Lincoln University
Te Whare Wānaka o Aoraki
CHRISTCHURCH • NEW ZEALAND

Lincoln University Digital Thesis

Copyright Statement

The digital copy of this thesis is protected by the Copyright Act 1994 (New Zealand).

This thesis may be consulted by you, provided you comply with the provisions of the Act and the following conditions of use:

- you will use the copy only for the purposes of research or private study
- you will recognise the author's right to be identified as the author of the thesis and due acknowledgement will be made to the author where appropriate
- you will obtain the author's permission before publishing any material from the thesis.

Assessing Urban Nonpoint Source Water Pollution in Christchurch

A Thesis in partial fulfilment of the requirements of the Master of Resource Studies degree, Lincoln University

Paul Scholes, March 1997

Abstract of a thesis submitted in partial fulfilment of the requirements

of the Degree of M.R.S.

ASSESSMENT OF URBAN NONPOINT SOURCE WATER

POLLUTION IN CHRISTCHURCH

by P. Scholes

A need has been identified for more information on the origins and impacts of contaminants to encourage moves towards preventative solutions to the problems of nonpoint source degradation of the aquatic environment. This study addresses information requirements by investigating the key nonpoint source contaminants of concern to water quality in Christchurch urban waterways, developing a ranking scheme to establish priority contaminants, and quantifying the sources of one priority contaminant. Using the Christchurch study as a template, the study also focuses on how the complex information generated on nonpoint source pollution may be effectively utilised in waterway management.

A review of historical, biological and physico-chemical data in urban Christchurch indicates that there are several degraded waterways and reveals that nutrients, heavy metal and sediments are the nonpoint source contaminants of most concern in Christchurch urban waterways. A contaminant ranking scheme is developed which incorporates the potential effects of nonpoint source contaminants on community values. A ranking scheme may provide water managers with a mechanism to prioritise monitoring or abatement.

One of the highest ranked contaminants was zinc and this metal was chosen for source analysis. Likely contributors of zinc to the aquatic environment were identified through a screening process. A quantitative assessment of the loads generated from various sources of zinc revealed that zinc is predominantly derived from tyres and zinc-clad roofing materials.

An integrated approach to analysis and management of nonpoint source water pollution is developed. Greater integration of the complex information needed to define nonpoint source water quality problems is the initial approach to qualifying the issues of nonpoint source pollution for planning and policy development. Management is facilitated by information gathering and utilisation processes that provide the justifications for pollution abatement.

Key words: nonpoint source; pollution; abatement; analysis; integrated; zinc.

ACKNOWLEDGMENTS

Numerous people helped in the completion of this thesis. I would especially like to thank Dr. Sandy Elliott for his time and effort in preparation of this thesis. Also I thank Dr. Ken Hughey for his input into the resource management component of this thesis.

A special thank you goes to Bianca Sullivan for her help in my hour of need.

Thanks to all the postgrads in DNRE who provide an atmosphere conducive to table tennis and always do their upmost to help with any problem, be it technical, theoretical or social.

CONTENTS

Page No.

FIGURES

Page No.

TABLES

Page No.

Now the stream of our common consciousness seems to be obliterating its own banks, loosing its central direction and purpose, flooding the lowlands, disconnecting and isolating the highlands and to no particular purpose other than the wasteful fulfilment of its own internal momentum. Some channel deeping is called for.

(Robert M. Pirsig from Zen and the Art of Motorcycle Maintenance)

1. INTRODUCTION

1.1 BACKGROUND

There are two classes of waterway pollution, nonpoint source and point source. 'Nonpoint' or 'nonpoint source' pollution can be defined as pollution created from diffuse sources, often entering surface waters at intermittent or irregular intervals, and often related to meteorological events. Water pollution resulting from nonpoint sources is influenced by a variety of land uses or activities as well as hydrological and geological conditions. Examples of activities that can give rise to nonpoint source pollution are the application of fertilisers and pesticides, construction, and transportation (Novotny and Chesters, 1981, p6).

Point source pollution is readily identifiable as emanating from discrete, usually single locations that are easily measurable and quantifiable. Examples of point sources are effluent emitted from industry, and sewage treatment plants (Novotny and Chesters, 1981, p6).

Several countries have found their waterways still polluted after extensive clean up efforts of point source emissions over the past 40 years (e.g. United States of America, Canada, Sweden). This led to the realisation that only one side of the water quality problem was being tackled, bringing into focus the nonpoint source pollution issue.

The focus on nonpoint source contamination primarily resulted from advances being made in controlling point source discharges, predominantly from industry and sewage. Countries like Sweden found widespread pollution of lakes and rivers, which could not be controlled by managing industrial and point sources alone. Thus nonpoint pollution studies, centred mainly on achieving a reduction in nutrient runoff, were implemented (Reinelt, Horner and Castensson, 1992). The US Environmental Protection Agency (USEPA) lists nonpoint source pollution as the largest source of water quality problems. It reported that "it has become evident that more diffuse source pollution such as agriculture and urban run-off, are important contributors to water quality problems and use, or impairment." Fifty-one States and Territories cited storm water run-off from a number of diffuse sources as the leading cause of water quality impairment (Lee and Jones-Lee, 1993).

Nonpoint source pollution of waterways in urban areas is usually associated with stormwater runoff. Novotny and Chesters (1981, p11) suggest that work carried out in the US equates the amount of pollution generated from urban areas as being of similar order as the raw sewage contribution.

Major sources of urban nonpoint source pollution include: accumulation of street rubbish, hydrocarbons, vehicle deposits, animal faecal wastes, and atmospheric fallout. Since nonpoint source contaminants by definition are diffuse in origin, revealing their sources becomes exceedingly complex. Previous research in this area has revealed that the origins of nonpoint source contaminants, and the contaminants themselves, have a wide spatial distribution, often linked to land-use (Novotny and Chesters, 1981; Thompson, 1983; Roesner and Hobel, 1992; James and Whitman, 1995).

Identification of specific pollutant origins is necessary if effective management strategies are to be formulated to restrict nonpoint source pollution. Pollutant identification allows development and justification of mitigation strategies and leads to more effective abatement. Hence delineation and quantification of nonpoint source contaminants is one of the areas of environmental information that provides environmental managers with a better understanding of nonpoint source pollution problems.

New Zealanders agree that environmental protection is an urgent and immediate concern. This is reflected in the Ministry for the Environments (MfE) 'Environment 2010 Strategy' (1996(c)) in which the management of New Zealand's water resources and the management of pollution are recognised as two priority environmental issues. Webster and Gold (1989) listed damage to rivers, lakes and coastal waters as New Zealanders' third highest environmental concern. The extent of water quality problems associated with nonpoint source pollution found overseas (see above) may indicate what is in store for New Zealand if this form of pollution is ignored. Possible effects of nonpoint source pollution are eutrophication, loss of biodiversity, loss of potable water, health hazard, and loss of other beneficial water uses.

Waterways play a significant role in Christchurch's urban environment in terms of economic, cultural, recreational and amenity value, and by adding to the city's tourism value. Three waterways predominate in the urban environment (see Figure 1.1). These are the Avon-Heathcote estuary, the Avon River, and the Heathcote River. The Christchurch City Council (CCC) recognises issues involved in the contamination of stormwater run-off and anticipates enhancement of aquatic life through policies which serve to mitigate the effects of stormwater run-off and through control of land use activities. The CCC also recognises that these sources need to be identified to reduce the risk of further contamination (CCC, 1995).

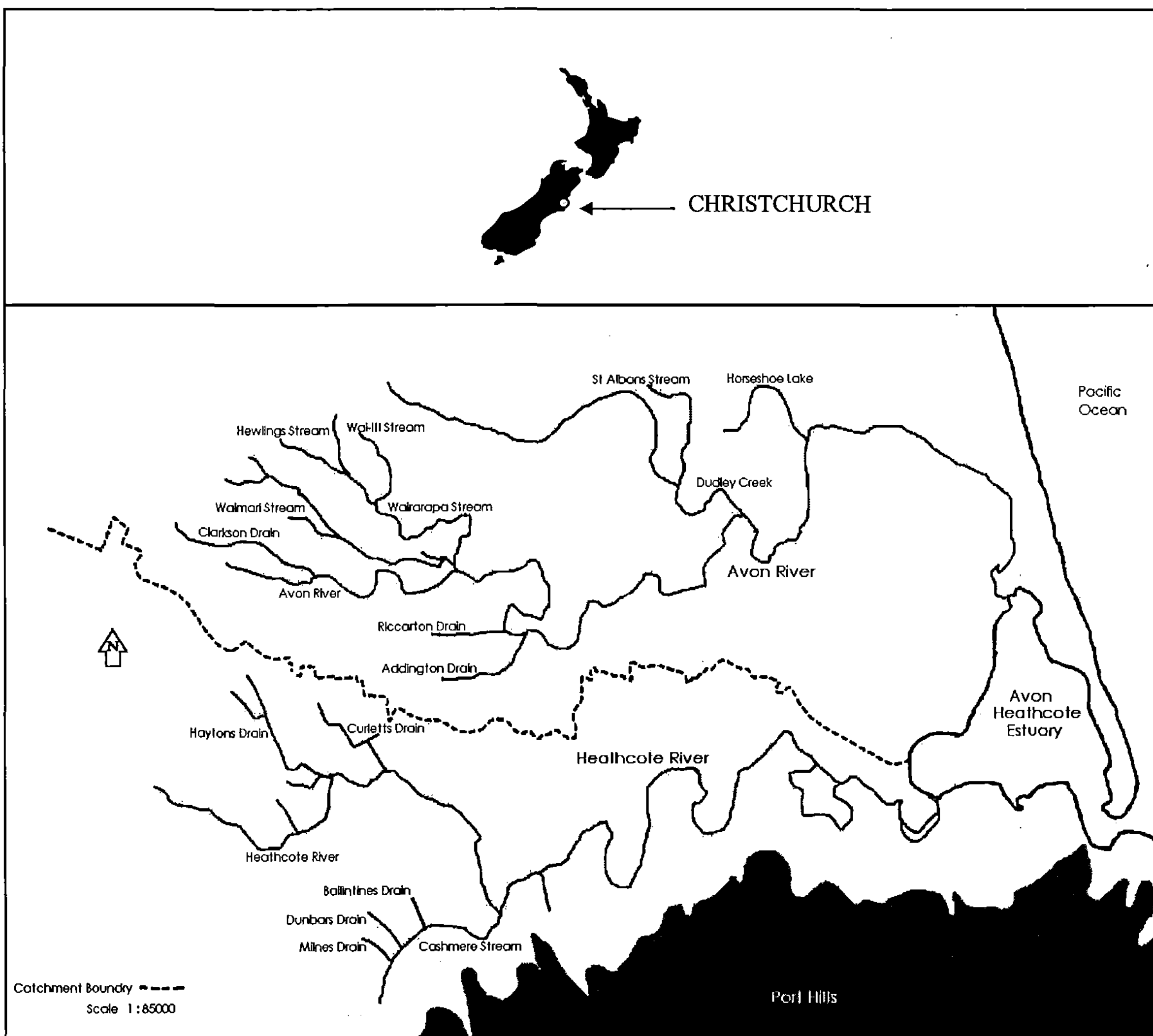

Figure 1.1. Christchurch urban waterways location map.

Little attention has been focused on the actual sources of nonpoint stormwater pollution. Most studies opt to determine contaminant quantities present in stormwater without qualifying their specific origins. Such studies infer that impervious areas (residential, commercial and industrial), transportation, and aeolian (wind blown) components are the main contributors to nonpoint source pollution (Roesner and Hobel, 1992; Prey, 1994; Novotny and Chesters, 1983).

The approach usually taken in recent stormwater quality control programmes, once stormwater pollution is identified, is to treat stormwater through engineered treatment works such as stormwater treatment ponds. While this approach can significantly reduce the impact of contaminants in the system it is not clear whether such controls are adequately alleviating surface water contamination. Such interception measures in stormwater management fail to deal directly with contaminant origins, that is, those sources in the urban environment directly responsible for nonpoint source contamination.

Nonpoint source pollution is evident in Christchurch urban waterways but it is an issue not adequately addressed by current management strategies. To be able to implement policies that reduce or control the contaminants generated from the sources of nonpoint source pollution, firstly requires sound information on those sources, the quanities produced from them, and their effects on waterway ecology. To be of further use to pollution abatement planning, information gathered on nonpoint source pollution should be in-line with waterway management objectives.

By exploring the existing historical, biological and physico-chemical data on Christchurch urban waterways this thesis will attempt to identify the key nonpoint source contributors to waterway degradation. Once this is achieved, this information will help to delineate a broader scope of planning tools to help alleviate or identify nonpoint source surface water pollution.

Thus this thesis through identification and quantification of urban nonpoint source pollution in the Christchurch urban environment outlines the information considerations necessary to initiate targeted pollution abatement options.

1.2 AIMS AND OBJECTIVES

This thesis investigates the effects and sources of urban nonpoint source surface water pollution. An assessment of nonpoint source pollution in urban Christchurch will provide the initial focus to find the information necessary for justifying nonpoint source pollution abatement. Greater delineation and quantification of the origins of urban nonpoint source contaminants may initiate more targeted preventative pollution control options. Consequently, providing waterway managers with comprehensive environmental information on nonpoint source issues enlarges the scope of nonpoint source pollution abatement strategies. Information such as provided by this investigation may provide the justification society needs to take the initiative and eliminate contaminants before they arrive in waterways. The aim of this investigation is:

> *To review and quantify the origins of key nonpoint source contaminants of concern in Christchurch waterways, and to establish a framework for incorporating nonpoint source pollution issues into waterway management.*

The following specific objectives will need to be addressed:

1. Review existing research and information on Christchurch waterways, to ascertain which key contaminants are, or are likely to be a pollution concern.

2. Develop an inventory of sources of key nonpoint contaminants and estimate the relative contribution of these sources to the contamination of Christchurch waterways, i.e. from readily identified origins, quantify key contaminants from impermeable surfaces (primarily corrosive and less durable building materials), transport (vehicle emissions and general vehicle wear) and other miscellaneous sources.

3. Investigate integrating information considerations identified through a Christchurch case study into water management and planning, with a view to providing a greater range of nonpoint source pollution abatement options.

1.3 OVERVIEW OF THESIS

In attempting to achieve the thesis objectives, this investigation will introduce the reader to the issues facing nonpoint source abatement and water quality in the urban region. The reader will be introduced to the problems of assessing aquatic environmental quality in the urban environment, the mechanisms used to measure environmental quality, and the associations between nonpoint source contaminants and degradation of the aquatic environment in Chapter 2.

Chapter 3 examines these issues in the context of the Christchurch urban environment. The Christchurch case study provides a focus by which the issues surrounding water quality protection can be illustrated in a New Zealand context. It also identifies contaminants of concern to water quality in Christchurch, the initial step in outlining waterway impairment and contaminant abatement.

Chapter 4 provides a more intense focus on nonpoint contaminants of concern in urban Christchurch's urban aquatic environment. It does this by way of a prioritisation mechanism which couples community perspectives with contaminant exposures to provide an impact ranking for contaminants.

In Chapter 5 sources of a priority contaminant are assessed. An inventory of sources emitting the contaminant is established and the contribution of each source is quantified.

Chapter 6 draws on the previous chapters to outline a range of information generation and management processes that can be adopted to define and assess nonpoint source water pollution. These are discussed with respect to their incorporation into the decision-making process.

Conclusions are presented in Chapter 7.

2. LITERATURE REVIEW: RELATIONSHIP BETWEEN URBAN AQUATIC DEGRADATION AND NONPOINT SOURCE CONTAMINATION

2.1 INTRODUCTION

Previous studies have tried to gain a better understanding of the contents of urban runoff and its impacts on receiving waters (Sartor and Boyd, 1975; Whipple, Berger, Gates, Ragan and Randall, 1975; Pitt, Field, Lalor and Brown, 1995). Such studies have examined complex interactions of physical, chemical and biological systems (Figure 2.1). Two of the largest studies have occurred in North America. One focused on agriculturally and urban derived contamination in the Great Lakes Region of North America (Novotny and Chesters, 1981) and the other on urban runoff in US cities (USEPA, 1993).

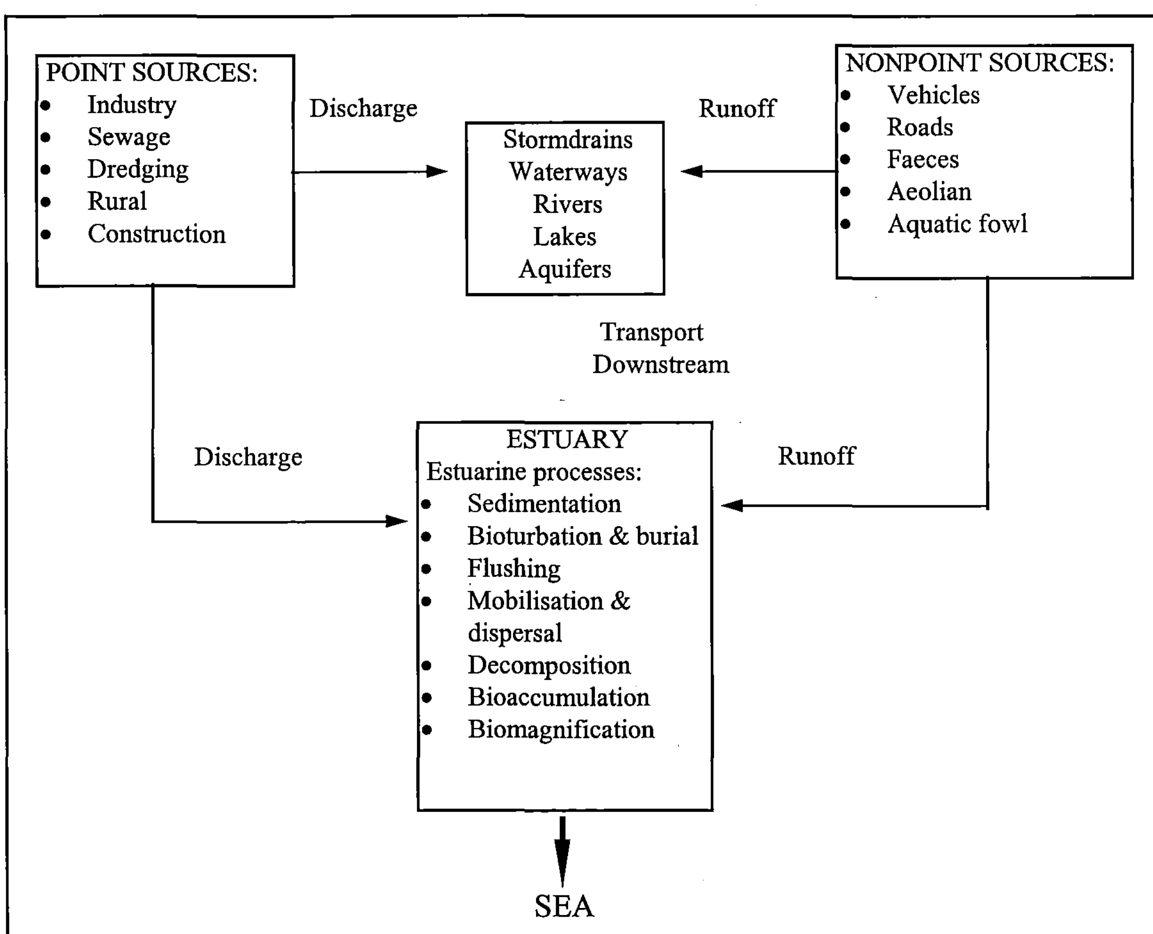

Figure 2.1. Possible flow of point source and nonpoint source contaminants in urban waterways.

The investigation into pollution of the Great Lakes in the early 1970s found detrimental effects from nonpoint sources. Contaminants found to be adversely effecting the lakes were phosphorus, sediments, industrial and agricultural organics, and some heavy metals (Marsalek, 1990).

Between 1978 and 1983 the US Environmental Protection Agency (USEPA; 1983) funded an investigation into urban nonpoint source pollution of waterways. Called the National Urban Runoff Program (NURP) it covered 28 cities and consistently found several contaminants in urban runoff. The most prevalent contaminants found were heavy metals, especially copper, lead, and zinc. Less commonly detected heavy metals were arsenic, cadmium, chromium and nickel. Other contaminants found included 63 organics, high levels of coliform bacteria, nutrients, oxygen demanding substances (oil, grease, organic matter), and suspended solids.

To understand the connections between nonpoint source contaminants and the aquatic environment requires the exploration of the physical, chemical and biological parameters and processes that combine to support healthy ecosystems. Establishing how contaminants collectively or singularly act to degrade these systems is of particular relevance if the possible mitigation measures of this form of pollution are to be adequately addressed and justified in the public arena.

2.2 ASSESSING QUALITY OF URBAN WATERWAYS

2.2.1 Urbanisation Effects

Generally, urbanisation leads to alteration of the landscape and morphology of the drainage network. Changes to the drainage system can result in ecosystem stress or loss. Alterations can include changes to flow regimes, altered organic contributions, disease, competition, addition of introduced species, alteration of biotic interactions (Karr, 1992). The extent of the change will depend on the type, size, and designated beneficial use of the waterway. The aquatic ecosystem will reflect these changes.

Changes in the physical aspect of the waterway, the allochthonous material that it receives, its chemical processes, or the amount of sunlight it receives, contribute to habitat alteration.

Measuring or assessing these alterations can be relatively straightforward (e.g. measure water temperature, flow rates). However, establishing the factors responsible for observed deterioration of the aquatic environment is not easy.

Physical alteration of a catchment by human development changes the amounts of chemicals and nutrients delivered to the aquatic environment. A variety of contaminants produced from anthropogenic actions will be added to background chemicals and nutrients.

