urban stormwater and are generally low (Williamson, 1993).

Metals found in waterways are transported to streams and rivers via two main sources; either by surface runoff or groundwater. They are present in a dissolved form or are bound to sediments. If dissolved, metals will simply travel in the direction and velocity of the water. Changes in concentration will only occur due to dilution or evaporation of the water body. When bound to sediment, metals will be affected by processes that affect the sediment directly, such as settlement in stagnant/slow moving parts of the water body, resuspension under turbulent conditions and flocculation/settlement in estuaries (Webster-Brown, 2005).

In a rural catchment most rain that falls into the catchment will either flow overland (surface water) or will be infiltrated through the ground (groundwater). The amount of rainfall that enters either of these sources will depend on variables such as slope and soil types present. Rain that infiltrates the ground as groundwater replenishes the natural aquifers (water table) where most sediment bound metals will be filtered out of the water (Doyle, 2005). The dissolved portion of the metals will remain in the groundwater and will be diluted by the volume of the watertable which will eventually be transported to streams to provide the stream base flow (Kelley *et al*., 2004; Doyle, 2005). Metals in surface water on the other hand, will generally be present in both dissolved form and sediment bound form (Doyle, 2005).

When a catchment becomes urbanised, the lack of vegetation and increased amounts of impervious surface, along with introduced drainage systems, causes the overland flow to greatly increase and discharge directly into the stream. This can cause increased contaminant loads, flooding and an increase in erosion during rain events (Doyle, 2005). With urbanisation comes the extensive use of landscaped lawns, which are generally less effective in detaining and treating stormwater (Kelley *et al*.,2004), and an increase in impervious surfaces which decreases the amount of water infiltrated into groundwater. These could, during drier weather, cause the base flow of the stream to greatly decrease and contaminant concentrations to increase (Doyle, 2005).

Metal concentrations in sediment are strongly dependant upon particle size (Wilbur & Hunter, 1980 *in* Pitt, 1995). Generally, metal concentrations increase with decreasing particle size, and this is typical of most urban runoff, where it appears that most of the heavy metals are associated with very fine particles (Pitt, 1995). Metals such as zinc, copper and lead all have an affinity to bind to sediments and often sediment size will determine which contaminant is associated with it (Pitt, 1995).

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The concentrations of lead, zinc, and copper in urban runoff often exceed the receiving water quality criteria that are designed to protect aquatic life (Williamson, 1993). This is particularly true during low flow conditions. Heavy metals (copper, lead and zinc) are of particular concern in runoff due to their prevalence, toxicity to aquatic organisms and persistence in the environment (Hoffman *et al*., 1984; Borchardt and Sperling, 1997; Walker *et al*., 1999 *in* Brown & Peake, 2005).

3.3.2 Local Information

Information presented in this section provides comments on heavy metal levels in the Avon-Heathcote Estuary/Ihutai since this is the major marine receiving environment for contaminants from the Avon/Ötakaro and Heathcote/Opawaho catchments. It is noted that metal concentrations in the rivers themselves are not discussed as literature sourced on this topic was extremely limited, however metal levels for some drains entering into the rivers are mentioned.

Suspended sediment that enters estuaries can act as a sink for contaminants (Deely, 1988 & Burge, 2007) and when these contaminants reach too high a level within the sediment they may adversely affect the estuarine ecosystem (Gillespie, 1993; Green, 2006 *in* Burge, 2007). Heavy metals are one category of contaminant that persist in the environment, and are capable of accumulating in organisms, culminating in sub-lethal or lethal effects. This, in turn, can affect species population levels and community structure, and can ultimately result in large-scale environmental impacts (Long *et al*. 1995 *in* Botherway & Gardner, 2002).

The effect of urbanisation on metal concentrations is described in a study by Deely & Ferguson (1993) which looked at concentrations of the heavy metals; chromium, manganese, iron, nickel, copper, zinc and lead in dated sediment cores of the Avon-Heathcote Estuary/Ihutai. The study showed that metal concentrations were greatest in sediments deposited since European settlement and that significant heavy metal pollution has entered the estuary since 1850.

The most significant sources of zinc and lead entering the estuary are the Avon/Ötakaro and Heathcote/Opawaho Rivers. (Environmental Services, 1993). A study carried out in 1986 (Purchase & Ferguson) on river sediments of the Avon/Ötakaro and Heathcote/Opawaho River and estuary showed high levels of lead near a lead accumulator battery factory (Exide batteries) on the Heathcote/Opawaho River. The high levels found in the river sediment near the factory were not reflected in the levels in the sediments of the estuary. Since the closure of the lead accumulator factory (local resident, *per comms*. 22nd June 2007) and the introduction of unleaded petrol in 1996 (Bates & Garrett, 1998), lead loads are thought to be less significant now. Zinc levels are still the major source of metal contaminant and this is discussed further in section 3.3.4.

Using dry weather flows and mean metal concentration values (for the period of 1989 to 1999) the Avon/Ötakaro River contributes 10kg/day of total heavy metals and the Heathcote/Opawaho River contributes 8kg/day into the estuary. These values are probably conservative, considering that river flows during heavy rainfall events would be much higher than the dry weather flows used here (Christchurch City Environmental Trends Report 2003).

The greatest proportion of copper, chromium and nickel into the Avon-Heathcote Estuary/Ihutai come from the Christchurch oxidation ponds. However only a small percentage is present in the potentially-toxic soluble form (Environmental Services, 1993).

As mentioned in section 3.3.1, metal concentrations in sediment are strongly dependant upon particle size. A study by Milne (1998 *in* Kingett Mitchell, 2003) examined trace element distribution in four areas of the Avon-Heathcote Estuary/Ihutai. Table 4 shows a summary of the concentrations of trace elements recorded in the Kingett Mitchell Ltd study (2003) with those of Milne (1998).

Table 4 - Heavy metals in Avon-Heathcote Estuary/Ihutai

Parameter	Kingett Mitchell Study	Avon-Heathcote Estuary (Milne 1998) (all units in mg/kg dry weight)			
		Area-A	Area-B	Area-C	Area-D
% Mud	15.1	43.4	15.5	43.5	6.8
Arsenic	5.0	2.33	0.99	2.32	0.965
Cadmium	0.020	0.115	0.055	0.0625	0.025
Chromium	12.70	15.04	14.29	11.16	7.075
Copper	3.90	9.19	5.82	5.30	2.42
Nickel	9.50	8.94	9.20	7.08	5.35
Lead	10.90	13.58	10.44	14.69	6.49
Zinc	35.80	78.75	57.98	70.15	39.11

Source: Kingett Mitchell Ltd, 2003

Area A comprised the part of the estuary influenced by the discharge from the Christchurch oxidation ponds and deposition from the Avon/Ötakaro River. Area B comprised an area in the centre of the estuary potentially influenced by both the Avon/Ötakaro and Heathcote/Opawaho Rivers and the pond discharges. Area C comprised sandy areas near the estuary mouth and also an area between the Heathcote/Opawaho River and the ponds. Area D comprised the area off the Heathcote/Opawaho River mouth subject to the influence of the River and the City Outfall Drain.

In general it was found that as mud percentage increased so did the concentration of most trace elements (Kingett Mitchell Ltd, 2003). However, over the last 30 years the bed of the Estuary has become less muddy overall and is currently composed of muddy sand (Christchurch City Environmental Trends Report 2003).

A study carried out by Deely & Ferguson (1993) looked at heavy metal concentrations for the Avon-Heathcote Estuary/Ihutai in respect to different particle sizes. Samples were split into sand (>63µm), silt (4-63µm) and clay (<4µm). The metal concentrations all showed a similar trend of increase from sand to silt to clay. The increase in concentration from sand to silt varies up to 2-fold, whereas the increase from silt to clay averages ~ 4-5-fold. The change can be explained in terms of increase in surface area and metal adsorption capacity in the order sand <silt << clay. The concentration profiles of the heavy metals in the silt tend to follow the clay but the levels are much lower and variations are less significant and may in fact be accounted for by experimental error. The similar profiles of silt and clay were thought to be due to some clay minerals (up to 10%) occurring in the silt fraction. For sand the metal concentration profiles did not change significantly with depth suggesting that their heavy metal content is mostly lattice bound.

In contrast, a study carried out by Purchase & Ferguson (1986) looked at the amount of lead in different sediment samples. Samples were separated into sand (>20µm), silt (2-20µm) and clay (<2µm) and results showed no great difference in lead levels for different particle sizing.

The above literature suggests that due to the muddy sand composition of the estuary, the levels of metals bound to sediment are relatively low throughout the estuary. This may be caused in part, by the dispersion of sediment during tidal movements. No literature was found in regard to sediment size or associated heavy metal concentrations in the Avon/Ötakaro and Heathcote/Opawaho Rivers.

A graduate study (Taffs, 2007) carried out on a tributary of the Avon/Ötakaro river (Okeover stream), looked at metal levels in both sediment and the water running through the heavily-urbanised catchment on the University of Canterbury campus. Zinc and copper in sediment were present at toxic concentrations throughout the stream. A similar pattern was seen for total copper in the water, and elevated levels of zinc were seen in one of the five sample points during base flow.

Elliot (1997) states that high concentrations of metals in the Haytons Drain, along with high concentrations in Curletts Road Drain are likely related to industrial discharges rather than general urban runoff. Furthermore, Elliot (1997) mentions that heavy metals in the baseflow of these drains may exceed criteria for the protection of aquatic organisms, however this is based on limited data.

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Brown *et al* (1996), looked at the Wigram retention basin (WRB) which incorporates and treats the Haytons Drain and Paparua Drain. Sampling was carried on four separate dates on both the Haytons Drain and the WRB outflow (which enters into the Heathcote/Opawaho River) and results were used to calculate the efficiency of the retention basin. Average concentrations of the metals zinc (0.412 g/m^3), copper (0.007 g/m^3) and lead (0.033 g/m^3) were measured for the Haytons Drain and were found to be significantly higher than the levels found exiting the WRB outflow (zinc 0.148 g/m^3, copper 0.002 g/m^3 and lead 0.006 g/m^3).

3.3.3 National Information

Studies elsewhere in New Zealand support the Christchurch literature.

Metals such as lead and iron tend to have a higher affinity towards sediment than metals such as manganese, copper, arsenic and zinc. However, a study of the Hatea River catchment and estuary in Whangerei (Webster *et al*., 2000) showed that along with lead and iron; zinc also tended to show a high association with sediment (Webster-Brown, 2005). The study also showed that manganese, copper, arsenic and zinc were partially or predominantly present in dissolved form, whereas iron and lead concentrations were often lower in dissolved state, suggesting that they tend to have a stronger association with the coarse sediment (>0.45µg). However it should be noted that it is possible that 'dissolved' metal components could in fact not be completely dissolved but in fact bound to sediment <0.1µg (Webster *et al*., 2000).

This study also showed that metal analyses of bed sediment and waters from the Hatea catchment indicate that the most likely sources for the copper, lead and zinc are, among other things, storm waters draining the central business and industrial district of Whangarei city. The Avon/Ötakaro and Heathcote/Opawaho River catchments vary in that the Avon/Ötakaro runs through the Central Business District and the Heathcote/Opawaho runs through some industrial zones. Although metal levels are not available for the rivers, this variation in zoning would be expected to result in different metal loadings from different land uses as suggested in ARC, 2005.

In Auckland a large amount of data was collected by the ARC from three separate studies in an attempt to identify and quantify the metal sources in three urban catchments. The data from these studies led to a general assumption that the primary sources of these elements are those listed in Table 5. Some of the sources have changed over time, such as lead from petrol and the residential use of chlorinated pesticides (ARC, 2005).

Table 5 - Primary sources of chemical contaminants in urban catchments

Chemical	Primary sources
Zinc	**Vehicle tyres, galvanised building materials (e.g. roofs), paints, industrial activities**
Copper	**Vehicle brake pads, plumbing, industrial activities**
Lead	**Residues from historic paint and petrol, industrial activities**

Source: ARC, 2005

Typical industry activities that are likely to be present in Christchurch that will contribute to metal levels are (in no particular order) airports, automotive repairs, spray painting, sewage treatment plants, cemeteries, petrol stations, market gardens, among others (Department of Environment, Western Australia, 2004).

Since the removal of leaded petrol and lead-based paints in New Zealand, the amount of lead in runoff has decreased significantly (ARC, 2005). Sources of lead vary, with studies carried out by ARC showing four main contributing areas; roofs, roads, natural soils and building walls. Studies carried out by ARC (2005) showed that residential areas contained the highest amount of lead, however a majority of this came from the walls of buildings, particularly older buildings which would contain lead-based paints. Other potential sources of lead would be specific point-source contaminants.

The main sources of copper are outlined above, however studies by ARC (2005) suggested that there are major gaps in the understanding of copper sources in urban catchments. A sizeable amount of copper was not accounted for during the study and further investigations would be required to determine all sources.

Zinc was found to be the most common metal species in urban watercourses due to the extensive use of galvanised building materials during the 1970s and 1980s in Auckland (ARC, 2005).

It is expected that sources of metals in Christchurch would be similar to those found in the Auckland study.

ARC and particularly Timperley have developed a contaminant load model derived from various urban runoff studies carried out throughout Auckland city. Table 6 presents typical zinc and copper loadings attributed to runoff from specific surfaces.

Table 6 - Urban Metal Loads (g m^{-2} a^{-1})

Roofs	Zinc	Copper
Galvanised unpainted	2.200	0.0008
Galvanised steel poor paint	1.600	0.0008
Galvanised well painted	0.150	0.0008
Zinc/aluminium unpainted	0.300	0.0008
Colorsteel/colorcote	0.400	0.0008
Concrete	0.020	0.0013
Clay	0.020	0.0008
Slate	0.020	0.0008
Copper	0.000	3.0000
Decramastic	0.200	0.0017
Other Materials	0.020	0.0008
Unknown (no galvanised steel/copper)	0.200	0.0008
Vehicles/Day		
<1000	0.021	0.0070
1000-5000	0.107	0.0349
5000-20000	0.537	0.1744
20000-50000	1.068	0.3472
50000-100000	2.281	0.7414
>100000	3.532	1.1480
Paved Surfaces		
Residential	0.070	0.0100
Industrial	0.100	0.1300
Commercial	0.050	0.0500

Source: ARC, 2006

Apart from pure copper roofs and spouting, copper appears to be a relatively low contributor to overall metal contaminant loadings. Of the three catchments studied, less than 0.1% of the total roof area was pure copper, so high copper concentrations in stormwater are unlikely to be caused by roofs. In contrast, zinc producing roofs, especially galvanised iron roofs, produce a high amount of zinc contaminant per year.

The ARC (2005) study concluded that roof runoff accounted for the majority of the zinc found in stormwater. The most problematic land use type was found to be the industrial area where over 80% of all roofs were found to be galvanised iron. The residential area had the lowest zinc loading, and can be attributed in part, to the high number of concrete tile, colour steel and clay tile roofs. Shedden *et al*. (2007) states that since the introduction of Zincalume as a roofing material to New Zealand in 1994, levels of galvanised iron roofs have decreased, and this change can be expected to lead to a reduction in zinc loadings from roof materials in the future.

Copper levels from roads appear to have a significant input to contaminant loads dependant on where they are situated. In the ARC (2005) study the copper input from roads in the commercial area (CBD) accounted for nearly 80% of all copper found. Residential and industrial areas were found to contribute approximately 50% and 25% respectively. Zinc loading from roads were found to be significantly higher than those of copper, however as a percentage of all zinc, road inputs are a relatively minor part.

Paved areas (other than roads) contributed negligible amounts of zinc and copper to the total contamination load.

Analysis of the trace metal content of stormwater suspended sediment in a study carried out by Brown & Peake (2005) in Dunedin showed copper and lead concentrations were found to be higher in areas of greater intensity of urban and industrial land uses within the catchment.

3.3.4 International Information

International studies further emphasise statements mentioned above.

A study carried out by Steele & Doefer (1983, *in* Pitt, 1995) examined the sediment quality in the South Platte River near Denver, Colorado and found consistent increasing trace metal concentrations with decreasing particle size. Sediment sources of lead indicated major lead sources from stormwater runoff.

Garie & Mcintosh (1986 *in* Pitt, 1995) examined urban sediment at eight sites along Shabakunk Creek in Mercer County, New Jersey and found significantly higher heavy metal concentrations below heavily developed areas.

A study carried out by Pitt and Bozeman (1982 *in* Pitt, 1995) on the Coyote Creek in San Jose, California found that metal levels were higher for urban areas than from nonurban areas especially for lead, and to a lesser extent zinc.

A study carried out by Barry *et al*. (1999 *in* CRC, 2004) measured low flow concentrations for zinc, lead and copper from two waterways entering Iron Cove, Sydney. The catchment is predominantly urban residential (>90%), which is similar to that of the Avon/Ötakaro catchment. Concentrations of zinc (0.037 & 0.051 g/m^3), lead (0.001 & 0.003 g/m^3) and copper (0.018 & 0.026 g/m^3) for the two waterways showed similar levels to those found throughout New Zealand urban streams and rivers, and were consistent with sampling done by Taffs (2007) on the Okeover Stream (tributary of the Avon/Ötakaro river) in Christchurch.

3.3.5 Background Levels

Literature providing concentrations of heavy metals in Christchurch rivers and streams found during the course of this study was very limited. The only metal concentrations found were for the Okeover stream (tributary to the Avon/Ötakaro River) and for three drains feeding into the Heathcote/Opawaho River.

Baseflow levels were determined by Taffs (2007) on the Okeover stream and results showed that concentrations for zinc (0.031 g/m^3), copper (0.0073 g/m^3) and lead (0.0018 g/m^3) were similar to concentrations cited for other urban streams throughout New Zealand (see appendix A).

Section 3 Urban Contaminants

Studies done by Farrant (2006) and Taffs (2007) looked into the effect of rain events on stormwater runoff into the Okeover stream. The 'first flush' phenomenon (described in section 3.2.5) was evident in both studies with regard to metal concentrations. Taffs measured metal concentrations during baseflow and storm conditions and found levels in both the total and dissolved states increased considerably during the storm event. Farrant measured total and dissolved metal levels of stormwater entering the Okeover Stream during two separate storm events. It was found that the level of both total and dissolved metals was highest during the first period of the storm. The two studies reported concentrations as follows: zinc concentrations ranged 0.274 – 0.300 g/m^3, copper concentrations ranged 0.0077 – 0.0301 g/m^3 and lead ranged from 0.0173 - 0.0324 g/m^3. Taffs (2007) study was based on 6 sample sites and Farrant's (2006) study was based on 15 samples which provides a relatively limited picture of Christchurch overall.

A study by PDP (2007b) looked at monitoring results for two Haytons Drain sites and Curletts Road Drain site which enter into the Heathcote/Opawaho River. These were analysed and compared against ANZECC guidelines. Zinc concentrations at all sites were all well above the trigger value of 0.008 g/m^3, with the exception of two or three non-detect values at each site. Reported detection limits for copper and lead were at times also greater than the guideline results.

Other relevant literature sourced described the testing carried out by Otago Regional Council (as described in section 3.2.5). This study found elevated levels of metals, particularly zinc, lead, and copper. An elevated level of arsenic was found at one site which was attributed to the industrial nature of the specific catchment.

Contaminant concentrations in the water can be assessed with reference to the Australian and New Zealand Environment and Conservation Council (ANZECC) trigger values for freshwater (ANZECC, 2000). The guidelines give four protection levels that can be applied to contaminant levels in an ecosystem. The levels provide an estimation of the percentage of species living in the aquatic habitat that are expected to survive the corresponding contaminant levels. The percentage protection levels that ANZECC prescribes for each contaminant are: 99%, 95%, 90% and 80% and can be seen in Table 7.

Table 7 - ANZECC Protection Levels

	Level of protection (% species)			
	99%	95%	90%	80%
	Concentration (g m^{-3})			
Zinc	0.0024	0.0080	0.0150	0.0310
Copper	0.0010	0.0014	0.0018	0.0025
Lead	0.0010	0.0034	0.0056	0.0094
Nitrate	0.017	0.700	3.400	17.000
Ammoniacal Nitrogen	0.32	0.90	1.43	2.30

Source: ANZECC, 2000

Looking at the metal concentrations found for the Okeover stream during baseflow readings, it can be seen that levels for zinc and copper are equal to, and below the 80% protection limit respectively. Levels for lead are slightly better with the recorded concentration showing a protection level of between 95 and 99%. Levels in the Auckland streams were all below 80% protection limit. In a highly disturbed ecosystem (Condition 3 ecosystem as per ANZECC) such as Okeover stream, it might be unrealistic to expect 99% or even 95% protection. A lower trigger level value such as 90% or 80% is perhaps more appropriate (Taffs, 2007).

The data available (see appendix A) may be limited in its comparability between New Zealand and that of the international sites listed due to the use of leaded fuel during the monitoring periods collected. The introduction of unleaded petrol in New Zealand in 1996 (Bates & Garrett, 1998) has seen a great decrease in lead in stormwater runoff. Numbers recorded for lead internationally are far greater than those found in Auckland and Dunedin sites and could be explained, in part, by the lack of lead in New Zealand fuel at the time of sampling.

Elevated total zinc levels are apparent in the international data provided (see Appendix A). A study done by NZ metal roof manufacturers in 2007 (Shedden *et al*.) tested six new metal roofing materials and four panels of old (approximately 5 years) roofing materials over a period of eight months in a rural residential area at Pukekohe. The study showed that loadings for unpainted galvanised iron were high, with the older panels producing the highest level of zinc. With this in mind, most of the Auckland roofs studied to date would fall under the 'old roof' type and this may be reflected in the zinc levels reported. However, zinc levels of the older residential area in Washington were found to be 0.397 g/m^3 compared to that of 0.041 and 0.042 g/m^3 for two areas in Auckland. Levels of a new suburban area in Washington (0.037 g/m^3) compared favourably with the two Auckland areas. These results are not directly comparable as roof types in the Washington studies are unknown.

Levels of zinc for roof materials in Christchurch were not identified during the course of this study and although it could be assumed that roof types would be similar to Auckland, differences in loadings are likely to occur due to climatic or site specific factors.

A study by PDP (2007a) compares average zinc concentrations found in stormwater from a newly developed subdivision (0.026 g/m^3) against stormwater from the existing Halswell township (0.204 g/m^3). Higher levels found in the existing Halswell township could possibly be due to older zinc roof materials.

3.3.6 Effects

This discussion of the environmental effects of metals contaminations focuses on the Avon-Heathcote Estuary/Ihutai for Christchurch area due to lack of data sourced for urban streams and the fact that the estuary is the initial receiving environment.