These transformations may make it difficult to ascertain a waterway's characteristic biological, chemical and physical state. Urbanisation makes it difficult to define what an aquatic ecosystem should consist of, its 'natural state'. The natural state of New Zealand's waterways could be defined as pre-European or perhaps pre-Maori impact. More realistically an assessment could be based on the chemical, physical and biological components needed to sustain a healthy aquatic environment.

To do this it is first important to establish what defines 'environmental health' or 'environmental quality' in a waterway. This will support a clearer concept of the requirements of the aquatic environment. It will also assist defining and measuring goals and/or objectives regarding the well-being of the aquatic environment, and the policies or mandates recommended to achieve these goals (Chapter 6).

2.2.2 Environmental Health

All New Zealand ecosystems are now recognised for their intrinsic values and native components by the Resource Management Act 1991 (RMA). This legislation has developed from the reckoning that the integrity of the biosphere is dependant on ecosystem sustainability (Wilson and Harris, 1991). Hence environmental health should be considered the central component when striving towards ecosystem sustainability.

The RMA was implemented to promote 'sustainable management' of natural and physical resources and provides a working definition of 'sustainable management' (Appendix 1). In defining policies for a sustainable environment, the emphasis can be biased towards either ecologically based criteria or social and/or cultural wellbeing through economic productivity (Haskell, Norton and Costanza, 1992). Ecologically based criteria are designed to protect ecosystems while social and/or cultural wellbeing through economic productivity protects society. The task of resource managers, future and present, is to find the balance between these two poles in the interests of ecosystem health. If ecosystem protection is ignored for too long in favour of societal resource use there exists a danger of ecosystem and species destruction.

To distinguish or define an ecosystem as healthy or impoverished requires a definition that recognises the dynamic nature of ecosystems, moulded by natural and anthropogenic processes. Haskell *et al.* (1992) provides such an operational definition:

> *An ecological system is healthy and free of "distress syndrome" if it is stable and sustainable - that is, if it is active and maintains its organisation and autonomy over time and is resilient to stress. "Distress syndrome" concerns irreversible system collapse.*

Thus, a biological system can be considered healthy when its innate potential is realised, minimal management input takes place, it has a stable condition, and has capacity for self-repair from stochastic disastrous events (Karr, 1992). Karr suggests to assess biological integrity a number of criteria encompassing the elements and processes of biological systems be used. In this sense the biological integrity of waterways would be maintained by the sum of chemical, physical, and biological components.

Defining the nature or extent of environmental degradation is hampered by the lack of attributes to measure biological conditions (Karr, 1992) and the paucity of knowledge on ecological systems. Thus, defining water quality has often relied on the use of physico-chemical indicators.

Many problems are apparent when ascertaining an ecosystem's state of health. Biological systems are extremely complex and our ecological knowledge is far from complete. The next section takes a brief look at common water quality tools available to water quality scientists and managers, used to determine aquatic ecosystem health. This is a vital stage in ascertaining if waterways are being effected by pollutants.

2.2.3 Water Quality Assessment Tools Used In Aquatic Ecosystem Protection

Verifying the condition of an ecosystem depends upon the combination and quality of information provided by measuring environmental parameters (biological, chemical and physical).

Most water quality tools suffer from numerous problems making their selection a complex task. Lack of understanding about which qualities of the environment are important can lead to problems in selection of water quality tools.

Two approaches can be used to ascertain a waterway's environmental quality:

1. comparison of measured physico-chemical parameters with physico-chemical water quality criteria or standards (e.g. pH, heavy metals); and/or
2. assessment of parts of an ecosystem's biological composition and/or comparison with previous assessments or other locations.

Criteria or standards are usually developed from scientific experiments or based on scientific principles. For example, toxicity tests use bioassay procedures to test organisms under controlled conditions to ascertain a relevant endpoint, such as mortality, reduced fertilisation or growth. They provide a reference point to which a measured quantity can be set against. Hvitved and Jacobsen (1986; cited House *et al.*, 1993) provide the following definition of criteria:

> *A water quality criterion represents ideally a concentration of a substance which results in a certain degree of environmental effect upon which scientific judgement may be based. For practical purposes a criterion means a designated concentration of a substance that, when not exceeded, will protect an organism, a community or a prescribed water use or quality with an adequate degree of safety.*

Criteria can also be developed from indicators that are sensitive to ecological change. Environmental indicators as yet have no standard definition. Below are a few definitions provided by the MfE/Department of Statistics (1991):

- *an element, or group of elements, which furnish indirect information concerning the state of an ecosystem and its evolution. For example, the energy balance of a system is an indicator;*
- *a variable used to identify the presence or condition of a phenomenon that cannot be measured directly;*
- *a measure of the welfare of the system under study.*

Standards are formed when criteria are adopted by a regulatory agency as policies or rules. Another form of standard recently introduced into New Zealand environmental reform is 'environmental bottom lines'. The MfE (1994) defines these as:

> *the thresholds below which ecological systems suffer irreversible damage, for example the reduction of water flows in a river to such a level that river ecosystems will not fully recover. It is also recognised that such thresholds are difficult to scientifically ascertain.*

Environmental bottom lines have a similar use to other environmental criteria, but can undertake a wider role in policy implementation or evaluation. In defining objectives or goals, 'environmental bottom lines' can outline the "boundaries or limits beyond which there is a high risk that the quality of the environment will be unacceptably degraded" (Brash, 1992).

Indices or index numbers refer to a condensed measure of several quantities or qualities related to an ecosystem. Numerical values delineated by an index can then be used to determine the trends and norms in ecosystem functioning. Indices may indicate a change in circumstances such as changes in species assemblage. Environmental indices have been used to monitor aspects of environmental quality ranging from water pollution to amenity aesthetics. One example used in New Zealand is the macroinvertebrate community index (MCI) developed by Stark (CCC, 1992). The MCI system involves allocating scores to taxa, with pollution-intolerant taxa gaining higher scores than pollution-intolerant taxa.

Combining water quality information ascertained from water quality assessment tools gives insight into the causes of impairment in Christchurch urban waterways (see Chapter

3). This may help to establish the extent of pollution and may build a picture of the causes and effects of waterway degradation. For example, data from 5 cities in the USA found urban streams to be grossly polluted by sediments and toxicants. In that study such conclusions could not have been reached without a combination of chemical analyses and biological analyses (e.g. biotic indexes) (Pitt *et al.,* 1995).

2.3 PROBLEMS IN ASSOCIATING NONPOINT SOURCE CONTAMINANTS WITH AQUATIC DEGRADATION

Establishing causal links between environmental data (e.g. pH, dissolved oxygen, diversity indices) and contaminants is an important step in ascertaining if, and what, urban nonpoint source contaminants are responsible for aquatic degradation.

Numerous studies have implicated urban runoff as a probable cause of degradation in the aquatic environment (Bradford, 1972; Baffor, Boyd and Agardy, 1974; Laxen and Harrison, 1977; Novotny and Chesters, 1981; EPA, 1983; Novotny *et al.*, 1985; Stotz, 1990; Linforth, Vorreiter, Constandopolous and Beddeph, 1994; Pitt *et al.*, 1995). However, these studies rarely provide direct evidence of a link between nonpoint source pollutants and deleterious effects to the aquatic ecosystem.

Linforth *et al.* (1994) in an investigation of sources and effects of major pollutants in Sydney stormwater fail to connect contaminants (faecal coliforms and nutrients) measured in stormwater with any deleterious effects on the aquatic environment. Consequently, elevated levels of contaminants measured in stormwater or the receiving environment may be deemed pollutants while they may have little of no adverse impact on the aquatic environment. Basing nonpoint pollution controls on the assumption that elevated physico-chemical levels are of environmental concern can waste limited resources and erode public support for abatement. It can also lead to researching causes that are not related to the effects.

Karr (1992) levels some criticism at water managers for predominantly focusing on chemical contamination, rather than biological effects. While this may be a valid point, Karr fails to acknowledge the great complexity of aquatic pollution problems when nonpoint sources are considered.

Lee and Jones-Lee (1993) have some sympathy with Karr's criticism, based on the few documented cases of toxicants causing impairment of beneficial uses of water. They argue that toxic materials (e.g. heavy metals, synthetic organics) actually rarely cause impairment of the beneficial use of waterways. However, some authors have found urban stormwater to have a strong heavy metal component.

Heavy metals within the urban environment predominantly stem from anthropogenic activities (apart from background concentrations), many of these being diffuse in nature. Unlike pervious areas no infiltration capacity is required to initiate runoff and thus small rainfall events can result in highly concentrated loads charged with a variety of heavy metals. Although other contaminants are present in runoff from impervious areas heavy metals are often the dominant contaminant in urban impervious runoff.

Several overseas studies have gauged heavy metal concentrations from nonpoint sources. The USEPA (1984; cited Wanielista and Yousef, 1995, p160) found that 57% of lead, 41% of copper and 70% of zinc were derived from nonpoint sources. Bannermann *et al.* (1993) and Prey (1994) collected rainfall runoff samples from various surfaces. Streets, parking lots and roofs were found to be critical source areas for heavy metals.

In the United States, where Lee and Jones-Lee operate, the emphasis of investigations on toxic or carcinogenic contaminants, namely heavy metals, may be a result of the National Pollution Discharge Elimination System (NPDES) program's push for contaminant reductions within limited time periods. This can force permit holders in the NPDES program to eliminate or reduce contaminants that may not have any adverse effects on the beneficial use of waterways at a huge cost.

Lee and Jones-Lee (1993) further question whether comparison with stringent standards based on acute toxicity give a true reflection of the state of an aquatic environment. However, if standards become too lenient, water body goals will not be achieved, and if discharge standards cannot be met due to standards being too rigorous they will be considered impractical and ignored (Australian and New Zealand Environment and Conservation Council (ANZECC), 1992).

Pitt, Field, Lalor and Brown (1995) found that stormwater contaminants can lead to water quality problems, although they do concede that acute toxicity effects in the water column are uncommon. More likely is that urban receiving waters are impaired by contaminants over an extended time, predominantly from contaminated sediment.

Why is it that stormwater toxicants in the short term do not often cause beneficial use impairments even though water quality criteria are not met? One of the problems in attempting to answer this question arises from the complexities associated with aquatic chemistry and aquatic toxicology. Potentially toxic or carcinogenic contaminants persist in several different forms or states. These forms are either toxic (available) or non-toxic (unavailable) to the aquatic ecosystem. Most authors agree that when the chemical form is associated with particulate material contaminants are generally less toxic. When associated with particulate or organic material the contaminant has to exert its effect through digestion of the sediment (Williamson, 1993).

Although contaminants coupled with particulate matter may initially be non-toxic, they may represent a future threat to the aquatic ecosystem as physical and chemical conditions change. Particulate contaminant forms can be introduced to the benthos environment through binding to sediment and organic matter, which settles on the waterway bed, or by hydraulic and gravitational forces. Once sediments are infiltrated by contaminants they can pose a significant ecological threat. The structure and health of the benthic and other aquatic communities can be impaired through resuspension of contaminants which may then exist in a more available form (USEPA, 1996).

Lee and Jones-Lee (1993) point out that while water quality numeric criteria are often exceeded, water quality criteria are usually based on total concentration of the representative contaminant. Hence, Lee and Jones-Lee (1994) find that structural stormwater control devices are being considered based on a "laundry list of chemical concentrations." Water quality is being judged on single numerical criteria that gives no actual data on the fluctuations, forms and intensities of contaminants.

Most toxicity standards are formulated predominantly from laboratory experiments. A laboratory simulation often uses a constant dose of toxin or mixture of toxins to measure the lethal or sub-lethal responses of test organisms (House *et al.*, 1993). This is markedly different than *in-situ* waterway situations where contaminants exposure, duration and availability can fluctuate dependant on event intensity, form of contaminant, pH, temperature, or water hardness, rendering a significant proportion of the contaminant unavailable.

One general assumption is that organisms can be exposed to higher concentrations of contaminants without detrimental consequences when exposure is of a shorter duration (Lee and Jones-Lee, 1994). Even highly toxic forms may be available for a brief period without detrimental effects.

This is dependant on the dilution effects and 'assimilative capacity' (see below) of the water body and organisms. The contaminant's environmental distribution and ecosystem availability will be determined by the physico-chemical form of the contaminant. Dilution will also affect the impact of the contaminant on the water body (Laxen and Harrison, 1977). However, only small amounts of contaminant are needed to affect function, efficiency and composition of organisms at the lowest trophic level. Novotny and Chesters (1981, p27) cite an example of heavy metals in trace measures effecting algal species resulting in disruption of the food web.

Evidence is compounding on intermittent contaminations having deleterious effects on aquatic organisms (House *et al.*, 1993). Such effects are not usually encountered in standard laboratory tests and can range from delayed mortality numbers to reduced respiration productivity (as noted in the freshwater shrimp example above).

However, it is suggested that water quality criteria should be less stringent when episodic discharges are involved (Mancini and Plummer, 1986). This is in accord with the recognition of surface waters having some ability to process, adapt, and/or endure contaminants. Known as 'assimilative capacity' it is primarily the breakdown and/or utilisation of effluent materials by bacteria, fungus and other organisms (e.g. macroinvertebrates). Water bodies generally have a large 'assimilative capacity' for biodegradable organic material and nutrients (Novotny and Chesters, 1981, p27). For many heavy metals and carcinogens this capacity is usually small or non-existent, with the ecosystem more likely to tolerate these rather than assimilate them.

High concentration effects, dilution and acclimatisation in urban discharge have been noted in a study by Adams and Pratt (1983). Immediately downstream from a discharge point macroinvertebrates have been limited and heavy metal sediment concentrations are high. With increasing distance downstream species increase, the habitat becomes more diverse, and aquatic macrophytes and heavy metal sediment contamination declines.

The use of organisms that better reflect the total mixture of contaminants and/or physical changes in the aquatic environment can better facilitate toxicity testing. Ecotoxicological studies often utilise benthic macroinvertebrates in a role of environmental response organism.

Segar and Milne's (1990, cited House *et al.*, 1993) study of an *in-situ* test is a good example of stormwater runoff impairing beneficial use of a waterway, with a cause and effect isolated in the study. Segar and Milne assessed stormwater toxicity using freshwater shrimp, *Gammarus pulex.* Acute effects increased 42% after a series of runoff events compared to freshwater shrimp in water unaffected by urban runoff.

This examination of the problems of using physico-chemical parameters to implicate stormwater runoff as a cause of waterway degradation highlights the difficulties water managers must face in protecting aquatic ecosystems.

Studies of urban runoff and urban receiving waters have tried to correlate urbanisation and/or land use with degradation of urban receiving waters. While heavy industrial areas and construction activities are often related to adverse effects in the aquatic environment, no consistent pattern concerning nonpoint contaminants emerges. To adequately assess contaminant contributions from an origin or source area to water pollution can only be of direct relevance to one specific locality.

2.4 CONCLUSION

To ascertain the effects of nonpoint source pollution on urban waterways it is first necessary for a planning authority to establish water quality objectives - the attributes that define the environmental health of a waterway.

Determining the detrimental effects of nonpoint source contaminants on aquatic ecological health may be achieved by assessing biological criteria or with physico-chemical water quality guidelines. However, both biological and physico-chemical methods of assessment have constraints and uncertainties. Hence a combination of analyses (chemical and biological) may help ascertain if nonpoint source contaminants are a threat to aquatic ecosystem health.

With respect to contaminant input, a surface waterbody's response to contaminant input will be 'site specific'. The response will be dependant on the nature and strength of contaminants, the ecosystem constitution, meteorological conditions, the physico-chemical state of the water body, and the type of water body and the physical mechanisms at work within that body.

The complexities of determining the effects of nonpoint source contaminants in the urban aquatic environment lends some credence to advocating pollution prevention. Thus looking at shifting methods of contaminant reduction from structural source controls to source controls that limit contaminants at their origins, before they enter the urban drainage system, is the underlying theme of this thesis. This is discussed further in Chapter 6.

3. JUSTIFYING NONPOINT SOURCE CONTAMINANT ABATEMENT IN CHRISTCHURCH URBAN WATERWAYS

3.1 INTRODUCTION

This chapter examines whether degradation is occurring in Christchurch urban waterways, and if so, whether nonpoint source contaminants are contributing to degradation. To determine the impacts nonpoint source pollutants may be having on waterway ecology three waterbodies in the Christchurch urban region are examined. Environmental quality data, biological surveys, monitoring information, and historical reports form the basis of a quantitative and qualitative assessment of the aquatic environment. Waterbodies reviewed are the Heathcote and Avon Rivers, and the Avon-Heathcote Estuary.

An understanding of the historical and present environmental health of Christchurch urban waterways will help determine to what extent degradation is occurring. This chapter also examines the correlation between contaminants and degradation to ascertain if there are any causal relationships. Finding the relationship between waterway impairment and nonpoint source contaminants would provide justification for abating nonpoint source contaminants.

For greater detail on biological and chemical components of Christchurch water quality refer to Appendix 2.

3.2 HISTORICAL REVIEW

The aim of this historical review is to provide information that may aid in determining whether or not Christchurch urban waterways are degraded. By helping to interpret present environmental health of aquatic ecosystems, historical data may reveal if present impairment is the residual effects of past activities or of present nonpoint source contamination. This may help determine nonpoint source origins and eliminate point source effects. For example, sedimentation from past episodes in Christchurch history may have been the predominant reason for the loss of certain benthic invertebrates. The historical causes of reduction in benthic invertebrates may parallel present causes of effects.

Historical information may also reveal the quality of the aquatic environment that may be achieved if maintenance and enhancement of the aquatic environment is maintained and improved.

3.2.1 Avon and Heathcote Rivers

Recorded history of the Avon has been traced back to 1847 by Lamb (1981). Edward Ward's diary captured the quality of the River around that period:

> *The water was cool and clear as crystal - most delicious to taste. I never enjoyed bathing so much, for I think I never had been so weary, hot and thirsty.*

The first pollution scare occurred when Christchurch Hospital was found to be emptying its wastes into the river. This prompted a review of Christchurch water supplies by the city surveyor. It was recommended that the Avon not be used for water supply purposes as it was "impregnated with vegetable matter." By 1866 Christchurch had artesian water to drink and dumping wastes into the Avon was recommended practice. Continued discharge of domestic slops and sewage was practiced into the 1920s.

Water tested in 1877 was reported as "pure and wholesome" (Lamb, 1981), the inference being waste could be continually discharged into the river unabated and without deleterious effects.

A survey of the river in 1887 found only occasional places free from siltation, revealing that most of the river bottom was covered in mud from 1 to 4 feet thick. Pooling precipitation was seen to drain within half an hour of falling due to efficient Christchurch drainage, taking with it large amounts of solid matter. Urbanisation was seen as the cause of increased sediment runoff.

Reports of fish numbers centre on the Acclimatisation Society's success in hatching brown trout in 1870. Continued fish releases resulted in anglers making large catches until the 1880s. Donne (1927; in Lamb 1981) recounts the Avon as a good trout fishery. Parrot

(1929; in Lamb 1981) also reports on the Acclimatisation Society trout releases, his dissection work revealing the stomach contents of trout to be mostly caddis larvae.

By 1955 trout sizes and takes were greatly reduced. Some observers equated this with disappearances of aquatic larvae, primarily larvae of the caddis fly. Changes in riparian vegetation that provided food and shelter for the caddis fly are blamed for the reduction. Also observed was a layer of silt instead of gravel composing the river beds, decreasing the growth of a film of plant material such as a caddis fly would utilise.

The Fish and Game Council (previously the Acclimatisation Society) have more recently released salmonoids into the Avon and Heathcote Rivers. The release of catchable trout in 1977 was followed by the release of chinook salmon in 1980 as a publicity stunt in light of Dunedin's salmon success (*pers comm.* Bruce Ross, Fish and Game Council). No establishment of these fish has been recorded. In the late 1980s trout ova were released into the Wirarapa tributary.

Watkins' (1989) history of the Heathcote County Council attests to a similar history for the Heathcote River. The environment changed from the more familiar flax lined banks to watercress which clogged the river, possibly fuelled by nutrients from human and animal excrement.

Effluent discharged by Christchurch City via the Ferry Road Drain added to the problem. The problem was notified in 1914, but it took to 1932 to connect the Heathcote suburbs to the Christchurch sewage system.

Industries located close to the estuary produced soap, candles and performed lime-burning, woolscouring, meat processing, tanning, and fat-rendering. Industrial pollution was tolerated until 1911 by local authorities, although frowned upon by ratepayers. In 1917 the Christchurch Drainage Board secured an injunction to prevent further discharges into the river.

The bed of the Heathcote River was originally shingle and sand populated by abundant invertebrates, bullies, galaxids, and trout. A marked decrease in species has been observed with the most notable period of deterioration occurring from 1956 to 1968 (Watkins, 1989).

3.2.2 Avon-Heathcote Estuary

When Europeans first started settling the Christchurch region they found a broad wetland pitted with shallow lakes, traversed by the meandering Avon and Heathcote Rivers.

The vegetation around the margin of the estuary was removed and the area landscaped to accommodate residential dwellings (CCC, 1992(c)). This change, along with the city effluent and silt pouring from the rivers, marked a period of transition in the estuary.

Formed from sand dunes in 1883, the Bromley sewage farm filtered sewage through sand before discharging it into the estuary. From 1880 to 1925 industrial pollution was another addition to the estuary via discharge into the rivers. Contaminants included arsenic, copper, chromium, iron, lead, nickel, zinc, acids, alkalies, tars, oils, and sulphur compounds. Some areas were reported to have been so polluted that all vegetation was decimated. Sediment cores identify these periods of severe pollution and attest to the large amounts of silt pushed down the rivers, encouraged by river sweeping (CCC, 1992(b)).

Bromley had a two stage treatment system in 1962. By 1970 almost all industrial effluent and sewage was being treated at Bromley, but it was not until 1981 that effluent containing phenols, tars, and oils from the Gas Works ceased to be discharged into the estuary (CCC, 1992(c)).

The influence to flora and fauna in the estuary is best documented through the reduction in eel grass (*Zostera nera*) and the shrimps and fish that utilised it. Increasing mud and silt swamped the grasses providing a substrate only suitable for burrowing organisms and algae. Mud and silt contributed to the rapid demise of eel grass and the loss of a vital niche.

Eel grass started re-establishing in the late 1950s as the Bromley operation expanded and suspended colloid matter decreased giving rise to more stable tidal flats.

An influx of nutrients from the Bromley sewage farm was marked by growth of the microorganism, *Euglena.* Several studies report the distribution of this single cell organism (Thompson, 1929, Bruce; 1953; Knox and Kilner, 1973) that thrives on decomposing wastes, reducing oxygen levels often producing hydrogen sulphide. Increased sewage effluent also produced other algal blooms such as sea lettuce and *Enteromorpha.*

Bruce's (1953) study on pollution in the estuary observed that fauna were more abundant with increasing distance from the effluent source (Bromley sewage farm). All the fauna that were observed by Thompson (1929, in Bruce, 1953) are still represented in the estuary including an increase in bird life associated with the increased productivity in the estuary.

Sediments have been polluted from previous periods of unrestricted industrialisation. Sediment quality has been experiencing a period of recovery since most industrial effluents were removed from the rivers and estuary in 1972 (CCC, 1992(c)).

3.2.3 Summary of Findings of Historical Review

Several conclusions on the present state of the Avon and Heathcote Rivers' health and nonpoint source contaminants' role in this may be deciphered from a historical review:

- decades of pollution from point and nonpoint sources have altered the ecology of the rivers and estuary;
- the effects of changing land uses have altered the ecology and geomorphology of the rivers and estuary;
- silt is a nonpoint source contaminant that has historically taken its toll on the river ecology and could have similar implications in the present aquatic environment (e.g. impacts on benthic invertebrates and trout);
- excessive silt build-up in parts of the Avon and Heathcote Rivers may reflect past conditions rather than present silt input;
- excess sediment has degraded estuarine ecology, probably as a result of river sediment and colloidal material from the sewage works;
- decline in trout numbers could be related to several factors - deteriorating water quality of river habitats, changing food sources and/or substrate;

- Avon and Heathcote River water quality was acceptable for drinking and bathing, a quality that may present an aim for future waterway management.

3.3 BIOLOGICAL ASSESSMENT

> *Proper management requires understanding of pattern and processes in biological systems and development of assessment and evaluation procedures that assure protection of biological resources. That assessment must include biological monitoring. This can often be controversial in water resources management.*
>
> Karr, 1986.

3.3.1 Method of Review of Biological Information

This section reviews available biological information to reveal occurrences of waterway degradation based on the state of ecosystem health. Ecosystem health is assessed on integrity of individual organisms (e.g. growth rate) and/or changes in population assemblages (diversity or composition).

The previous chapter (Section 2.2) elucidates the aspects that comprise a healthy ecosystem and tools used to assess this. These tools and further analyses are used in an attempt to establish the state of the aquatic habitats and assess if these habitats contain organisms capable of maintaining a balanced, integrated and adaptive community structure and function (Karr, 1986). This may also help reveal what causes changes to the integrity of aquatic ecosystems.

3.3.2 Freshwater Biological Impacts

3.3.2.1 Invertebrates and Periphyton

From the studies by the Christchurch Drainage Board (CDB; 1980), the CCC (1992(b), 1994(a)) and Suren (1993) the predominant effect noted in the freshwater tributaries and drains of the Avon and Heathcote Rivers has been a temporal change in composition of invertebrates.

The application of Stark's macroinvertebrate community index (MCI) to the 1980 and 1989-91 invertebrate surveys found a general decrease in scores possibly indicating a change to more pollution tolerant species (Appendix 2). Invertebrates indicative of moderate to fast flowing waters and low sedimentation appear to be succeeded by invertebrates more tolerant of pollution, and characteristic of slower waters and increased sedimentation (CCC, 1992(b), 1994(a); Suren, 1993). Reduced flow has been observed for the Avon River CCC (1992(b)) between the 1980 and the 1989-91 surveys, but there is little evidence to suggest sedimentation has increased.

Increased siltation is often a feature of slower moving waters providing a habitat suitable for burrowing organisms such as molluscs and oligochaetes. These organisms are found to dominate in many areas of the Avon and Heathcote Rivers.

An increase in the number of taxa was observed from 1980 to 1989-91 in the Avon and Heathcote Rivers. A proportion of this increase has been attributed to differing sampling techniques and better taxa identification (CCC (1992(a)), although some of the increases and changes in taxa suggest that riverine conditions have also changed. One of the most noted biological changes is an increase in filamentous algae throughout the Avon-Heathcote catchment (CCC (1992(a)).

The expansion in filamentous algae chronologically parallels changes in the invertebrate composition. This periphyton provides a niche for several new taxa while possibly smothering the substrate vital to other taxa. Filamentous algae usually proliferate due to increased available nutrients introduced into the waterways and changes in river hydrology. Thus, increased invertebrate diversity and periphyton could be a result of elevated river nutrient levels increasing food availability (e.g. periphyton).

Adverse effects of elevated contaminants, such as heavy metals, may have been compounded due to changes in the hydrology (slower waters) of the drainage system. Increased retention times of heavy metals and other contaminants, dependant on their chemical behaviour, is likely to have occurred within certain river reaches (see Appendix 2). Heavy metals like zinc can inhibit algal growth, possibly affecting invertebrate distributions. These factors could be the mechanism for the succession of certain invertebrate species.

Reaches with severe contamination also experience reductions in invertebrate diversity. These are noticeably pronounced in industrial areas (e.g. Haytons Drain) and downstream of certain stormwater outlets (e.g. Mackenzie Avenue).

3.3.2.2 Synthesis - Invertebrates and Periphyton

Measures of invertebrate diversity and composition assessed in the biological evaluation of the Avon-Heathcote catchment may be useful in determining the relative health in isolated reaches of the rivers. However, to relate these assessments to pollution indices, such as the macroinvertebrate composition index (MCI), indices need to be representative of the invertebrate compositions and habitats found in the Christchurch urban waters (*pers comm.* Jonet Ward). MCI scores may be useful for relating the catchment wide health of the ecosystem, but are less useful for determining reaches of moderate to light chemical contamination.

In summary, while changes in macroinvertebrates and periphyton indicate degradation to be occurring in several reaches of the Avon and Heathcote Rivers, the cause(s) of impairment remain unclear. The most likely explanation is degradation is the result of a combination of factors. These include reduced baseflow, increased siltation, increased nutrients, chronic effects of contaminants, and excessive periphyton growth.

3.3.2.3 Fish

Possibly a better indicator of the overall aquatic ecosystem health and areas of moderate to light chemical contamination are fish. Fish according to Karr (1986) are excellent indicators of biological change due to their sensitivity to a wide range of environmental conditions. The reasons for monitoring fish can include, for example:

- *functional attributes (debilitated growth and reproduction) and species composition (acute toxicity) can be rapidly assessed,*
- *fish are usually present in most streams, the exceptions being those severely polluted,*
- *macroenvironmental effects dominate, not the microenvironmental influences that can affect algae and invertebrates,*
- *fish incorporate a temporal dimension to biological assessment due to their longevity.*

Abundance of the trout occupying the headwater tributaries was greater than main-stem counterparts in one study (Ministry of Agriculture and Fisheries (MAF), 1992; Figure 3.1). This may be due to urbanisation effects, for example, increased peak flows and elevated contaminant levels in the headwaters. Stunted trout growth also was found in the headwaters of the Avon River (MAF, 1992), the dominant habitat of trout during the 1991-92 MAF survey (Appendix 2). There may be several reasons for this. For example, Hellawell (1986, p58) found in several studies that the growth and longevity of trout is dependant on water quality. Therefore the Avon River brown trout populations might indicate that the chemical constitution of the waters of some reaches is of substandard quality.

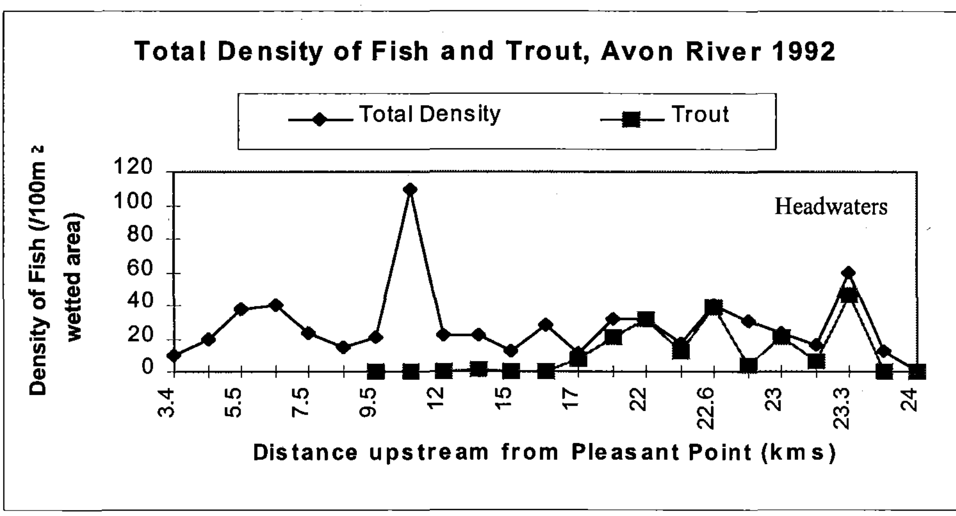

Figure 3.1. Comparison of trout densities to total fish densities for the Avon River. Data from MAF, 1992.

In nutrient rich waters with moderate hardness, trout growth would be expected to be rapid with an average lifespan of approximately 6 years (Hellawell, 1986, p59). Since the river waters are not lacking in nutrients it is likely that other contaminants, such as heavy metals, may be limiting trout growth.

Diet may also be a factor in slowed trout growth. Changes in the benthic community can mean alternative food sources must be sought. As discussed in Section 3.3.2.1, changes in benthic community may be caused by increases in sediment and possibly other contaminants.

As the contaminants generated from impervious areas and the hydrological impacts of runoff from impervious areas are related to the extent of urbanisation, it is likely that urbanisation affects trout populations. Therefore in this study trout densities are used in an attempt to assess the impact of urbanisation on water quality. For each subcatchment included in a trout survey (MAF, 1992), the percentage impervious area was calculated based on impervious area data from Elliott (1996). Percentage impervious area is plotted against total density of trout in Figure 3.2. Several of reaches with high and zero trout densities indicated in Figure 3.1 are not included in Figure 3.2. This is because alternative fishing methods were used to count fish populations or the presence of a weir makes it unlikely that there will be any trout present in these reaches.

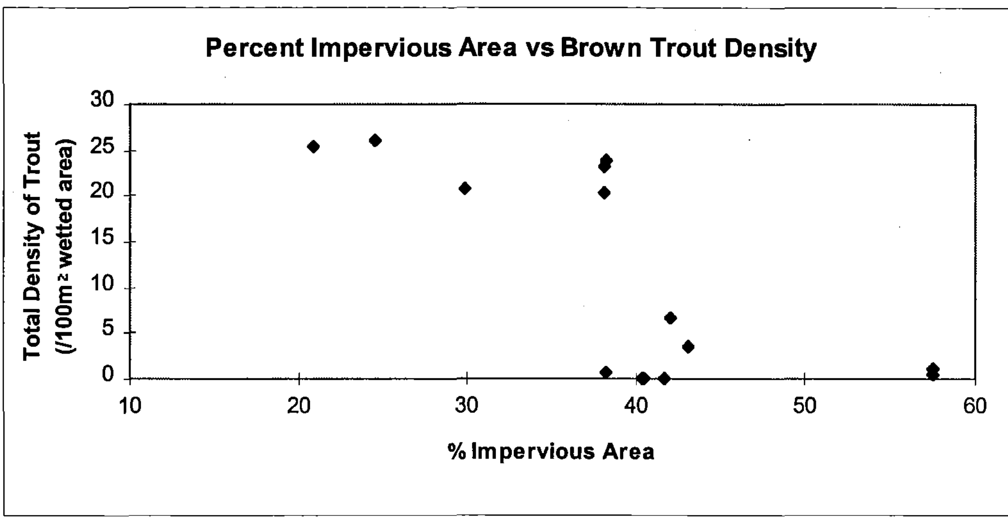

Figure 3.2. Total density of trout (per 100 m^2 wetted area) vs impervious area, Avon River 1992. Trout density data from MAF, 1992.

A negative correlation between impervious areas and trout density is apparent in Figure 3.2. This suggests that trout densities decrease with increased impervious area.

Similar trends were found by Klein (1975) using fish diversity. Waterway degradation was found to occur from impervious areas greater than 15%, with severe reductions occurring when 30 to 70% of a watershed was covered by impervious surfaces.

There may be several reasons for this correlation. The synergistic effects of contaminants contained in runoff may be affecting trout. Increased peak flow due to high impervious areas or changes to the baseflow regime also may affect the benthic environment of the rivers and the food web which supports certain fish populations. Differences in vegetation and vegetation management may provide favourable or less favourable habitats for trout. For example, reaches that are shaded and have vegetation overhangs are the preferred habitat of many fish species (MAF, 1992), in contrast to concrete lined and sunny reaches.

It may be that at the time of the fish survey preferred habitats coincided with areas of lower impervious area.

3.3.2.4 Synthesis - Fish

Fish are generally good indicators of the wider health of the aquatic ecosystem. Stunted trout growth in some reaches of the Avon River indicates water quality or habitat may not be of a standard capable of maintaining a healthy trout population. This is reiterated by the past history of trout in the Avon River, changing from an angler's paradise with trout supported by benthic dwelling caddis larvae to the present restricted trout population. Further analysis of the relationship between urbanisation and brown trout reveals that increased impervious area is related to decreased trout populations. Possible reasons for this are increased peak flow and elevated contaminant levels from impervious runoff. These can affect food sources, visibility, respiratory function, breeding sites, and general health.

3.3.3 Saltwater Biological Impacts

The Avon-Heathcote estuary has been going through a period of recovery from the pollution, siltation, and reclamation that occurred earlier this century. At present the estuary supports more life than previously recorded. This is substantiated by the quantity of avian life present in the estuary (CCC, 1992(c)).

Such a productive ecosystem is still threatened by the encroachment of urbanisation. Similar to the rivers, the estuary has high nutrient levels due to anthropogenic activities (urbanisation). However, the most notable impact of urbanisation is demonstrated by the number of pollution-tolerant species that flourish in an oxygen depleted environment (see Appendix 2). Nutrient enrichment and effluent disposal create an environment in which oligochaetes, mud-flat snails, and blue-green algae can thrive.

Treated effluent from the Bromley Sewage farm discharged into the Avon-Heathcote estuary has several impacts (Appendix 2). Pollution loadings from this point source are of the same order of magnitude, if not greater, than those from nonpoint sources. The combined effects of both point and nonpoint source contamination make determination of the effects of nonpoint source pollution difficult. This is further compounded by the difficulties in determining the health of a complex environment where many species live on the limit of their range of their tolerance (NIWA, 1995).

Since a large proportion of urban runoff is discharged into the estuary via the freshwater drainage system it is prudent to concentrate the aims and objectives of this investigation on the freshwater waterways. Future research may uncover the intricacies of estuarine contamination with more detailed monitoring and comparisons of nonpoint source loadings to effluent discharges. For further detail on biological review of the Avon-Heathcote estuary refer to Appendix 2.

3.3.4 Biological Assessment Summary

OBSERVED ECOLOGICAL EFFECTS	POSSIBLE STRESSORS	IMPACTED SITES	LAND USE/ POSSIBLE SOURCES
Reduced Fish abundance over time[1]	• Toxic pollution • Fish habitat • Lack of food	1. Haytons Drain 2. Addington Drain 3. Reaches with high impervious area	1. Ind/comm 2. Salesyard/res 3. General urban
Stunted trout growth	• Sediment loading • Toxic pollution • Lack of food • Other?	4. Avon R. headwaters	4. General urban. Possible rural component
Changes in invertebrate composition (reduced MCI scores)	• Sedimentation • Nutrients • Habitat changes • Flow • Periphyton growth	5. Addington Drain 6. Taylors Drain 7. Waimairi Str. 8. Wai-iti Str. 9. St Albans Ck. 10. Clarkson drain 11. Haytons Drain 12. Curletts Rd Drain 13. Lower Heathcote R. 14. Lower-mid Heathcote R.	5. Salesyards/res 6. Res/comm 7. Res 8. Res 9. Ind/comm/res/rural 10. Res/comm 11. Ind/comm 12. Res/comm 13. Res/comm/ind/rural 14. Res/comm/ind & groundwater
Nuisance biological growths	• Nutrients • Flow	15. Horseshoe Lk. 16. Mid-upper Avon R. 17. Dudley Ck. 18. Hewlings Str. 19. Riccarton Drain 20. Wairarapa Str. 21. Addington Drain	15. Res/rural/g.water 16. Res/comm/g.water 17. Res/rural/g.water 18. Res/g.water 19. Res 20. Res 21. Salesyards/res

Notes: [1] Based on the observations of CBD and CCC, MAF biological surveys
Numerated 'Impacted site' details corresponds to the equivalently numbered 'Land use/source'.
Res = residential, comm = commercial, ind = industrial.
Data source: CCC, 1992(a,b,c); CCC, 1994(a,b); CBD, 1980; MAF, 1992; Suren, 1992.

Table 3.1. Ecological responses, possible contaminants and stressors, impacted sites, and possible sources of nonpoint source surface water contamination for the freshwater reaches in the Avon-Heathcote catchment.

Table 3.1 provides a synthesis of the observed biological effects in the freshwater reaches found in biological surveys and analysis as outlined in the previous sections and Appendix 2. These ecological changes are the effects of a number of possible stressors. These are also listed in Table 3.1 along with the locations of observed effects.

3.4 PHYSICO-CHEMICAL ASSESSMENT

This section reviews the physico-chemical data, measured over the past ten years, to ascertain degraded reaches and the contaminants most likely to be responsible for adverse ecological effects. Comparison of physico-chemical data with the relevant contaminant criteria or standard will be the primary method of assessment.

The contaminants that may cause freshwater urban aquatic degradation are:

- nutrients,
- heavy metals (Cu, Pb and Zn),
- sediment,
- trace organic contaminants (see Appendix 2), and
- pathogens (see Appendix 2).

Indicator pathogens are present in excessive quantities in many localities. However, the impact of pathogens on the ecology of receiving waters is uncertain. They are unlikely to be of concern to most aquatic organisms, but may have some effects on higher trophic levels such as fish. Viruses and pathogens, such as salmonella, may endanger fish health (*pers comm.* Mike Beare, Lincoln University).

Human health concerns from pathogens are of concern to local government authorities. However, little contact recreation occurs in the upstream reaches of the Avon-Heathcote catchment due to their shallow depth. Indicator pathogens generated in these areas do have downstream consequences. The primary health concerns due to pathogens occur in the Avon-Heathcote estuary. Contaminated shellfish and elevated bacteria levels pose health risks. Health risks come not only from urban runoff but from the outflow of effluent from the sewage works. Thus until the point source problem is addressed it is unlikely that health concerns in the estuary will be effectively addressed.

Dieldrin has been measured in levels in excess of recommended guidelines, but as this compound is no longer sold in New Zealand it will be disregarded as an ongoing pollution concern. However, it is recommended that any toxicity monitoring should include testing for this compound, as its longevity and mobility in the Christchurch aquatic environment are uncertain.

Generally reductions in dissolved oxygen due to urban runoff are short lived, episodic events that are not well recorded in urban monitoring data (House *et al.*, 1993). Although recorded levels in the baseflow in Christchurch generally meet ANZCC (1992) recommended criteria, diurnal fluctuations are not measured on a regular basis to detect extreme levels.

Therefore pathogens and dieldrin are generally ignored as key nonpoint source contaminants for the rest of this investigation. Also traditional indicators of pollution such as dissolved oxygen (DO) and biological oxygen demand (BOD) will not be discussed here.

3.4.1 Nutrients

Undesirable biological growths are potentially the most damaging impact of elevated nutrient levels. In the Avon-Heathcote freshwater tributaries a common undesirable biological growth is filamentous algae (a common type of periphyton). Elevated dissolved inorganic nitrogen (DIN, ammonia and nitrate) and dissolved reactive phosphorous (DRP) are the nutrients responsible for enabling filamentous algae to attain a large biomass (MfE, 1992).

The literature suggests that in the urban environment nonpoint sources are one of the major contributors of nutrients. Williamson (1993) found that stormwater runoff contains elevated concentrations of plant-available nutrients, however a large component of nutrient is associated with particulate matter. Particulate associated nutrient is only partly available for plant growth. Novotny and Chesters (1981, p55) estimated that over 50% of phosphorous and nitrogen is generated from nonpoint sources. Osborne and Wiley (1988; cited House *et al.*, 1993) correlated water column nutrient concentrations with urban density in low gradient streams. Generally nutrient concentrations were found to increase with increasing urbanisation.

3.4.1.1 Phosphorus

DRP in baseflow exceeds the MfE (1992) criteria for limiting undesirable biological growths in freshwater for most sites in the Heathcote Catchment. However, DRP only exceeds MfE criteria for the drains, Dudley Stream, Horseshoe Lake, and the lower Avon River in the Avon catchment (see Appendix A 2.3.3.1). In comparison to the Avon River, the Heathcote River has higher DRP levels. This may be attributable to industrial emissions, probably arising from a superphosphate factory near Haytons Drain. The location of the fertiliser factory (the Hornby area) was included in a stormwater sampling programme (CRC, 1994) which collected data from 3 storm events. DRP concentrations were found to be no greater than other areas in the Heathcote catchment. However, in a recent stormwater monitoring programme (Brown, Mason and Snelder, 1996) it was estimated that a mean contribution nearing 100% of DRP (measured in at the Hayton Drain confluence) is sourced from the fertiliser factory. Knox and Kilner (1973) found increased nutrient levels in the Heathcote River coincided with evening flushing of upstream milk sheds.