Stormwater runoff from urban areas is a significant source of organic and inorganic contaminants to receiving environments (Forstner & Wittmann, 1979 *in* Williamson, 1985). These contaminants derive from vehicles and other sources, and include heavy metals, notably copper, lead and zinc, and organic compounds, notably polycyclic aromatic hydrocarbons (PAHs) (Velinsky, Wade, Schlekat, McGee, & Presley, 1994; Williamson, 1991 *in* Morrisey *et al*., 2002). Since much of the contaminant load is associated with suspended particulate material (Forstner & Wittmann, 1979 *in* Williamson, 1985), contaminants will tend to accumulate in environments where particulate material is deposited and remains for relatively long periods. The eventual, long-term sinks for this material are sheltered coastal environments, particularly estuaries. Contaminants derived from stormwater may reach concentrations in estuarine sediments potentially capable of causing biological effects (e.g. as identified by the sediment quality guidelines of Long, MacDonald, Smith, & Calder, 1995). Such levels have been identified, for example, in urbanised estuaries in New Zealand (Deely & Ferguson, 1994; Morrisey, Williamson, & Roper, 1997; Morrisey, Williamson, Van Dam, & Lee, 2000 *in* Morrisey *et al*., 2002).

The form of metals also affects bioavailability with dissolved metals being more available for uptake by aquatic organisms. Filter feeders ingest sediment particles, and if inhabiting areas close to storm drain discharge or affected by urban contaminants, will also ingest contaminants adsorbed to the particles that they are feeding on (Williamson *et al*. 1999 *in* Botherway & Gardner, 2002).

Several studies have shown that urbanisation has increased heavy metal contamination within sediment. One such study of the Hatea River catchment in Whangarei (Webster *et al*., 2000), where bed sediment and core sediment samples were analysed, have found that copper, lead, and zinc concentrations are higher in the most recently deposited sediment, than in buried estuarine sediment. The concentrations of copper, lead, and zinc in sediment of the Hatea River and estuary were found to be consistently (and sometimes significantly) higher than those at which an adverse effect on benthic aquatic life might be expected, as indicated by freshwater and marine sediment quality guidelines (NOAA 1987; Persaudetal, 1993 *in* Webster *et al*., 2000).

Another such study carried out by Glasby *et al*. (1990 *in* Botherway & Gardner, 2002) on the Porirua Inlet showed that again copper, lead, and zinc concentrations were high in sediment samples analysed, and also showed that lead and zinc concentrations declined with increasing distance up Porirua Inlet from Porirua City. This was also shown in a study carried out by Morrisey *et al*. 2002 where four estuaries (two rural and two urban) all show decreased heavy metal concentrations with distance downstream.

A study carried out by Rodrigo (1989) on the sediment of the Avon-Heathcote Estuary/Ihutai showed that concentrations of the metals zinc, lead, nickel and chromium were higher in the estuary than levels of the same metals in that of the uncontaminated Saltwater Creek, north of Christchurch (Rodrigo, 1989).

The Avon-Heathcote Estuary/Ihutai is one of the few examples in New Zealand where a large and varied wildlife population occurs within such a heavily urbanised area (Environmental Service, 1993 & Christchurch City Environmental Trends Report 2003). The estuary is a highly productive system. The plant matter within the estuary forms the basis of the food chain, along with a major contribution to algal growth from the oxidation ponds. Organism such as zooplankton and filter feeders (cockles, crabs, mussels) consume this matter as well as grazing and deposit feeding animals. In turn other fish and bird species feed on these grazing organisms (Environmental Service, 1993).

However, the studies described above didn't have a biological component with which to assess the ecological effect of the heavy metals. In a joint study carried out by Wellington Regional Council (WRC) and Porirua City Council (PCC) levels of sediment and shellfish contaminations were investigated in Porirua Harbour (Berry *et al*. 1997 *in* Botherway & Gardner 2002). The cockle Austrovenus Stutchburyi collected at five sample sites, and the sediment samples taken at 11 sample sites all showed high levels of copper, lead, and zinc concentrations from the southern end of Porirua Inlet near to the storm drain.

Another such study carried out by Morrisey *et al*., 2002 on benthic macrofauna in four Auckland estuaries (two rural and two urban) showed that there was some correlation between biological effect of contamination derived from stormwater runoff (Morrisey *et al*., 2002).

In support, international studies have also shown that there is not always a correlation between high contaminant levels and abundance of taxa. A study carried out by Schlekat *et al*. (1994 *in* Morrisey *et al*. 2002) on tidal rivers around Washington DC showed that although concentrations varied hugely for copper, lead, and zinc there appeared to be no significant correlation with respect to abundance and diversity of taxa (Morrisey *et al*., 2002).

In the case of Christchurch, and particularly the Avon-Heathcote Estuary/Ihutai, levels of metals in both the dissolved state and sediment bound states are important in the diverse wildlife population and productive system. It is hard to predict the effects that metals would have on the aquatic life within the estuary with limited information on metal loads and concentrations entering the marine environment. The literature (Berry *et al*. 1997 *in* Botherway & Gardner 2002) states that there appears to be some correlation between metal levels and taxa contamination, but there appears to be some disagreement within the literature on whether the levels of metals in the water environment directly correlate to the abundance and diversity of these taxa.

3.3.7 Outline Analysis of Key Literature

Table 8 below summarises the literature cited in this section of this report and comments on validity and relevance of the information provided.

Table 8 - Summary of Literature in Section 3.3

Reference	Year	Comments
	Local	
Purchase and Ferguson	1986	Scientific paper on lead in river sediment in Christchurch. Old data. Good background information, examples used.
Environmental Services	1993	Overview paper relevant to the Avon-Heathcote area. Descriptive text rather than technical detail and scientific data. Relatively old, may no longer be accurate.

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Reference	Year	Comments
Kingett Mitchell Ltd	2003	Scientific paper on sediment quality in Pegasus Bay. Extensive study, small amount relevant to the Avon-Heathcote Estuary/Ihutai.
Christchurch City Environmental Trends Report	2003	Overview of the environmental issues within Christchurch City. Lots of facts and figures but minimal references. General information still relevant, some stats out of date.
ANZECC	2000	Australian and New Zealand guidelines for fresh and marine water quality. These are the latest water quality guidelines.
Burge	2007	Literature review on sedimentation. Limited to the Avon-Heathcote Estuary/Ihutai only. Older literature is backed up with more recent studies.
Taffs	2007	New Zealand University paper. Small case study on stormwater discharge in Okeover stream. Useful information. Small study area, limited amounts of sampling.
Elliot	1997	Analysis report on stormwater quality controls. Extensive study. Old report.
Rodrigo	1989	Scientific paper on sediment based heavy metals in the Avon-Heathcote Estuary/Ihutai. Relevant as used for general context and comment only.
Brown *et al.*	1996	Scientific paper on runoff in Wigram Retention Basin. Small study area. Old report, some contaminant levels may have changed.
Farrant	2006	New Zealand third year university paper. Small case study on stormwater discharge in Okeover stream. Small study area, limited amounts of sampling.
Deely and Ferguson	1993	Scientific paper on metal concentrations in the Avon-Heathcote Estuary/Ihutai. Some contaminant levels used may have changed due to age of paper.
Pattle Delamore Partners Ltd (PDP)	2007a	Small case study done for Christchurch City Council on a subdivision. The numbers used in section 3.2.2. of our report thought to be relevant based on age of the report and the number of samples taken. Study uses data from 2005-2007
Pattle Delamore Partners Ltd (PDP)	2007b	Analysis of monitoring data for 1992-2006. Very relevant based on local information and age of data. Compares results to national guidelines. Limited amount of metal results.
	National	
Shedden *et al.*	2007	Scientific paper on roof runoff. Very relevant. Considered accurate based on age of paper and comparison with ARC studies.
Botherway and Gardner	2002	Scientific paper on storm drain discharge in Wellington. Statements and information used.
Brown and Peake	2005	Scientific paper on heavy metals in urban stormwater runoff. Only two catchments sampled. Up to date information.
Webster *et al.*	2000	Scientific paper on trace metals in Whangarei. Statements and information used.
Williamson	1985	Scientific paper on urban stormwater quality. Relevant as used for general context and comment only.
Morrisey *et al.*	2002	Scientific paper on macrofauna in estuaries. Relevant as used for general context and comment only
Webster-Brown	2005	Scientific paper on trace metals in Whangarei. Statements and information used.
ARC	2005	Significant study by Auckland Regional Council. Study limited to one catchment of each type. Levels of contaminants in similar catchments assumed to have similar concentrations and loadings. This

Reference	Year	Comments
		assumption is a simplification of actual conditions. Most accurate and up to date data available nationally. Based on studies from 2000-2002.
International		
Pitt	1995	Scientific paper on effects of urban runoff. Used only for relevant examples.
CRC	2004	Literature review on contaminant levels in Australia. Extensive amounts of data. Relevant examples used. Age of data relevant. Local conditions may differ.

Much of the data presented in this section is limited to the Avon-Heathcote Estuary/Ihutai. Metal concentrations and loads were not found for Christchurch rivers and streams. One report was bought to our attention regarding heavy metals in the rivers and estuaries but was unable to be sourced, however given the age of the report (1988) it is likely that contaminant levels reported would not compare to today's concentrations.

The information for metals concentrations in the Avon/Ōtakaro and Heathcote/Opawaho Rivers is limited. Reports by Taffs (2007) and Farrant (2006) look at metal levels in the Okeover Stream (a tributary to the Avon/Ōtakaro River) and a report by Brown *et al.* (1996) looks at runoff quality from the Wigram Retention Basin (enters into the Heathcote/Opawaho River). Further studies would be recommended for the Avon/Ōtakaro and Heathcote/Opawaho Rivers.

3.4 Organic Compounds

3.4.1 General

A large number of semi-volatile organic compounds are released into the environment through discharges to water. A key group of these has been identified. Polycyclic Aromatic Hydrocarbons (PAHs) are an important group of aromatic hydrocarbons that are emitted to the atmosphere from fossil fuel burning such as motor vehicle emissions and petroleum sources. These are of special interest as runoff from roads into urban waterways is a significant transport mechanism.

PAHs are a major concern because they are carcinogenic (Stein *et al*., 2006), hydrophobic (having little or no affinity for water), environmentally persistent and potentially toxic (Depree & Ahrens, 2005). The environmental effects that they have are similar to those of metals in that they have the potential to impact on marine life and the presence in the food chain, possibly ultimately impacting on humans (Environmental Services, 1993). This is extremely important in the case of Christchurch, as PAHs have been shown to accumulate in coastal estuarine and marine sediments (Stein *et al*., 2006).

PAHs consist of two, or more, fused benzene rings and are a group of over 100 different chemicals (ARC, 2003), however only 16 of these have been identified as priority by the USEPA (See Appendix B; Depree & Ahrens, 2005). PAHs are found naturally in crude oil and its products (petroleum, lubricating oils, and bitumen) as well as being formed during the incomplete burning of coal, wood, oil and gas (ARC, 2003a). Sources of PAHs in urban runoff derive from atmospheric particles from exhausts (and fires), abraded bitumen, petroleum products and sump oil (Williamson, 1993). Motor vehicle emissions, drips of crankcase oil, vehicle tyre wear and asphalt road surfaces, are all diffuse sources of chemical contaminants in urban environments. During rainfall, these contaminants are washed from roofs, roads and other surfaces into the stormwater system and then discharged into surface waterways and estuarine environments (Brown & Peake, 2005). PAH source material can be classified as either petrogenic (derived from petroleum) or as pyrogenic (derived from combustion) (Depree & Ahrens, 2005).

Other diffuse sources of PAHs include domestic fire emissions, the spillage or deliberate dumping of waste oil and the corrosion of roofing materials. Specific point sources, such as electroplating workshops, gasworks and commercial incinerators may also exist in urban catchments (Brown & Peake, 2005).

Many industrial yards have inadequate treatment facilities to deal with spills which may enter into stormwater, however most local authorities try and ensure that this does not occur by inspecting stormwater collecting systems and following up complaints from the public. Traffic accidents account for a minor part of the PAHs in the waterways as petrol spills from accidents may be washed into the nearest stormwater system (Williamson, 1993).

Total Petroleum Hydrocarbons (TPH) are another concern to the receiving environment. TPH is a term used to describe a broad family of several hundred chemical compounds that originally come from crude oil. Because modern society uses so many petroleum-based products (for example, gasoline, kerosene, fuel oil, mineral oil, and asphalt), contamination of the environment by them is potentially widespread (Encyclopedia of Earth website).

TPHs are primarily absorbed by suspended solids and the dissolved concentrations of these contaminants are generally lower than the absorbed concentrations.

Organochlorine compounds (OCs) are another broad group of compounds that include various OC insecticides and polychlorinated biphenyls (PCBs). These organic compounds are largely found in pesticides which are predominantly used in farming, agricultural and horticultural applications. PCBs can also be found in the leaching of lubricants, hydraulic fluids, landfills and old transformer fluids. They are slightly soluble in water, decreasing in solubility with added chlorines. Stormwater data for PCBs and many pesticide contaminants in urban runoff studies (except the OC compounds) is limited (Makepeace *et al*., 1995).

3.4.2 Local Information

PAHs in Christchurch have been studied in depth by Depree and Ahrens of National Institute of Water and Atmosphere (NIWA). Much of the sediment in the Christchurch waterways contain exceptionally high levels of PAHs (Ahrens *et al*. 2005). These high PAH levels have previously been attributed to domestic solid fuel burner emissions (Depree & Ahrens, 2005). However extensive analyses of stream sediments, road/pavement cores, atmospheric particles and potential source materials indicate that the major source of PAHs is historic coal tar used in road and footpath construction in the 1970s (Depree and Ahrens, 2005). Due to the very high PAH levels in coal tar, only a small fraction of abraded material need to enter into streams to elevate sediment PAH levels (Ahrens *et al*. 2007).

Although coal tar is no longer used in road construction, stream sediments have accumulated high levels of PAHs over many years (Ahrens *et al*. 2007). Furthermore, large amounts of coal tar still reside in deeper seal layers of older roads and roadside soils, providing a large reservoir of PAHs for potential export into nearby waterways (Depree & Ahrens, 2005, Depree *et al*. 2006).

Levels of PAH in Christchurch sediment (50-90 µg/g; Ahrens *per comms*. 22nd June 2007) have been found to be up to 50 times higher than PAH levels measured in most other New Zealand cities (1-2 µg/g; Ahrens *per comms*. 22nd June 2007, Ahrens *et al*. 2007). However, this statement compares values found in coal tar laden sediment in Christchurch with sediment from new residential areas elsewhere in the country. Recent studies have found that coal tar was also used in some older areas of Auckland and levels within these (20-25 µg/g; Ahrens *per comms*. 22nd June 2007) are much higher than those in the new residential areas. The difference in PAH levels from the most recent study equate to about 4 times difference (as compared to 50 from the earlier study) to those found in Christchurch (Ahrens *per comms*. 22nd June 2007).

A study was carried out during 1991-92 (Holland & Trower) for organic contaminants in both sediment and water samples from the Avon/Ōtakaro and Heathcote/Opawaho Rivers and the Avon-Heathcote Estuary/Ihutai. Concentrations of most organic compounds (including total hydrocarbons, organochlorine insecticides, polychlorinated biphenyls, chlorophenol and PAHs) in the water, sediment and cockles were generally either not detected or low at most sites. However, some of the sediment-sorbed contaminants exceeded recommended guideline values for water quality and threshold levels for apparent biological effects at some sites. Contamination was most prevalent closest to the Avon/Ōtakaro River mouth, the City Outfall Drain, the Heathcote/Opawaho River mouth, Beachville Road, Brighton Spit and Plover Street (Holland & Trower). This pattern shows the significance of the Avon/Ōtakaro and Heathcote/Opawaho

Rivers as sources of the organic contaminants to the Estuary. It is noted that the Christchurch oxidation ponds do not appear to be an important source of organic compounds. There is no clear concentration gradient in the sediments away from the point sources but there is some contamination over the entire estuary (Environmental Services, 1993).

In a study of past and present information by Burge (2007) he concluded that the study done in 1991-92 (Holland & Trower) and another such study of two sites within the Avon-Heathcote Estuary/Ihutai undertaken by the Ministry for the Environment in 1998 showed that data collected was consistent between the two studies in that both studies showed similar low concentrations.

A later study by Mills & Williamson (1999 *in* Burge, 2007) concluded that the distribution of organic contaminants in 1999 and at the time of the initial survey (1991-92) were similar. The greatest concentrations of organic contaminants were found to be in the region of the Avon/Ötakaro and Heathcote/Opawaho Rivers, and were related to the muddier nature of the sediment in these zones. They further concluded that the levels of organic contamination in the Estuary were below or similar to those observed elsewhere in New Zealand (Mills & Williamson, 1999; Mills, 2001 *in* Burge, 2007) and, based on draft Canadian Sediment Quality guidelines (Mills, 2001 *in* Burge 2007), are below the level estimated to cause adverse affects in most sediment dwelling organisms (Mills, 2001 *in* Burge, 2007) although some sensitive organisms may be affected (Thompson & Davies, 1993; Elliot, 1997 *in* Burge, 2007).

A recent study by Thompson (2005 *in* Burge, 2007) however, implied a reduction in organic contaminant concentrations, as examination of samples for a suite of 251 organic compounds (including PCBs, organonitrogen and organophosphorous pesticides, petroleum hydrocarbons and semi-volatile and volatile organic compounds (Thompson, 2005 *in* Burge, 2007)) indicated that only Dicholoromethane (Methylene chloride), a volatile organic compound, was above the analysis detection limit, occurring at 0.8 mg/kg of dry weight sediment. While this general lack of detectable organic contaminants in the Thompson (2005) study may represent an actual reduction in organic contamination of sediments compared to the previous sampling it must be treated carefully as the information is limited and the variation may simply relate to site specific differences (Burge, 2007).

A study by Main (2004) for Environment Canterbury looked at pesticide levels in Canterbury streams and rivers for the period from 1991 to 2002. The sampling was conducted for 42 pesticides from nine chemical groups. Most pesticides were not detected from streams and rivers in Canterbury, however, five members from the triazine group of herbicides, six acidic herbicides and a substituted urea compound were detected from some of the sites, at least once. The Avon/Ötakaro and Heathcote/Opawaho Rivers are relatively more contaminated with more positive samples coming from these than any other river or stream in the Canterbury region. This said, the number of detections and the mean concentrations of these are relatively low in most cases. The most common pesticides found were simazine, terbuthylazine and triclopyr however none of these records have been at concentrations of environmental concern. The use of triazines (such as simazine and terbuthylazine) is increasing and this raises the concern that the frequency of detection and the concentrations recorded may also increase. More sampling is recommended by Main that should cover the whole region systematically, rather than targeted sampling.

3.4.3 National Information

Levels of PAHs have also been studied elsewhere in New Zealand. PAHs were measured in road debris collecting in urban areas and in the suspended sediment component of runoff from two stormwater catchments in Dunedin, New Zealand. Levels in the road debris ranged from 1.20–11.6 µg/g for Σ16PAH (sum of the 16 USEPA priority listed PAHs). The suspended sediment from the largely rural catchment (20% urban) had similar concentrations to the road debris, indicating that this urban material was the main source of the contaminants measured in the stormwater. Similar PAH fingerprint profiles and isomer ratios indicative of dominant pyrogenic (combustion) sources were also found in these two groups of materials. The suspended sediment from the 100% urban catchment contained 10-fold greater levels of Σ16PAH. The PAH profiles and isomer ratios were different for this urban catchment and suggested that a disused gasworks was contributing PAHs to the stormwater runoff (Brown & Peake, 2005).

Previous work on urban stormwater runoff from two catchments in Dunedin, New Zealand (Brown, 2002; Brown *et al*., 2003 *in* Brown & Peake, 2005), indicated that significantly higher concentrations of Σ16PAH (sum of the 16 USEPA priority listed PAHs) were present in the runoff from an urban catchment (Portobello Road) as compared to a local river that has 83% of its catchment in rural land uses but receives stormwater discharges from several small urban sub-catchments.

These studies suggest that urban landuses are major contributors of PAHs to waterways.

Analysis of the trace metal and PAH content of stormwater suspended sediment, in comparison with that of road debris from the same catchments, enabled the apportionment of the contaminant sources in the stormwater. The road debris, in particular street dust and tanker effluent solids, were the principal sources of the PAHs in the stormwater suspended sediment from the Water of Leith catchment. The road debris was also a significant contributor to the contaminants in the Portobello Road catchment but significantly higher PAH concentrations suggested that additional contaminant sources were present. During one storm event, high PAH concentrations appeared to be the result of maintenance activities within the stormwater system disturbing or adding a large amount of road debris. In another event, where PAH concentrations were highly elevated, input of PAH-rich sludge from a closed gasworks facility was implicated. This additional input was the likely explanation for the high annual PAH loading from this catchment.

In Auckland, extensive studies have determined typical TPH loads for Auckland roads which have been used by the ARC (2005) in their contaminant load model and can be seen in Table 9.

Table 9 - Urban TPH Loads (g m^{-2} a^{-1})

Vehicles/Day	Total Petroleum Hydrocarbons
<1000	0.11
1000-5000	0.54
5000-20000	2.68
20000-50000	5.34
50000-100000	11.41
>100000	17.66

Source: ARC, 2006

Roads are one of the main contributors of TPHs to stormwater and the extent of contamination will depend on the number of highly trafficked roads in the catchment. The largest road in Christchurch on a vehicle/day basis is Moorhouse Avenue with approximately 40,000 vehicles per day. Other large roads throughout Christchurch were found to be between 25,000 and 35,000 vehicles per day (data as at 25th June 2007, Christchurch City Council).

No literature was found concerning OCs and PCBs in New Zealand, however the Australian and New Zealand Environment and Conservation Community (ANZECC) gives trigger levels for selected organochlorine pesticides and selected herbicides and fungicides. PCB levels are not set, due to insufficient data being available.

3.4.4 International Information

A study carried out by Stein *et al*. (2006) in the greater Los Angeles, California region on PAH concentrations during storm events (see section 3.1.7) over a four year period showed that the largely undeveloped Arroyo Sequit catchment gave a PAH flux load of 1.3 g/km^2 whereas the highly urbanized Verdugo Wash catchment gave a flux load of 223.7 g/km^2. In general, it was found that both PAH loads and concentrations were higher for developed catchments versus undeveloped catchments, thus supporting the New Zealand situation.

No other literature regarding organic compounds was sourced during this literature study.

3.4.5 Background Levels

Only a few local Christchurch studies were sourced that included levels of organics in the Christchurch waterways. Generally levels of organic contaminant were low in the waters for the Avon/Ötakaro and Heathcote/Opawaho Rivers and the estuary, however PAHs were found at some sites along both rivers. This can be expected as levels of hydrocarbons (including PAHs and TPHs) from vehicles can be found in most urban runoff. This is shown by the typical TPH loads reported by the ARC contaminant load model, which indicates that number of vehicles per day using specific roads directly affects the amount of contaminant levels.

Studies carried out by Ahrens *et al*. indicate that background levels of PAHs in Christchurch are higher than those in other urban cities around New Zealand due to the extensive use of coal tar in roading throughout the 1970s. Levels of PAH in Christchurch sediment range between 50-90 µg/g (Ahrens *per comms*. 22nd June 2007) compared to recent studies carried out on some older areas of Auckland which range from 20-25 µg/g (Ahrens *per comms*. 22nd June 2007).

Levels of OCs and PCBs were found in two studies and indicated levels were exceedingly low in both water and sediment samples. Further studies would have to be conducted to assess the extent, if any, of these contaminants, specifically found in the Christchurch area.

Main (2004) reports levels of different pesticides found in the Avon/Ötakaro and Heathcote/Opawaho Rivers. Many of the samples collected returned non-detect results (those that are below the detection limit). Those that were detected on the Heathcote/Opawaho River range between 0.01 and 0.14 mg/m^3 for simazine, between 0.02 and 1.9 mg/m^3 for terbuthylazine, and between 0.04 and 0.16 mg/m^3 for triclopyr. Detected levels on the Avon/Ötakaro River ranged between 0.02 and 0.42 mg/m^3 for simazine, between 0.02 and 0.29 mg/m^3 for terbuthylazine, and between 0.04 and 0.06 mg/m^3 for triclopyr.

3.4.6 Effects

The specific effects of organic compounds will vary depending on the type of compound concerned. In general organic contaminants tend to accumulate in an ecosystem, causing long-term toxicity (Chiew *et al*., 1997).

In cases where the concentrations of organic contamination have been determined to be equal to or exceeding water quality and sediment quality guidelines for the protection of aquatic ecosystems, the related effects are likely to be long term rather than an acute nature, affecting sensitive life cycle stages and or species abundance (Environmental Services, 1993).

Conversely, Kennedy (1999) suggests that PAHs emitted by vehicles and present in stormwater discharged to freshwater environments have the potential for bioaccumulation (accumulation of contaminants in an organism). Although uptake from PAHs has been identified, no adverse effects of bioaccumulation appear to have been identified and bioaccumulation is not likely to occur to a level that would result in adverse effects.

Very little is information was found during this study regarding TPHs and their effects on the environment. It is likely that effects would be similar to those of PAHs due to their similar chemical properties. A study done by Poulton *et al*. (1997) looked at the effects of a crude oil spill on the macroinvertebrate community on a large river in Missouri. It was found that concentrations in sediments decreased dramatically in riffle habitats (those affected by the flow of the river) within 6 months of the spill, but elevated levels were still present in backwater habitats (those not affected by the flow directly). Correspondingly, riffle macroinvertebrate communities recovered rapidly, but overall benthic diversity continued to be reduced in backwater areas until the end of the study, 18 months after the spill. This would indicate that high levels of petroleum based contaminants into Christchurch rivers could have an effect on invertebrate communities in deposited areas of the rivers and estuary.

No literature was sourced specifically describing the effects of Organochlorines and PCBs however if levels were to exceed of levels found in the ANZECC guidelines then the diversity and abundance of taxa are likely to be affected.

3.4.7 Outline Analysis of Key Literature

Table 10 below summarises the literature cited in this section of this report and comments on validity and relevance of the information provided.

Table 10 - Summary of Literature in Section 3.4

Reference	Year	Comments
Local		
Ahrens *et al.*	2005	Conference paper on bioavailability of contaminants in New Zealand Harbours. Statement used. Backed up by other Ahrens and Depree papers. Thorough and relevant.
Environmental Services	1993	Overview paper relevant to the Avon-Heathcote area. Descriptive text rather than technical detail and scientific data. Relatively old, may no longer be accurate.
Ahrens *et al.*	2007	Conference paper on PAHs in Christchurch. Most recent data available. Ahrens is national expert on PAHs.
Depree *et al.*	2006	Conference paper on PAHs in Christchurch. Statement used. Considered an expert on PAHs.
Holland and Trower	1992	Scientific report on organochlorine and hydrocarbons in the Avon-Heathcote Estuary/Ihutai. Concentrations are quite dated (1991-1992) but useful (and reasonably consistent) for comparison to more recent data.
Main	2004	Scientific report on pesticides in streams and rivers in Canterbury. Detailed study with large data set (1992-2002). Most recent information.
Gilson	1996	Analysis of water quality results based on Christchurch City Council monitoring. Based on a small data set (1991-1995). Data is old. Appendix A of this report cites more recent data source (1996-2006).
National		
Depree and Ahrens	2005	Conference paper on PAHs from New Zealand roads. Information used from this thought to be valid based on expertise of authors and age of paper.
Brown and Peake	2005	Scientific paper on PAHs in urban stormwater runoff. Only two catchments sampled. Up to date information.
Kennedy	1999	Scientific paper on road transport and effect on ecosystem. Relevant as used for general context and comment only.
ARC	2005	Significant study by Auckland Regional Council. Study limited to one catchment of each type. Levels of contaminants in similar catchments assumed to have similar concentrations and loadings. This assumption is a simplification of actual conditions. Most accurate and up to date data available nationally. Based on studies from 2000-2002.
International		
Chiew *et al.*	1997	Basic industry report on urban stormwater. Relevant examples used.
Poulton *et al.*	1997	Scientific paper on benthic invertebrate community. Relevant as used for general context only.
Stein *et al.*	2006	Scientific paper on PAHs in urban stormwater. Information is based on sampling over a period of four years, and is up to date.

The literature sourced for PAH levels in Christchurch are predominantly that of Depree and Ahrens of NIWA. The information contained within all their reports is recent and although it is useful in giving a very detailed overview of PAH levels within sediment in Christchurch, information such as soluble and total PAH levels in the water and specific locations of the sampling are omitted from the reports.

The literature for other organic compounds is relatively limited and those found have been presented. Each report gives a different number of detections and slightly different results but all agree that the levels found are below those of environmental concern. The study by Main (2004) seems to be the most relevant as it is the latest and most detailed study. Some of the earlier studies will be affected by organic chemicals that are no longer used, whereas the study carried out by Main (2004), will have had a chance to see the gradual decline in concentration of some of these chemicals over time and points to the emergence of new compounds of concern.

3.5 Nutrients

3.5.1 General

Nutrients are usually defined as nitrogen and phosphorus compounds that enable plant growth and when in excessive concentrations can over stimulate plant and algal growth. Nutrient levels can cause daily fluctuations in oxygen concentrations, including phases of aerobic decomposition, which remove dissolved oxygen from the receiving waters (ARC, 2003a).

Nutrients will occur naturally to some extent, but the main source of nutrients will be farming, agricultural and horticultural activities in rural areas. These will include excessive use of fertilisers, manure from livestock, irrigation, drainage, and soil enrichment (Galbraith & Burns, 2007). Other less significant sources of nitrogen will be from wastewater, from the breakdown of organic nitrogen in protein waste matter, and the oxidation of the ammonia in urine. Lesser sources of phosphates are present in detergents used in washing and laundering, and are also produced by organic breakdown (Mfe website).

Phosphorus is present in both particulate and dissolved forms. Particulate phosphorus adsorbs to soil particles and is carried in runoff travelling over the ground surface. Dissolved phosphorus is dissolved within water and therefore travels with waters carrying less sediment and can travel in subsurface flow where waters flow directly below the soil surface. The final form of phosphorus movement occurs in groundwater flow. This is generally the smallest portion of phosphorus transport (Sowles, 2005).

Nitrogen is available in both particulate and dissolved forms. Particulate nitrogen attaches to soil particles and is carried in runoff travelling over the ground. During rainfall, significant amounts of nitrogen enter the soil. Dissolved nitrogen is found in various forms. Nitrogen in the form of ammonia comes from fertilisers and organic matter. This is chemically altered into nitrite and further modification converts this nitrite to nitrate. Nitrate is often used to measure nitrogen concentrations because it is very soluble in water (PhysicalGeography website).

Concentrations of nitrogen and phosphorus are highest in stormwater from rural catchments, followed by residential and then by industrial land uses (Main, 1994).

3.5.2 Local Information

A study carried out by Main (1994) investigated contaminant loadings from different land uses within the Avon/Ötakaro - Heathcote/Opawaho catchment during three separate rainfall events. Five sites were selected, predominantly from the Heathcote/Opawaho catchment, and are representative of an industrial, a flat urban, a flat rural and a Port Hills rural sub catchment. The study found that concentrations of nitrogen (excluding ammonia-nitrogen) were highest for the rural sites, then from urban sites and the lowest concentrations were from the industrial site. Ammonia-nitrogen was found to be highest in the industrial site, followed by rural catchments. Total phosphorus showed no such pattern, but it appeared that higher concentrations of this were discharged from rural and industrial, rather than the urban catchment.

Average nitrogen loadings and concentrations for the flat rural site (0.08kg/hr) were lower than those from the Port Hills residential site (0.09kg/hr), but higher still were the concentrations and loadings coming from the Port Hills rural site (2.2 kg/hr). With respect to phosphorus, the study reported that the highest average total phosphorus concentrations recorded during the study were from the Port Hills rural site (5.5 kg/hr), but the flat rural stream (0.09 kg/hr) had concentrations which were lower than those from other sites. It appears that in the rural flat sub-catchment phosphorus is not readily discharged, perhaps because of the topography. Phosphorus runoff is most typically present in the particulate form (which requires overland flow to occur), which may explain why dissolved reactive phosphorus concentrations were relatively low at all sites (Rosich & Cullen, 1982 *in* Main, 1994).

Another such study by Meredith and Hayward (2002) on Canterbury streams and rivers states that increased nitrogen and phosphorus concentrations are generally related to increasingly intensive land use. Levels of ammonia-nitrogen were generally found not to be a problem in any of the river types of Canterbury.

In contrast to the study mentioned above, dissolved reactive phosphorus in four of the six tributaries on the Avon/Ötakaro River, particularly Dudley creek and Horseshoe Lake, exceed the background concentrations. Both of these tributaries receive drainage from farmland (principally market gardens) to the north of the city. These two tributaries also significantly influence the concentration of ammoniacal nitrogen in the river. The Heathcote/Opawaho River contains higher levels of ammoniacal nitrogen and dissolved reactive phosphorus than the Avon/Ötakaro, particularly sources from Haytons Drain (Environmental Services, 1993).

A study by Brown *et al* (1996), looked at concentrations of ammoniacal nitrogen and dissolved reactive phosphorus from Haytons Drain. Sampling was carried on four separate dates and the average concentration for both ammoniacal nitrogen (1.93 g/m^3) and dissolved reactive phosphorus (1.85 g/m^3) were found to be relatively high. Ammoniacal-nitrogen results can be compared to ANZECC guidelines which state that for protection of 90% of a species levels should be below 1.43 g/m^3 and protection of 80% of a species should be below 2.3 g/m^3.

Brown *et al* (1996) also looked at the effect of a point source on the levels of ammoniacal nitrogen and dissolved reactive phosphorus. Average concentrations from five dates were measured from the stormwater runoff from Ravensdown Fertiliser Company and levels for both ammoniacal nitrogen (34 g/m^3) and dissolved reactive phosphorus (75 g/m^3) were extremely high. A large proportion of the nutrients entering into the Wigram Retention Basin were attributed to the Fertiliser Company discharge.

It is suggested in literature that, both the Avon/Ötakaro and Heathcote/Opawaho Rivers contain naturally elevated concentrations of nitrates (Environmental Services, 1993).

The Avon-Heathcote Estuary/Ihutai is one of the marine receiving environments for nutrient loads from the Avon/Ötakaro and Heathcote/Opawaho Rivers. The nutrient loads from the Avon/Ötakaro (~80kg/day from 2002/03 median) and Heathcote/Opawaho (~90kg/day from 2002/03 median) enter into the Avon-Heathcote Estuary/Ihutai and together with the water discharged from the wastewater treatment plant's oxidation ponds (3850kg/day from 1989-1999 historical median) make up the majority of nutrients present (Christchurch City Environmental Trends Report 2003). The annual median values for nutrients entering from the Avon/Ötakaro and Heathcote/Opawaho Rivers have been decreasing over time (from ~190 to 80 kg/day for the Avon/Ötakaro and ~150 to 90kg/day for the Heathcote/Opawaho; Christchurch City Environmental Trends Report 2003).

Approximately 80% of the nitrogen and 95% of the phosphorous present in the estuary comes from the daily discharge of treated effluent from the oxidation ponds. The release of pond effluent on the outgoing tide means that the majority of nutrients are taken out of the estuary, and the remaining nutrients are absorbed by the plant and animal community and sediment (Environmental Services, 1993).

In addition, a number of small drains from farmland adjacent to the oxidation ponds also flow into the estuary. Although some of the drains have high nutrient levels, the limited flow from these drains means that they have little impact (Christchurch City Environmental Trends Report 2003).

Nutrient levels in sediment have also been studied in the estuary and are considered a useful indicator of the quality of sediment entering the estuary. None of the sites studied showed nutrient enrichment and most of the sediments were of a type and makeup that indicate sufficient wave movement to prevent finer, nutrient-rich sediment from depositing and leading to excessive enrichment or development of algal blooms (Environmental Services, 1993). It is noted that more recent data, if available, may counter this view.

3.5.3 National Information

A study carried out by Galbraith and Burns (2007) found that water quality was positively linked to land use types and modifications of the catchment. Main points of interest of the study found that as elevation decreased nutrient levels increased which they found was consistent with other studies. Nitrogen supply to surface waters was highest from catchments with dairy farms, followed by hill pasture (sheep and cattle grazing) and urban catchments and lowest from low intensity pastoral grazing, indigenous bush and scrub, and exotic pine forest. In contrast, phosphorus supply to surface waters was highest in catchments of hill pasture, followed by dairy farming, then low intensity pastoral grazing, urban development and forestry. Nutrient levels from land associated with intensive agriculture such as livestock grazing and arable crops tend to be higher than those from other land uses (Johnes *et al*., 1996 *in* Galbraith & Burns, 2007).

Baseline studies of 16 streams around Auckland were carried out by Auckland Regional Council both in 2000 and 2003. Results showed that levels of nitrates were relatively low in most land use types except for land use which was influenced by market gardens. Values for dissolved reactive phosphorus were generally very low with values of 0.1 or more g/m^3 occurring only in urban and mixed land use catchment streams (ARC, 2000; ARC, 2003b). These levels for reactive phosphorus are similar to those found in the urban and mixed land use areas of Christchurch. Concentrations for nitrates around the market gardening area of Christchurch are not available so no direct comparison can be made.

3.5.4 International Information

A review of literature by CRC (2004) reports numerous studies reporting land use effects on the levels of nutrients. A select few of these have been summarised below.

A study by Hollinger *et al*. (2001 *in* CRC, 2004) looked at soluble nitrogen and phosphorus concentrations from a market garden southwest of Sydney, Australia during 13 storm events over a two year period. Average concentrations were found to be 22.9 g/m^3 for nitrogen and 0.24 g/m^3 for phosphorus.

Another such study in 1994 by the Brisbane City Council (*in* CRC, 2004), Australia compared base flow concentrations against storm flow concentrations from different land use types. Levels of both total nitrogen and total phosphorus were elevated during storm flows in all land use types. Rural land use showed the highest concentration increase with levels of total nitrogen increasing from 0.42 to 2.76 g/m^3 and levels of total phosphorus increasing from 0.06 to 0.36 g/m^3. Urban residential land use areas showed an increase from 1.79 to 2.12 g/m^3 in total nitrogen and 0.14 to 0.45 g/m^3 in total phosphorus.

3.5.5 Background Levels

Levels of ammoniacal nitrogen in Christchurch rivers in rural catchment areas ranged from <0.01 to 0.16 g/m^3 and were all below the ANZECC trigger level for 95% protection (0.90 g/m^3). The levels found in urban catchment areas ranged from <0.01 to 0.91 g/m^3, with only one value falling outside the 95% protection limit (Appendix A; Gilson, 1996). Of the limited data available it appeared that ammoniacal nitrogen levels were slightly higher in urban areas than in rural areas. However, there was little evidence (locally and nationally) to suggest a pattern in ammoniacal nitrogen levels with regard to landuse.

A few noticeably high levels of phosphorus (ranging from 0.115 to 0.610 g/m^3; Appendix A) were found within the Heathcote/Opawaho River, most probably caused by the influence of the Port Hills, but these high levels were not present in the Avon/Ötakaro River. Rural land use on areas of the Heathcote/Opawaho and Halswell Rivers generally showed higher levels of nitrates compared to urban areas, which were higher than levels found throughout the Styx River. This is because the Styx River is fed from relatively clean groundwater, which has been derived from the Waimakariri River further up the plains. The Heathcote/Opawaho and Halswell Rivers are influenced by the Port Hills and are largely fed from groundwater sources from rainfall on the plains, and therefore, pick up more nitrates from the land (Styx website).

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PDP (2007b) analysed monitoring data for the Avon/Ötakaro and Heathcote/Opawaho Rivers and compared these to national guidelines. In general, the majority of ammoniacal-nitrogen results for all sites were below the ANZECC trigger level, which agrees with the findings mentioned above. In contrast, median concentrations of dissolved phosphorus in the Heathcote/Opawaho River were found to exceed the MfE guideline of 0.03 g/m^3 in nearly all sites. Median concentrations of dissolved phosphorus in the Avon/Ötakaro River were generally lower but most exceeded the ANZECC guideline of 0.01 g/m^3.

Environmental Services, 1993 stated that levels of nutrients in the water of the estuary are important because in excessive concentrations they can lead to algae growths, and reduction in water clarity. Levels of nutrients in the estuary are kept low as most nutrients entering the Estuary are removed during the outgoing tide. However more recent studies have been carried out to investigate nutrient levels further. A report by Bolton-Ritchie and Main (2005) which looked at nutrient levels in the Avon-Heathcote Estuary/Ihutai showed for seven sites around the estuary, that during tidal movements concentrations of nitrates were generally lowest for all sites at high tide.

Concentrations of nutrients were looked at for the period of 1989-1999 and for 2002-2005 and can be seen in Table 11. Concentrations of nutrients recorded in the Avon-Heathcote Estuary/Ihutai were compared to the ANZECC (2000) trigger levels for ‘slightly disturbed estuarine water’ (south-east Australia). Comparison was made to these as marine trigger levels for New Zealand have not been developed and the guidelines suggest comparison of New Zealand to those for south-east Australia. At all sites the ANZECC (2000) trigger values for nitrate-nitrite nitrogen, ammoniacal nitrogen, total nitrogen, dissolved reactive phosphorus and total phosphorus were exceeded. It should be noted however that as a consequence of using the guidelines set out for south-east Australia that the trigger levels are conservative and that in general nutrient concentrations in New Zealand estuarine waters tend to be naturally higher than those on which the guidelines are based. This could, in part, account for the high number of samples from the estuary for which the guideline values were exceeded (Bolton-Ritchie and Main, 2005).

Table 11 - Average Nutrient Levels within the Avon-Heathcote Estuary

Sites:
A – South Spit
B – Penguin Street
C – Pleasant Point Jetty
D – Pleasant Point Yacht Club
E – Sandy Point
F – Humphries Drive
G – Mt. Pleasant Yacht Club
H – McCormacks Bay Outlet
I – Beachville Road Jetty
J – Moncks Bay
K – Shag Rock

		A	B	C	D	E	F	G	H	I	J	K
Dissolved Reactive Phosphorus	1989-1999	-	-	0.26	0.16	0.92	-	0.22	0.04	0.06	-	0.09
Total Phosphorus	1989-1999	-	-	0.35	0.35	1.40	-	0.30	0.07	0.11	-	0.14
Nitrite-Nitrate Nitrogen	1989-1999	-	-	0.60	0.67	0.32	0.384	0.46	0.08	0.10	-	0.12
	2002-2005	0.018	0.042	-	0.315	-	-	0.115	-	0.023	0.024	
Ammoniacal Nitrogen	1989-1999	-	-	1.14	1.07	5.45	0.807	0.94	0.12	0.23	-	0.40
	2002-2005	0.079	0.216	-	0.841	-	-	0.594	-	0.118	0.078	
Total Nitrogen	1989-1999	-	-	2.39	2.36	7.63	-	2.13	0.55	0.65	-	0.93

Source: Bolton-Ritchie and Main (2005)

Large differences were noted in the mean values for the different sites within the estuary. These can be attributed to the proximity of these sites to a particular nutrient source. It should be noted that the 1989-1999 sampling was year round and 2-4 hours after high tide, whereas the 2002-2005 sampling was done 1 hour after high tide and only during summer months which is unlikely to cover the range of rainfall and other meteorological events that the 1989-1999 data did. Therefore a direct comparison between the two data sets is not appropriate.

3.5.6 Nutrient Effects

When nutrients, particularly nitrogen and phosphorus accumulate in waterbodies, an increase in biological productivity will generally occur (called Eutrophication). Eutrophication occurs naturally and slowly in water over time, but this process can be greatly accelerated by human activity and cause a sudden deterioration in water quality (Rowe, 2004). This will promote the growth of one species of aquatic plant, to the exclusion of others and may reduce light penetration and oxygen exchange between the water and atmosphere (Chiew *et al*., 1997). In contrast, a decrease in nutrients would result in a low biological production, known as Oligotrophic (Rowe, 2004).

The concentrations of nutrients in the waters of the Avon-Heathcote Estuary/Ihutai are important because in excessive concentrations they can lead to excessive algae growths, and reduction in water clarity (Environmental Services, 1993). The majority of the nitrogen and phosphorous present in the Estuary comes from the daily discharge of treated effluent from the oxidation ponds. Before 1973, dense growths of sea lettuce (*Ulva* spp.), grass and other algal growths were present in the estuary, however since the introduction of effluent discharge with the outgoing tide, levels of algal masses no longer appear to be a problem. The release of pond effluent on the outgoing tide means that the majority of nutrients are taken out of the Estuary, and the remaining nutrients are absorbed by the plant and animal community and sediments (Environmental Services, 1993).

In contrast to this, Bolton-Ritchie and Main (2005) found that levels of green algae (*Ulva* spp. and *Enteromorpha* spp.) and red algae (*Gracilaria chilensis*) often proliferate on the estuary mudflats in summer. *Ulva* spp. is the main macroalgae found in the estuary and the density have varied greatly since 1972. In the summer of 1997-98 (a summer of serious drought in Canterbury) there was, after many years of low sea lettuce growth, a large bloom of *Ulva*. Bressington (2003 *in* Bolton-Ritchie and Main) reported differences in the distribution and abundance of *Ulva* spp. between the summer of 2001/2002 and the summer of 2002/2003. The factors that favour the prolific growth of *Ulva* spp. in summer are the subject of some debate, but nutrient concentrations, among other factors, do have a part to play in the abundance of algae over the summer.

When macroalgal blooms occur in the Avon-Heathcote Estuary/Ihutai, large quantities become dislodged from the bottom which result in a living/growing mobile drift population, as well as the accumulation of decaying, rotting algal masses along the shoreline in some areas. In this estuary these shoreline mats have caused the sediments to become anoxic and devoid of fauna (Bressington, 2003 *in* Bolton-Ritchie and Main, 2005). Such mats can also smother shellfish beds, undermine food chains and cause deterioration of the substrate (Hawes, 1994 *in* Bolton-Ritchie and Main, 2005).