Other likely sources of DRP are aquatic fowl, domestic animals and farm animals. Elevated levels of DRP have been measured in stormwater runoff from the Port Hills in comparison to low-land counterparts (CRC, 1994). As the Port Hill catchments are predominantly rural and contain domestic farming stock, this may provide additional evidence of animal waste as a source of DRP. However, these catchments also contain elevated sediment levels in stormwater runoff which may also elevate DRP levels.

3.4.1.2 Ammoniacal Nitrogen

Ammoniacal nitrogen is present in concentrations below the USEPA (1986) criteria for ammonia in baseflow (Appendix 3), in all sites in the Avon and Heathcote Rivers (see Appendix A 2.3.3.2). However, ammoniacal nitrogen is present in concentrations above Williamson's (1993) typical value for urban baseflow in the waters of Haytons Drain and Curletts Drain.

The variation in concentration of ammoniacal nitrogen measured at different sites along the Avon and Heathcote Rivers corresponds to the rise and fall of DRP concentrations for most reaches of the rivers (see Appendix A 2.3.3.1). This suggests that the source(s) of DRP and ammoniacal nitrogen are similar. Thus it is possible that measures aimed at reducing DRP concentrations would also reduce ammoniacal nitrogen.

3.4.1.3 Nitrate

Nitrate concentrations were found to exceed MfE criteria for limiting undesirable biological growths in freshwater (see Appendix 3) at the spring fed headwaters of the Heathcote River. This is sourced from groundwater. A similar situation is occurring within the Avon River (see Appendix 2). Elliott (1996) in a mass balance assessment concluded that nitrates must be entering the Avon-Heathcote waterways from sources other than urban stormwater. Elevated nitrate levels are likely to be rurally sourced. Rural localities close to urban Christchuch have recorded surface water nitrate levels in excess of 10 mg/l (*pers comm.* K. Nicole). This correlates with elevated nutrients levels found in Canterbury groundwater. No correlation of baseflow nitrate with particulate material or faecal sources was found, also indicating that nitrate levels may predominantly emanate from contaminated groundwater.

Stormwater sampling in the Riccarton area gave nitrate levels typical of urban stormwater (see Appendix 2 and 3). Loadings produced by storm events add available nitrogen to baseflow on an intermittent basis as well as to the nitrogen sediment reservoir. Nitrates stored in river sediments during storm runoff may then be gradually released in baseflow. High nitrate levels measured in stormwater from the Port Hills catchments may be predominantly sourced from animal waste as these catchments contain a large rural component.

3.4.1.3 Synthesis - Nutrients

Nutrients in many reaches of the Avon and Heathcote Rivers exceed recommended guidelines for the avoidance of periphyton growths.

Within the Christchurch urban environment nutrients derived from urban nonpoint sources are masked by the addition of nitrate from groundwater and DRP from a fertiliser factory. This creates difficulties in ascertaining the influence of nutrients from urban nonpoint sources. It is likely that any mitigation measures aimed at addressing nutrient concerns in the urban aquatic environment will also have to address non-urban sources.

3.4.2 Heavy Metals

Several Christchurch urban freshwater reaches show evidence of heavy metal contamination. Limited heavy metal data measured in baseflow shows that the median zinc concentration exceeds USEPA acute criteria at Curletts Road and Haytons Drain (see Appendix 2).

Limited stormwater sampling by the CRC (1994) found most zinc and some copper samples exceeding USEPA acute criteria. The highest concentrations of zinc were found in industrial locations, while copper concentrations were highest from the Port Hills catchment.

In the river sediments near stormwater outlets, such as the Mackenzie Avenue outlet, there were elevated concentrations of heavy metals, which suggests stormwater is a significant source of heavy metals. Heavy metals in the sediments generally exceed Ontario low-effects-level criteria for heavy metals in sediment (see Appendix 3).

Impervious areas in the urban environment are important contributors of heavy metals and other contaminants. Heavy metals are often derived from industrial sources. Industrially sourced heavy metal degradation of waterways is suspected in locations such as Haytons and Curletts Road Drain. Unfortunately no data exists to adequately delineate which fraction of heavy metals are derived from point sources or nonpoint sources.

3.4.3 Sediments

Historically the Avon and Heathcote Rivers have experienced periods of intensive sedimentation. The worst recorded period of sedimentation occurred in the early decades of this century, the Heathcote River accumulating 4 feet of mud in places (Lamb, 1981). The effects during that time were obvious. Generally, riffles and substrate were choked with fine sediment, destroying the sensitive benthic ecology and fish populations.

Some authors (Suren, 1993; CCC, 1992(a),(b)) have suggested that succession of invertebrate species over the last couple of decades is the result of reduced baseflow and increased sedimentation. Reduced baseflow can result in increased sedimentation in some locations due to increased sediment fallout. This in turn can affect the benthic ecology. Reduced baseflow is evidenced within the Avon-Heathcote catchment (Suren, 1993; CCC, 1992(a),(b)) but little data exists on sedimentation levels. In reports on biological surveys sedimentation has been implicated as a mechanism for faunal succession (Suren, 1993; CCC, 1992(a),(b)). However, this is not substantiated by data on sedimentation and in places (particularly the Avon River) contradicted by suspended sediment data. Suspended solids data has been collected by the CCC over the past decade. No trend is apparent within this data to suggest sedimentation has increased. However, increased peak flow from urban runoff can lead to resuspension of sediment in baseflow. Resuspended sediment may effect aquatic biological functioning in the short term.

If abundant macrophytes and periphyton are present then some resistance to scour and resuspension of sediments will occur. This may cause sediment to be trapped. Thus biological growths rather than increased sediment yields may be the cause of increased silt retention in the streambeds. This may be the case at some locations within the Avon River, for example, Addington and Riccarton Drains.

The occurrence of filamentous algae may indicate a change in substrate conditions, but whether this is due to increased sedimentation, nutrient levels or reduced base flow is uncertain.

Urbanisation results in the establishment of impervious areas, which may affect peak flows, bank erosion, and sedimentation. However, it is beyond the scope of this study to assess such hydrological effects on sedimentation.

Haytons Drain is the only reach with recorded median suspended sediment concentrations in excess of ANZECC guidelines (see Appendix 2). The Heathcote catchment generally has higher sediment concentrations in baseflow than the Avon River (see Appendix A

2.3.5.1). Proximity to the sparsely vegetated Port Hills is the major difference between the two catchments, although the Haytons Drain area is relatively unaffected by the erosion of the Port Hills.

For a mature catchment, sedimentation rates and the effects of sediment deposition reach an equilibrium usually only disrupted by changing land uses (e.g. new subdivisions). Usually the contaminants associated with sediments are of greater concern than the sediment itself for urban catchments (Whipple *et al.*, 1975).

3.4.4 Physico-Chemical Summary

WATER QUALITY PARAMETER	BASEFLOW	SITES EXCEEDING WATER QUALITY CRITERIA/STANDARDS
Heavy Metals	1. Cu, Zn > EPA acute criteria 2. Pb > EPA acute criteria	1. Haytons, Curletts, & Riccarton drains, Halswell basin 2. Haytons drain, Halswell basin
Organics	3. Dieldrin > RG	3. Haytons drain
Nutrients	4. DRP > RG 5. Ammoniacal N > RG 6. Nitrate > RG	4. Most of Heathcote R., Haytons & Curletts drains, Dudley Ck., Riccarton & Addington drains, Horseshoe Lk. 5. Haytons drain, most of Heathcote R., Addington drain, Dudley Ck, Horseshoe Lk. 6. Most sites on the Avon & Heathcote R.
Sediment	7. SS > 25 mg/l	7. Avon St bridge, Haytons drain, Worsleys Rd. bridge, Ferniehurst St. bridge
	RIVER SEDIMENTS	
Heavy Metals	1. Cu > LEL 2. Pb > LEL 3. Zn > LEL 4. Cd > LEL	1. Curletts, Addington, Riccarton, Taylors drains., St Alban Ck., Clarkson drain, Dudley Ck., St Albans Ck., Waimairi St., Dunbars, Ballintines drains, Lower Heathcote R. 2. Curletts, Haytons, Dunbar, Ballintine, Riccarton, Addington drains. Lead accumulation in most of Avon & Heathcote R. tributaries 3. Most of Avon and Heathcote R. (not at Wai-iti, Wairarapa & Cashmere streams, Milnes & Henderson drain) 4. Taylors & Curletts drains
Sediment	5. Observed siltation	5. Lower reaches of Heathcote R., Haytons & Addington drains

Notes:
- Numerated 'River Water' detail corresponds to the equivalently numbered 'site'.
- Numerical data listed in Appendix 2.
- RG = Recommended Guidelines, refer to Appendix 3 - nutrients from MfE (1993) & Makepeace *et al.* (1995); organics from Snelder and Trueman (1995), Williamson and Wilcock (1994); sediment from Makepeace *et al.,* (1995).
- LEL = Low effects guideline, Ontario MoE (1989).

Table 3.2. Contaminants exceeding recommended water quality guidelines and their locations, Avon-Heathcote catchment, 1989-94.

Table 3.2 summarises the reaches where contaminants have exceeded water or sediment quality criteria or standards. Examination of the biological assessment summary and this physico-chemical summary begins to reveal a pattern of water quality impairment in Christchurch freshwater reaches. For example, elevated DRP levels predominate in one reach in the Heathcote River implicating a point source rather than nonpoint sources as a possible threat to aquatic ecology. The next section attempts to unravel these relationships and associate the impacts on Christchurch waterways with nonpoint source contaminants.

3.5 INTEGRATED ENVIRONMENTAL ANALYSIS: KEY NONPOINT SOURCE CONTAMINANTS IN CHRISTCHURCH URBAN SURFACE WATERS

3.5.1 Correlating Biological and Physico-Chemical Impacts

This section attempts to integrate the historical, biological and physico-chemical information reviewed in the previous sections (and Appendix 2), to ascertain the key nonpoint source contaminants that may be responsible for environmental degradation in Christchurch urban waterways. More specifically this section will try to form a correlation between observed biological impacts and the chemical quality of waterways.

Even with well designed monitoring the identification of key contaminants in the urban aquatic environment is not easily accomplished. To help negotiate these problems this assessment will use toxicity, nutrient and sediment guidelines (see Appendix 3) in tandem with the observations from historical and biological assessments of the urban aquatic environment. Correlating these indicators of waterway degradation if successful would help to highlight likely nonpoint source contaminants threatening the integrity of waterway ecology.

Tables 3.1 and 3.2 represent a breakdown of the known problems, stressors and possible sources of aquatic degradation for certain localities in the Christchurch urban drainage system. The biological assessment (summarised in Table 3.1) and physico-chemical assessment (summarised in Table 3.2) both contain measures of waterway impairment. Biological effects were observed and measured in several surveys as discussed in Section 3.2 and Appendix 2. The effects listed in Table 3.2 are interpreted as impacts that could be detrimental to the maintenance of a balanced, integrated ecosystem. Impacts such as reduced diversity, changes in species assemblages reflective of a polluted environment, and nuisance biological growths can indicate pollution or hydrological problems due to urbanisation.

Correlating contaminant data and observed biological impacts reveals several conclusions on the causal mechanism of water quality degradation (Table 3.3). These are:

- Where prolific or increased nuisance growths are found, DRP exceeds the concentration for limiting periphyton growth, with the exception of Wairarapa Stream. This also generally applies for nitrates.

- Nitrates exceed the concentration recommended for limiting biological growths in all reaches where nitrates were measured whereas growths are not observed in all reaches , indicating that nitrate may not be causing increased biological growths. However, the growths may be limited due to other factors such as stream shading.

- No trend is apparent for reduced trout growth. This is to be expected as data are limited and the condition of adult trout may be indicative of the whole river rather than just a few reaches.

- There is no apparent correlation between contaminants and an increase in pollution-tolerant invertebrates.

- Where metals do not exceed the low effect level (LEL) for sediments there are no observed biological impacts.

- Median taxa numbers for each reach are ranked in Table 3.3 to see if there is a correlation between median taxa number and physico-chemical impacts. The lowest taxa number for the Avon and Heathcote Rivers is allotted a rank of one and this is increased incrementally for higher taxa numbers. If taxa numbers have the same value then they share the next ranking values equally. There is a trend apparent between the median taxa per site and chemical water quality, particularly for the Heathcote River. The relationship shows the lower the observed number of taxa the worse the chemical quality of the water. This correlation is less obvious in the Avon River, perhaps due to other factors such as the effects of reduced flow in several reaches.

FRESHWATER REACH	PHYSICO-CHEMICAL IMPACTS							BIOLOGICAL IMPACTS					HYDROLOGICAL IMPACTS
	Cu	Pb	Zn	DRP	NH_4-N	NO_3-N	SS	[1]Increase in Pollution Tolerant Invertebrates over the period 1979-91	[2]Ranking of Lowest to Highest Median No.Taxa/Site 1990/91 *Heathcote*	*Avon*	Reduced Trout Growth	Prolific or increased Biological Growths	Observed Reduced Flow
Dunbars Drain	✓	✓	✓	n.d.	n.d.	n.d.	n.d.		3		n.d.		
Ballintines Drain	✓	✓	✓	n.d.	n.d.	n.d.	n.d.		4.5		n.d.		
Milnes Drain				n.d.	n.d.	n.d.	n.d.		7		n.d.		
Henderson Drain				n.d.	n.d.	n.d.	n.d.		4.5		n.d.		
Haytons Drain	✓	✓	✓	✓	✓	✓	✓	✓	1		n.d.	✓	
Curletts Drain	✓	✓	✓	✓	✓	✓		✓	2		n.d.		
Cashmere Stream						✓	✓		8		n.d.		
Heathcote - Main		✓	✓	✓	✓	✓			6		n.d.	✓	
Riccarton Drain	✓	✓	✓	✓		✓		✓		3.5	n.d.	✓	
Addington Drain	✓	✓	✓	✓	✓	✓		✓		2	n.d.	✓	
Taylors Drain	✓	✓	✓	n.d	n.d	n.d	n.d	✓		1	n.d.		✓
Clarkson drain	✓	✓	✓	n.d	n.d	n.d	n.d	✓		6	✓		
Hewlings Stream		✓	✓	n.d	n.d	n.d	n.d.			5	n.d.	✓	✓
Waimairi Stream	✓	✓	✓			✓		✓		10.5	✓		✓
Wai-iti Stream		✓		n.d	n.d	n.d	n.d			8	n.d.		
Wairarapa Stream		✓				✓				12	✓	✓	
St Albans Ck	✓	✓	✓	n.d	n.d	n.d	n.d	✓		3.5	n.d.		
Dudley Ck	✓	✓	✓	✓	✓	✓				8	n.d.		
Horseshoe Lk	n.d.	n.d.	n.d.	✓	✓	✓				8	n.d.	✓	
Avon - Main	✓	✓	✓			✓		✓		10.5		✓	

Notes: ✓ = Impact ❑ = No impact n.d. = no data

[1] Evaluated from a change in Median MCI scores; CCC 1992(a), 1994 (b).

[2] From CCC 1992(a), 1994(a).

Table 3.3. Physico-chemical, biological impairment and hydrological observations in Christchurch urban freshwater reaches.

There are few clear correlations between physico-chemical indicators and biological indicators in this assessment. While it is likely that the chemical quality of waterways is impacting negatively on the aquatic ecology it is just as likely that hydrological impacts, habitat changes due to urbanisation, and possibly sediments are also affecting aquatic ecosystems.

No specific causal agent is positively identified as causing biological impairment. There are several likely candidates but without specialised or in-depth monitoring these cannot be determined as the specific causal agents of waterway degradation.

This analysis demonstrates that it is difficult to determine aquatic degradation using biological assessment or environmental impact monitoring. While biological assessments can indicate that adverse effects are occurring, in the case of Christchurch waterways the assessments do not adequately identify the causal agents. Attempts at correlations between physico-chemical indicators and biological indicators did not adequately identify the causal agents either.

3.6 CONCLUSION

The quality of Christchurch waterways is now quite different from what it was when Europeans first began to colonise the Christchurch area. Urbanisation has taken its toll on the waters of Christchurch, but in the last few decades changes in management of Christchurch waterways has resulted in a recognised improvement in water and sediment quality. However, the Christchurch urban aquatic environment is far from pristine, due to continued contamination from nonpoint and point sources.

It is difficult to ascertain the integrity of Christchurch urban aquatic ecosystem based on previous biological evaluations of the Avon-Heathcote River systems. It would appear that the aquatic environment undergoes constant changes like the urban landscape. Thus using spatial and temporal variations in biological diversity and abundance to indicate changes in ecosystem integrity is often inconclusive. However, some trends are apparent.

Urbanisation appears to detrimentally affect the population of trout in the Avon River. Recent biological surveys also show that some reaches of Christchurch urban waterways may be improving, in particular in the Cashmere Stream. However, several reaches are clearly degraded.

Contaminants derived from urban nonpoint sources were found to be metals (zinc and copper), suspended solids, and nutrients. However, while nutrient loadings from urban runoff are a problem, nutrients derived from other sources (nitrates from groundwater, dissolved reactive phosphorous from a fertiliser works) are also likely to adversely affect the aquatic environment.

The chemical quality of baseflow in the Avon-Heathcote catchment may be acceptable in several reaches but the chemical quality of sediment is often unacceptable. Sediment quality is likely to reflect the toxic contaminants in stormwater runoff from urban catchments.

Using biological information in conjunction with contaminant toxicity data has helped to weakly implicate some contaminants as responsible for aquatic degradation. High phosphorus levels occur in the same reaches as nuisance biological growths and where there is no heavy metal contamination in reaches, reaches appear to have no impairments. However, these conclusions are tentative and in general the correlation technique of correlating physico-chemical parameters with biological indicators did not clearly identify the cause of the aquatic ecosystem degradation.

Available physico-chemical data indicates nutrients, heavy metals, and sediments to be the major contaminants of concern in the Christchurch aquatic environment. This data provides the major justification for further investigation into nonpoint source contaminant abatement.

4.0 RANKING CONTAMINANTS: A STEP TOWARDS ABATEMENT

4.1 INTRODUCTION

The previous chapter identified several contaminants as being of a threat to the integrity of urban Christchurch's aquatic ecology. This section outlines a prioritisation mechanism to assess which contaminants pose the greatest threat to the aquatic environment and the community's use of it.

Identification of priority contaminants and priority waterways is important if the community is to gain maximum benefit from urban waterways. As resources available for source abatement measures or other control measures are limited, resources must be allocated where they can be of most effect. Establishing which contaminants pose the greatest risk will enhance the effectiveness of mitigation strategies, and help decide abatement priorities.

Chapter 3 assessed waterway degradation from an ecological perspective. While this may justify further investigation into contaminant abatement in some sectors of the community, this may not fit into the broader community's perception of degraded waterways. Thus this section attempts to incorporate a wider, unified community perspective of waterway degradation into a priority mechanism, by using some measure of community waterway values.

A prioritisation mechanism is defined by applying methods used in comparative risk assessment (see glossary) to prioritise contaminants implicated as causes of water quality degradation in Christchurch's urban freshwater environment. This ranking scheme attempts to incorporate disjointed environmental data into a form that can be easily used to assess water quality in terms of the community's environmental values and the contaminants likely to undermine these values.

The objectives of this chapter are:

- to develop a method by which waterway importance, as defined by or for the community, is incorporated into the assessment of aquatic environmental health, and thereby justify contaminant abatement to the wider community;
- to establish a rank order of contaminants identified as of concern in the aquatic environment,
- to develop a water management tool that provides a simple guide to water quality and waterway degradation due to nonpoint source contaminants.

The prioritisation mechanism developed in this section has certain limitations. For example, limited information on community waterway values and the uncertainty of causal relationships between contaminants and waterway impairment could undermine justifications for abatement. However, this exercise serves to emphasise the importance of delineating waterway degradation in terms of community values.

4.2 APPROACH TO PRIORITISING CONTAMINANTS

Anthropogenic inputs of chemicals from urban areas have altered aquatic environments from their natural state, even though some reaches may seem relatively unimpacted (Schonter and Novotny, 1993). Consequently, nonpoint source pollution can have deceptive effects over long periods of time. Due to these complexities, abatement of urban nonpoint source pollution is often perceived as being in the 'too hard basket' (Harrison, 1991).

Some engineering solutions to urban stormwater problems have been employed on a trial and error basis. However, increasingly sophisticated models and assessment methods are being used to manage waterways. Management approaches are beginning to integrate risk assessment tools with water quality models (Chen *et al.,* 1993). Models have been useful in predicting the quantities of contaminants contained in runoff, and for predicting the fate and transport of contaminants in waterways. However, while such approaches to water quality assessment provide increasingly robust models for estimating ecological effects within ecosystems, they often overlook the importance of defining water quality within a community perspective.

Problems with efficiently managing water resources occur when water managers must determine a waterway's pollution concerns, the key pollutants and a course of remedial action based on scant information. Establishing if a waterway's values are being compromised, especially by diffuse forms of pollution, may be difficult if changes are deceptive and/or over a lengthy period. Thus it is a complex task to determine priority pollutants in an urban surface water environment. It is also difficult to ascertain the levels of reduction needed to remedy effects of contaminants without adequate monitoring specifically designed to assess a contaminant's spatial and temporal fluxes, effects on in-stream ecology, and bioavailable fractions.

The approach taken here to rank contaminants and waterways is to simply amalgamate some measure of community waterway values with the effects contaminants may be having on the ecology of waterways. Christchurch environmental waterway data are not extensive enough to reliably apply any available water quality modelling approach to identify high risk contaminants. Thus this approach relies on adapting limited physico-chemical monitoring data to indicate some degree of ecological impairment. This provides the basis for delineating a core waterway value indicating the cleanliness and health of the aquatic environment in terms of the RMA. This value is an intrinsic ecological value.

Figure 4.1 shows schematically the flow of effects of a contaminant once it enters the aquatic environment, and the relationship between effects and actions to combat effects. The first impacts of contaminants are on the physico-chemical parameters and aquatic ecology of the aquatic environment (Figure 4.1), which may ultimately compromise the environmental values of the waterway held by the community.

How waterway degradation, caused by nonpoint source contaminants, impacts on the community, depends upon contaminant characteristics and their impacts on the needs and wants of the community. To reduce the effects of contaminants on the community requires defining and prioritising the environmental values of the community's water resources (see Figure 4.1). The scale of impact each contaminant imposes on environmental values can then be used to assess contaminants that pose the greatest risk to the aquatic environment.

The water quality required to maintain or restore the environmental values of a particular waterbody is determined partly by the community. Environmental values include water uses such as potable water supply, irrigation, fishing, recreational uses, and ecosystem integrity (ANZCC, 1992). These can also be described as beneficial uses of waterways.

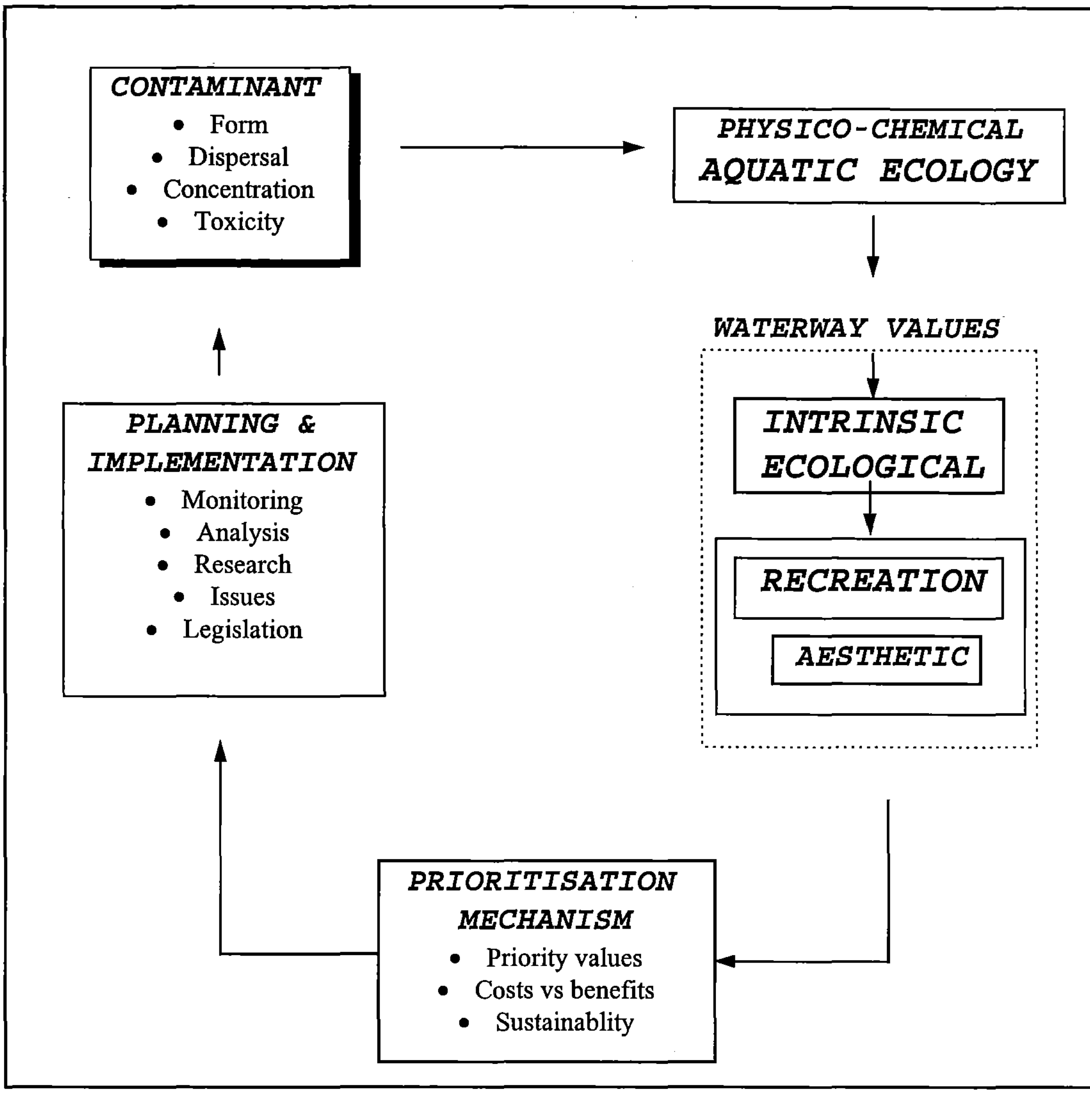

Figure 4.1. Schematic framework for a prioritisation mechanism through contaminant impact on waterway values.

In keeping within the context of the RMA definition of the 'environment'(see glossary), contaminants may have adverse effects on ecosystems, on the community and on amenities. To provide some recognition of the importance of community and amenity values, the assessment used here ranks waterway importance based upon recreational and aesthetic uses of Christchurch waterways (Figure 4.1). Other community values, such as cultural and historical values, were not considered as they cannot be readily evaluated in relation to risk or given a priority standing. For example, from a Maori perspective any form of pollution of New Zealand waterways is considered abhorrent (*pers comm.* Maurice Nutira).

4.3 METHOD USED TO RANK KEY CONTAMINANTS

4.3.1 Overview

Contaminants are evaluated and ranked based on their potential to affect environmental values. To reflect a contaminants' potential impacts in the Christchurch aquatic environment and the community's use of it three categories, based on environmental values, have been used to rank contaminants and reaches. These are:

- intrinsic ecological value (distribution, toxicity/concentration of contaminants),
- recreational value,
- aesthetic value.

Ranking occurs on a reach by reach basis. A reach is the basic geomorphic unit that biological, physico-chemical data has been measured by and is therefore the logical unit to evaluate intrinsic ecological, recreational and aesthetic environmental values. Hence, reaches are the stretches of waterway that begin at a spring, or when piped flow ends, or at a confluence of two reaches, and end at their confluence (i.e. when they run into another waterway).

Ranking reveals the problem areas likely to be caused by nonpoint source contaminants. It does this in three ways. Firstly, for each freshwater reach, contaminants can be singled out as contaminants of most concern or priority contaminants. Secondly, ranking scores can indicate priority reaches, which is helpful for abatement strategies (e.g. where to locate stormwater retention basins). Thirdly, a total contaminant score will reveal which urban nonpoint source contaminants represent the greatest threat to urban surface waters. This information can be useful in implementing city-wide abatement strategies.

For each reach the effects of a contaminant on the intrinsic ecological values is assessed, and the importance of the reach in relation to recreational and aesthetic values is assessed.

Recreational and aesthetic rankings provide a scale of waterway importance. Recreation and aesthetic values are based on the differing levels of community involvement in these activities. The greater the community involvement in these activities, the greater the likelihood of nonpoint source contamination being an issue in a reach.

Intrinsic ecological rankings are based on exceedence of water quality criteria. The median level for each contaminant for each reach is compared to water quality criteria to provide a measure of possible ecological impact. This is described further in Section 4.3.2.

A contaminant rank value for a single reach is then determined for each contaminant by multiplying intrinsic ecological value for the reach (ecological impact) with the sum of aesthetic and recreational values for the reach. This relationship is represented by the equation:

$$E_{ir} = [M_{ir}][A+REC]_r \qquad \text{- Equation 4.1}$$

where E_{ir} is the contaminant ranking score for contaminant i, in reach r; M is the concentration or toxicity ranking; A is the aesthetic ranking; and REC is the recreational ranking. The larger the rank the greater the impact.

Ranking values are listed in Appendix 4 for several reaches in the Avon-Heathcote catchment. Sections 4.3.2 to 4.3.4 describe how these values are derived.

A total contaminant rank for all reaches is determined by summing contaminant ranking scores (E_i) using the equation:

$$E_i = \Sigma_r E_{ir} \qquad \text{- Equation 4.2}$$

Priority reaches may also be found by comparing the total reach rank (R_r), which is found by adding contaminant rankings over a single reach (see Appendix 4):

$$R_r = \Sigma_r E_{ir} \qquad \text{- Equation 4.3}$$

An example of how a total contaminant ranking for a catchment or part thereof is presented in Figure 4.2.

CONTAMINANT RANKING EXAMPLE	CONTAMINANT 1 (i = 1)	CONTAMINANT 2 (i = 2)
	Cu	DRP
Step 1: Substitute ranking values for M, A, REC (see sections below and Appendix 4) into ranking Equation 4.1 to calculate for E_{ir}		
Curletts Drain (r = 1)	E_{11} =[0.5] [0.5+0.3] = 0.4	E_{21} = [1] [0.5+0.3] = 0.8
Dudley Creek (r = 2)	E_{12} = [0.5] [1.0+1.7] = 1.3	E_{22} = [0] [1.5+1.7] = 2.7
Step 2: Total values obtained for E_{ir} over reaches to obtain E_i		
	Total Cu E_i = 1.7	Total DRP E_i = 3.5
Step 3: CONCLUSION - E_i for DRP greater than E_i for Cu thus DRP is the higher prority		

Figure 4.2. Example of ranking contaminants in Christchurch urban freshwater reaches.

This mechanism does not evaluate the possibility of adverse ecological effects occurring as a result of infrequent or rare exposure to contaminants. Such a risk assessment would incorporate a probability factor to determine the probability of certain events occurring. Instead the mechanism in this study prioritises contaminants and reaches based on the premise that the higher the *median* concentration of a contaminant in relation to an effects criterion, the greater the likelihood of it having an impact.

To add to the confidence of such an assessment or to just help guide decision making, other factors may be taken into account in prioritising contaminants in a nonpoint source investigation. For example, bioavailable concentrations or frequency of exceedence of criteria may help decide contaminant abatement priorities.

The next sections detail how the three ranks categories (intrinsic ecological effect, recreation importance, aesthetic importance) are ranked.

4.3.2 Environmental Impact - Intrinsic Ecological Value

Commonly-measured aspects of contaminant exposure used to assess environmental impacts are the intrinsic toxicity (for substances such as metals) or effects potential (for non-toxic substances such as nutrients) of contaminants and the intensities, duration or extent of their exposure in the environment. These are described by concentrations and temporal or spatial distributions (Figure 4.3).

Concentration criteria (Figure 4.3) are used in this study to reflect the toxicity or effects potential. Water quality criteria are discussed further in Section 2.2. Each contaminant is ranked according to its concentration relative to the contaminant criteria (see Table 4.1).

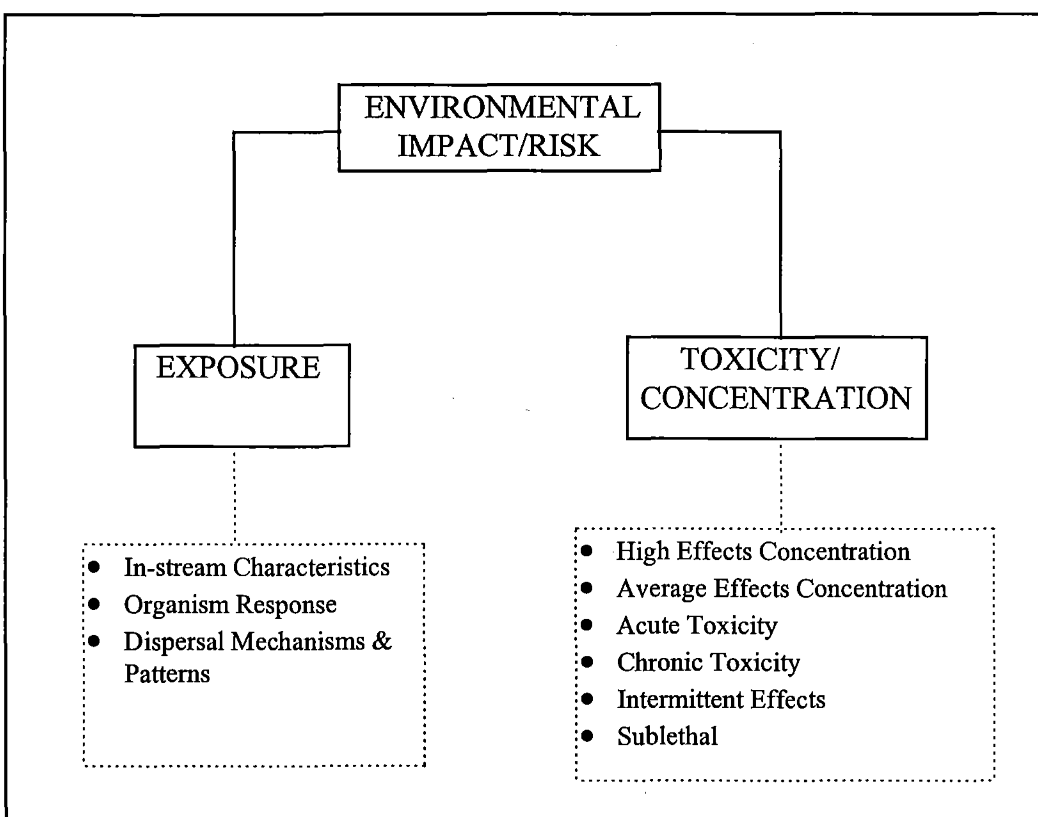

Figure 4.3. Impact characteristics of contaminant exposure and toxicity/concentration on surface waters. Adapted from Ellis *et al.* (1992), cited House *et al.* (1993).

In this study the measured median concentration is used as the measure of exposure. Exposure may also be related to speciation, in-stream characteristics, as well as frequency of exposure (which is in turn related to frequency of contaminant input into the waterway).

Many of these other measures of exposure are difficult, costly and time consuming to assess, hence only median data will be used to indicate exposure.

SUBCATEGORY	TOXICITY/CONCENTRATION CRITERIA	RANK
Nutrients - baseflow		
No Effect	< MfE criteria	0
Likely Effect	> MfE criteria	1
Suspended Sediment - baseflow		
No Effect	< US criteria	0
Likely Effect	> US criteria	1
Metals - sediment		
No Effect	< LEL criteria	0
Possible Effect	> LEL criteria	0.5
Likely Effect	> SEL criteria	1
Notes: see Appendix 3 for toxicity/concentration criteria LEL = Lowest Effects Level SEL = Severe Effects Level		

Table 4.1. Toxic/concentration ranking (M value).

4.3.3 Recreation

The public's recreational enjoyment of Christchurch's urban waterways will depend on the aspects of the ecosystems which are adversely affected, the location of the affected ecosystem, and the aspects of the ecosystem the public perceives as part of their recreational experience.

Recreational values may differ from one individual to the next. While one person may perceive any body of water suitable for kayaking as of recreational value, another may perceive only those areas with catchable sporting fish as of recreational value. Subsequently it could require rigorous surveying of the Christchurch public to determine the recreational valuable stretches of waterway. Since this was beyond the scope of this study, recreational importance was decided by two aspects of importance to recreational activities. That is waterway access and the size of waterbody. Ranks attributed to these two subcategories (Table 4.2) provide a measure of recreational importance of individual waterbodies to the community.

Waterway access is ranked depending on the proximity of the waterway to a road or walkway access, proximity to parks or reserves, and proximity to the local residential community. These were split into three grades: poor access; moderate access; and good access. Waterways with poor access are considered to be of less value than those with moderate or good access.

Recreational activities in and around Christchurch urban waterbodies include angling, whitebaiting, netting, punting, paddling, model boating, canoeing, rowing, boating, and swimming. Generally, the larger the waterbody the greater the number of structured recreational activities that are able to take place there. This is especially true for activities that use a vessel of some description on the water's surface. Applying this generalisation, waterbodies have been split into two classes. Class 1 waterbodies are the smaller waterbodies unable to accommodate structured recreational activities that require buoyant vessels, while class 2 can accommodate these activities.

Six subcategories were forged from the amalgamation of these two factors influencing recreational activities. These are depicted in Table 4.2. The ranking value a stretch of waterway obtains as a result of these subcategories can then be used in conjunction with other ranking values to set waterway abatement priorities.

SUBCATEGORY	RANK
Poor Access - Class 1	0.33
Mod Access - Class 1	0.67
Poor Access - Class 2	1
Mod Access - Class 2	1.33
Good Access - Class 1	1.67
Good Access - Class 2	2

Table 4.2. Recreational ranking.

Activities that occur on river banks (e.g. walking, running, picnicking, relaxing) are usually linked to the aesthetic atmosphere of the riparian environment. Therefore river bank recreation is assumed to be an inherent component of aesthetic values and will be included in the aesthetics section below.

4.3.4 Aesthetics

Individuals in the community each have their own perception of the aesthetic qualities that ideally bring about a satisfactory waterway experience. To quote an old adage "beauty is in the eye of the beholder". Public perception of the aesthetic value of the riparian environment can be dictated by a wide range of attributes. For example, some individuals may feel that the number of midges in a riverine environment is a good sign of food production for sporting fish, while others may consider this insect a nuisance, detracting from their aesthetic enjoyment. Each experience cannot be valued above the other. Hence, it would be a complex and difficult task to evaluate any aesthetic preference above another. To cater for the urban community as a whole, promotion of a range of riparian environments that provide a total experience in terms of historical, cultural, ecological, and recreational aspects can therefore be a sensible planning strategy.

While it may be impractical to define quantitatively the aesthetic value of a stretch of waterway, perhaps those elements that detract from the aesthetics of the waterway can be established. Landscape features such as barrenness, eroded banks, impervious surfaces, and pollution (rubbish, oil slicks, garden clippings) are such detracting elements.

Nonpoint source contaminants often have more subtle effects than the degradation features mentioned above. Their effects on the aesthetic value of the riparian environment may not be easily determined. Subsequently this assessment will employ an aesthetic ranking in terms of waterway 'audience', a method adopted by CCC in aquatic vegetation management (Snelder *et al.,* 1995). This approach ranks a stretch of waterway in terms of the population that interacts with that particular area, identifying the audience that is likely to be affected by the aesthetics of that reach. Using an audience ranking thus avoids the subjectivity of determining what defines the aesthetic experience and centres on the population affected.

The audience ranges from immediate residents (properties that extend to the river's edge) to worldwide travellers (tourists and visitors from New Zealand and abroad) (Table 4.3).

For this assessment the aesthetic rankings for individual reaches are taken from the rankings defined by Snelder *et al.* (1995) for Christchurch urban waterways.

CATEGORY	DEFINITION	RANK
Immediate Residents	Waterway viewed by residents with houses built adjacent to it	0.5
Local Residents	Waterway has public access, predominantly used by local residents	1
City Residents	Waterway has citywide aesthetic appeal, high physical access and may be followed or crossed by minor arterials	1.5
Regional Plus	Waterway is of regional aesthetic appeal, a defining characteristic of the urban area and may be crossed or followed by major arterials	2

Table 4.3. Audience ranking. From Snelder *et al.* (1995).

4.4 CONTAMINANT RANKING OF IMPAIRED URBAN CHRISTCHURCH FRESHWATER REACHES

4.4.1 Results

For several urban Christchurch freshwater reaches a ranking is determined for a number of contaminants of concern as described in Section 4.3. Eight impaired reaches are selected for analysis based on the physico-chemical and biological assessment in Chapter 3. Rankings for impaired freshwater reaches and contaminants of concern are shown in Figure 4.4. The higher the score the greater the risk that the community's environmental values are compromised. Detailed results of the analysis are presented in Appendix 4.

Results of this analysis indicate the nutrient nitrate, the heavy metals lead and zinc, are the contaminants of most concern to the eight freshwater reaches assessed in this study. These contaminants could then be considered as priority contaminants in a catchment-wide abatement strategy. However, other contaminants ranked in this assessment are also likely to be a problem to the aquatic ecosystem and the community.

To indicate the difference between impacts on the community and impacts on ecology, the contaminant ranking scheme is compared to contaminants ranked soley on ecologically-based criteria. For this latter function, the percentage a contaminant exceeds the relative water quality criteria for each of the eight reaches is calculated and totalled. These are called cumulative percentage exceedence figures as shown in Figure 4.5.

Comparing the contaminants ranked in this assessment (Figure 4.4) with the cumulative percentage exceedence of contaminants above the relevant water quality criteria (Figure 4.5) shows a different order of priority contaminants. Nitrate is the highest priority contaminant in both Figures 4.4 and 4.5. However, lead, zinc and DRP are the next highest ranked contaminants in the exceedence figures, rather than lead, zinc and copper, as indicated by the priority ranking procedure. Thus considerations of aesthetic and recreation importance does make some difference.