High levels of nutrients can cause an increase in plant and phytoplankton growth, which strip the water of oxygen. Water clarity can decrease due to increasing phytoplankton abundance and suspended inorganic particles (Clayton & Edwards, 2007). There is no available information on the species of phytoplankton present in the estuary, and there are no records of phytoplankton blooms (Bolton-Ritchie and Main, 2005).

The toxicity of ammonia-nitrogen is primarily attributed to its concentration, and the effect that pH, temperature and salinity have on this. Ammonia is a non-persistent and non-cumulative toxicant to aquatic life (ANZECC, 2000). To assess the potential of ammonia-nitrogen concentrations in the estuary to cause adverse biological effects, the concentrations recorded have been compared to ANZECC (2000) trigger values and USEPA guidelines (which incorporate pH, temperature and salinity). Concentrations from the periods 1989-1999 and 2002-2005 were looked at. Results from sites on the eastern and southern parts of the estuary show that in nearly all samples most were either below trigger values or small amounts exceeded those likely to be toxic to 1-5% of species. In sites in and around the main sources of ammonia-nitrogen (Avon/Ōtakaro River, Heathcote/Opawaho Rivers and the oxidation plant) a high number of samples exceeded those likely to be toxic to 1-10% of species. Results suggest that ammonia-nitrogen concentrations in some areas of the estuary are likely to be toxic to some marine species at times (Bolton-Ritchie and Main, 2005).

3.5.7 Outline Analysis of Key Literature

Table 12 below summarises the literature cited in this section of this report and comments on validity and relevance of the information provided.

Table 12 - Summary of Literature in Section 3.5

Reference	Year	Comments
Local		
Brown *et al.*	1996	Scientific paper on runoff in Wigram Retention Basin. Small study area. Old report, some data may have changed.
Environmental Services	1993	Overview paper relevant to the Avon-Heathcote area. Descriptive text rather than technical detail and scientific data. Relatively old, may no longer be accurate.
Meredith and Hayward	2002	Scientific paper on water quality on the Canterbury region. Report broad, not specific to Avon/Ōtakaro and Heathcote/Opawaho Rivers.
Christchurch City Environmental Trends Report	2003	Overview of the environmental issues within Christchurch City. Lots of facts and figures but minimal references. General information still relevant, some statistics out of date.
Bolton-Ritchie and Main	2005	Scientific report on nutrient water quality in the Avon-Heathcote Estuary/Ihutai. Information is relevant but not specific to Avon/Ōtakaro and Heathcote/Opawaho Rivers. Most current data sourced. Data range from 1989-1999 and 2002-2005.
Main	1994	Scientific paper on nutrient concentrations for the Avon/Ōtakaro and Heathcote/Opawaho Rivers. Age of the report may be of concern for some results but it was the most up to date specific literature sourced.
Gilson	1996	Analysis of water quality results based on Christchurch City Council monitoring. Based on a small data set (1991-1995). Data is old. Appendix A of this report cites more recent data source (1996-2006).
National		
Galbraith and Burns	2007	Scientific report on land-use, water body type and water quality. Information is able to be related to Christchurch and is the latest data available.
Rowe	2004	Scientific paper on Lake restoration. Relevant as used for general context and comment only.
Clayton and Edwards	2007	Scientific paper on Lake modelling software. Relevant as used for general comment only.
ARC	2000	Water quality summary report. Details results of sampling from 1999. Description of analytes tested for. Data may be superseded.
ARC	2003b	Annual water quality report. Details results of sampling from 2003. Data is most recent available.
International		
Chiew *et al.*	1997	Basic industry report on urban stormwater. Used for comment only.
CRC	2004	Literature review on contaminant levels in Australia. Extensive amounts of data. Relevant examples used. Age of data relevant.

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3.6 Pathogens

3.6.1 General

Coliform bacteria are a collection of relatively harmless micro-organisms that live in large numbers in the intestines of humans and other animals to aid in the digestion of food. A subgroup of these is the *Faecal coliform* bacteria, the most common member being Escherichia coli (E-coli). These can grow at elevated temperatures and are associated only with the faecal matter of warm-blooded animals (UIS Analytical Services website).

The presence of *Faecal coliform* bacteria including *E.Coli* in aquatic environments indicates that the water has been contaminated with the faecal matter of man or animal. This indicates that the source water may have been contaminated by pathogens or disease producing bacteria or viruses and therefore pose a potential health risk to any individual exposed to this water (Ministry for the Environment website).

However, *E.Coli* are only indicators of the pathogenicity of water and are not a direct measure of disease causing organisms. The human response to pathogen concentrations and exposure varies from person to person (Ministry for the Environment website).

Two main modes of micro-organism transport were identified during the study; those that attach to soil particles and those that are freely suspended in water flow (Yeghiazarian *et al*., 2004). As for other contaminants, micro-organisms that are attached to soil will get transported in surface runoff during rain events (Ferguson *et al*., 2003). Major sources of micro-organisms in surface runoff include agricultural practices such as dairy farming, septic tank seepages and domestic animal excrement (Ferguson *et al*., 2003; Buchan *et al*., 2005). Ground water can also become contaminated. Wastes can percolate through the soils into underground water or aquifers. Given that many smaller communities and farms obtain their water from bores or wells into these aquifers, this contamination can be a serious issue (Ministry for the Environment website).

3.6.2 Local Information

Faecal coliforms numbers are generally much higher throughout the Heathcote/Opawaho catchment than they are in the Avon/Ötakaro. Those entering the estuary at the Ferrymead Bridge (300/100ml median) were substantially higher than those determined for the Avon/Ötakaro River at Bridge Street (180/100ml) (Environmental Services, 1993).

Faecal coliform levels at several sites below Colombo Street on the Heathcote/Opawaho River were measured during and immediately after four periods of prolonged rainfall when the river was strongly discoloured and running high. *Faecal coliform* numbers recorded varied between 11 times and 55 times the standard for contact recreation (Environmental Services, 1993). Similar data could not be found for the Avon/Ötakaro.

Apart from the input of *Faecal coliforms* from the two rivers into the Avon-Heathcote Estuary/Ihutai, sources also include the Christchurch sewage works and birdlife on the oxidation ponds and estuary. The contribution of the effluent discharge from the Christchurch oxidation ponds is estimated to be almost 94% of the total dry weather loading to the Estuary, however this proportion would be considerably less during and after periods of rainfall. Oxidation pond effluent is only discarded on the ebbing tide and therefore cannot flow directly up estuary (Environmental Services, 1993).

Wind conditions play an important role in determining water quality within the section of the Avon-Heathcote Estuary/Ihutai directly in front of the Christchurch oxidation pond discharges. Data collected suggests that when there is no wind or during periods of strong, persistent southerlies then the levels of bacteria are such that it is rendered unsuitable for contact water sports.

Since Christchurch sewage works discharge such a major amount of the total loading of bacteria into the estuary it should be noted that concentrations within the pond effluent are normally higher during winter months (Environmental Services, 1993).

3.6.3 National Information

The use of *Faecal coliforms* to predict microbacterial contamination is not foolproof. An example of the advantage of using E. coli as an indicator of human health risk is illustrated by the following case. A mismatch between *Faecal coliform* (high) and *E.Coli* (low) results occurred in March 2004 when a catchment on the North Shore (Auckland), upstream of a sampling point, was loaded with rotting vegetation. It is likely that in this case, certain strains of coliforms (Klebsiella, Enterobacter and Citrobacter) which are derived from vegetative sources were able to grow under the conditions defined for thermotolerant coliforms (*Faecal coliforms*). Hence, total *Faecal coliform* count was very high, but the actual pathogenic disease risk, as indicated more specifically by the *E.Coli* count, was below guideline levels (MfE website).

During baseline studies of 16 streams around Auckland in 2000 (ARC, 2000) and 2003 (ARC, 2003b) levels of faecal concentrations were found to be uniformly high with a median value of 800MPN/100ml. Comparison to Christchurch concentrations is not directly possible due to different testing techniques used during analysis.

3.6.4 International Information

Data from the 2001 Annual Report for Hornsby Shire Council in Australia give levels of *Faecal coliforms* in different landuse areas. Concentrations of *Faecal coliforms* in the urban zones had a mean range of 34-4301 cfu/100ml while concentrations in the rural zones had a mean range of 77-14458 cfu/100ml (CRC, 2004). Concentrations in Christchurch from both the urban and rural zones show relatively low mean ranges (Appendix A) compared to these results.

3.6.5 Background Levels

In the report prepared by Gilson (1996) for Christchurch City Council the levels for *E.Coli* and *Faecal coliforms* are relatively low in some parts of the rivers (Appendix A). The Avon/Ötakaro (@ Bridge Street) and the Heathcote/Opawaho (@Tunnel Road and Ferrymead Bridge) range between 152 to 175 cfu/100ml for *E.Coli* and range between 161 to 274 cfu/100ml for *Faecal coliforms*. This is based on limited data (1991 to 1995) and when compared to a much larger data set (Christchurch City Council 1996 to 2006) seems to be quite conservative. Average concentrations for the same sites in the larger data set ranged from 285 to 708 cfu/100ml for *E.Coli* and 346 to 1017 cfu/100ml.

PDP (2007b) compared *E.Coli* results against a single ‘action mode’ contact recreation guideline of 550 cfu/100ml. The Avon/Ötakaro and Heathcote/Opawaho Rivers are rarely used for contact recreational purposes, however comparison of *E.Coli* concentrations with this guideline provides an indication of the level of microbiological contamination at the sites. In the Avon/Ötakaro River the majority of data from most sites was below the 550 cfu/100ml guideline value. Sites that are nearest to areas likely to be used for recreational activities, such as rowing and kayaking, are the tidal sites and these had the lowest overall distributions of *E. coli* concentrations. For the Heathcote/Opawaho River a majority of sites had over 50% of data in exceedence of the 550 cfu/100ml guideline, with the exception of the upper Cashmere Stream site. *Faecal coliforms* showed similar trends for both the Avon/Ötakaro and Heathcote/Opawaho Rivers.

Levels of *E.Coli* and *Faecal coliforms* were looked at in a study carried out by the Otago Regional Council (2005) which investigated the water quality of 18 selected stormwater outfalls after two storm events. An interesting comparison was done between long-term State of Environment (SOE) monitoring results with some of the upstream storm water outlet results from the second storm event (seen in Table 13).

Table 13 - Comparison of Indicator Organisms - ORC + SOE Studies

	E.Coli (cfu/100ml)	F.Coli (cfu/100ml)
Leith SOE	390	680
Leith Storm	**9200**	**8300**
Kaikorai SOE	445	665
Kaikorai Storm	**2900**	**2000**
Owhiro SOE	240	240
Owhiro Storm	**48400**	**47000**
Silverstream SOE	175	160
Silverstream Storm	**1800**	**1900**

Source: ORC, 2005

Table 13 shows much higher levels of both *E.Coli* and *Faecal coliforms* under storm conditions which indicates signs of the 'first flush' phenomenon.

The SOE levels from Table 13 show a similar range to those found in the data for the Avon/Ötakaro and Heathcote/Opawaho Rivers, and would indicate that during storm events similar increases could be expected. However, with the potential presence of climatic and/or site specific factors, testing should be carried out on the Avon/Ötakaro and Heathcote/Opawaho Rivers during storm events to determine whether any actual differences are noted.

A study carried out in 2003 (Eyles *et al*.) on the levels of the human pathogen Campylobacter in the Lower Taieri River, South Island, showed seasonal variations in the levels of the pathogen. Higher median levels were detected in summer, when human exposure through recreational water use was maximal. A decrease of notified cases of campylobacter in the human population was shown to coincide with low levels of campylobacter at the main recreational bathing site on the river.

3.6.6 Effects

Microbacterial contaminants absorb to the surface of sediment particles and can contaminate filter feeding organisms such as shellfish which feed of this contaminated sediment (Doyle, 2005).
In the past the Avon-Heathcote Estuary/Ihutai was used for collection of shellfish for human consumption, however since contamination was found, the eating of shellfish from the estuary is discouraged and many signs have been erected to warn people of these dangers. Any micro-organisms reaching the estuary are easily accumulated by shellfish, especially filter-feeding shellfish such as cockles. Pathogenic bacteria or viruses derived from human or animal faecal material that may be present becomes a threat to public health if they are retained in shellfish that are subsequently taken as food for human consumption.
The currently accepted *Faecal coliform* guidelines for shellfish growing waters is 14/100ml and samples taken from the estuary generally exceed these guidelines by considerable margins, especially during wet weather. The main impact on shellfish comes from the Avon/Ötakaro and Heathcote/Opawaho Rivers and from the large volume of treated sewage from the Christchurch treatment plant. It is not surprising then that the highest levels of contamination are found near the low tide channels adjacent to, or within the influence of the two rivers and the oxidation pond outlets (Environmental Services, 1993).

In addition, microbacterial contaminant of surface water and groundwater has the potential to infect livestock and lead to human health issues (Olsen, 2000).

3.6.7 Outline Analysis of Key Literature

Table 14 below summarises the literature cited in this section of this report and comments on validity and relevance of the information provided.

Table 14 - Summary of Literature in Section 3.6

Reference	Year	Comments
Local		
Environmental Services	1993	Overview paper relevant to the Avon-Heathcote area. Descriptive text rather than technical detail and scientific data. Relatively old, may no longer be accurate.
Gilson	1996	Analysis of water quality results based on Christchurch City Council monitoring. Based on a small data set (1991-1995). Data is old. Appendix A of this report cites more recent data source (1996-2006).
National		
Otago Regional Council	2005	Small study looking at effects of first flush. Relevant based on age and number of samples.
ARC	2000	Water quality summary report. Details results of sampling from 1999. Description of analytes tested for. Data may be superseded.
ARC	2003b	Annual water quality report. Details results of sampling from 2003. Data is most recent available.
International		
Olsen	2000	Scientific paper on pathogens in manure. Relevant as used for general comment only.
CRC	2004	Literature review on contaminant levels in Australia. Extensive amounts of data. Relevant examples used. Age of data relevant.

An extremely limited amount of data was found regarding coliform levels throughout the Avon/Ötakaro and Heathcote/Opawaho Rivers and Estuary.

3.7 Litter

A large quantity of urban litter consisting of manufactured materials such as bottles, cans, plastic and paper wrappings, newspapers, and other modern day wastes are finding there way into drainage systems. These wastes have the potential to travel via stormwater conduits, streams, rivers and estuaries. The existence of such litter in the waterways can cause a great increase in contaminants such as heavy metals and pathogens. Waterways can become blocked, stopping the flow of water, which can cause build up of contaminants further up-stream (Armitage & Rooseboom, 2000).

A study carried out in Auckland (Cornelius *et al*., 1994 *in* Armitage & Rooseboom, 2000) indicated the following litter loading rates:

- commercial : 1.35kg/ha.yr (0.014m^3/ha.yr)
- industrial : 0.88kg/ha.yr (0.009m^3/ha.yr)
- residential : 0.53kg/ha.yr (0.006m^3/ha.yr)

Of interest was the fact that although commercial and industrial areas produced higher litter loading rates than the residential areas, the residential areas actually contributed more litter than all the other areas combined because of the much larger percentage of the city that it covers.

No studies of gross contaminant with respect to litter were found for Christchurch in the course of this literature study.

3.8 General Effects of Urbanisation

Urbanisation can affect stream morphology, physical conditions and biological and chemical characteristics. Increased concentrations and loads of several chemical pollutants in stream water appear universal in urban streams, often occurring even at low levels of catchment urbanisation (Hatt *et al*. 2004 *in* Walsh *et al*. 2005). This can have detrimental effects on stormwater runoff which in turn has a great impact on receiving waters. It has been shown that during urbanisation certain contaminants will have a much greater impact on the receiving water than pre and post urbanisation.

According to Baird (1992), the natural vegetation of the margins and banks of the freshwater reaches of the Avon/Ötakaro and Heathcote/Opawaho catchments have been devastated. At best small groups of several individual natural plants are still evident. On public land along the watercourses there are occasional planted woodland areas utilising native species which represent what may have occurred naturally in these parts of Canterbury. Removal of vegetation reduces the amount of shading available to the stream which can lead to algal blooms and increased temperature (Quinn *et al*.1997, Rutherford *et al*.1997, 1999 *in* Parkyn & Wilcock, 2004) along with a reduction in organic matter inputs (leaves) which are habitat and food resources (Scarsbrook *et al*.2001 *in* Parkyn & Wilcock, 2004) for crayfish, other invertebrates and fish. It can also reduce the stability of the stream banks to flood erosion (Parkyn & Wilcok, 2004) which can increase sediment load and cause further damage. Many urban surfaces (roads, roofs and carparks) hold and store heat from solar radiation efficiently, and this heat can be quickly transferred to urban streams during brief summer thunderstorms (Suren & Elliott, 2004). An increase in temperature can have an effect on the distribution of fish and invertebrates. Preferred temperatures for native fish species, determined from laboratory species, ranged from 16ºC to 27ºC (Richardson *et al*., 1994 *in* Parkyn & Wilcok, 2004).

Whereas the removal of natural vegetation can have negative effects on stream community, an increase in vegetation such as macrophytes can also be detrimental. The decrease in shade caused by the removal of natural vegetation can cause an increase in levels of macrophyte growth (Suren & Elliott, 2004) and excessive levels of macrophytes can impede stream drainage (Newell, 1997 *in* Suren & Elliott, 2004) and interfere with recreational values (Schwarz & Snelder, 1999 *in* Suren & Elliott, 2004). This is of particular concern to Christchurch where each year, macrophytes are removed from sections of the Avon/Ötakaro, Heathcote/Opawaho, and Styx Rivers (Suren & Elliott, 2004). Studies carried out over the last 50 years on the Styx River have shown large changes in levels of submerged aquatic macrophyte vegetation. Levels of two native species have decreased dramatically, while levels of varies introduced species are now dominant (Suren & Elliott, 2004).

Another group of plants found in urban streams is the byrophytes (mosses and liverworts) but unlike macrophytes these plants often provide the only instream cover for invertebrates in concrete-lined urban streams (Suren & Elliott, 2004). They can support high densities of invertebrates (Suren, 1991 *in* Suren & Elliott, 2004) and thus, they represent an important habitat within urban streams, especially in concrete-lined streams (Wilding, 1996; Linhart *et al*., 2002 *in* Suren & Elliott, 2004).

Species abundance of invertebrates can also indicate levels of pollution. A study carried out by Suren *et al*. (1998 *in* Suren 2000) showed levels of oligochaeta, molluscs and crustacean were most abundant in streams around Christchurch of the 10 taxa looked at. The abundance of these species, which are more tolerant to pollution, and the lack of sensitive species, suggest that there are signs of pollution.

As stated above, removal of vegetation can have significant consequences on the habitat of species present in waterways. A survey carried out on 30 randomly selected stream sites within the Auckland city area showed that nearly half of them had no canopy cover, and only five sites had >75% canopy cover (A.Suren, *pers. obs*. *in* Suren & Elliot, 2004). With no shade coverage comes increased temperatures, an example of this was recorded by Webster *et al*. (2000), who recorded a stream temperature of 29.2ºC at a site without any shading in Oakley Creek, Auckland, and noted that the stream temperature was regulated more by direct solar radiation and cloud cover than by air temperature (Suren & Elliot, 2004). A study by Allibone *et al*. (2001), looking at 64 urban Auckland streams, found eight species of fish present in streams that ranged in temperatures from 15.1ºC to 27.2 ºC. Although water temperatures at no sites exceeded the lethal levels (Richardson *et al*. 1994 *in* Allibone *et al*., 2001) for any of the fish species found, there was evidence for at least 7 of the 8 fish found that a correlation between some form of cover and fish species abundance was found.

Macroinvertebrates have been widely used to assess environmental conditions in water systems in New Zealand (Hogg & Norris, 1991;Stark, 1993;Quinn & Cooper, 1997 *in* Hall *et al*., 2001). In New Zealand, studies have indicated that changes in land use at the catchment scale can have significant impacts on macroinvertebrate communities (Suren, 2000). Conversion of land-use practices are frequently associated with reductions in macroinvertebrate diversity, and loss of sensitive taxa are often seen (Quinn & Hickey 1990; Scott *et al*. 1994; Harding & Winterbourn 1995; Boulton *et al*. 1997; Harding *et al*. 2000; Quinn 2000 *in* Hall *et al*., 2001). In particular, urbanisation has generally been associated with marked changes in the physical structure, chemical conditions, and invertebrate community composition both in New Zealand and elsewhere (Suren 2000). Changes in the invertebrate communities of urban streams typically include reductions in diversity and increasing dominance of pollution tolerant taxa such as oligochaetes and chironomids (Campbell 1978; Hogg & Norris 1991; Moore 1999; Suren 2000 in Hall *et al*, 2001).

There have been several national studies that have looked at invertebrate communities in urban environments. Allibone (2001) studied 64 urban Auckland streams and found 78 invertebrate taxa of which the predominant taxa collected were Oligochaetes (freshwater worm), molluscs, and dipteran larvae. Other more pollution sensitive taxa were considerably rarer. The Macroinvertebrate Community Index (MCI), which measures the general water quality based on scores given to each taxa, for the 64 sites ranged from 119 to 40 with a mean of 64. The majority of the sites were ranked as ‘probably severely polluted’ (scores between 40-80). The top ten sites had scores of between 119 and 89 and contained the presence of native forest riparian zones.

A study carried out by Hall *et al*. (2001) on the Water of Leith catchment in Dunedin, found that relative to native bush and agricultural streams, urban streams had low abundances of most taxa, except for oligochaetes.

Suren (1998 *in* Suren 2000) found that the invertebrate faunas of 59 urban streams in nine New Zealand cities were dominated by taxa such as oligochaetes, the snail potamopyrgus antipodarum and orthoclad chironomids.

The amount of imperviousness has also been shown to be correlated to inverterbrate levels (Paul & Meyer, 2001; Beach, 2002 *in* Suren & Elliott, 2004). A study carried out by Herald (2003 *in* Suren & Elliott, 2004) reported a decrease in the MCI with increasing % impervious area among streams draining the Waitakere Ranges. Allibone *et al*. (2001), reported a reduction in numbers of EPT (Ephemeroptera, Plecoptera and Trichoptera) taxa from 11, in catchments with 10% imperviousness, to only 1 and 2 in catchments with 30-40% imperviousness. No EPT was found at sites with >40% catchment imperviousness. Findings from a study in Australia (Walsh *et al*., 2004) state that only a very small part of a catchment needs to be developed and conventionally drained before the biological community is severely degraded. In contrast, Suren *et al*. (1998 *in* Suren & Elliott, 2004) found no relationship between percent imperviousness and invertebrate levels in a study of 59 New Zealand urban streams. It is hard to say, without doing similar studies, what effect, if any, high levels of imperviousness in Christchurch would have on invertebrate communities.