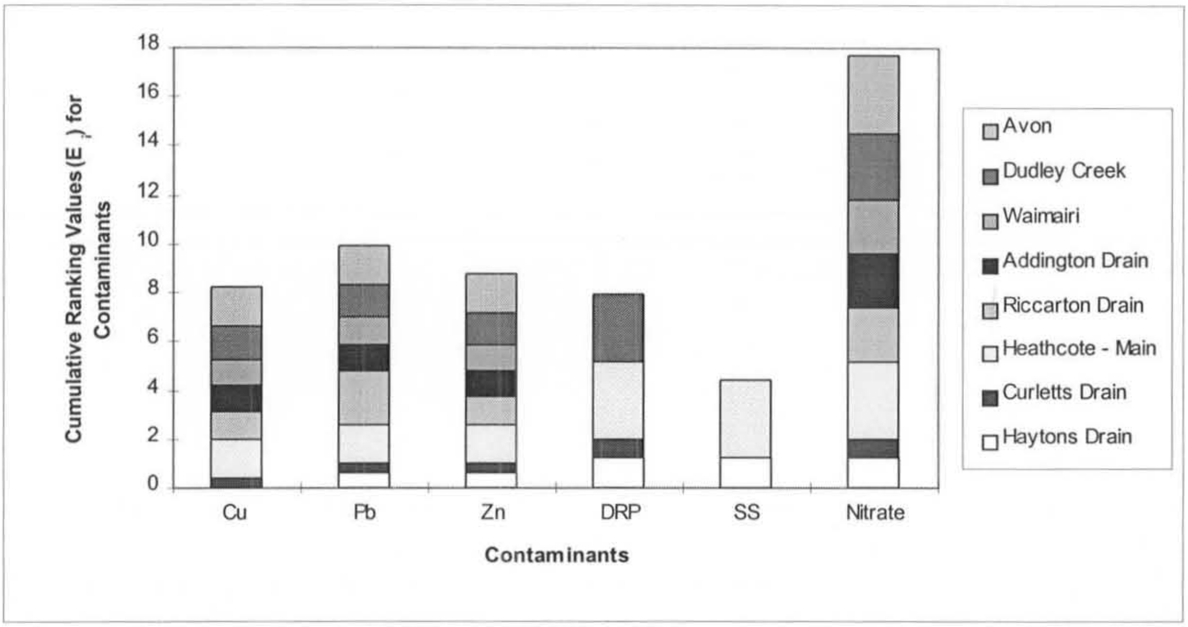

Figure 4.4. Contaminant ranking of impaired Christchurch urban surface freshwater reaches. The total contaminant ranking over a series of waterways for a contaminant (E_i) is indicated by the total length of the column for the contaminant.

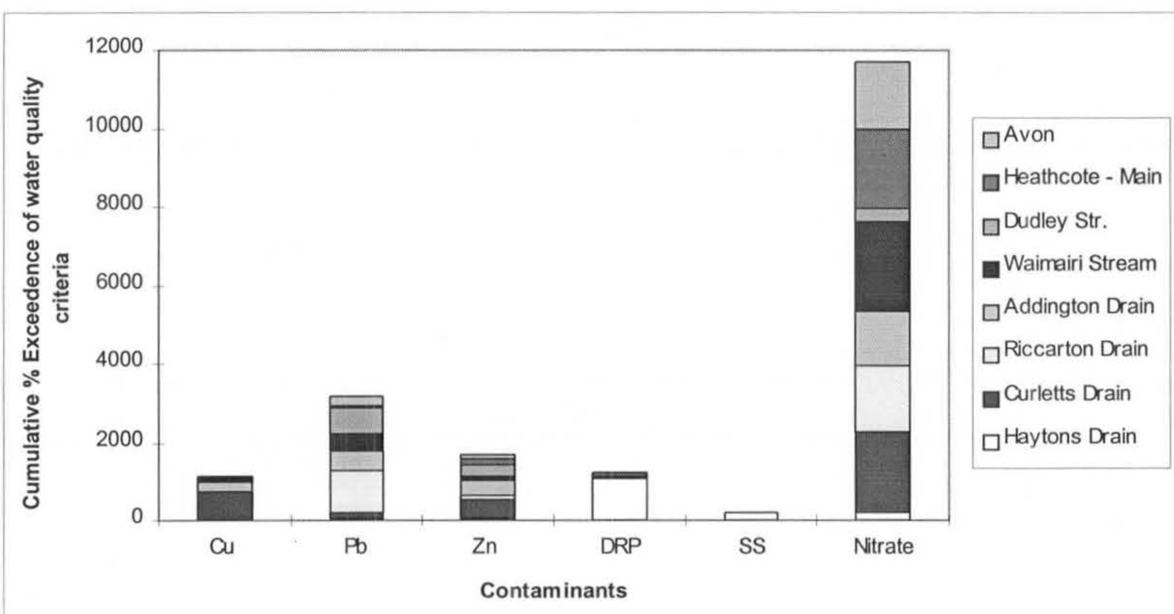

Figure 4.5. Cumulative % exceedence above recommended water quality criteria for leading contaminants in Christchurch urban freshwater reaches.

4.4.2 Further Discussion

With future monitoring a contaminant priority ranking could provide a measure with which future rankings can be compared. Such a comparison may determine if abatement schemes are successful in addressing waterway degradation in the eyes of the community. Ranking contaminants may also reveal similarly sourced contaminants (e.g. heavy metals from vehicles) to be of similar environmental concern. Abatement measures may then be formulated to best address a suite of contaminants.

Ranking contaminants to ascertain which contaminant may be considered of greatest concern to the Christchurch community has an advantage of being a simple index or indicator of waterway degradation. This not only incorporates some measure of water quality but also a greater certainty that contaminants are having detrimental effects on aquatic ecology and the community.

However, the ranking scheme has several drawbacks. While incorporating aspects of waterway importance formulated on certain community values associated with waterway use, it does not actually portray how the community value waterways. For this to be possible, extensive surveying would be needed to establish what the community wants from its waterways and how it would define if this resource is degraded. As this is out of the scope of this study, the best available alternatives are used. Another problem is the lack of definition in ranking contaminant exposure. Lack information on dispersal and/or distribution of contaminants makes it difficult to determine nonpoint source contaminants from point source contaminants. If this information was available other modelling techniques may be more appropriate for defining and predicting nonpoint source contaminants of concern.

4.5 CONCLUSION

To fully assess the effects of contaminants on Christchurch urban waterways requires consideration of the perceived values of the aquatic environment. As part of the urban 'environment' (see glossary for a definition), urban waterways under the RMA encompass

social, cultural, economic, and aesthetic qualities and characteristics. These aspects will help define whether water quality standards or goals are being met.
Combining a range of community waterway values with data on contaminant exposure creates a mechanism by which both contaminants and reaches alike can be ranked. Ranking provides water managers with a tool by which to prioritise further water quality concerns, for example, monitoring or abatement.

Ranking freshwater reaches of the Avon-Heathcote catchment using this mechanism found nitrate, lead and zinc to be the contaminants of greatest concern in the Christchurch urban aquatic environment.

5.0 SOURCE IDENTIFICATION AND QUANTIFICATION: ZINC ASSESSMENT STUDY

5.1 INTRODUCTION

From the prioritisation study of selected key contaminants (Chapter 4) nitrate and the heavy metals, lead and zinc, stand out as the nonpoint source contaminants of most concern to the 'values' of Christchurch's urban aquatic ecosystem. Nitrate is likely to predominantly be sourced from groundwater (as discussed in Chapter 3.4.1) and is therefore excluded as an urban nonpoint source contaminant for assessment. Lead also is not included as a contaminant for quantification as the recent introduction of unleaded petrol in New Zealand is likely to substantially reduce lead in the receiving environment. Hence this chapter will determine and quantify the predominant sources of zinc in the Christchurch urban environment.

Quantifying and delineating contaminant sources will aid in the development of abatement strategies to reduce contamination within the urban Christchurch receiving environment using least-cost policies. Once sources have been identified and quantified, abatement measures can be applied to priority source targets to reduce pollution.

Source identification usually involves a combination of guesswork and monitoring. When lead accumulation in soils was discovered as health hazard particularly to children several sources were suspected. Leaded petrol used in most motor-vehicles was suspected as a major contributor lead poisoning statistics. Monitoring the lead fraction found in road dirt shows a decreasing concentration away from roads validating the guess that vehicles using leaded fuels are a major source of lead (Laxen and Harrison, 1977).

Exploration of the origins of contaminants can involve backtracking from the depositional environment of the contaminant (e.g. an estuary) along the contaminant transport path. For a contaminant to enter a receiving waterway requires a contaminant transport mechanism. For nonpoint sources of contaminants entering waterways, the transport mechanism in the urban environment is predominantly urban runoff.

Rainfall is the primary mechanism for contaminants becoming entrained in urban runoff. Consequently, source investigations can be limited to those surfaces in the urban environment that come into contact with rainwater and the contaminant-producing activities on the surfaces.

5.2 METHODOLOGY

A screening analysis is the method used in this study to identify and quantify major sources of zinc based on the likely contributors. This screening analysis involves discounting sources of zinc which are likely to contribute insignificant amounts of zinc to stormwater. Only the predominant sources of zinc will then remain after the screening. The steps taken to perform this analysis are:

- From a literature review identify all zinc sources likely to be entrained in stormwater.
- Screen zinc sources identified in literature review to remove from further consideration those sources which are unlikely to be significant contributors.
- Estimate zinc loads from the remaining zinc contributors.

5.3 ORIGINS OF ZINC

Zinc is a metal that forms many compounds and has many uses in the urban environment. As discussed above this study focuses on the human activities that mobilise zinc and allow zinc to be washed into the receiving environment via stormwater. In Christchurch, runoff is channelled from hydrologically active surfaces such as roofs, paths, driveways, lawns, and roads, either directly into storm drains or via curbside gutters into stormdrains. Stormdrains are separate from the sewage system and discharge directly into urban streams and rivers.

The first step in finding the materials and compounds that yield potentially harmful levels of zinc is to conduct a literature review. Several overseas studies of stormwater runoff found high levels of zinc naming a number of sources (Laxen and Harrison, 1977; Novotny and Chesters, 1981; Hoffman *et al.,* 1985; Bannerman *et al.*, 1993, Good, 1993). Classes of sources of zinc are listed below:

- Building materials (e.g. cladding, paints, preservatives).

- Automobiles.
- Residential sources:
    - ◊ fertilisers and pesticides;
    - ◊ household products;

Each of the these main classes of zinc sources will now be examined in more detail, and the potential zinc sources will be screened.

5.3.1 Buildings Materials

There are several materials in building construction that potentially generate zinc. However, the major surfaces exposed to precipitation is the roofs of most dwellings. Roofs are the major feature of building to be connected to the stormwater system in Christchurch. Some roofing materials that leach or oxidise can contribute zinc to runoff.

The other constituents of a building that could produce contaminants (wall paint, wall cladding, wood preservatives) are not usually connected directly to the drainage network. Vegetation and soils with high infiltration capacities will adsorb many of contaminants washed from other parts of buildings such as cladding and window framing. An exception may be buildings which have a high, near-by coverage of paths, roads and parking lots. However, this contaminant pathway will be disregarded as its contribution to the overall load is small. Therefore the zinc sources associated with building materials other than roofs will be disregarded.

Roofs can consist of a variety of materials and can be assessed for contaminant loads by measuring concentrations of contaminants in runoff. A summary of zinc concentrations from different roofing materials and differing land uses is presented in Table 5.1, the results of a literature survey.

Galvanised roofs (galv-steel or zinc sheet) contribute high zinc (Quek and Forster, 1993; Thomas and Greene, 1993; Bannerman *et al.*, 1993; Prey, 1994), especially in coastal environments and areas with industrial land uses (Good, 1993).

Quek and Forster (1993) examined 5 different roof types (zinc sheet, asbestos cement, flat gravel, pantile (s-shaped tile), and tar) and found that the zinc sheet provided the greatest concentrations of zinc. The other roofing types were found to adsorb or filter contaminants contained in rainfall and deposited by atmospheric deposition. Runoff from the zinc sheet was found to have the highest concentration of zinc with the first flush with zinc concentrations remaining high during the rest of the runoff.

Bannerman *et al.* (1993) in comparing contaminant loads from roof runoff to other urban surfaces (parking lots, lawns, roads, footpaths) found residential roofs to have total recoverable zinc 2 to 20 times higher than zinc from other surfaces. Industrial roofing was also the predominant source of total recoverable zinc for the industrial land use.

REFERENCE	AREA	ROOF TYPE	ZINC (ug/l) Total	Dissolved
Good (1993)	Rural	• Rusty galvanised • Galvanised - deteriorating Aluminium paint • Tar • Tar - Al paint	12200 1980 1040 877 297	11900 1610 1080 909 257
Thomas & Greene (1993)	• Rural • Urban • Industrial	Galvanised	1300 1200 3400	
Quek & Forster (1993)	Urban	• Zinc sheet • Gravel	43000 44000 950 880	
Bannerman *et al.* (1993)	• Residential • Commercial • Industrial	• Unknown	149 330 1155	

Table 5.1. Concentration of zinc in roof runoff.

Runoff from roofs appears to possibly be a major contributor of zinc to Christchurch's aquatic environment. Therefore roofs as a source of zinc are included in the zinc load analysis.

5.3.2 Automotive Sources

There is plentiful literature on the health hazards and pollution effects of emissions from motorised vehicles. Besides the well-recognised emissions of lead, CO_2, CO, and NO, there are many other components used in automobiles that can contribute detrimentally to the aquatic environment. These components include oil, tyres, brake linings, brake and clutch fluid, antifreeze/coolant, transmission fluid, lubricating grease, metal and paint oxidation (Novotny and Chesters, 1981; Santa Clara Valley Nonpoint Source Pollution Control Program, 1992).

Previous studies have centred on roads and parking lots as an urban surface generating contaminants during runoff (Sartor *et al.*, 1974; Bradford, 1977; Hoffmann *et al.*, 1985; Novotny *et al.*, 1985; Bannerman *et al.*, 1993; Prey, 1994), but few studies have attempted to demonstrate the relative contribution of contaminants directly from motor vehicles. Shaheen (cited Novotny and Chesters, 1981) recognised the potential for contamination from various motor vehicle parts, and estimated a solids emission rate of 0.7 g/km/axle based on roadside accumulated solids.

Bannerman *et al.* (1993) in a comparison of contaminant loads found in runoff from various urban surfaces, found that runoff from parking lots and arterial streets produced the largest contaminant loads. Hence, automobiles are implicated as a critical contaminant producer.

The recent report on 'Environmental Externalities" from the Ministry of Transport (1996) also recognises the impact of contamination from our highways and reviews emissions of contaminants from the transport sector into the aquatic environment. The report states that 40% of zinc in stormwater is attributable to road transportation, with 4 mg of zinc emitted per vehicle per kilometre. They assumed that only a tenth of the emissions is deposited on the roadways.

Several studies of urban stormwater in New Zealand cities cite vehicle related contaminants as the major contributors to contaminant loading in the receiving environment (Williamson, 1986(a); Auckland Regional Water Board, 1992; Northland Regional Council, 1993). Estimation of zinc contribution through urban runoff predominantly from vehicles was 3.3 tonnes per year for Whangarei City (Water Quality Centre, 1988).

The Santa Clara Valley Nonpoint Source Pollution Control Program (1992) implemented a study to identify major sources of heavy metals in urban runoff. Cadmium, copper, lead, nickel and zinc were selected as critical metals due to their prevalence in urban runoff. Of these metals, copper from brake linings, and cadmium and zinc from tyre wear were targeted as priority contaminant sources that require reduction. Zinc contained in tyres, coolant and oil was found to add a significant contribution to zinc loading of stormwater runoff.

Huang *et al.* (1994) performed extensive emission testing on over 49 vehicle makes.

The information in the literature regarding specific automotive sources is summarised in Table 5.2.

AUTOMOTIVE PART	ZINC CONCENTRATION	REFERENCE
Tyres	Rubber 617 *ug/g* 0.73% of tyre rubber by weight 1.018% of tyre rubber by weight 0.7% of tyre rubber by weight	Shaheen (1975)[3] Christensen & Gunn (1979)[3] Radian (1990)[3] Ministry of Transport (1996)
Oil	0.24% by weight (SF) 0.13% by weight (SE) 890 mg/l[1]	Peng, Hong & Lu (1994) Huang, Olmez, Aras & Gordan (1994)
Used Oil	1060 *ug/g* 550 *ug/g*	Shaheen (1975) Pyziak & Brinkman (1992)
Transmission Fluid	244 *ug/g*	Shaheen (1975)
Brake Fluid	15 *ug/g*	Shaheen (1975)
Petrol	10 *ug/g*	Shaheen (1975)
Coolant	14 *ug/g*	Shaheen (1975)
Exhaust Emissions[2]	20000ng/ hr (catalyst) 24000 ng/ hr (pre-catalyst)	Huang, Olmez, Aras & Gordan (1994)
Notes: [1] Average of six different brands of motor oils [2] Based on sampling of 49 vehicles of American, Japanese and European make. [3] Cited in Santa Clara Valley Nonpoint Source Pollution Control Programme, 1992.		

Table 5.2. Zinc concentrations from automotive components.

5.3.3 Residential Sources

Residential activities or practices can involve the use of a variety of products that are potentially harmful to the aquatic environment. The most common use of these products is in the cleaning and/or preservation of residences, industrial or commercial premises. Products range from domestic cleaners and assorted household products, paint, pesticides, and fertilisers (Williamson, 1985; Santa Clara Valley Nonpoint Source Pollution Program, 1992; Bannerman, *et al.*, 1993; Jenkins and Russell, 1994).

5.3.3.1 Household Products

There is a variety of household products that contain varying concentrations of zinc. These include floor and wall cleaners, bathroom cleaners, washing powders, shampoo, and detergents. Products such as laundry detergents can have zinc concentrations ranging from 4.2 mg/kg to 83 mg/kg (Jenkins and Russell, 1994). However, studies by the Santa Clara Valley Nonpoint Source Pollution Program (1992) and Jenkins and Russell (1994) found that household washing products contributed less than 1% of zinc to the net residential waste water component.

Christchurch residential waste water is connected to the sewage system. As the sewage and stormwater drainage systems are separate, zinc contamination of the aquatic environment from household products is of little concern. Domestic waste water contaminated with household products may find its way into the stormwater drainage system via illegal connections or through sewage breaks. However, as the volume of wastewater is likely to be small in relation to the stormwater volume and the concentration in domestic wastewater is likely to be low, illicit domestic connections and sewage breaks can be discounted as a major source of zinc.

Household products are also used outside the house for purposes such as car cleaning. A certain percentage of the household cleaning product will be disposed of directly to the stormwater drainage system. Due to the likely differences in practices and frequency of occurrence from house to house, without a thorough domestic survey it is impractical to make an estimate of the quantity of zinc loads from this source. Such a survey may also be inconclusive as a proportion of contaminated runoff from activities using household products will be assimilated by lawns and gardens. Thus in this investigation household products will not be considered as a critical source of zinc.

5.3.3.2 Pesticides, Herbicides and Fertilisers

Garden products are another source of contaminants that have the potential to threaten the integrity of the aquatic environment. Pesticides, herbicides and fertilisers contain a range of synthetic organic compounds and heavy metals. These are added to waterways directly by spray drift or more commonly as a component of runoff from pervious areas in the urban environment.

Similar to household products, there is a large range of garden products for a variety of applications. Zinc salts form the basis for some domestic pesticides and are also important for specialised plant nutrition as fertilisers (e.g. zinc sulphate and zinc phosphate). However, there are no readily available figures on the quantities of these compounds used in the domestic market. The 'Pesticide Handbook" (Hurst, Hay and Dudley, 1991) lists over 1000 pesticides. Only 6 of these have major zinc constituents. Fertilisers commonly in use in Canterbury have negligible zinc content (*pers comm.* Bruce Pownall, Lincoln University Field Service Centre).

There are also difficulties in ascertaining the quantity of pesticides or fertiliser likely to be entrained in surface runoff. Pesticides have varying life expectancies in lawns or gardens. Differences in infiltration rates, soil dynamics, moisture content, floral and faunal uptake, and the amount of organic activity make predicting pesticide and fertiliser quantities in runoff an exceedingly complex task.

For runoff to occur, rainfall or watering must overcome the infiltration capacity of the soil. Bannerman (1992) estimated that rainfall intensities above 63.5 mm/hour are required to initiate runoff from lawns. Infiltration capacities will change with varying soil type and moisture content so less intense rainfall may result in runoff. Christchurch has a maximum recorded rainfall intensity of 84 mm/hour. Thus it can be assumed that surface runoff is likely on occasion from pervious areas, especially from hillsides. While lawns have one of the largest land-use areas they produce relatively small runoff volumes as the surfaces are pervious and in Christchurch the surfaces are generally flat. However, once rainfall results in significant runoff from pervious surfaces, contaminant loads from pervious areas may become significant (Bannerman *et al.*, 1993).

Bannerman *et al.* (1993) measured runoff from suburban lawns. The findings in this study attributed 2% of the total zinc load to runoff from lawns, although this was an estimate based on one sample.

The conclusions that can be drawn from this examination of the literature are that a significant contaminant contribution may come from pervious urban areas during the occasional high intensity storm event. In the context of an annual total zinc loading from all sources the zinc generated from pervious areas is likely to be a minor contributor and so will not be included for further load analysis.

5.4 ZINC LOAD ANALYSIS

This section analyses the loads of the main zinc sources as determined by the screening analysis (Section 5.3). Some potential sources are not considered in this section as the screening analysis indicates they are not likely to be significant. Data for a quantitative load estimate of zinc was generally obtained from the literature. Where data was not available in the literature it was obtained by telephone conversation with people familiar with zinc-sourced materials and compounds.

The method used to quantify contaminants for this load analysis is:

Step 1: For a given source, quantify the total number of source-emitting units for Christchurch (e.g. total number of tyres in Christchurch).

Step 2: Estimate the annual quantity of zinc released from the source per source-emitting unit on an annual basis.

Step 3: By combining information from step 1 and step 2 estimate zinc entrained in stormwater.

Details of calculations are provided in Appendix 5. These will now be summarised.

5.4.1 Roofing and Guttering

5.4.1.1 Overview of Roofing Types and Durability

It is quite probable that a significant proportion of zinc from roofing products finds its way into Christchurch's urban receiving environment. The primary mechanism for this is attributed to the corrosion of zinc coated products followed by washing off by rain. Zinc coating forms a protective oxide layer over steel roofing products. Over time the protective zinc coating can be leached by rainwater which in rain enters waterways.

Steel is the most common roofing product in New Zealand, commanding 93% of the present total roofing material market (35% prepainted and 58% other steel products). The residential market uses 70% of steel roofing products. Examples of these products include galvanised steel or "galv-steel", pre-painted steel or coloursteel, pressed steel tiles, and chip coated tiles (Crossley, 1990). Zinc coating is achieved by various processes (e.g. galvanised hot dip, coil coating, zinc spray), zinc acting as the first line of defence against corrosion, protecting the steel below.

Some zinc-coated products are "sacrificed" to the elements without additional protection such as paint. Such unprotected products have a life directly proportional to the weight of the zinc coating (BRANZ, 1971). Zinc coatings are measured in g/m^2. Common New Zealand roofing products and their weight of zinc coating are listed in Table 5.3.

Zinc corrosion is dependant on the severity of the atmosphere, the duration and frequency of moisture contact, and the rate at which the surface dries (Slunder and Boyd, 1971). Urban and industrial environments that produce sulphur emissions and other particulate material accelerate corrosion compared to a rural or non-corrosive environment. Wind-driven salt in coastal locations can also cause accelerated corrosion of zinc coated roofing products (BRANZ, 1971). Typical corrosion rates are given in Table 5.3.

ROOFING PRODUCT	ZINC COATING g/m^2 (1/2 on each side)	WARRANTY
Galvsteel	275	none
Zincalume	150 (45% Zn)	15 years
Coloursteel G2z Coloursteel VP	275 oven-cured painted 150 (45% Zn) oven- cured painted	15-30 years[1] 15-25 years[1]
Steel tiles	275 oven-cured painted 150 (45% Zn) oven- cured painted	25 years
New Zealand Standard	400	
ENVIRONMENT	**CORROSION RATE OF ZINC $mg.m^{-2}$ day^{-1}**	
Rural Atmosphere	17	
Marine Atmosphere	31	
Industrial Atmosphere	100	
Notes: [1] Depends on type of atmospheric exposure		

Table 5.3. Zinc coated roofing products and atmospheric corrosion rates for zinc. From BRANZ, 1978; BHP, 1993.

Added protection of zinc surfaces is gained by painting. Factory-painted products such as coloursteel are thought to be more durable than products where the finishes are applied on site (see Table 5.3). These painted products can be compromised by oily films deposited on the surface or damage to the coating. On-site paint systems for zinc coated steel products can have a surface life of up to 10-15 years. One of the most durable systems employs an inorganic zinc silicate primer coated with epoxy intermediate coat and a polyurethane topcoat (Crossely, 1990).

The most commonly-used and cheapest roof paints are acrylics and enamels. The durability of these paints is typically 5 to 7 years (Crossley, 1990; Consumer Home and Garden, 1990), dependant upon priming, application, and atmospheric environment.

Two methods are used to estimate zinc loads from Christchurch roofs. One method utilises an average concentration of zinc in roof runoff and the second is by estimation of zinc in runoff from corroding, unpainted galvanised steel.

5.4.1.2 Concentration Approach To Roof Load Analysis

A field survey of Christchurch roofs was undertaken to establish the area of corroding zinc coated roofs and to assist with the estimation of concentration in runoff (see Appendix 6). The survey determined the condition and paint coverage of galv-steel roofing in residential and industrial Christchurch (see Appendix 6.2). From the Christchurch field survey there is 955.5 ha of galv-steel in the residential sector and 205.2 ha for the industrial sector.

To determine a zinc concentration suitable to apply to Christchurch residential and industrial roofs a literature review was undertaken (see Section 5.3.1). However, the only appropriate zinc data similar to Christchurch conditions was that of 1.2 mg/l from Thomas and Greene (1993).

Further inquiries found that an Institute of Environmental Science and Research Limited (ESR) database contained zinc data on roof runoff from 35 New Zealand schools. The concentrations from the literature review (Table 5.2) which relate to overseas studies, were all greater than the zinc concentrations from 35 New Zealand schools (Appendix 6). Therefore a new survey of roofing materials and conditions of school roofs was performed to use in estimating an average zinc concentration in residential and industrial roof runoff (see Appendix 7). The results of 20 returned surveys are summarised in Table 5.4.

Using the data from New Zealand schools and the Christchurch roof survey (Figure 5.1), an average concentration figure of 0.40 mg/l zinc is used to estimate zinc loads generated from galv-steel roofing surfaces for residential roofs. The average concentration figure is obtained by first finding the percentage of five galv-steel roofing conditions found in the Christchurch field survey. These are then averaged over the concentration figures for the same 5 roofing conditions found in by the school survey. The zinc load from Christchurch residential roofs for 648 mm of rain per year (New Zealand Meteorological Service, 1980) and a residential roof area of 955.5 ha (see Appendix 5) is estimated at 2.00 tonnes/year.

DESCRIPTION OF PAINT COVER	CONDITION OF ROOF	[1]% OF CHRISTCHURCH GALV-STEEL ROOFS		[2]AVERAGE ZINC CONCENTRATION (mg/l)
		Residential	Industrial	
No paint deterioration Recent to newly painted	Excellent	11.0	6	0.18
Visible oxidation of paint Very minor flaking	Good	46.4	15.2	0.16
Paint consistently oxidised Visible flaking in patches	Moderate	17.2	12.1	0.24
Areas of total paint loss Most paint flaking or peeling	Deteriorating	8.7	36.4	0.61
Large % of paint loss All paint flaking or peeling Possible patches of rust	Poor or unpainted	16.8	30.3	1.3

Notes: [1] From Christchurch field survey, Table A 6.3 and Section A 6.2.2.
[2] From school survey.

Table 5.4. Average zinc concentrations from galv-steel roof runoff for excellent to poor roofing conditions, based on data from 20 New Zealand schools, and number of houses surveyed in those conditions in the Christchurch field survey.

New Zealand schools and the Christchurch roof field survey data were also used to obtain an average concentration figure of 0.90 mg/l zinc for industrial roofs. This concentration is used to estimate zinc loads generated from galvanised roofing surfaces for industrial roofs. The zinc load from Christchurch residential roofs for 648 mm of rain per year (New Zealand Meteorological Service, 1980) and an industrial roof area of 205.2 ha (see Appendix 5) is estimated at 1.07 tonnes/year.

The average concentration of 0.40 mg/l is lower than a concentration of 1.2 mg/l from Thomas and Greene (1993). However, the paint coverage from that study is unknown. From the schools survey analysis (see Appendix 7) a concentration of 1.2 mg/l correlates with a roof having 0% paint cover. This suggests the possibility that the Thomas and Greene study was for unpainted roofs.

There are several sources of uncertainty in this analysis. The zinc concentrations used in this analysis are based on one sample from school water tanks. This raises some doubt to the validity of these concentrations being truly representative of the amount of zinc being washed off school roofs. Zinc concentrations vary with the amount of rainfall, antecedent conditions, and the atmospheric environment. Ideally a number of samples would be taken from each tank to establish a mean concentration more indicative of the actual situation. Roof conditions and paint coverage was estimated by survey recipients. There is uncertainty related to the estimation of roofing conditions. There is also some uncertainty in the accuracy in the estimated area of galvanised material in Christchurch. Finally for any given roof condition there was a range of concentrations with considerable scatter, which introduces further uncertainty.

5.4.1.3 Corrosion Approach To Roof and Gutter Load Analysis

An average corrosion rate was calculated for galv-steel using an average lifespan of 32.5 years for a moderate coastal atmosphere (see Appendix 4). The corrosion rate for galv-steel coated with 275 g m^{-2} (137.5 g m^{-2} one side) over this period of time equates to 4.23 g m^{-2} $year^{-1}$. Using this corrosion rate for the estimated exposed galv-steel area (see Appendix 6.1), the zinc load washed from residential roofing is estimated at 11.51 tonnes/year.

Using the same corrosion rate for industrial roofs similar calculations gave a zinc load of 6.18 tonnes/year.

An appreciable amount of guttering is also made from zinc-coated products. Estimating the surface area of corroding guttering is made difficult by not being able to observe the inside of most gutters. The roofing survey found that 70% of gutters were galv-steel (Appendix 6.2) and it was assumed that at least half of these will have no protection. Thus 460260 m^2 of exposed guttering surface is calculated for residential Christchurch (see Appendix 4.1.5).

Using the same corrosion rate for galv-steel as above and assuming the same effect, the zinc load to the stormwater drainage system is approximately 1.95 tonnes/year.

These estimates may be low as there is likely to be a contribution of zinc to runoff from deteriorating zinc coated products such as pressed steel tiles and coloursteel. However, the load from these products has not been assessed as it is relatively difficult to estimate the quantity of zinc generated from these products and they probably make a relatively small contribution in relation to the load from galv-steel.

Other uncertainties, besides those inherent in the load analysis (such as area estimates), arise from corrosion dynamics. The movement of corrosion products is dependant on what percentage of zinc corrosion products are removed from roofing by wind either as oxide dust or attached to sediment and paint. Also uncertainty arises as to the quantity of zinc which is held in a gutter by the reservoir of sediment and detritus collected there.

Corrosion products also form part of the protective layering of the steel roofing product. Development of corrosion products depends on atmospheric conditions, particularly moisture contact and the rate of drying (Slunder and Boyd, 1971). Thus development and loss of corrosion products are dependant on climatic cycles. Low rainfall in Christchurch may give a lower corrosion rate than the one estimated for this assessment. A corrosion rate for galv-steel based on the on an average lifespan of 100 years would yield a zinc load from residential and industrial roofs of approximately 5 tonnes/year. Thus the average corrosion factor used in this assessment may not accurately reflect the actual conditions. The zinc load calculated by using the concentration method may therefore give a better indication of the actual zinc load.

5.4.1.4 Paint from Roofing

The concentration method incorporates a component of zinc from paint as well as from the building product. Further calculations can be performed using the weathering rate of paint. Little data exists on the amount of zinc contained in roof paints and primers. They commonly range from about 100 to 1000 ppm (Santa Clara Valley Nonpoint Source Pollution Program, 1992). Two coats of average acrylic roof paint is approximately 0.3 mm thick. Assuming a 6-year life (Crossley, 1990) 220000 litres of paint is washed from 440.3

ha of painted residential roofs per year. Using the lower concentration value (100 ppm) the zinc load is approximately 22 kg/year. This is relatively minor compared to zinc yielded from galvanised products. The higher value gives 0.22 tonnes/year, although this is probably an over estimate as not all paint is likely to come from roofs over 6 years.

5.4.1.5 Summary and Discussion

The total estimated zinc load to the stormwater drainage system is 19.64 tonnes/year using corrosion analysis and 3.07 tonnes/year using runoff concentration analysis. These results are summarised in Table 5.5 below. Zinc loads from galvanised roofing are probably more accurately represented by using a concentration method rather than estimated corrosion rates as discussed in Section 5.4.1.3. Zinc from roof paint makes an insignificant contribution to the total zinc load (only 22 kg/year).

	ZINC - CORROSION tonnes	ZINC - CONCENTRATION tonnes
Residential Roofing	11.51	2.00
Residential Gutters	1.95	
Industrial Roofing	6.18	1.07
TOTAL	**19.64**	**3.07**

Table 5.5. Results of zinc loading analysis from roofing for Christchurch, 1996.

5.4.2 Automotive

As indicated in Section 5.3.2, zinc is found in many automobile components. It exists in forms from zinc oxide in tyres (Ministry of Transport, 1996), to zinc dialkyldithiophosphate in engine oils and fuels (Pyziak and Brinkman, 1993).

Zinc load analyses have been performed on those automobile components identified in the screening analysis, as detailed in Section 5.3.2 (Table 5.2), that have zinc in concentrations of possible environmental consequence and that have a high probability of entering the aquatic environment. This amounted to five automotive components. Others such as brake and clutch fluid or transmission fluids were unlikely to represent a significant zinc load.

5.4.2.1 Fraction of Automobile-Related Emissions Entering Stormwater

Establishing what fraction of the zinc load emitted from automobiles finds its way into the aquatic environment not easy. Various methods to estimate this fraction will now be discussed.

A large percentage of the *particulate* material derived from vehicles is found near the roadside. 95% of street refuse is found within 1m of the curb (Novotny and Chesters, 1981, p315). The deposition flux of materials drops rapidly as a fraction of distance from the roadside, as demonstrated by Shaheen (1975, cited Novotny and Chesters, 1981, p320). Most of the wear from tyres has been shown to settle near or on a road (Cadle and Williams, 1978; Malmquist, 1983; cited Santa Clara Valley Nonpoint Source Pollution Program, 1992).

Several studies have measured the concentration of zinc accumulated in roadside dirt (e.g. 397 μg/g for residential land use; Novotny and Chesters, 1981, p318), but do not demonstrate the percentage of emissions of metals left on roads. The Ministry of Transport (1995) have given a figure of 0.4 mg vehicle^{-1} kilometre^{-1} of zinc deposited on roadways, which is 10% of the total estimated automotive-related emissions.

For the purposes of this investigation it will be assumed that approximately 80% of zinc generated from tyres and brake linings will be flushed into the stormwater. This is based on the findings of Cadle and Williams (1978; cited Santa Clara Valley Nonpoint Source Pollution Program, 1992) and Malmquist (1983; cited Santa Clara Valley Nonpoint Source Pollution Program, 1992), as stated above, that most tyre debris settles on the road. Comparison with the Ministry of Transport figure of 10% deposition of zinc to roadways 80% might seem excessive but it is in line with northern hemisphere studies.

A different fraction of exhaust emissions is likely to be entrained in stormwater. Fergusson *et al.* (1980) found 62% of the lead on the sides of the road (within 100 m of the road) lies within 10 m of the road. However, not all the lead emitted from vehicles is deposited within 100 m of the road. Fergusson cites other studies which estimate between 10% and 50% of the exhaust emissions of lead are deposited within 100 m of the road. Therefore between 3.7% and 29.8% of the lead emissions lie within 10 m of the road. An average figure for this might be 17%. Further, zinc emitted from exhausts has a similar distribution pattern compared to lead according to data presented in Appendix 5. Therefore the load calculation in this analysis assumes that 17% the zinc exhaust emissions are deposited within 10 m of the road. All of this is assumed to be washed into stormwater. Although this is not entirely realistic, the assumption allows for some exhaust emissions which are deposited directly on the road to enter stormwater.

Coolant and oil, leaks directly into the road surface or other paved surfaces. Hence it will be assumed that 100% of the zinc from these vehicle fluids are entrained in stormwater.

5.4.2.2 Tyres

Tyres are an obvious high-wearing automotive component easily deposited on the road or roadside. Figures extrapolated for 1996 show that extensive tyre wear is expected from the estimated 166760 vehicles in Christchurch. Each vehicle travels an average of 17000 kilometres per year (CCC, 1995).

In the analysis of tyres, an initial load analysis was performed and this was checked by two supplementary analyses (Appendix 5.2.1). For the initial load analysis, a figure of 12.95 g zinc oxide (ZnO) lost from each tyre as it wears from new to warrant of fitness standard (Ministry of Transport, 1996) is used. With an average tyre life of 30000 kilometres (*pers comm* Dunlop Tyres) an average tyre in Christchurch lasts approximately 1.76 years (based on the number of kilometres travelled per year). Thus the ZnO shed per tyre per year is approximately 7.36 g/year. Multiplying this by the number of vehicles in Christchurch, it is estimated that 4.91 tonnes of ZnO was deposited into the environment from tyres in 1996. Assuming 80% of this is deposited on or near the roadway, and accounting only for the zinc component of zinc oxide, 2.44 tonnes/year of zinc is likely to be introduced into the urban waterways.

Supplementary checks on this load analysis are performed (see Appendix A 5.2.1) using tyre wear data based on tyre volume and densities from overseas studies. Both analyses are within the same order of magnitude (zinc loads of 5.28 tonnes/year and 1.98 tonnes/year). The initial analysis is thought to be the most representative of the actual Christchurch situation, as the tyre wear is based on New Zealand data.

5.4.2.3 Coolant

Coolants are easily disposed of to the stormwater drainage system via leaking vehicle cooling systems or from improper disposal by backyard and professional mechanics. Estimates put improper disposal of coolants to the environment at 25% to 50% of coolant used (Hudgens and Bustamante, 1993). One estimate also showed that heavy-duty vehicles lost 10% of their coolant volume over 23000 kilometres (Hudgens and Bustamante, 1993).

Heavy metals are at very low concentrations in many new coolants, but metals can be added to the coolant when they are leached from cooling system. Consequently, concentrations of 200 mg/l zinc can be reached in some cooling systems (Hudgens and Bustamante, 1993), but 14 mg/l is probably an average concentration (Shaheen, 1975; cited Santa Clara Valley Nonpoint Source Program, 1992).

For this load analysis it is assumed that 37.5% of coolant ends up in the waterways. Since the average coolant capacity in a vehicle is 6 litres and is changed every 3 years (*pers comm* Shanta Mannapperuma , mechanic), for the 166760 vehicles in Christchurch (1996) 125070 litres of coolant (mixture of water and coolant) is added to the waterways per year (Appendix A 5.2.2). At an average concentration of 14 mg/l the estimated quantity of zinc added to the aquatic environment is approximately 1.75 kg/year.

5.4.2.4 Oil

Oil used in Christchurch vehicles is most likely to enter the aquatic environment in two ways. One is by improper or illegal disposal of used motor oil directly into the stormwater drainage system. The second is oil deposited on roads from leaking vehicles being washed into waterways.

Improper oil disposal is not considered a problem in urban Christchurch, due to the recycling facilities available. Most service stations collect and properly dispose of oil via transfer stations or through recycling (*pers comm* Norm Fitts, CCC). Only an average of eight complaints per year is received by the Canterbury Regional Council (*pers comm* Jackie Jones, CRC) regarding oil in the aquatic environment. As 1 litre of oil can cover a hectare of surface area on water, it is highly visible. Thus it seems reasonable that the number of complaints received by the CRC is an accurate estimate of the quantity of oil improperly disposed of in the aquatic environment. The conclusion is that little zinc is contributed to the aquatic environment through the improper disposal of oil.

However, with every deluge that rinses the city's streets an oily sheen can often be seen with the first flush of the stormwater drains on urban waterways (*pers comm* Norm Fitts, CCC). Many roads and carparks show the tell tale signs of leaking vehicles. In a telephone survey of 15 service stations in the Christchurch metropolitan area, mechanics were asked to estimate the number of vehicles with major oil leaks. Approximately 50% of vehicles have obvious oil leaks but only 10% of these would be called major. A major oil leak was defined as a vehicle losing around 250 ml of oil per month.

With approximately 10% of Christchurch's vehicles leaking 250 ml of oil per month, 16676 leaking vehicles deposit approximately 50028 litres of used oil on to roads in 1996. The average concentration of zinc in oil used to calculate zinc load is 468 mg/l (see Appendix A 5.2.3; Huang *et al.*, 1994 and Pyziak and Brinkman, 1992). Assuming all oil deposited on the roadway is washed into the stormwater drain, the estimated quantity of zinc washed into receiving waters from oil leaks in 1996 is 34 kg/year.

5.4.2.5 Exhaust Emissions

Zinc is introduced into the combustion system of most vehicles through oil and fuel. The most comprehensive exhaust emission study that included zinc in its analysis found in the course of this investigation is that of Huang *et al.* (1994). The average zinc emitted from the 49 vehicles tested for 30 minutes at idling speed, was found to be 10000 ng per vehicle for vehicles fitted with catalytic converters, and 12000 ng per vehicle for those vehicles without (although only particles of $\leq 10\ \mu m$ were measured). Assuming an emission rate of 11000 ng per vehicle per 30 minutes, and assuming Christchurch vehicles spend 56698400 hours on the road per year (calculated using 1996 figures, see Appendix A 5.2.4), the estimated zinc from exhaust emissions is 1.2 kg/year. Of this 0.2 kg/year is likely to be washed into the drainage system assuming 17% zinc emitted from exhausts is deposited within 10 m of the roadway (see Section 5.4.2.1).

The rate of zinc emitted is dependant on the speed and acceleration at which a vehicle is driven. Dispersal and deposition will be largely dependant on the range of particle size. This introduces some uncertainty to the load figures.

5.4.2.6 Brake Linings

The linings of brakes are composed of varying materials. Asbestos linings have been updated with more durable metallic brake pads in many vehicles. The most commonly used metal is copper, but other such as zinc and lead are also used. Modern brakes are also increasingly using hard wearing resins in brake linings. These may be reinforced with metallic compounds.

From an investigation into brake linings, the Santa Clara Nonpoint Source Pollution Programme (1992) estimated that 130 g of brake dust is emitted for every 17000 kms travelled by the average vehicle. Using mass of zinc of 124 μg for every gram of brake lining (Shaheen, 1975; cited Santa Clara Nonpoint Source Pollution Programme, 1992), the estimated quantity of zinc from brake linings in 1996 is 2.7 kg. Assuming 80% of emissions are washed into stormwater then approximately 2.2 kg of zinc will be washed into stormwater per year.

5.4.3 Summary of the Results of Automotive Source Load Analysis

An estimated 4.95 tonnes/year of zinc is derived from tyres, coolant, motor oil, exhaust emissions, and brake linings based in Christchurch. Of this, approximately 2.5 tonnes/year is washed into stormwater (see Table 5.6). Based on these estimates, the average zinc emissions from the standard Christchurch vehicle is 30 g vehicle^{-1} year^{-1} or 1.7 mg vehicle^{-1} kilometre^{-1}. It is estimated that 52% of this or 0.88 mg vehicle^{-1} kilometre^{-1} enters stormwater.