Comment on Literature

Most literature used in this section are discussion type documents and used only for general context and comments. Those that contain specific statistics and data are summarised below.

Suren and Elliott, 2004 – scientific paper on impacts of urbanisation. Relevant to local streams. Data and information most recent found.

Suren, 2000 – scientific paper on effects of urbanisation. Relevant to Christchurch. Most recent paper with respect to information used.

Allibone *et al.*, 2001 – scientific paper on 64 streams in Auckland. Gives a national overview, only data found on effects on fish. Relevant in national context. Highlights gaps for Christchurch.

Section 4 Gap Analysis

The literature review has established that a reasonable amount of stormwater quality data is available on a national level. However data sources are limited in the local Christchurch area. However where available, many observations made in Christchurch are generally supported by national and international literature.

Key observations are listed below.

- The relationship between landuse and contaminant loads and concentrations are poorly researched in the Christchurch area.
- Information on contaminant levels in sediments is available for the Avon-Heathcote Estuary/Ihutai but very little information was sourced for heavy metals in the watercolumn contributing to urban waterways or the estuary itself.
- The effect of roof types on metal loads and concentrations (and to a lesser extent other contaminants) in Christchurch were not available.
- There is extensive research on PAHs in Christchurch, less so for other organic compounds such as organochlorine compounds which may result from herbicides and pesticides usage.
- The review indicates a need for more study on effects of nutrient levels on aquatic ecosystems.
- Microbacterial contamination information was available in the estuary but little supporting information was found on surface waters and groundwaters.
- Minimal studies were found on the effects of contamination from stormwater on macroinvertebrates, invertebrates and vertebrate communities of Christchurch streams.

In general limitations with the data set as a whole were found to be as follows:

- Contaminant loads are often reported simply as g/m^3 and it is not always possible to decipher if the loads are total or soluble rates;
- It is not always clear when samples were taken in an event i.e. whether they represent first, flush of "average" contaminant conditions ; and
- For suspended solids there is very little information relating to different particle sizes (again reporting is usually as g/m^3) and this is an important factor in sediment transport.

The above points means it is not always clear if contaminant estimates are being compared "like with like". There is generally a range of methods for collecting and reporting stormwater quality data. This most likely reflects that the various sampling methods are being undertaken for different purposes.

Studies suggested for the future:

- Land use versus contaminants. Similar to that of ARC (2005).
- Contaminant levels entering the Avon/Ötakaro and Heathcote/Opawaho Rivers during normal conditions and storm events.
- Identify main point sources and determine levels of contamination entering into the Avon/Ötakaro and Heathcote/Opawaho Rivers.
- Contamination levels entering into the Avon/Ötakaro and Heathcote/Opawaho Rivers from construction sites.
- Continued research into levels of pesticides and herbicides in Christchurch waterways.

Section 5 Glossary

Adsorption
The accumulation of gases, liquids, or solutes on the surface of a solid or liquid.

Aromatic Hydrocarbon
A hydrocarbon that contains one or more benzene rings.

Flocculated
Form aggregated or compound masses of particles.

Impervious
A surface that is impenetrable, not permitting penetration or passage.

Loading
An expression of the amount of contaminant present. Usually expressed in kg/unit area and time.

Macroinvertebrates
Animals without backbones that are larger than ½ millimetre.

Macrophytes
Aquatic plants, growing in or near water that are either emergent, submergent, or floating.

Non point source pollution
Pollutants detected in a concentrated water source such as a stream, river or lake, that come from a wide range of sources.

Organochlorines - various hydrocarbon pesticides, such as DDT, that contain chlorine.

Overland Flow – water flowing over the ground surface toward a stream channel

Pathogen
Any disease-producing agent, esp. a virus, bacterium, or other microorganism.

Point source pollution
Pollution that can be traced back to a single origin or source such as a sewage treatment plant discharge.

Polycylic Aromatic Hydrocarbons
Type of organic compound that consists of fused aromatic rings and is primarily formed by incomplete combustion.

Precipitation
Any form of water, such as rain, snow, sleet, or hail, that falls to the earth's surface.

Riparian
A riparian zone is the interface between land and a flowing surface water body.

Riverine
Located on or inhabiting the banks or the area near a river or lake.

Taxa
Any taxonomic category (e.g., species, genus)

Section 6 References

Ahrens, M., C. Depree, and L. Golding. 2005. How Bioavailable are Sediment Bound Contaminants in New Zealand Harbours?. 2005 South Pacific Stormwater and Aquatic Resource Protection Conference.

Ahrens, M., D. Bremner, C. Depree, and M. Martin. 2007. Toxicity and Recolonisation Potential of PAH-Contaminated Urban Stream Sediments from Christchurch. 2007 South Pacific Stormwater Conference.

ANZECC. 2000. Australia and New Zealand Guidelines for Fresh and Marine Water Quality-Volume 1: The Guidelines. National Water Quality Management Strategy-Paper No. 4.

Allibone, R., J. Horrox, and S. Parkyn. 2001. Stream Classification and Instream Objectives for Auckland's Urban Streams. NIWA Client Report Prepared for Auckland Regional Council: ARC 00257:1-79.

ARC. 2000. Baseline Water Quality Stream, Lake, and Saline Waters. Annual Report January-December 2003. Auckland Regional Council Technical Publication-TP234:1-237.

ARC. 2003a. Design Guideline Manual: Stormwater Treatment Devices 2003. Auckland Regional Council Technical Publication-TP10 2003:2-1-11.

ARC. 2003b. Baseline Water Quality Stream, Lake, and Saline Waters. Year 2000 Summary Report Auckland Regional Council Technical Publication-TP132:1-219.

ARC. 2005. Sources and Loads of Metals in Urban Stormwater. Auckland Regional Council Technical Publication No-TP318 2005:1-77.

ARC. 2006. Contaminant Load Model May 2006. Auckland Regional Council. Available at http://www.arc.govt.nz/fms/stormwater/ContaminantLoadModelMAY06.xls

Babich, J. 2001. Waitakere City Contamination Loading Study. Report Prepared for EcoWater Solutions by URS New Zealand Version 1.0.

Bates, M. N., and N. Garrett. 1998. Vehicle Fires and the Introduction of Premium Unleaded Petrol into New Zealand. Journal of the Royal Society of New Zealand 28:321-328.

Blakley, T. J., and J. S. Harding. 2005. Longitudinal Patterns in Benthic Communities in an Urban Stream under Restoration. New Zealand Journal of Marine and Freshwater Research 39:17-28.

Bolton-Ritchie, L., and M. Main. 2005. Nutrient Water Quality Avon-Heathcote Estuary/Ihutai:Inputs, Concentrations and Potential Effects. Report prepared for Environment Canterbury.

Botherway, K. J., and J. P. A. Gardner. 2002. Effect of Storm Drain Discharge on the Soft Shore Ecology of Porirua Inlet, New Zealand. New Zealand Journal of Marine and Freshwater Research 36:241-255.

Brown, J. N., and B. M. Peake. 2005. Sources of Heavy Metals and Polycyclic Aromatic Hydrocarbons in Urban Stormwater Runoff. Science of the Total Environment 359:145-155.

Brown, S., P. Mason, and T.Snelder. 1996. Runoff Quality in the Catchment of the Wigram Retention Basin. Report prepared for Christchurch City Council.

Buchan, G., K.Cameron, M.Noonan, G.Jiang. 2005. Pathogen Transport via Soils from Land-Applied Animal Wastes. Geophysical Research Abstracts, Vol. 7.

Burge, P. I., 2007. Sedimentation in the Avon-Heathcote Estuary/Ihutai – an Analysis of Past and Present Studies. Report prepared for Avon-Heathcote Estuary/Ihutai trust and Environment Canterbury.

Chiew, F. H. S., L. B. Mudgway, H. P. Duncan, and T. A. McMahon. 1997. Urban Stormwater Pollution. Cooperative Research Centre for Catchment Hydrology Industry Report 97/5.

Section 6 References

Christchurch City Council. 2003. Christchurch City Environmental Trends Report 2003 (Draft). Environmental Trends Report Prepared for the Long Term Council Community Plan-Christchurch City Council:35-40.

Christchurch City Council data. Road vehicle data supplied in excel format by Bruce Kelly.

Christchurch City Council website. Accessed 27th June 2007. http://www.ccc.govt.nz/christchurch/factsstatsandfigures/population/historicgrowth-populationsummary.pdf. http://www.ccc.govt.nz/Christchurch/FactsStatsAndFigures/Land/LandUseZones.pdf.

Clayton, J., and T.Edwards. 2007. LakeSPI: A Method for Monitoring Ecological Condition in New Zealand Lakes. Technical Report Version 2.

CRC. 2004. Stormwater Flow and Quality, and the Effectiveness of Non-Proprietary Stormwater Treatment Measures – A Review and Gap Analysis. Cooperative Research Centre for Catchment Hydrology. Technical Report – 04/8.

Deely, J. M. 1988. Trace Metal Distribution in Sediments of the Avon-Heathcote and Saltwater Creek Estuaries, Christchurch. Trace Elements in New Zealand: Environmental, Human and Animal. Proc. New Zealand Trace Elements Group Conference.:47-56.

Deely, J. M., and J. E. Fergusson. 1993. Heavy Metal and Organic Matter Concentrations and Distributions in Dated Sediments of a Small Estuary Adjacent to a Small Urban Area. The Science of the Total Environment 153:97-111.

Department of Environment, Western Australia. 2004. Potentially Contaminating Activities, Industries and Landuses. Report for the Department of Western Australia, Government of Western Australia.

Depree, C., and M. Ahrens. 2005. "Propactive" Mitigation Strategies: Reducing the Amount of PAHs Derived from NZ Roadways. The Fourth South Pacific Conference on Stormwater and Aquatic Resource Protection, Auckland, May 2005.

Depree, C., and M. Ahrens. 2006. Legacy Contaminants in Christchurch: Are Roadside Soils an Ongoing Major Source of PAHs in Runoff Today? 2006 NIWA Stormwater Conference.

Doyle, P. N. 2005. The Effects of Human Activities on Stream Water Quality: Case Studies in New Zealand and Germany. Thesis submitted in Partial Fulfilment of the Degree of Master of Applied Science, Auckland University of Technology:2-56.

Driscoll, E. D., P. E. Shelley, and E. W. Strecker. 1990. Pollution Loadings and Impacts from Highway Stormwater Runoff, Volume 1: Design Procedure (FHWA-RD-88-006). Research, Development, and Technology Turner-Fairbank Highway Research Center, McLean, Virginia.

Ecan website. Accessed 21st June 2007. http://www.ecan.govt.nz/Our+Environment/Air/School+resources/smog-video.htm

Elliott, A. H. 1997. Analysis of Potential Stormwater Quality Controls in Christchurch. Report prepared for Canterbury regional Council.

Elliott, A. H. 1998. Model for Preliminary Catchment Scale Planning of Urban Stormwater Quality Controls. Journal of Environmental Management 52:273-288.

Encyclopedia of Earth website. Accessed 22nd June 2007. http://www.eoearth.org/article/Health_effects_of_Total_Petroleum_Hydrocarbons_(TPH)

Eyles, R., D. Niyogi, C. Townsend, G. Benwell, and P. Weinstein. 2003. Spatial and Temporal Patterns of *Campylobacter* Contamination Underlying Public Health Risk in the Taieri River, New Zealand. Journal of Environmental Quality 32:1820-1828.

Farrant, S. 2006. Contaminant Characterisation of Stormwater Discharge into Okeover Stream and Treatment Recommendations. Natural Resources Engineering Research Project 2006:7-63.

Section 6 References

Ferguson, C., A. de Roda Husman, N. Altavilla, D. Deere, and N. Ashbolt. 2003. Fate and Transport of Surface Water Pathogens in Watersheds. Critical Reviews in Environmental Science and Technology, Vol. 33:299-361.

Galbraith, L. M., and C. W. Burns. 2007. Linking Land-Use, Water Body Type and Water Quality in Southern New Zealand. Landscape Ecol 22:231-241.

Gilson, M. 1996. Christchurch City Surface Water Quality Data 1994-95. A Report Prepared for the Christchurch City Council:1-129.

Hall, M. J., G. P. Closs, and R. H. Riley. 2001. Relationships between Land Use and Stream Invertebrate Community Structure in a South Island, New Zealand, Coastal Stream Catchment. New Zealand Journal of Marine and Freshwater Research 35:591-603.

Herald, J. Pointing the Way to Reducing Stormwater Impacts on Urban Streams. The Third South Pacific Conference on Stormwater and Aquatic Resource Protection, Auckland, May 2003.

Holland, P.T., and T.M. Trower. 1992. Organochlorine and Hydrocarbon Contaminants in the Avon and Heathcote River and Estuary System. Report prepared for the Canterbury Regional Council.

Kelley, G., D. Stein, J. Bebb, B. Buckle, K. Cox, J. Dixon, and T. Doss. 2004. Willamette River Conditions Report, City of Portland.

Kennedy, P. 1999. The Effects of Road Transport on Freshwater and Marine Ecosystems. A Report Prepared for Ministry of Transport by Kingett Mitchell Limited.

Kidd, S., J. Miller, K. Reininga, and R. Kapur. 2005. Storm Water BMP Effectiveness Workgroup Report.1-5.

Kingett Mitchell Limited. 2003. Sediment Quality in Inshore Pegasus Bay. Report Prepared by Kingett Mitchell Ltd on behalf of URS New Zealand Limited:1-32.

Kingett Mitchell Limited. 2005. Water Quality Assessment: South-West Christchurch Integrated Catchment Management Plan Technical Series. Technical Report No.2 Prepared for Christchurch City Council by Kingett Mitchell Limited 2:1-86.

Kingett Mitchell Limited. 2007. Water Quality Assessment: South-West Christchurch Integrated Catchment Management Plan Technical Series. Technical Report No.4 Prepared for Christchurch City Council by Kingett Mitchell Limited.

Larned, S. T., M. R. Scarsbrook, T. H. Snelder, N. J. Norton, and B. J. F. Biggs. 2004. Water Quality in Low-Elevation Streams and Rivers of New Zealand: Recent State and Trends in Contrasting Land-Cover Classes. New Zealand Journal of Marine and Freshwater Research 38:347-366.

Lee, H., S.-L. Lau, M. Kayhanian, and M. K. Stenstrom. 2004. Seasonal First flush Phenomenon of Urban Stormwater Discharges. Water Research 38:4153-4163.

Macpherson, J. M. 1979. Response to Urbanization of the Avon-Heathcote Estuary, Christchurch, New Zealand. Environmental Geology 3:23-27.

Main, M. R. 1994. A Limited Investigation of Stormwater Quality in the Avon-Heathcote Catchment. Canterbury Regional Council Technical Report R94(24):1-20.

Main, M. R. 2004. Pesticides in Streams and Rivers in Canterbury: Results of sampling from January 1991 to June 2002. Canterbury Regional Council Report R04/04.

Makepeace, D. K., D. W. Smith, and S. J. Stanley. 1995. Urban Stormwater Quality: Summary of Contamination Data. Critical Reviews in Environmental Science and Technology 25:93-139.

Meredith, A.S. and S.A. Hayward. 2002. An Overview of the Water Quality of the Rivers and Streams of the Canterbury Region. Environment Canterbury Technical Report R02/25.

Section 6 References

MfE Website. Accessed 22nd June 2007.
http://www.mfe.govt.nz/publications/waste/wastewater-mgmt-jun03/html/part1-section2
http://www.mfe.govt.nz/issues/water/water-quality-faqs.html.

Morrisey, D. J., S. J. Turner, G. N. Mills, R. B. Williamson, and B. E. Wise. 2002. Factors Affecting the Distribution of Benthic Macrofauna in Estuaries Contaminated by Urban Runoff. Marine Environmental Research 55:113-136.

Olsen, M.E. 2000. Human and Pathogen in Manure. Microbiology and Infectious Diseases, University of Calgary.

Osterkamp, W.R., and Gray, J.R. 2003. Hazard Management Related to Water and Sediment Fluxes in the Yellow River Basin, China, Based on Comparable Basins of the United States. International Yellow River Forum on River Management, Vol. II, Oct. 21-24, 2003, Zhengzhou, Henan Province, China: The Yellow River Conservancy Publishing House, p. 465-473.

Otago Regional Council. 2005. Stormwater Quality-Dunedin Urban Streams. Report prepared for Environment and Science Committee.

Parkyn, S., and B. Wilcock. 2004. Impacts of Agricultural Land Use. Freshwaters of New Zealand 2004, edited by Jon Harding, Paul Mosley, Charles Pearson, Brian Sorrell.:34.31-16.

Pattle Delamore Partners Ltd (PDP). 2007a. Stormwater Monitoring at Kirkwood Subdivision. Report Prepared for Christchurch City Council.

Pattle Delamore Partners Ltd (PDP). 2007b. Avon and Heathcote Rivers: Analysis of Water Quality Data from 1992-2006 (Draft). Report Prepared for Environment Canterbury.

Pauling, C. 2007. Ngāi Tahu Association with the Ihutai Catchment (unpublished). Report prepared for Environment Canterbury.

Physical Geography Website. Accessed 27th June 2007.
http://www.physicalgeography.net/fundamentals/9s.html

Pitt, R. E. 1995. Biological Effects of Urban Runoff Discharges. Stormwater Runoff and Receiving Systems: Impact, Monitoring, and Assessment, Edited by Edwin E. Herricks and Jackie R. Jenkins:127-162.

Poulton, B.C., S.E. Finger, and S.A. Humphrey. 1997. Effects of a Crude Oil Spill on the Benthic Invertebrate Community in the Gasconade River, Missouri. Archives of Environmental Contamination and Toxicology. Volume 33: 268-276.

Purchase, N. G., and J. E. Fergusson. 1986. The Distribution and Geochemistry of Lead in River Sediments, Christchurch, New Zealand. Environmental Pollution (Series B) 12:203-216.

Ray, D., T. Snelder, B. Williamson, A. Suren, Y. Tian, and C. Chagué-Goff. 2000. Effects of Urban Stormwater on Lake Ellesmere (Te Waihora). NIWA Client Report Prepared for Environment Canterbury: CRC 00615:1-47

Rhoads, B. L. 1995. Stream Power: A Unifying Theme for Urban Fluvial Geomorphology. Stormwater Runoff and Receiving Systems: Impact, Monitoring, and Assessment, Edited by Edwin E. Herricks and Jackie R. Jenkins:65-75.

Rodrigo, A. G. 1989. Surficial Sediment-Heavy Metal Associations in the Avon-Heathcote Estuary, New Zealand. New Zealand Journal of Marine and Freshwater Research 23:255-262.

Rowe, D. 2004. Lake Restoration. Freshwaters of New Zealand 2004, edited by Jon Harding, Paul Mosley, Charles Pearson, Brian Sorrell.: 39.1-16.

Royds Garden Environmental Services. 1993. Avon-Heathcote Estuary and Rivers: Water Quality/Ecology Overview. A Report Prepared by Royds Garden Environmental Services:1-26.

Section 6 References

Shedden, B., J. Batcher, and J. Chizmar. 2007. Roof Runoff Study by New Zealand Metal Roofing Manufactures. 2007 South Pacific Stormwater Conference.

Smith, P. 2006. Regional Rivers Water Quality Monitoring Programme: Data Report 2005. Environment Waikato Technical Report 2006/29:1-41.

Soller, J., J. Stephensona, K. Olivieria, J. Downingb, and A. W. Olivieria. 2005. Evaluation of Seasonal Scale First Flush Pollutant Loading and Implications for Urban Runoff Management. Journal of Environmental Management 76:309-318.

Sowles , M. 2005. Assessing Phosphorus Transportation and the High Risk Runoff Areas: the Cannon River Watershed, Southeastern MN. Submitted for the Requirements for a Bachelor of Arts from Carleton College, Northfield, Minnesota.

State of the Takiwa Project

Stein, E. D., L. L. Tiefenthaler, and K. Schiff. 2006. Watershed-Based Sources of Polycyclic Aromatic Hydrocarbons in Urban Storm Water. Environmental Toxicology and Chemistry 25:373-385.

Styx Website. Accessed 27th June 2007. http://www.thestyx.co.nz/assets/Monitoring/Documents/ComparisonChristchurchStreams.pdf

Suren, A., and S. Elliott. 2004. Impacts of Urbanisation on Streams. Freshwaters of New Zealand 2004, edited by Jon Harding, Paul Mosley, Charles Pearson, Brian Sorrell.:35.1-18.

Suren, A. M. 2000. Effects of Urbanisation. New Zealand Stream Invertebrates: Ecology and Implications for Management. New Zealand Limnological Society, Christchurch:260-288.

Taffs, E., and A. O'Sullivan. 2007. Quantifying Stormwater Contaminants in Water and Sediment in the Okeover Stream, Christchurch. Natural Resources Engineering Summer Research Project:2-42.

USGS website. Accessed 18th June 2007. http://co.water.usgs.gov/sediment/conc.frame.html

Walsh, C. J., and A. W. Leonard. 2004. Urban Stormwater and the Ecology of Streams. CRC for Freshwater Ecology and for Catchment Hydrology Report, Canberra:1-44.

Walsh, C. J., A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. M. II. 2005. The Urban Stream Syndrome: Current Knowledge and the Search for a Cure. Journal of North American Benthological Society 24:706-723.

Webster-Brown, J. 2005. A Review of Trace Metal Transport and Attenuation in Surface Waters. Metal Contaminants in New Zealand-Sources, Treatments, and Effects on Ecology and Human Health. Edited by Tim A. Moore, Amanda Black, José A. Centeno, Jon S. Harding, Dave A. Trumm:193-212.

Webster, J. G., K. L. Brown, and K. S. Webster. 2000. Source and Transport of Trace Metals in the Hatea River Catchment and Estuary, Whangarei, New Zealand. New Zealand Journal of Marine and Freshwater Research 34:187-201.

Williamson, R. B. 1985. Urban Stormwater Quality I, Hillcrest, Hamilton, New Zealand. New Zealand Journal of Marine and Freshwater Research 19:413-427.

Williamson, R. B. 1993. Urban Runoff Data Book: A Manual for the Preliminary Evaluation of Urban Stormwater Impacts on Water Quality. Water Quality Centre Publication No. 20:1-51.

Williamson, R. B., and D. J. Morrisey. 2000. Stormwater Contamination of Urban Estuaries. 1. Predicting the Build-up of Heavy Metals in Sediments. Estuaries 23:56-66.

Wong, T. 2002. Urban Stormwater Quality- Project 4.1 Stormwater Quality Pollutant Sources, Pathways and Impacts. CRC for Catchment Hydrology 1999-2006.

Section 6 References

Yeghiazarian, L.L., P. Kalita, M.S. Kuhlenschmidt, S.J McLaughlin, and C.D. Montemagno. 2004. Field Calibration and Verification of a Pathogen Transport Model.

http://www.civil.canterbury.ac.nz/staff/osullivan/stormwater.shtml. 2007. CBD Stormwater Runoff from Carpark of the University of Canterbury Analysis Results Sheet of "3rd Pro Stormwater Project".

Section 7 Bibliography

Local

Ahrens, M., *et al*. (2005). "How Bioavailable are Sediment Bound Contaminations in New Zealand." 2005 South Pacific Stormwater and Aquatic Resource Protection Conference.

> Investigation into whether accumulation of PAHs from sediments by bivalve tissues can be predicted by laboratory based "biomimetic" extractions. 17 urbanised estuaries and streams in New Zealand were analysed for PAH concentrations in sediment and bivalve samples (*Macomona liliana* and *Austrovenus stutchburyi*).

Ahrens, M., D. Bremner, *et al*. (2007). "Toxicity and Recolonisation Potential of PAH-Contaminated Urban Stream Sediments from Christchurch." 2007 South Pacific Stormwater Conference.

> To investigate to what extent these elevated PAH levels in urban stream sediments might limit the recolonisation of aquatic macroinvertebrates, a short-term sediment toxicity test with crustaceans and insect larvae was conducted. Amphipods and larval mayflies were exposed in laboratory microcosms to stream sediments collected from Addington Drain, Dudley Creek, Avon/Ötakaro River and St Albans Stream (total PAH levels 3-87 ppm), and their survival was quantified after 4 and 10 days. Exposure of amphipods and mayfly larvae to stream sediments for 10 days resulted in 15-95% mortality in amphipods, yet little mortality of mayflies (5-35%). Approximately 70% of the toxicity response in amphipods correlated with extractable PAH levels.

Blakley, T. J. and J. S. Harding (2005). "Longitudinal Patterns in Benthic Communities in an Urban Stream under Restoration." New Zealand Journal of Marine and Freshwater Research 39: 17-28.

> This study focused on quantifying the response of an urban stream-Okeover Stream (on the University of Canterbury campus in Christchurch, New Zealand) to current restoration efforts. Physico-chemical conditions and biological communities at three sites along the Okeover Stream were compared with three physically similar sites on each of nearby Waimairi Stream and Avon/Ötakaro River. Benthic taxonomic richness and benthic communities were compared. The results indicated that the presence of high heavy metal concentrations, intermittent flows in headwaters, and possible barriers to adult recolonisation seem to be having a continuing negative impact on benthic communities, especially in the headwaters.

Bolton-Ritchie, L. and M. Main (2005). " Nutrient Water Quality Avon-Heathcote Estuary/Ihutai:Inputs, Concentrations and Potential Effects." Report prepared for Environment Canterbury.

> This study focuses on the concentrations of nutrients in the estuary. It looks at the assessment of nutrient inputs into the estuary, a summary and analysis of nutrient data, an assessment of the effects of the nutrient concentrations and proposed future sampling.

Brown, S., P.Mason and T.Snelder (1996). "Runoff Quality in the Catchment of the Wigram Retention Basin." Report prepared for the Christchurch City Council.

> This report investigated the contaminant removal efficiency of the Wigram Retention basin and assessed the contribution of the runoff from the Ravensdown Fertiliser Company to the nutrient inflow to the basin.

Burge, P.I. (2007). "Sedimentation in the Avon-Heathcote Estuary/Ihutai – an Analysis of Past and Present Studies." Report prepared for Avon-Heathcote Estuary/Ihutai trust and Environment Canterbury.

> A review of literature that focuses on summarising and critiquing studies of sedimentation in the Estuary since the last major review on the topic in the early 1990s.

Christchurch City Council (2003). "Christchurch City Environmental Trends Report 2003 (Draft)." Environmental Trends Report Prepared for the Long Term Council Community Plan-Christchurch City Council: 35-40.

Section 7 Bibliography

Information for the Christchurch coastline, the Avon-Heathcote Estuary/Ihutai hydrological and geological environment, as well as its important ecological position.

Christchurch City Council (2007).

Road vehicle data supplied in excel format by Bruce Kelly.

Deely, J. M. (1988). "Trace Metal Distribution in Sediments of the Avon-Heathcote and Saltwater Creek Estuaries, Christchurch." Trace Elements in New Zealand: Environmental, Human and Animal. Proc. New Zealand Trace Elements Group Conference.: 47-56.

By examining sand, silt, and clay fractions, the levels of selected trace metals (lead, copper, nickel, chromium, zinc) and organic matter in the historical sedimentary profile of the Avon-Heathcote Estuary/Ihutai were investigated. Analyses of a core from the rural Saltwater Creek Estuary are used as a background reference to calculate the enrichment factors for the Avon-Heathcote Estuary/Ihutai.

Deely, J. M. and J. E. Fergusson (1993). "Heavy Metal and Organic Matter Concentrations and Distributions in Dated Sediments of a Small Estuary Adjacent to a Small Urban Area." The Science of the Total Environment 153: 97-111.

The concentrations and distributions of the heavy metals chromium, manganese, iron, nickel, copper, zinc and lead and organic matter were investigated in dated sediment cores of a small micro-tidal estuary adjacent to a small urban area. Despite maximum anthropogenic metal fluxes to the estuary the extra 'dean' sediment diluted the heavy metal concentrations in the sediments. The concentration profiles of the metals can be explained by the historical events occurring around the estuary and rivers, and the introduction of storm water drains and a sewage plant.

Depree, C. and M. Ahrens (2005). ""Propactive" Mitigation Strategies: Reducing the Amount of PAHs Derived from NZ Roadways." The Fourth South Pacific Conference on Stormwater and Aquatic Resource Protection, Auckland, May 2005.

High levels of PAHs in Christchurch streams are almost certainly derived from the historic use of coal tar in road construction. Based on the available data, proactive mitigation strategies would be to prioritise the reconstruction of problematic streets in order to completely remove the legacy coal tar contaminants from the system.

Depree, C. and M. Ahrens (2006). "Legacy Contaminants in Christchurch: Are Roadside Soils an Ongoing Major Source of PAHs in Runoff Today?" 2006 NIWA Stormwater Conference.

Shoulder soils, berm soils, frittered roading material and recently deposited gutter particulate material were collected from different streets for PAHs analysis. A strong correlation between PAHs levels in roadside shoulder soil and runoff particulates collected from gutter channels was found. Roadside soils appear to be continually releasing PAH contaminated soil in runoff and thereby account for the very high concentrations of PAHs in runoff particulates from low trafficked suburban streets in Christchurch.

Elliott, A. H. (1997). "Analysis of Potential Stormwater Quality Controls in Christchurch." Report prepared for Canterbury Regional Council.

In this study the cost and benefits of potential urban stormwater quality controls in Christchurch were assessed. The analysis was assisted by a critical data review and the use of a catchment model.

Elliott, A. H. (1998). "Model for Preliminary Catchment Scale Planning of Urban Stormwater Quality Controls." Journal of Environmental Management 52: 273-288.

A systems modelling approach was adopted for the preliminary planning of urban stormwater quality controls, and this approach was applied to the city of Christchurch, New Zealand. The model predicts that stormwater treatment ponds and infiltration are of little benefit in relation to improving sediment quality.

Farrant, S. (2006). "Contaminant Characterisation of Stormwater Discharge into Okeover Stream and Treatment Recommendations." Natural Resources Engineering Research Project 2006: 7-63.

Six heavy metals, zinc, copper, lead, nickel, cadmium and chromium were determined from samples collected from first flush stormwater runoff on the 11-12th May and 24th May 2007, lower stretches of the Okeover Stream through University of Canterbury. Their levels were assessed, and a treatment strategy involving catchment management, lime rock filtering, pond detention, swales and a wetland is proposed to treat this urban runoff to an extent that Okeover Stream can contribute to be rehabilitated.

Gilson, M. (1996). "Christchurch City Surface Water Quality Data 1994-95." A Report Prepared for the Christchurch City Council: 1-129.

This report is essentially a record of all chemical and biological data (between July 1994 and 30 June 1995) collected from such locations as the Avon/Ötakaro, Heathcote/Opawaho, Styx and Halswell Rivers and their tributaries including the Wigram East and the Halswell Junction Road retention basins, selected drains discharging directly to the Avon-Heathcote Estuary/Ihutai, the Christchurch and Belfast wastewater treatment plants' oxidation pond effluents and selected bacteriological data from surface waters of the Avon-Heathcote Estuary/Ihutai. It also updates the summary statistics of the previous years monitoring for most parameters.

Holland, P.T., and T.M. Trower (1992). "Organochlorine and Hydrocarbon Contaminants in the Avon and Heathcote River and Estuary System." Report prepared for the Canterbury Regional Council.

Study that investigated persistent pollutants in the Avon/Heathcote Rivers and estuary system. Study involved 13 sites where sediment samples and cockles were taken and 24 sites where water samples were taken.

Kingett Mitchell Limited. (2003). "Sediment Quality in Inshore Pegasus Bay." Report Prepared by Kingett Mitchell Ltd on behalf of URS New Zealand Limited: 1-32.

The results of sediment sampling carried out offshore to a distance of 4km between the Waimakariri River and the Ashley River in Pegasus Bay over the period January to May 2003 were presented. Samples were also examined for a range of chemical constitutes to provide information on current quality of the seabed sediments and a description of the nature of the seabed sediments in the investigated area in Pegasus Bay was therefore provided.

Macpherson, J. M. (1979). "Response to Urbanization of the Avon-Heathcote Estuary, Christchurch, New Zealand." Environmental Geology 3: 23-27.

Changes in the tidal compartment, deposition of sediment during early urbanization and changes in the configuration of the Avon-Heathcote Estuary/Ihutai were discussed, emphasizing that small microtidal estuaries-especially those thoroughly dominated by urban areas-are capable of adjusting quickly to changing water and sediments budgets.

Main, M. R. (1994). "A Limited Investigation of Stormwater Quality in the Avon-Heathcote Catchment." Canterbury Regional Council Technical Report R94(24): 1-20.

To determine the quality of stormwater discharged from rural, residential and industrial land uses, samples were collected and analysed. The concentration levels of different contaminants, the alkyl benzene hydrocarbons and halogenated hydrocarbons, heavy metals (zinc and copper, lead), nitrogen and total phosphorus, as well as the mass loadings of contaminants were discussed. For better characterization of the quality of stormwater discharged within Avon-Heathcote catchment, further sampling from several larger rainfall events were recommended.

Main, M. R. (2004). " Pesticides in Streams and Rivers in Canterbury: Results of sampling from January 1991 to June 2002." Canterbury Regional Council Report R04/04.

Section 7 Bibliography

Report presents sampling results for pesticides for the period of January 1991 to June 2002. Some pesticides have been detected in Canterbury, but none of the records have been at concentrations of environmental concern.

Meredith, A.S. and S.A. Hayward (2002). "An Overview of the Water Quality of the Rivers and Streams of the Canterbury Region." Environment Canterbury Technical Report R02/25.

> This report looks at the current state of water quality in the rivers and streams of Canterbury by assessing a subset of water quality data held by Environment Canterbury. Water quality was described for six determinants that were considered appropriate. Six major river types were identified, and analysis described the susceptibility to degradation, the actual state of water quality and the likely causes of degraded water quality.

Pattle Delamore Partners Ltd (2007a). "Stormwater Monitoring at Kirkwood Subdivision." Report prepared for Christchurch City Council.

> This report presents sampling results for 42 pesticides from nine chemical groups from streams and rivers in the Canterbury area. Sampling occurred either once or twice a year with a total of more than 10,000 individual pesticide analyses to date.

Pattle Delamore Partners Ltd (2007b). "Avon and Heathcote Rivers: Analysis of Water Quality Data from 1992-2006 (Draft)." Report prepared for Environment Canterbury.

> The data analysis project involved analysis of longitudinal water quality data held by the Christchurch City Council (CCC), which had been collected from numerous sites on city waterways since 1989. The length of the data set available enabled rigorous statistical analysis for identification of trends.

Pauling, C. (2007). "Ngāi Tahu Association with the Ihutai Catchment" (unpublished). Report prepared for Environment Canterbury.

> The importance of the Ihutai / Avon-Heathcote Estuary to the local Maori people and the impact of European settlement on the area. This has lead to the estuary and its catchment being of little, if any, value as a mahinga kai for tangata whenua.

Purchase, N. G. and J. E. Fergusson (1986). "The Distribution and Geochemistry of Lead in River Sediments, Christchurch, New Zealand." Environmental Pollution (Series B) 12: 203-216.

> The lead levels in the river sediments of two small rivers draining the city of Christchurch, New Zealand, reflect nearby inputs from a lead accumulator battery factory and street dust carried into the river. The high levels found in the river sediments are not reflected in the levels in the sediments of the rivers' estuary. The lead species distribution was also presented.

Ray, D., T. Snelder, *et al*. (2000). "Effects of Urban Stormwater on Lake Ellesmere (Te Waihora)." NIWA Client Report Prepared for Environment Canterbury: CRC 00615: 1-47.

> This report focuses on the effects of stormwater contaminants in the discharges from future residential development on the surface water quality of Lake Ellesmere/Te Waihora and its tributaries. The effects of urbanisation on stream habitat were also addressed.

Rodrigo, A. G. (1989). "Surficial Sediment-Heavy Metal Associations in the Avon-Heathcote Estuary, New Zealand." New Zealand Journal of Marine and Freshwater Research 23: 255-262.

> Adsorbed Zinc, Cu, Pb, Cr and Ni were determined from surficial sediment samples of 330 sites in the Avon-Heathcote Estuary/Ihutai. Total heavy metal concentration was shown to be highly correlated with mean sediment surface area, and their partition depends strongly on sediment particle size.

Royds Garden Environmental Services. (1993). "Avon-Heathcote Estuary and Rivers: Water Quality/Ecology Overview." A Report Prepared by Royds Garden Environmental Services 1-26.

This report gives an overview of water quality and ecological features of the Avon-Heathcote Estuary and discusses the management implications of particular trends or problems identified in these various reports.

Suren, A. M. (2000). "Effects of Urbanisation." New Zealand Stream Invertebrates: Ecology and Implications for Management. New Zealand Limnological Society, Christchurch: 260-288.

The many habitat modifications that characterize urban streams are described, in particular changes to flow regimes and water quality. Effects of urbanization on invertebrate communities are reviewed, and reason behind these changes explained. Ways to mitigate the effects of urbanization are discussed.

Taffs, E. and A. O'Sullivan (2007). "Quantifying Stormwater Contaminants in Water and Sediment in the Okeover Stream, Christchurch." Natural Resources Engineering Summer Research Project: 2-42.

A survey of water and sediment chemistry at five points along Okeover Stream transect during baseflow conditions was conducted and compared to the water chemistry at the most visibly degraded transect sampling point during a storm event. The levels heavy metals, as well as organic contaminants such as BTEX and PAHs were presented

http://www.civil.canterbury.ac.nz/staff/osullivan/stormwater.shtml (2007). "CBD Stormwater Runoff from Carpark of the University of Canterbury " Analysis Results Sheet of "3rd Pro Stormwater Project" (Lab Job Number 450353).

Physical and chemical analysis sheet for stormwater samples collected from University of Canterbury carpark. Levels of contaminants including PAHs, heavy metals, nitrogen, phosphate, sulphate, chloride were provided.

National

ANZECC (2000). "Australia and New Zealand Guidelines for Fresh and Marine Water Quality-Volume 1: The Guidelines." National Water Quality Management Strategy-Paper No. 4.

The guidelines for aquatic ecosystems, primary industries, recreational water quality and aesthetics, drinking water, as well as monitoring and assessment in Australia and New Zealand are presented.

Allibone, R., J. Horrox, *et al*. (2001). "Stream Classification and Instream Objectives for Auckland's Urban Streams." NIWA Client Report Prepared for Auckland Regional Council: ARC 00257 1-79.

To determine what biological values were suitable to attempt to retain or enhance in Auckland streams and to develop a classification process for the streams, field surveys of 64 urban Auckland streams were carried out to assess the potential for each of the biology objectives to be achieved. The fish and invertebrate communities in each stream were analysed in conjunction with the habitat data to determine if different stream types with distinct stream communities could be recognized.

ARC. (2000). "Baseline Water Quality Stream, Lake, and Saline Waters". Year 2000 Summary Report Auckland Regional Council Technical Publication-TP132:1-219.

Long-Term Baseline data were summarized for 16 streams (January 1992 to January 2000), 18 saline water sites in Manukau, Waitemata and Kaipara Harbours (October 1997 to January 2000) and 7 lakes (November 1992 to November 1999). The complete data records for all sites have been examined for trends and for the effects of human activities.

ARC (2003). "Baseline Water Quality of Stream, Lake and Saline Waters." Annual Report January-December 2003 Auckland Regional Council Technical Publication-TP234:1-237.

Long-Term Baseline data were presented for 16 streams, 14 saline water sites in Manukau, Waitemata and Kaipara Harbours and the Hauraki Gulf, and for 7 lakes for the period January-

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December 2003. Monitoring data for investigations of sites in Mahurangi Estuary, Upper Waitemata Harbour and Tamaki Estuary have also been summarised.

ARC. (2003). "Design Guideline Manual: Stormwater Treatment Devices 2003." Auckland Regional Council Technical Publication-TP10 2003: 2-1-11.

Effects of land use on stormwater runoff.

ARC. (2005). "Sources and Loads of Metals in Urban Stormwater." Auckland Regional Council Technical Publication- TP318: 1-77.

This report describes a study commissioned by the Auckland Regional Council to combine the data from three separate studies to produce mass budgets for heavy metals such as zinc, copper and lead in the stormwater from the three urban catchments and thereby to determine the contributions of each known metal source to metal loads in urban stormwater.

ARC. (2006). "Contamination Load Model May 2006." Auckland Regional Council.

Spreadsheet developed to easily calculate how much sediment, zinc, copper and petroleum hydrocarbons are produced within a given land area.

Babich, J. (2001). "Waitakere City Contamination Loading Study." Report Prepared for EcoWater Solutions by URS New Zealand, Version 1.0.

Annual mass contamination loadings, associated with both stormwater and wastewater discharges, were calculated for each of the investigated 33 stormwater management units in Waitakere City Council. The impacts of contaminants from these units on receiving water were also presented.

Bates, M. N. and N. Garrett (1998). "Vehicle Fires and the Introduction of Premium Unleaded Petrol into New Zealand." Journal of the Royal Society of New Zealand 28(2): 321-328.

Based on the analysis of data obtained from the New Zealand Fire Service and three major vehicle insurance companies, it was concluded that the overall numbers and rates of care fires in the first quarter of 1996 had remained fairly consistent with what would have been expected on the basis of data from previous years (premium unleaded fuel was introduced into New Zealand to replace 96-octane petrol in January 1996). It seems unlikely that there was a general increase in care fires related to the introduction of unleaded fuel in early 1996, yet analysis of data covering a more extended period was suggested for a definitive conclusion.

Botherway, K. J. and J. P. A. Gardner (2002). "Effect of Storm Drain Discharge on the Soft Shore Ecology of Porirua Inlet, New Zealand." New Zealand Journal of Marine and Freshwater Research 36: 241-255.

The effect of storm drain discharge on the ecology of the soft shore community near the Semple Street outfall in Porirua Inlet, New Zealand was investigated from December 1998 to April 1999. Biological structure, sedimentary properties, and heavy metal concentrations of surficial sediments were examined were examined at increasing distance from storm drain at two shore heights. Concentrations of copper, lead and zinc at nine sites from the storm drain to the mouth of the inlet were estimated in April 1999.

Brown, J. N. and B. M. Peake (2005). "Sources of Heavy Metals and Polycyclic Aromatic Hydrocarbons in Urban Stormwater Runoff." Science of the Total Environment 359: 145-155.

Polycyclic aromatic hydrocarbons (PAHs) and heavy metals were measured in road debris collecting in urban areas and in the suspended sediment (SS) component of runoff from two stormwater catchments in Dunedin, New Zealand. The higher levels of lead (119-527ug/g) and copper (50-464ug/g) were probably a result of industrial land uses in this catchment, while the additional zinc was linked to an abundance of zinc-galvanised roofing iron in the catchments residential suburbs. The PAH profiles and isomer ratios were different for this urban catchment and suggested that a disused gasworks was contributing PAHs to the stormwater runoff.

Section 7 Bibliography

Buchan, G., K. Cameron, *et al*. (2005). "Pathogen Transport via Soils from Land-Applied Animal Wastes." Geophysical Research Abstracts, Vol.7.

> Paper looks at pathogen transport via soils on an experimental level and at farm level, looking at the effectiveness of soils as filtration media for bacteria.

Clayton, J., and T.Edwards (2007). "LakeSPI: A Method for Monitoring Ecological Condition in New Zealand Lakes." Technical Report Version 2.

> Report presents a tool for monitoring the ecological condition of New Zealand lakes. The tool (LakeSPI) uses carefully selected features of submerged plant communities to assess the effects of catchment and water management on a lake and the impact of aquatic weed invasion in a lake.

Doyle, P. N. (2005). "The Effects of Human Activities on Stream Water Quality: Case Studies in New Zealand and Germany." Thesis submitted in Partial Fulfilment of the Degree of Master of Applied Science, Auckland University of Technology: 2-56.

> Three case studies were carried out in New Zealand and Germany to explore the effects of human activities on coastal streams and review measures to control the negative consequences of human activities. Parameters were determined and compared to related guidelines, and recommendations were made to ameliorate the potential negative impacts of the development.

Eyles, R., D. Niyogi, *et al*. (2003). "Spatial and Temporal Patterns of *Campylobacter* Contamination Underlying Public Health Risk in the Taieri River, New Zealand." Journal of Environmental Quality 32: 1820-1828.

> Spatial and temporal distribution of the human pathogen *Campylobacter* in the lower Taieri River, South Island New Zealand was investigated. Result shows that seasonal variation in *Campylobacter* was evident with higher median levels detected in summer, when human exposure through recreational water use is maximal, and *Campylobacter* levels varied significantly among investigated 10 sampling sites. This research indicated that continuing land use change and intensification in New Zealand may result in increased mircobial contamination of freshwater and an associated increase in waterborne enteric diseases, including campylobacteriosis.

Galbraith, L. M. and C. W. Burns (2007). "Linking Land-Use, Water Body Type and Water Quality in Southern New Zealand." Landscape Ecol 22: 231-241.

> Physical variables and nutrient chemistry of 45 water bodies were measured, which are representative of the wide range of lentic wetland environments (swamps, riverine wetlands, estuaries, reservoirs, shallow lakes, deep lakes) in Otago, New Zealand, and related these to catchment variables and land-use in order to assess the potential influence of catchment modification on water quality of these diverse wetlands. The strong negative correlations between nutrient concentrations, suspended sediment, water colour and the percentage of tussock cover in the catchment imply that increased conversion of the native tussock grassland to pastoral farming in Otago will increase nutrient concentrations and reduce water quality of the diverse lentic ecosystems.

Hall, M. J., G. P. Closs, *et al*. (2001). "Relationships between Land Use and Stream Invertebrate Community Structure in a South Island, New Zealand, Coastal Stream Catchment." New Zealand Journal of Marine and Freshwater Research 35: 591-603.

> Macroinvertebrate community composition was compared across streams draining catchments dominated by either native bush, agricultural or urban land uses within the Water of Leith stream catchment near Dunedin, New Zealand. Land use was associated with differences in taxon richness and faunal composition of communities present in each stream. Increasing dominance of the urban and agricultural streams by pollution tolerant taxa was reflected in the Macroinvertebrate Community Index and Quantitative Macroinvertebrate Community Index scores.

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Herald, J. "Pointing the Way to Reducing Stormwater Impacts on Urban Streams." 2003 South Pacific Stormwater Conference.

> Four catchments representative of different urban and peri urban land covers in Waitakere City were investigated to quantify the impacts of the urbanization and evaluate the benefits of improved stormwater management practices. The impacts of urbanization, particularly catchment imperviousness on stream flow regimes and aquatic ecosystem health was assessed, confirming that increased areas of impervious surface and man-made drainage networks have increased storm discharges and reduced the sustainability of baseflows.

Kennedy, P. (1999). "The Effects of Road Transport on Freshwater and Marine Ecosystems." A Report Prepared for Ministry of Transport by Kingett Mitchell Limited.

> This report examines the effects of contaminants derived from road transport on aquatic ecosystems in a New Zealand context wherever possible. The report aims to provide an overview as to what is known about the effects of the contaminants released by motor vehicles.

Larned, S. T., M. R. Scarsbrook, *et al*. (2004). "Water Quality in Low-Elevation Streams and Rivers of New Zealand: Recent State and Trends in Contrasting Land-Cover Classes." New Zealand Journal of Marine and Freshwater Research 38: 347-366.

> Data from the surface-water monitoring programs of 15 regional councils and unitary authorities, and the National River Water Quality Network were used to assess the recent state (1998–2002) and trends (1996–2002) in water quality in low-elevation rivers across New Zealand. Assessments were made at the national level, and within four land-cover classes (native forest, plantation forest, pastoral, and urban).

Morrisey, D. J., S. J. Turner, *et al*. (2003). "Factors Affecting the Distribution of Benthic Macrofauna in Estuaries Contaminated by Urban Runoff." Marine Environmental Research 55: 113-136.

> Multivariate methods were used to test two hypotheses relating to the effects of urban-derived contaminants on estuarine benthic communities. Four estuaries Waiheke, Paremoremo, Hellyers and Pakuranga, as well as the related catchments were investigated in this study. Concentrations of Cu, Pb, zinc and DDT in estuaries and catchments were examined and compared. Results also showed that distributions of benthic invertebrates were significantly related to those of environmental variables, and were ordinated along axes that correlated with both natural environmental variables (nature of the sediment, position in estuary) and contaminants.

Otago Regional Council. (2005). "Stormwater Quality-Dunedin Urban Streams." Report Prepared for Environment and Science Committee.

> To establish the extent of contamination of the "first flush" of stormwater, samples were collected from selected Dunedin urban stream and analysed for metal, microbiological and nutrient contaminants. Results showed that the concentrations of most contaminants are elevated and levels of *E.coli* of 15,000cfu/100ml are not unusual.

Parkyn, S. and B. Wilcock (2004). "Impacts of Agricultural Land Use." Freshwaters of New Zealand 2004, edited by Jon Harding, Paul Mosley, Charles Pearson, Brian Sorrell.: 34.1-16.

> This paper reviews the current levels of understanding of the effects of agriculture on the water quality and ecology of stream, focusing on ways of reducing the impact of farming on stream, identifying some of the important research problems for the future of sustainable land use in New Zealand.

Rowe, D. (2004). "Lake Restoration." Freshwaters of New Zealand 2004, edited by Jon Harding, Paul Mosley, Charles Pearson, Brian Sorrell.: 39.1-16.

> This paper deals with types of environmental problems encountered in New Zealand lakes, our knowledge of the causes, and the technologies that have been developed to restore lakes.

Section 7 Bibliography

Shedden, B., J. Batcher, *et al*. (2007). "Roof Runoff Study by New Zealand Metal Roofing Manufactures." 2007 South Pacific Stormwater Conference.

> Zinc level in stormwater roof runoff from various metal roofing materials commonly used in New Zealand was investigated by analysing the runoff from standardised test roofs located in a rural residential area at Pukehohe over an eight-month period in 2004. Results were compared with similar studies from Sweden, France, UK and New Zealand.

Smith, P. (2006). "Regional Rivers Water Quality Monitoring Programme: Data Report 2005." Environment Waikato Technical Report 2006/29: 1-41.

> Information on the routine monthly monitoring of water quality at 100 locations across the Waikato Region was provided, including Year 2005 summary statistics for major ions, tabulated by parameter, spatial contour plots for four water quality parameters using spatial interpolation of the median of the previous 5 years, and summary tables identifying samples meeting 'Satisfactory' and 'Excellent' water quality guidelines and standards.

Suren, A. and S. Elliott (2004). "Impacts of Urbanisation on Streams." Freshwaters of New Zealand 2004, edited by Jon Harding, Paul Mosley, Charles Pearson, Brian Sorrell.: 35.1-18.

> This paper deals with the problematic issue of stormwater and its effects on streams, as sewage management in most large urban areas in New Zealand is well advanced and its effects on the receiving waters are relatively well understood.

Webster-Brown, J. (2005). "A Review of Trace Metal Transport and Attenuation in Surface Waters." Metal Contaminants in New Zealand-Sources, Treatments, and Effects on Ecology and Human Health. Edited by Tim A. Moore, Amanda Black, José A. Centeno, Jon S. Harding, Dave A. Trumm: 193-212.

> This paper reviews trace metal transport and attenuation processes in freshwater and estuarine systems, using mainly New Zealand case studies to demonstrate important processes. Trace metal partitioning between dissolved and suspended particulate matters, sorption of heavy metals by mineral oxides, and precipitation of metals, as well as attenuation by organic material and biota were discussed.

Webster, J. G., K. L. Brown, *et al*. (2000). "Source and Transport of Trace Metals in the Hatea River Catchment and Estuary, Whangarei, New Zealand." New Zealand Journal of Marine and Freshwater Research 34: 187-201.

> A survey of copper, lead, zinc, chromium, and arsenic concentrations in bed sediment, fresh waters, storm waters, and suspended particulate matter (SPM) has been undertaken in the Hatea River catchment, Whangarei, New Zealand. Hatea River under different flow regimes indicated that trace metals were predominantly conveyed by coarse (>0.45 um) SPM during the periods of highest river flow. Of the trace metals studied, Pb showed the strongest association with coarse SPM and the greatest potential for accumulation in estuarine sediment, demonstrating little tendency to be leached from sediment under simulated estuarine conditions.

Williamson, R. B. (1985). "Urban Stormwater Quality I. Hillcrest, Hamilton, New Zealand." New Zealand Journal of Marine and Freshwater Research 19: 413-427.

> Water quality parameters associated with siltation, oxygen depletion, nutrient enrichment (N, P), toxicity (lead, zinc, copper, chromium, nickel, cadmium), and human pathogenic micro-organisms were measured in baseflow and stormflow from a residential catchment in Hamilton, New Zealand, from November 1979 to December 1981. A macro-invertebrate survey was conducted. All parameters, except nitrogen, were predominantly associated with particulate material, and closely followed suspended solids behaviour during storm runoff. The concentrations of these particulate parameters are linearly related to suspended solid concentrations, which implies a reasonable consistency in the particulate source material, probably attributable to the uniform stable land use.

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Williamson, R. B. (1993). "Urban Runoff Data Book: A Manual for the Preliminary Evaluation of Urban Stormwater Impacts on Water Quality." Water Quality Centre Publication No. 20: 1-51.

Published data on urban runoff in New Zealand (before year 1991) were collated, including concentration data for dry weather and storm flows, export coefficients and presentation of database and selection of recommends values.

Williamson, R. B. and D. J. Morrisey (2000). "Stormwater Contamination of Urban Estuaries. 1. Predicting the Build-up of Heavy Metals in Sediments." Estuaries 23(1): 56-66.

A model was developed to predict the build-up of contaminants (lead, zinc, and copper) in the sediments of sheltered estuaries. The information required to develop and run the model, and the sensitivity of the model to variation in its parameters, is described in detail.

International

Chiew, F. H. S., L. B. Mudgway, *et al*. (1997). "Urban Stormwater Pollution." Cooperative Research Centre for Catchment Hydrology Industry Report 97/5.

This report consists of a review of more than 800 studies of urban stormwater quality processes, statistical analyses of overseas and Australia data to characterize urban stormwater quality and treatment by storage, methods for estimating runoff and pollutant load in urban catchments, and a modelling study of the dry weather pollutant accumulation process for estimating storm-event and washoff loads.

CRC. (2004). "Stormwater Flow and Quality, and the Effectiveness of Non-Proprietary Stormwater Treatment Measures-A Review and Gap Analysis." Cooperative Research Centre for Catchment Hydrology Technical Report 04/8.

This report reviews available data on urbanization impacts on flow and water quality, and on Best Management Practices used to address these impacts. Modelling was undertaken to derive applicable information for prediction of stormwater flow, treatment and performance behaviour, and related guidance was also provided.

Department of Environment, Western Australia (2004). "Potentially Contaminating Activities, Industries and Landuses." Report for the Department of Western Australia, Government of Western Australia.

Part of a series of guidelines developed by the Department of Environment to provide guidance on the assessment and management of contaminated sites.

Doyle, P. N. (2005). "The Effects of Human Activities on Stream Water Quality: Case Studies in New Zealand and Germany." Thesis submitted in Partial Fulfilment of the Degree of Master of Applied Science, Auckland University of Technology: 2-56.

Three case studies were carried out in New Zealand and Germany to explore the effects of human activities on coastal streams and review measures to control the negative consequences of human activities. Parameters were determined and compared to related guidelines, and recommendations were made to ameliorate the potential negative impacts of the development.

Driscoll, E. D., P. E. Shelley, *et al*. (1990). "Pollution Loadings and Impacts from Highway Stormwater Runoff, Volume 1: Design Procedure (FHWA-RD-88-006)." Research, Development, and Technology Turner-Fairbank Highway Research Center, McLean, Virginia.

An investigation dealing with the characterization of stormwater runoff pollutant loads from highways, and the prediction of water quality impacts they cause. Study results are based on monitoring data from 993 individual storm events at 31 highway sites in 11 states. This report provides a step-by-step procedure for computing the estimated impacts on water quality of a stream or lake that receives highway runoff directly.

Ferguson, C., A. de Roda Husman, *et al*. (2003). "Fate and Transport of Surface Water Pathogens in Watersheds." Critical reviews in Environmental Science and technology, Vol. 33:299-361.

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This article reviews the fate and transport of pathogens in watersheds supplying drinking water, from their deposition in faeces and septic seepages on land to their dispersion in major tributaries. Pathogens considered representative of those associated with waterborne disease included enteric viruses derived from human faecal contamination, bacterial pathogens represented by *E.Coli*, and the protozoan pathogens Cryptosporidium and Giardia.

Kelley, G., D. Stein, *et al*. (2004). "Willamette River Conditions Report, City of Portland."

This report summarizes the results of some of the research and analytical work that the City of Portland has accomplished since the City Council endorsed the River Renaissance Vision. It concentrates primarily on the Willamette River and the land along the river corridor, but includes important references to the larger economic, cultural, recreational and urban systems that extended beyond the corridor.

Kidd, S., J. Miller, *et al*. (2005). "Storm Water BMP Effectiveness Workgroup Report." 1-5.

Median and mean land use concentrations were calculated from the “Analysis of Oregon Runoff Water Quality Monitoring Data Collected from 1990-1996” report (Prepared by Woodward Clyde in 1997), for pollutants of concern in stormwater runoff. And computed MLE (maximum likelihood estimate) mean effluent concentrations for the major BMP types and stormwater pollutants were presented.

Lee, H., S.-L. Lau, *et al*. (2004). "Seasonal First flush Phenomenon of Urban Stormwater Discharges." Water Research 38(19): 4153-4163.

To investigate the existence of a seasonal first flush, four major data sets were analysed. Trends in seasonal loads were quantified by plotting pollutant concentrations of cumulative pollutant load versus cumulative rainfall or cumulative runoff volume. Results showed that a seasonal first flush existed for most cases and was strongest for organics, minerals and heavy metals except lead, which suggested that applying treatment Best Management Practices (BMPs) early in the season could remove several times more pollutant mass than randomly timed or uniformly applied BMPs.

Makepeace, D. K., D. W. Smith, *et al*. (1995). "Urban Stormwater Quality: Summary of Contamination Data." Critical Reviews in Environmental Science and Technology 25(2): 93-139.

A literature review to identify and quantify contaminant data available on stormwater, which focuses on specific chemical, physical, and biological parameters rather than the traditionally used overall water quality parameters. Values were also compared with pertinent guidelines, regulations, and levels that have been reported to cause possible adverse impacts.

Olsen, M.E. (2000). "Human and Pathogen in Manure." Microbiology and infectious Diseases, University of Calgary.

Study looks at faecal wastes from domestic animals, wildlife and humans and the effect that the pathogens from these have on human and animal health.

Osterkamp, W.R., and Gray, J.R. (2003). "Hazard Management Related to Water and Sediment Fluxes in the Yellow River Basin, China, Based on Comparable Basins of the United States." International Yellow River Forum on River Management, Vol. II, Oct. 21-24, 2003, Zhengzhou, Henan Province, China: The Yellow River Conservancy Publishing House, p. 465-473.

A paper looking at the Yellow River in China and two similar rivers in the United States, and identifying potential approaches to reducing continuing aggradation and increasing flood hazard along the lower Yellow River.

Pitt, R. E. (1995). "Biological Effects of Urban Runoff Discharges." Stormwater Runoff and Receiving Systems: Impact, Monitoring, and Assessment, Edited by Edwin E. Herricks and Jackie R. Jenkins: 127-162.

This paper summarized the results presented about the receiving water effects associated with urban runoff, in particular, this the specific effects on receiving water biota were addressed. This paper also describes selected studies that have investigated water quality and sediment quality impacts of urban runoff.

Poulton, B.C. *et al*. (1997). "Effects of a Crude Oil Spill on the benthic Invertebrate Community in the Gasconade River, Missouri." Archives of Environmental Contamination and Toxicology. Volume 33:268-276.

Looks at the effects of a crude oil spill on the benthic macroinvertebrate community of the Gasconade River, Missouri. Effects were evaluated by comparing several macroinvertebrate community indices in riffle and backwater habitats above and below the spill. Concentrations of total petroleum hydrocarbons in sediments decreased dramatically in riffle habitats within 6 months of the spill, but elevated hydrocarbon levels were still present in backwater habitats at the end of the study.

Rhoads, B. L. (1995). "Stream Power: A Unifying Theme for Urban Fluvial Geomorphology." Stormwater Runoff and Receiving Systems: Impact, Monitoring, and Assessment, Edited by Edwin E. Herricks and Jackie R. Jenkins: 65-75.

This paper shows how the concept of the stream power provides a unifying theme for the entire range of issues associated with urban fluvial geomorphology.

Soller, J., J. Stephensona, *et al*. (2005). "Evaluation of Seasonal Scale First Flush Pollutant Loading and Implications for Urban Runoff Management." Journal of Environmental Management 76: 309-318.

How the occurrence and magnitude of first flush events in stormwater may influence the effective management of urban runoff pollution was investigated in the City of San Jose, between May 1997 and April 2000. Concentrations of pollutants in local water bodies during eight storm events were characterized. The results suggest that first flush phenomena did not occur consistently throughout most of the stations investigated. The results further suggest that there are specific combinations of site and storm conditions that result in a first flush effect with respect to dissolved metals. Based on the results of this and related investigations, implications for urban runoff management are discussed.

Sowles, M. (2005). "Assessing Phosphorus Transportation and the High Risk Runoff Areas: the Cannon River Watershed, Southeastern MN." Submitted for the Requirements for a Bachelor of Arts from Carleton College, Northfield, Minnesota.

This study examines the potential risk of phosphorus runoff in the Cannon River Watershed specifically above the Byllesby reservoir. Based on four variables (available phosphorus amount, slope, the K-factor, and land use), the results showed that the majority of the watershed was at high risk for phosphorus runoff.

Stein, E. D., L. L. Tiefenthaler, *et al*. (2006). "Watershed-Based Sources of Polycyclic Aromatic Hydrocarbons in Urban Storm Water." Environmental Toxicology and Chemistry 25(2): 373-385.

This study characterized the sources and temporal patterns of PAHs in urban storm water by analysing PAH concentrations and loads from a range of homogeneous land use sites and in-river mass emission sites throughout the greater Los Angeles, California, USA, region. Polycyclic aromatic hydrocarbon storm fluxes, as well as average storm fluxes were presented and compared for the largely undeveloped Arroyo Sequit and the highly urbanized Verdugo Wash watersheds. Early-season storms repeatedly produced substantially higher loads than comparably sized late-season storms. Within individual storms, PAHs exhibited a moderate first flush with between 30 and 60% of the total PAH load being discharged in the first 20% of the storm volume. The relative distribution of individual PAHs demonstrated a consistent predominance of high-molecular-weight compounds indicative of pyrogenic sources.

Walsh, C. J. and A. W. Leonard (2004). "Urban Stormwater and the Ecology of Streams." CRC for Freshwater Ecology and for Catchment Hydrology Report, Canberra: 1-44.

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This report focuses on the product of urban stormwater that drains from the impermeable surfaces that are part of urban land-use, describing the physical, chemical and biological processes of streams, how these processes are affected by urban development built using conventional stormwater drainage design, and how these impacts may be minimized by new design approaches. The research suggests that it is possible to develop an urban catchment at least up to a density typical of Australian suburbs and have an ecologically healthy stream flowing out of it.

Walsh, C. J., A. H. Roy, *et al*. (2005). "The Urban Stream Syndrome: Current Knowledge and the Search for a Cure." Journal of North American Benthological Society 24(3): 706-723.

A review: recent literature to describe symptoms of the syndrome, explores mechanisms driving the syndrome, and identifies appropriate goals and methods for ecological restoration of urban streams.

Wong, T. (2002). "Urban Stormwater Quality- Project 4.1 Stormwater Quality Pollutant Sources, Pathways and Impacts." CRC for Catchment Hydrology 1999-2006.

This project report focuses on integrating the disciplines of science and engineering into storm water management strategies by developing a suite of models for estimating stormwater pollutant loads from different sources areas, defining their impacts on aquatic ecosystems, and predicting the performance of stormwater management practices.

Yeghiazarian, L.L., P. Kalita, *et al*. (2004). "Field Calibration and Verification of a Pathogen Transport Model." Report prepared for the Water Environment Research Foundation..

The researchers developed an integrated modelling strategy to quantify the risk of surface water contamination by waterborne pathogens, in particular from agricultural nonpoint pollution sources. The main experimental effort focused on the measurement of Cryptosporidium oocysts partitioning in the soil/water systems to find the parameters of the transport model.

Not Cited

Abrahim, G. and R. Parker (2002). "Heavy-Metal Contaminants in Tamaki Estuary: Impact of City Development and Growth, Auckland, New Zealand." Environmental Geology 42: 883-890.

The study of seven estuary cores shows that sedimentation rates as well as the sediment coarse fraction have increased with the development of the catchment. Significant enrichments were also found for cadmium, copper, lead, and zinc in the upper part of the cores, compared to the much lower concentrations found below 40–50 cm (considered to represent pristine background levels). Spatial association of contaminants with industrial areas and yacht anchorages, and temporal enrichments associated with the intensive urbanisation and development of the catchment since 1945 indicate that these pollutants are related to anthropogenic activities.

Armitage, N. and A. Rooseboom (2000). "The Removal of Urban Litter from Stormwater Conduits and Streams: Paper 1 - The Quantities Involved and Catchment Litter Management Options." Water SA 26(2): 181-188.

The potential annual cost of cleaning South Africa's waterways of urban litter assuming current practices is conservatively estimated. The main factors influencing the quantity of litter finding its way into the waterways are identified, and suggestions are made for reducing this quantity through catchment litter management. Data from Australia and New Zealand are also reported to illustrate the potential for major reductions in the quantity of litter entering South Africa's waterways. The influence of these factors is then summarised in the form of simple equations to assist designers in the sizing of litter traps.

Bibby, R. L. and J. G. Webster-Brown (2005). "Characterisation of Urban Catchment Suspended Particulate Matter (Auckland Region, New Zealand): A Comparison with Non-Urban SPM." Science of the Total Environment 343: 177-197.

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The Kaipara River suspended particulate matter (SPM) was found to be mineralogically, chemically and biologically similar to the urban SPM. However, major differences between urban catchment SPM and SPM from the much larger (non-urban) Waikato River were observed, and attributed to a higher abundance of diatoms. Such differences observed between urban and non-urban SPM did not appear to affect the partitioning of zinc and copper; however, lead in the Kaipara and Waikato Rivers was found to be more associated with the dissolved phase. This is likely to reflect higher particulate lead inputs to urban systems.

Bruce, A. (1953). "Report on A Biological and Chemical Investigation of the Waters in the Estuary of the Avon and Heathcote Rivers." A Report Presented to Christchurch Drainage Board: 1-41.

To find the extent of pollution in the Avon-Heathcote Estuary/Ihutai, a biological and chemical survey carried out in the estuary during the year December 1950 to December 1951. The results were presented in this report.

Chapman, M. A. (1996). "Human Impacts on the Waikato River System, New Zealand." GeoJournal 40(1-2): 85-99.

Waikato river ecosystem had enough resilience to retain diverse though modified communities which still contain at least some native species, Major point sources of pollution and eutrophication were being controlled and further amelioration of these impacts will occur as new techniques are developed. A current challenge was the more difficult task of reducing the impacts of diffuse sources of nutrients and sediments. The native biota had been little-studied and the biological processes operating in the river are poorly understood. It was not possible to assess the relative importance of eutrophication and habitat change, or to predict the impacts of future changes.

Christchurch City Council, Town Planning Division, *et al*. (1980). "Planning for the Avon-Heathcote Estuary." A Report Produced by Christchurch City Council, Town Planning Division, *et al*.: 1-71.

A report on the resources, activities and values of the Avon-Heathcote Estuary/Ihutai.

Christchurch City Council, Canterbury Regional Council and Department of Conservation. (1992). " Avon and Heathcote Catchment, Rivers and Estuary: Issues and Options for Managing These Resources." Christchurch City Council, Canterbury Regional Council and Department of Conservation Report.

This document presents the issues obtained from a series of resource investigations carried out for the Avon-Heathcote Catchment, Rivers and the Heathcote Floodplain.

Deely, J. M., J. C. Tunnicliff, *et al*. (1992). "Heavy Metals in Surface Sediments of Waiwhetu Stream, Lower Hutt, New Zealand." New Zealand Journal of Marine and Freshwater Research 26: 417-427.

Surface sediment samples from the Waiwhetu Stream, Lower Hutt City, New Zealand, were leached with dilute HCl to remove the mobile heavy metal fraction. Cadmium, chromium, copper, lead, zinc, aluminium , iron, and manganese analyses of the leachates show that sediments of the upper reaches area of the stream are generally uncontaminated. In contrast, sediments in the lower reaches area are highly contaminated.

Evans, J. F., B. F. Evans, *et al*. (2003). "Development of Standard Protocols for Macroinvertebrate Assessment of Soft-Bottomed Streams in New Zealand." New Zealand Journal of Marine and Freshwater Research 37: 793-807.

Macroinvertebrate communities in hard-bottomed (HB) and soft-bottomed (SB) streams were compared to address questions on sample substrata, sample area, and data interpretation. Communities at HB and SB (native bush catchments) were distinctly different. Results from this research supported separate collection methods and data interpretations for HB and SB streams proposed in recently published New Zealand protocols.

Hayward, S. A. (2002). "Christchurch-West Melton Groundwater Quality: A review of groundwater quality monitoring data from January 1986 to March 2002." Environment Canterbury Technical Report U02/47

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The report presents groundwater quality data for the Christchurch-West Melton area which was analysed to determine spatial, seasonal and long-term patterns, and were compared to New Zealand drinking-water standards. Inorganic and microbiological data was available for 3000 samples collected from 438 wells for the period January 1986 to March 2002.

Hayward, S. A. and A.S.Meredith (2000). "Rangitata River Results of Water Quality Monitoring: August 1993 to May 2000." Environment Canterbury Technical Report R00/22: 1-41.

The report presents preliminary analyses of the water quality data obtained far from the Rangitata River based on a water quality monitoring program conducted in 1993.

Kasai, M., G. J. Brierley, *et al*. (2005). "Impacts of Land Use Change on Patterns of Sediment Flux in Weraamaia Catchment, New Zealand." Catena 64: 27-60.

Analysis of the historical record, air photograph interpretation, and field survey indicates that both erosion types occurred across the catchment in the 1938 storm, aggrading channel beds and widening the active channel zone. The changing volume and calibre of materials delivered to the valley floor, and the distribution of gully complexes, altered patterns and rates of channel adjustment after the events, and the resulting sediment flux. Upstream–downstream connectivity along the trunk stream was altered by the formation of a large debris fan at the confluence with a tributary subjected to gully complex erosion. Although shallow landslide activity will continue to induce intermittent aggregation in the future, it is inferred that average sediment yield will continue to diminish to levels approaching those experienced prior to clearcutting, and the pattern of sediment flux will recover by 2030.

Kennedy, P. and J. Gadd (2003). "Preliminary Examination of Organic Compounds Present in Tyres, Brake Pads and Road Bitumen in New Zealand." A Report Prepared for Ministry of Transport by Kingett Mitchell Limited.

This report presents the results of a preliminary examination of the organic composition of three key components (tyres, brake pads and road bitumen) of the vehicle-road transport systems that contribute to the presence of materials and contaminants in stormwater.

Kennedy, P. and J. Gadd (2003). "Preliminary Examination of Trace Elements in Tyres, Brake Pads and Road Bitumen in New Zealand." A Report Prepared for Ministry of Transport by Kingett Mitchell Limited: 1-22.

This report presents the results of a preliminary examination of the inorganic composition of three key components (tyres, brake pads and road bitumen) of the vehicle-road transport systems that contribute to the presence of materials and contaminants in stormwater.

Kingett Mitchell Limited. (2005). "Water Quality Assessment: South-West Christchurch Integrated Catchment Management Plan Technical Series." Technical Report No.2 Prepared for Christchurch City Council by Kingett Mitchell Limited 2: 1-86.

This report is on a survey of sediments in the South-West Christchurch project area, including sediments in the downstream sections of the Heathcote/Opawaho and Halswell Rivers. Locations of the studied sites, methods of sampling and analysis, as well as the raw results were presented. It provides interpretation of the results including comparisons with those obtained in 1988. A further comparison with similar studies in other regions provides an indication of how Christchurch sediments compare with those in waterways in other New Zealand cities.

Kingett Mitchell Limited. (2007). "Water Quality Assessment: South-West Christchurch Integrated Catchment Management Plan Technical Series (Draft)." Technical Report No.4 Prepared for Christchurch City Council by Kingett Mitchell Limited.

This report is to provide technical support on water quality controls and management to the Integrated Catchment Management Plan. A comprehensive assessment of treatment systems and mitigation options has been carried out. The life cycle costs of each option have been assessed and presented as NPV and, along with the-compliance approach, these have been used to determine options that are both feasible and meet the required standards.

Main, M. and S. Hayward (2005). "An Investigation of Car Park Stormwater Quality." Environment Canterbury Technical Report: 1-18.

This report examines some of the principle contaminants in stormwater runoff from a car park attached to the offices of Environment Canterbury. The contaminants concerned are oil and grease, total petroleum hydrocarbons and the metals copper, lead and zinc. It was found that the concentrations of oil and grease and metals discharged from the car park during the storm evens are higher than have been recorded from roadways in New Zealand, and at times the concentrations of copper and zinc are quite high by New Zealand standards.

Moseley, L. M. and B. M. Peake (2001). "Partitioning of Metals (Fe, Pb, Cu, Zn) in Urban Run-Off from the Kaikorai Valley, Dunedin, New Zealand." New Zealand Journal of Marine and Freshwater Research 35: 615-624.

Urban run-off from a catchment in Dunedin, New Zealand was sampled and chemically characterised. The results indicate that copper and zinc may be more bio-available, and more difficult to remove by storm-water treatment, than lead.

Pilotto, P. J., J. R. Gof, *et al*. (1998). "A Contemporary Contamination Record of Stormdrain and Harbour Sediments, Wellington, New Zealand." Environmental Geology 36(1-2): 159-166.

Timperley, M., G. Bailey, *et al*. (2003). "Zinc, Copper and Lead in Road Run-Off." ATRF 2003: 1-11.

Samples were collected from Ash Street and Richardson Road in Auckland. Vehicle numbers and size, atmospheric particulates and PAHs, gases, wind speed and direction and rainfall were monitored continuously. A contaminant accumulation/run-off model was developed and fitted to the measured metal concentrations in the road run-off to provide estimated concentrations for each minute of the monitoring periods.

Webster, J. G. (1995). "Chemical Processes Affecting Trace Metal Transport in the Waihou River and Estuary, New Zealand." New Zealand Journal of Marine and Freshwater Research 29: 539-553.

Trace metals' transport in the bed sediments in Waihou River and estuary was discussed. It is concluded that trace metal partitioning between dissolved and particulate phases appears to be generally consistent with regulation by adsorption onto hydrous iron-oxide in the sediments.

Williamson, R. B. (1986). "Urban Stormwater Quality II. Comparison of Three New Zealand Catchments." New Zealand Journal of Marine and Freshwater Research 20: 315-328.

The variability in water quality of urban runoff was assessed by comparing the concentration distributions and variations of various parameters over storm events in three catchments. The parameters chosen for assessment were nutrient, total oxygen demand, sediment, and toxic metal levels. The three catchments were located in Wairau Valley, Takapuna (Auckland) and Hillcrest (Hamilton). It was concluded that geographical differences were more important in determining stormwater quality than urban infrastructure.

Section 8 Limitations

URS New Zealand Limited has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Environment Canterbury and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 1st May 2007.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between 24th May 2007 and 19th July 2007 and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

Appendix A Water Quality Data

LOCAL

All measurements in g/m^3 unless stated otherwise

Site	Area	Mean/Median	Conductivity (µS)	Dissolved Oxygen (mg/L)	BOD5	Ammoniacal Nitrogen	Nitrate	Reactive Phosphorus	Suspended Solids	E.Coli	Faecal Coliforms	Total Zn	Total Cu	Total Pb	Year
Avon above Mona Vale	Residential	Mean, *Median	178	9.1	0.93	<0.01*	2.31	0.004*	2.0*	292	289	-	-	-	July 1991- June 1995
		Mean	167	9.3	1.00	0.03	1.86	0.010	6.3	411	529	-	-	-	August 1995 - December 2006
Avon @ Carlton Mill Corner (includes Wairarapa and Waimairi streams)	Residential	Mean, *Median	173	9.5	1.04	0.02*	1.77	0.008*	3.0*	369	344	-	-	-	July 1991- June 1995
		Mean	158	10.3	1.09	0.02	1.35	0.011	5.4	527	687	-	-	-	August 1995 - December 2006
Avon @ Dalington Bridge (includes Dudley creek)	Medium/High Density Residential	Mean, *Median	182	7.7	1.17	0.05	1.22	0.026	<1*	264	285	-	-	-	July 1991- June 1995
		Mean	169	8.1	1.10	0.05	0.94	0.026	9.7	316	443	-	-	-	August 1995 - December 2006
Avon @ Avondale Bridge (includes Horseshoe lake input) **(tidal)**	Residential	Mean	166	8.7	0.72	0.04	0.82	0.029	2.5	191	164	-	-	-	1994 - June 1995
		Mean	335	9.1	1.19	0.04	0.80	0.031	4.6	300	370	-	-	-	July 1995 - October 2006
Avon @ Bridge Street **(tidal)**	Estuary Inlet	Mean	1884	8.7	1.02	0.09	0.71	0.044	12.6	170	161	-	-	-	1994 - June 1995
		Mean	2182	9.0	1.21	0.07	0.70	0.041	14.0	285	346	-	-	-	July 1995 - October 2006
Heathcote @ Templetons Road	Residential	Mean, *Median	286	4.5	0.90*	0.04*	2.47	0.017*	4.0*	200*	200*	-	-	-	January 1989 - June 1995
		Mean	298	6.0	3.39	0.08	2.31	0.032	15.8	621	681	-	-	-	July 1995 - Feb 2007
Heathcote @ Motorways Bridge (includes Haytons & Curletts Road Drain)	Residential	Mean, *Median	285	7.2	2.15	0.91	1.96	0.610	23.1	1023	1305	-	-	-	January 1989 - June 1995
		Mean	234	8.9	2.50	0.52	1.77	0.295	20.2	1413	1809	-	-	-	July 1995 - Feb 2007
Heathcote @ Ferniehurst	Residential	Mean, *Median	269	8.5	1.72	0.20	0.02*	0.164	61.3	837	973	-	-	-	January 1989 - June 1995
		Mean	257	8.8	1.70	0.11	1.77	0.078	22.7	1327	1726	-	-	-	July 1995 - Feb 2007
Heathcote @ Ford Road Bridge	Residential	Mean, *Median	287	8.0	1.56	0.05*	1.79	0.069	18.8	492	638	-	-	-	January 1989 - June 1995
		Mean	269	7.7	1.75	0.08	1.72	0.053	34.7	1596	3502	-	-	-	July 1995 - Feb 2007
Heathcote @ Catherine Street **(tidal)**	Residential	Mean	274	7.1	1.80	0.14	1.11	0.074	8.6	241	304	-	-	-	1994 - June 1995
		Mean	388	7.2	1.30	0.11	1.34	0.058	10.5	700	982	-	-	-	July 1995 - October 2006
Heathcote @ Tunnel Road **(tidal)**	Residential	Mean	2098	8.1	1.92	0.15	0.92	0.080	28.6	152	255	-	-	-	1994 - June 1995
		Mean	3487	8.3	1.27	0.17	1.13	0.079	24.4	708	1017	-	-	-	July 1995 - October 2006
Heathcote @ Ferrymead Bridge **(tidal)**	Estuary Inlet	Mean	11104	8.1	1.86	0.35	0.92	0.130	37.6	175	274	-	-	-	1994 - June 1995
		Mean	14462	8.4	1.34	0.35	0.93	0.115	36.2	582	802	-	-	-	July 1995 - October 2006
Styx @ Main North Road	Residential	Mean, *Median	134	9.1	0.97	0.03*	0.69	0.008*	7.0*	291	320	-	-	-	Apr 1989 - June 1995
		Mean	125	9.6	1.05	0.03	0.55	0.012	7.1	581	755	-	-	-	August 1995 - November 2006
Knights Stream @ Whincops Road	Residential	Mean, *Median	76	9.7	1.39	0.01*	<0.04*	0.006*	3.2*	-	-	-	-	-	May 1990 - May 1995
		Mean	77	9.8	1.44	0.04	0.08	0.030	15.5	-	-	0.080	0.0077	0.0021	June 1995 - February 2007
Halswell @ Sabys Road	Residential	Mean, *Median	238	8.7	0.87	0.02*	5.02	0.009*	5.0*	-	-	-	-	-	April 1990 - May 1995
		Mean	-	-	-	-	-	-	-	1650	-	-	-	-	June 1995 - February 2007
Nottingham Stream @ Candys Road	Residential	Mean, *Median	313	9.0	1.58	0.09	1.50	0.027	7.7	-	-	-	-	-	April 1990 - May 1995
Cashmere Steam @ Worsleys Road	Rural/Residential	Mean, *Median	266	8.5	1.33	0.05	1.80	0.013*	34.8	566	615	-	-	-	January 1989 - June 1995
		Mean	265	8.6	1.51	0.08	1.71	0.018	27.7	1135	1451	-	-	-	July 1995 - Feb 2007
Cashmere Steam @ Springs Lodge	Rural	Mean, *Median	288	3.3	0.50*	<0.01*	2.70	0.004*	<2*	4*	6*	-	-	-	January 1989 - June 1995
		Mean	315	1.5	1.32	0.01	3.16	0.011	10.3	6	8	-	-	-	July 1995 - Feb 2007
Styx @ Claridges Road	Rural	Mean, *Median	125	5.7	0.75	-	0.90	0.004*	<2*	32	36	-	-	-	Apr 1989 - June 1995
		Mean	121	5.2	0.66	0.02	0.87	0.009	3.2	77	97	-	-	-	August 1995 - November 2006
Smacks Creek @ Gardiners Road	Rural	Mean, *Median	135	6.2	0.87	0.01*	0.89	0.009*	2.0*	183	229	-	-	-	Apr 1989 - June 1995
		Mean	124	6.5	1.19	0.07	0.71	0.01	22.2	323	379	-	-	-	August 1995 - November 2006
Kaputone Creek @ Belfast Road	Rural	Mean, *Median	175	7.6	1.43	0.16	0.67	0.030*	6.0*	714	762	-	-	-	Apr 1989 - June 1995
		Mean	164	7.4	1.43	0.15	0.70	0.044	11.0	2908	3725	-	-	-	August 1995 - November 2006
Styx @ below Marshland Road	Rural	Mean, *Median	145	8.5	1.20	0.06	0.58	0.018*	8.6	478	436	-	-	-	Apr 1989 - June 1995
		Mean	136	8.5	1.19	0.04	0.56	0.023	8.9	747	914	-	-	-	August 1995 - November 2006
Styx @ Harbour Road	Rural	Mean, *Median	195	8.1	1.13	0.07	0.49	0.023*	2.0*	153*	146	-	-	-	Apr 1989 - June 1995
		Mean	193	8.2	1.25	0.05	0.45	0.039	7.4	282	406	-	-	-	August 1995 - November 2006
Halswell @ Branthwaites Bridge	Rural	Mean, *Median	238	8.4	1.03	0.06	3.39	0.013*	3.0*	-	-	-	-	-	April 1990 - May 1995
Halswell @ Tobecks Road	Rural	Mean, *Median	244	7.5	1.19	0.04*	2.85	0.025	15.2	-	-	-	-	-	April 1990 - May 1995
Halswell @ Hodgens Road	Rural	Mean, *Median	264	7.9	1.21	0.08	2.34	0.042	3.0*	-	-	-	-	-	April 1990 - May 1995
		Mean	262	9.1	1.42	0.08	2.26	0.062	5.5	-	-	0.024	0.0031	0.0033	June 1995 - February 2007
Avon @ Manchester Street (includes Addington and Riccarton Main Drain)	Central City	Mean, *Median	178	9.0	1.18	0.02*	1.57	0.011*	3.0*	600*	569	-	-	-	July 1991- June 1995
			163	9.7	1.16	0.03	1.17	0.013	5.1	808	1151	-	-	-	
Okeover Stream, Christchurch	University/CBD	Mean	142	8.3	-	-	2.71	-	-	-	-	0.031	0.0073	0.0018	2007
Okeover Stream, Christchurch **(during storm event)**	University/CBD	Mean	-	-	-	-	0.74	-	-	-	-	0.287	0.0301	0.0324	2007
Okeover Stream, Christchurch **(during storm event)**	Stormwater	Mean	60	8.4	-	-	-	-	38.1	-	-	0.274	0.0077	0.0173	2006
Okeover Stream, Christchurch **(during storm event)**	Stormwater	Mean	-	-	-	-	-	-	37.2	-	-	0.300	0.0093	0.0194	2006
University Carpark	Stormwater	Mean	714	-	-	-	0.28	-	26.2	-	-	0.116	0.0155	0.0054	March 2007
University Carpark	Stormwater	Mean	264	-	-	-	0.09	-	13.0	-	-	0.057	0.0062	0.0021	April 2007

These results are the latest data available at the time of writing this literature report.

NATIONAL

All measurements in g/m^3 unless stated otherwise

Site	Area	Mean/Median	Conductivity (µS)	Dissolved Oxygen (mg/L)	BOD5	Ammoniacal Nitrogen	Nitrate	Reactive Phosphorus	Suspended Solids	E.Coli	Faecal Coliforms	TKN	Total Nitrogen	Total Zn	Total Cu	Total Pb	Year
Waihou River @ Okauia (Spring-fed)	Rural	Mean	101	9.7		0.02	1.111	0.072		1785		0.25	1.36				2005
Tokaanu Stream @ Off SH41, Turangi (Spring-fed)	Rural	Mean	99	8.7		0.01	0.425	0.078		NM		0.05	0.48				2005
Ngakaroa Stream @ Mill Road, Auckland	Rural	Median	147		1	0.02	2.52	0.005	1.0	800	400						2003
Papakura Stream @ Porchester Road, Auckland	Rural	Median	180		1	0.045	0.586	0.03	2.0	6500	4000						2003
Kirikiriroa Stream @ Tauhara Drive, Hamilton	Residential (new)	Mean	177	7		0.31	0.911	0.016		5925		0.96	1.87				2005
Mangakotukutuku Stream (Rukuhia) @ Peacock Road, Hamilton	Residential (light)	Mean	190	8.9		0.29	1.081	0.225		1760		1.37	2.45				2005
Waitawhiriwhiri Stream @ Edgecumbe Street, Hamilton	Residential	Mean	181	7.9		0.67	0.789	0.05		10710		1.6	2.39				2005
Kaikorai Stream @ Green Island Bridge, Dunedin	Residential/Industrial	Mean	136	11.8	1.47	0.04	0.386	0.01	12.4	1448	1450.34		0.76				1997 - Pres
Lindsays Creek @ North East Valley Bowling Club, Dunedin	Residential	Mean	163	11.13	1.67	0.017	0.662	0.02	3.4	1284	956.43		0.90	0.016	0.0039	0.014	2004 - Pres
Owhiro Stream @ Burns Street, Dunedin	Residential	Mean	201	9.7	2.06	0.047	0.332	0.021	7.7	704	488.21		1.00				2001 - Pres
Silverstream @ Riccarton Road, Dunedin	Residential	Mean	149	11.5	0.98	0.012	0.214	0.006	5.5	207	291.42		0.40				1995 - Pres
Water Of Leith @ Dundas Street Bridge, Dunedin	Residential	Mean	140	11.79	1.19	0.025	0.452	0.019	10.9	1111	1184.5		0.72				1995 - Pres
Oakley Creek, Auckland	Residential	Median	229		1	0.045	1.61	0.02	6.5					0.041	0.006	0.01	2003
Oteha Stream @ Days Bridge, Auckland	Residential (new)	Median	208		1	0.035	0.357	0.005	9.0					0.042	0.006	0.01	2003
Puhinui Stream @ Ford, Auckland	Residential/Industrial	Median	189		1	0.045	0.642	0.013	5.6					0.054	0.006	0.01	2003
Pacific Steel, Auckland	Industrial Stormwater	Mean						0.447	124					2.785	0.075	0.226	1993
Roads, Waitakere	Stormwater	Median			8.9			0.255	114	21115	26000			0.199	0.041	0.04	2001
Auckland	Stormwater	Median												0.200	0.041	0.48	1986
Motorway, Otahuhu (90,000 daily traffic)	Stormwater	Median												0.159	0.053	0.108	Unknown
Motorway, Porirua (~50,000 daily traffic)	Stormwater	Median												0.060	0.080	<0.05	1998

INTERNATIONAL

All measurements in g/m^3 unless stated otherwise

Site	Area	Mean/Median	Conductivity (µS)	Dissolved Oxygen (mg/L)	BOD5	Ammoniacal Nitrogen	Nitrate	Reactive Phosphorus	Suspended Solids	E.Coli	Faecal Coliforms	TKN	Total Nitrogen	Total Zn	Total Cu	Total Pb	Year
Santa Clara Valley, California, USA	Industrial	Mean			13				152			1.80		1.471	0.053	0.1335	1989
Washington, USA	Older residential	Mean										7.20		0.397	0.105	0.3890	1987
Washington, USA	New Suburban	Mean			5.1							1.51		0.037		0.0180	1987
Malaysia	Urban	Mean							85					1.100	0.090	0.5000	
Oregon, USA	Commercial	Mean							92					0.168	0.032		1997
Santa Clara Valley, California, USA	Commercial	Mean			10				76			2.10		0.251	0.051	0.0608	1989
Washington, USA	CBD	Mean							36					1.490	0.370	0.2500	1987
America Urban Highway	Stormwater	Median					0.76	0.40	142			1.83		0.329	0.054	0.4000	1990
America Rural Highway	Stormwater	Median					0.46	0.16	41			0.87		0.080	0.022	0.0800	1990

Appendix B USEPA PAH List

Appendix B USEPA PAH List

Below is the list of the16 priority PAHs as identified by the USEPA.

Acenaphthene

Acenaphthylene

Anthracene

Benz[a]anthracene

Benzo[a]pyrene

Benzo(b)fluoranthene

Benzo[ghi]perylene

Benzo[k]fluoranthene

Chrysene

Dibenz[a,h]anthracene

Fluoranthene

Fluorene

Indeno[1,2,3-cd]pyrene

Naphthalene

Phenanthrene

Pyrene

Christchurch
58 Kilmore Street, PO Box 345, Christchurch

General enquiries: 03 365 3828
Fax: 03 365 3194

Customer services: 03 353 9007
or: 0800 EC INFO (0800 324 636)

Timaru
75 Church Street, PO Box 550, Timaru

General enquiries: 03 688 9069

Fax: 03 688 9067

www.ecan.govt.nz