Tyres are the most significant contributor of zinc to the aquatic environment, contributing 98.7% of the zinc load from automotive sources.

Not included in the load estimation is the zinc contribution from automotive components such as car body parts, clutch plates and other fuel additives. It is thought the zinc emitted from such parts would be insignificant compared to the components analysed in this investigation.

The zinc entering stormwater estimated in this investigation (0.88 mg vehicle^{-1} kilometre^{-1}) is significantly smaller than the 22 mg vehicle^{-1} kilometre^{-1} estimated by Hoffman *et al.* (1985). Hoffman *et al.* (1985) also stated that 77% of the zinc budget received by the river under study was from highway runoff. The difference in load estimates between this study and Hoffman *et al.* (1985) may be due to Hoffman's estimates being based on roadside and stormwater sampling and not a vehicle emission analysis.

Estimates in this investigation are more in line with data from the Ministry of Transport (1996). According to the 1996 Environmental Externalities Report, total zinc emissions are 4 mg vehicle^{-1} kilometre^{-1}, with a tenth of this being deposited on roadways (i.e. 0.4 mg vehicle^{-1} kilometre^{-1} entering stormwater)

AUTOMOTIVE PART	ZINC kg To stormwater	ZINC kg From Vehicles
Tyres	2440	4910
Coolant	1.75	1.75
Motor Oil	34	34
Exhaust Emissions	0.2	1.2
Brake Linings	2.3	2.8
TOTAL	2478	4950

Table 5.6. Estimated automotive source loads in urban Christchurch, 1996.

5.5 SUMMARY OF TOTAL ZINC LOAD

The total zinc load washed into the stormwater drainage system for urban Christchurch is estimated at 5.57 tonnes/year (based on 1996 figures). Table 5.7 summarises the individual sources contributing to the total load. The sources are shown diagrammatically in Figure 5.1.

Each source calculation is an estimate, and often is based on limited data. Thus individual load estimates may have a large error component, which may be reflected in the total load.

Elliott (1996) calculated the zinc load to stormwater for urban Christchurch based on Williamson (1993) yield per hectare for various land uses. Comparison of this zinc yield of 7.1 tonnes/year for the Avon-Heathcote catchment with the 5.57 tonnes/year calculated from a range of nonpoint sources in this study shows reasonable parity. However, a figure estimated by yield per hectare for various land uses (as calculated by Williamson, 1993) does not provide sufficient information on the sources and associated loads from those sources to be useful in implementing preventative pollution policies.

SOURCE	LOAD TO STORMWATER (kg/year)	% OF TOTAL LOAD
AUTOMOTIVE		
Tyres	2440	43.81
Motor oil	34	0.61
Coolant	1.75	0.03
Exhaust emissions	0.2	0.00
Brake linings	2.3	0.04
Others	negligible	-
BUILDING MATERIALS		
Residential Roofs	2000	35.9
Industrial Roofs	1070	19.20
Roof Paint	22	0.3
Preservatives	negligible	-
Claddings	negligible	-
RESIDENTIAL		
Fertilisers and Pesticides	negligible	-
Household Products	negligible	-
TOTAL	**5570**	**100**

Table 5.7. Summary of nonpoint sources and loads of zinc in urban Christchurch.

5.6 CONCLUSION

The major contributors of zinc to the stormwater drainage system in urban Christchurch were found to be tyres and zinc clad roofing products (Table 5.7). These sources should be the focus of any abatement strategy to limit zinc in the urban aquatic environment. Other sources are insignificant in comparison.

There was reasonable agreement between the total load estimated from this study (calculated from the sum of sources) and the load estimated by Elliott (1996) (calculated on a yield basis).

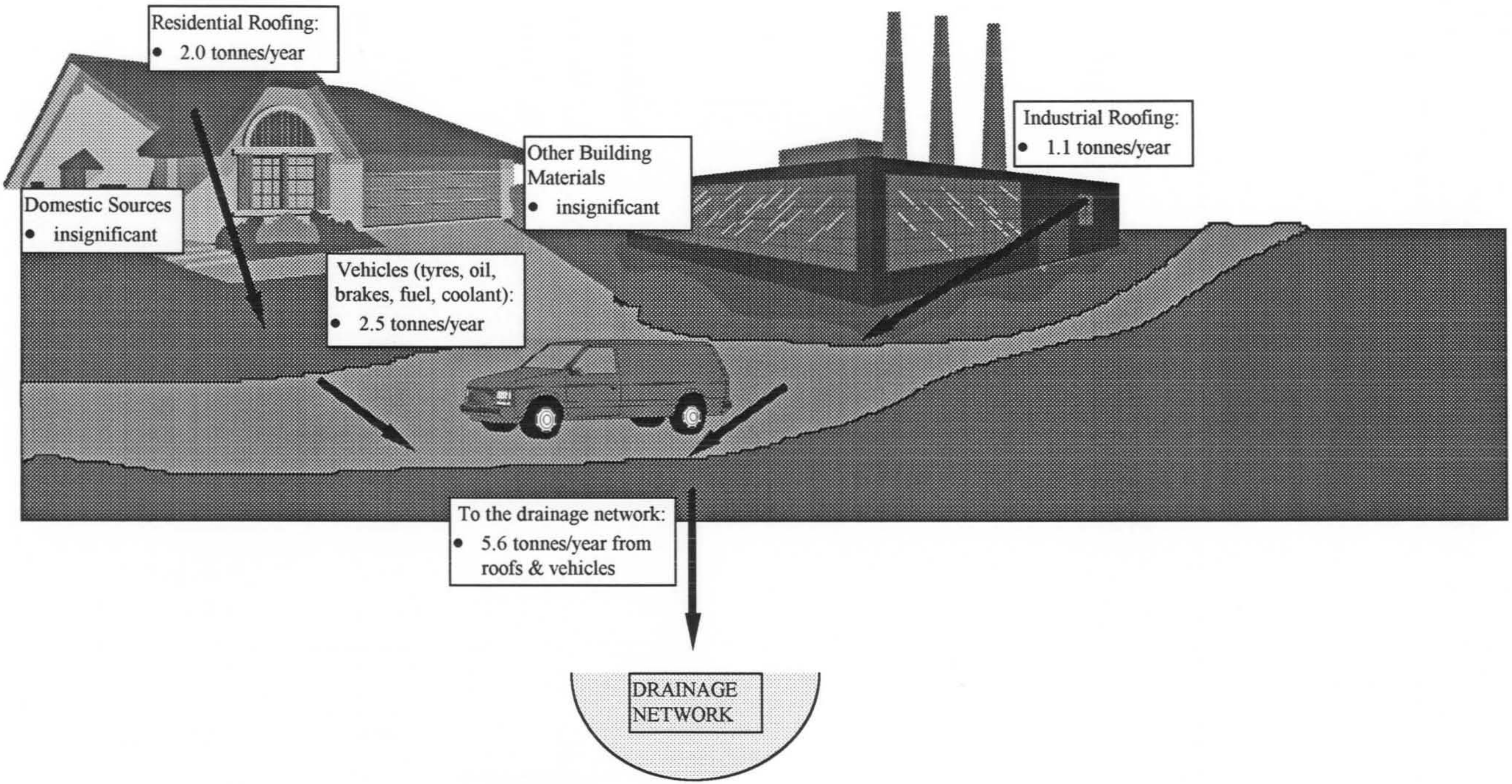

Figure 5.1 Flow and yield of zinc from major nonpoint pollution sources.

6.0 INTEGRATING NONPOINT SOURCE POLLUTION ISSUES INTO WATERWAY MANAGEMENT

6.1 INTRODUCTION

The emphasis of source control has changed from point to nonpoint sources since many pollution risks to humans have been reduced through point source controls. Water quality objectives have also shifted from human health concerns to also include ecologically and culturally based goals. Nonpoint source pollution represents a substantial threat to some of today's water management goals, but in many cases may not be adequately identified. Environmental managers may not recognise nonpoint source pollution as a problem if it is not adequately identified. Hence better information on nonpoint source pollution and greater feedback of this information into the planning and managing of waterways will provide decision-makers with a greater range of abatement options.

This chapter utilises the lessons learnt from previous chapters to provide an overview and discussion on the methods and tools used to assess nonpoint source water pollution. Also discussed are the links between the information generated from assessments and the decision-making process.

First an examination of why nonpoint source issues may not be receiving the same attention as point source pollution issues is presented. Following this the benefits of adopting an integrated approach to information management are explored. The next section examines some of the information management strategies that may be implemented to ascertain the state of the environment, assess if nonpoint source contaminants are a concern to the aquatic environment, and define nonpoint source contaminant sources. The information considerations and processes that help identify nonpoint source contamination of the aquatic environment are discussed under four headings:

- Assessing a water quality problem;
- Analysis and Modelling;
- Monitoring;
- Priority setting - risk assessment.

These four methods of information definition and interpretation are discussed with reference to integration into decision-making to help achieve and evolve environmental management objectives. A final discussion looks at the links between the decision-making process and information generation.

An analysis of economic, political or institutional mechanisms is not explored in this chapter. The focus is instead on the linkages between objective-setting and the fundamental parameters that contribute to comprehensive waterway management at a grass roots level. While the ideas and strategies presented here may represent a process to defining and justifying nonpoint source pollution issues, each problem will have its own intricacies and should therefore be approached independently.

6.2 NONPOINT SOURCE POLLUTION: A DIRTY WORD?

Often considered dirty, urban stormwater does not seem to draw the attention from the public or water resource agencies that point source pollution generates (Harrison, 1991). This section discusses whether nonpoint source pollution is an issue recognised by the public and the institutions managing water resources.

The impacts of nonpoint source pollutants in the aquatic environment can be subtle and are often induced over extensive periods of time. Thus the public and the agencies responsible for water management may not register incremental loss of amenities. In many cases only scientists pick up the effects of pollution (Irwin, 1991).

Due to this lack of recognition, urban nonpoint source contamination is often not a priority issue in the public arena. Hence, water managers working with limited budgets and set agendas linked to short term interim political agendas may not devote their resources to dealing with nonpoint source pollution in the urban environment. This is not to say that water quality of urban streams is neglected, but waterway management may be dictated by macroscopic waterway values, such as aesthetics, rather than aspects such as the intrinsic ecological value of aquatic habitats and their constituents (Holdgate, 1979). However, some water management agencies resist devoting attention to nonpoint source water quality problems due to their inherent complexities (Novotny, 1988).

Direct human health concerns are most often at the forefront of environmental policy and because of these aquatic organisms and ecosystem functioning may be neglected. Thus a water quality problem may not receive attention from resource management agencies until community lobbying establishes a problem (*pers comm.* Ken Taylor, CRC).

To draw a management response to nonpoint source issues equal to the issues associated with point source pollutants requires information on nonpoint source pollution problems that not only identifies water quality problems but also relates the problem to management objectives. Thus an approach that can relate human actions (i.e. pollution generation) to the affects of human actions on aquatic ecological systems is desirable, thereby identifying the best options for lessening undesirable impacts. It is envisioned that such an approach would encompass a holistic view of nonpoint source pollution abatement. This would involve not only responding to water quality problems based on narrow scientific guidelines, but investigating all aspects of pollution generation, the possible effects and the available remediation options in the best interests of community objectives.

6.3 APPROACHING NONPOINT SOURCE WATER POLLUTION PROBLEMS

It is likely that certain critical issues will predominate (e.g. reduced fish stock, loss of intrinsic ecological value) when assessing nonpoint source water quality problems possibly emphasising further information needs. To guide environmental managers through the complex maze of environmental information that surrounds nonpoint source water pollution requires an approach that identifies the key water quality issues, while keeping a focus on management objectives. However, critical issues can set priorities for waterway management and should not wholly define water management lest other water quality problems be disregarded (Montgomery *et al.*, 1995).

Ascertaining the causes of nonpoint source pollution in the aquatic environment is only one of many problems to be tackled when investigating pollution abatement strategies. In Chapter 3, information from a range of disciplines was brought together in an attempt to establish the intricate relationships of nonpoint source pollutants, their effects, and the sources of pollution in the Christchurch urban environment. Chapter 4 expanded the analysis further to link a social dimension to the problem of waterway degradation and provide a method of prioritising the problem. These case study examples traced the possible causal links between pollutants and the environment to make it possible to formulate further questions on the source and quantities of contaminants (Chapter 5). The progression of these three assessments represents a possible systems approach to interpreting and justifying the impacts of nonpoint source contaminants in the urban environment.

If improved water quality through nonpoint source control is a management objective then questions should be formulated that address this objective. Answers to the questions on this objective or similar ones will provide a model of the components and pathways of nonpoint source pollutants, providing the right questions are asked. Questions addressing management objectives or pollution problems may focus on the core of the issue. For example, if it is assumed that elevated nutrient levels are causing undesirable biological growths, the nutrients become the focus. However, if other questions are not asked about other ecological, geomorphological or hydrological impacts, the true cause(s) of the problem may not be revealed. Thus, elaborating on the previous example, a combination of features such as reduced flow, increased sedimentation and elevated nutrients may be creating a habitat for undesirable growths. Hence an interdisciplinary approach to assessing water quality problems should be considered.

Environmental data can be collected on a large scale. If the information gained from environmental data is not presented, utilised, channelled or interpreted towards management goals and objectives, then there is a danger of information becoming redundant (Montgomery *et al.*, 1995). Redirecting information gained from nonpoint source assessments to the planning or management process requires a scheme that incorporates or considers nonpoint source issues in an overall water management context. Hence, to formulate and justify nonpoint source pollution abatement might require an integrated strategy.

An integrative approach, following the path of recent policy, legislation and mandates (i.e. RMA), builds on a holistic view of the environment linking ecosystems, resources and social amenities. Integrated environmental management can be defined as:

> *involving a strategic approach to the management of environmental problems and the diverse, often conflicting aspirations and perspectives that people hold. It is designed to be anticipatory but can also deal with issues on a reactive*

> *basis. It is based on a systematic effort to understand, through interpretation and analysis, the linkages between ecosystems, resources and people. This involves the bringing together of a diversity of perspectives, disciplines, and practices, along with evaluation of associated institutions and policies.*
>
> Buhrs, Hughey and Montgomery, 1996

For the purposes of this discussion integration is the approach adopted to help incorporate science into decision-making and to manage the information considerations that define a nonpoint source pollution problem. Integration of the information building bricks that provide the foundation of pollution abatement will facilitate policies that cross the broad spectrum of policy sectors (e.g. manufacturing, housing, transport, agriculture) to help achieve goals such as pollution prevention. Social, economic and cultural issues should also be addressed in a fully integrated approach, however these are not discussed here.

While this approach elucidates on the benefits of an integrated approach to nonpoint source pollution assessments, it does not discuss the options to be implemented once information is generated. Rather, it identifies some of the processes used to gather and interpret information so an informed decision can be made on a nonpoint source pollution issue.

6.4 ASSESSING A WATER QUALITY PROBLEM

The initial recognition of a water quality state as a 'problem' may arise from a variety of sources. The community may view a certain state of water quality as being a problem that demands attention or a scientific study may reveal certain degrading factors that were previously unknown. The assessment of a state as a 'problem' is related to the designated use of the water resource, such as human consumption, recreation, aesthetics and agriculture. A problem for a resource designated for human consumption may not be regarded as an aesthetic problem.

Once a problem has been identified, the spatial and temporal extent needs to be identified. This will involve locating and reviewing existing knowledge and initiating further studies where existing knowledge is not sufficient or where further pertinent questions are raised. Sufficient data may delineate trends that identify present aquatic conditions similar to past patterns of disturbance. This will help facilitate a greater understanding of the ecology of a waterway and the effects of the landscape on the aquatic system (Montgomery *et al.*, 1995).

Through this information, an understanding of the urban landscape's components can lead to identification and quantification of nonpoint contaminant sources.

An example of such a process is illustrated in Chapter 3. This chapter brought together a collection of data, historical and current, to provide a window through time of past and present processes influencing water resources. Through compiling and integrating land use, soil, hydrological, climatic, vegetation and biological data a greater understanding of environmental processes was achieved. This exposed important considerations for assessing the causes and sources of waterway degradation and gave an insight into contemporary waterway conditions. For example, the silt dominated substrate of many freshwater reaches in Christchurch urban rivers is likely to have been initiated by past conditions rather than being indicative of present silt input.

Thus documentation of a water quality problem should:

- define water use(s);
- define location and hydrological attributes;
- delineate what has happened in the past;
- depict waterway degradation and/or threats to water use(s);
- state the contaminants of concern, the contaminant sources, and the magnitude of sources;
- identify trends;
- define further monitoring and research needs; and
- identify future implications.

Once such information as described above is documented, clear recognition of the water quality problem can be achieved. Water quality problem definition will then be able to define the waterways under threat of impairment, state the contaminants creating the problem, and define the pollutant sources and their magnitude. Once this level of understanding is achieved, monitoring can be implemented to further assess and gain a better understanding of the problem. By augmenting traditional water quality information with biological, social, ecological, and quantitative information on nonpoint source pollution and its impacts, waterway management goals will be better serviced.

Thus to comprehensively identify and document nonpoint source pollution an approach that investigates a range of parameters to determine which would best meet the government's and public's information needs would be recommended. Information needs could be based upon: sensitivity, economic constraints, ability to show measurable trends, flexibility, responsiveness, and ability to act as an early warning system. In the urban environment, community values and activities such as recreation, aesthetics, ecological, economic, and potable water, may be included. Information needs can then be designed to the meet the reqirements of the management issue at hand.

6.5 MONITORING

Monitoring programmes provide the information needed to update and revise management decisions and prescriptions (Montgomery *et al.,* 1995). A monitoring system also provides the major link between the natural ecosystem or resource, and the decision-makers. This connection occurs as monitoring is involved in the flow of information through a system of monitoring components. Monitoring components are the links and network elements that are put in place to translate raw scientific data into planning information. Thus, environmental monitoring processes aspire to integrate scientific knowledge into the policy process, bridging the gap between science and policy-making. Consequently, monitoring provides feedback and links between policy objectives and outcomes (Steven, 1990).

Thus, monitoring usually takes place at two levels:

- monitoring the condition or state of the environment (Ward, 1990).
- monitoring the decision-making process, i.e. monitoring the effectiveness of policies and achievement of objectives.

The first of these levels will now be discussed. The latter monitoring level is beyond the scope of this report, however, the role of decision-makers in monitoring at the environmental level is discussed.

6.3.1 Monitoring The Condition Or State Of The Environment

Clear definition of objectives should be the priority step in developing a water quality monitoring programme (Reinelt *et al.*, 1992). Monitoring objectives for nonpoint source contaminants should include defining ecological condition, habitat and anthropogenic attributes limiting to ecological integrity, and to identify and locate the contaminants responsible for deleterious effects in the aquatic environment. Monitoring will provide a clearer picture of what the critical issues are confronting a water resource, as well as helping to define further information needs.

Environmental management strategies are enhanced if water resource monitoring systems are designed from information needs. Identifying information needs from pollution problem definition or from decision-makers will increase the likelihood of collecting information useful to a management purpose. This alleviates the risk of monitoring information being overlapping, becoming redundant or providing information not relevant to the problem being addressed.

The Christchurch case study found some sources of information not at a frequency or resolution adequate to make a detailed assessment of the impacts of nonpoint source contaminants in the Christchurch urban aquatic environment. Hence, difficulty was had in ascertaining any causal relationship between nonpoint source contaminants and biological impact. Thus, one focus in attempting to implicate nonpoint source contaminants as causes of aquatic biological degradation could be to monitor contaminants and waterway ecology, possibly through employing environmental indicators as currently being developed by the MfE's National Environmental Indicators Programme.

Monitoring design will include determining the range of variables needed to reach an information goal, as well as defining the nature of the information goal in more definite terms. The variable selection process may be simplified and expedited by contaminant prioritisation assessments (see section 6.5). Thus monitoring nonpoint contamination sources may target specific representative outfalls, representative of residential, commercial and industrial land uses, or may target selected degraded waterways. Priority contaminants can also be targeted for monitoring but it is wise to develop monitoring schedules for other contaminants to ensure minor contaminants in water systems are not impairing aquatic health.

Ward *et al.* (1990) outline four monitoring classifications that may be undertaken to ascertain waterway goals or the state of the aquatic environment:

1. *length of projected life of monitoring system: e.g. long term (fixed station), short term (specific problem);*
2. *types of measurements to be made: e.g. physical/chemical, biological (toxic, fisheries survey, bioaccumulation, ecosystems);*
3. *location of water in hydrological cycle: e.g. groundwater monitoring, lake monitoring, surface water monitoring, effluent monitoring, estuary monitoring;*
4. *type of water quality tool to be managed: e.g. compliance monitoring, enforcement monitoring, trend monitoring, background monitoring.*

If adequate identification and documentation of a nonpoint source water quality is not possible further monitoring may be necessary. Monitoring should build on previous assessments of historical conditions where possible, but should be specifically designed to meet set objectives and answer specific questions. This may help narrow the information range to focus on specific components of the ecosystem being degraded as well as the possible causes and sources of degradation.

6.3.2 The Role of Decision-makers

Monitoring is invaluable to evaluate and assist in the achievement of specified environmental outcomes through objectives, policies, rules, and other methods. Monitoring programmes should be looking to answer questions developed in the planning forum in the interests of effective environmental control and supervision, to avoid poor decision-making. This means developing a monitoring system that answers the questions posed by decision-makers. However, initially decision-makers have to anticipate the questions needed to attain goals stated for the environment or water resources.

Difficulties may arise as goals conflict, resulting in goals being left open for interpretation (Ward *et al.*, 1990). Government agencies (national, regional and local) usually have fragmented and shared responsibilities, with each agency having its own monitoring agenda. Staff in each agency base monitoring on implications of given legislations. The role of monitoring in management is open to interpretation by personnel implementing the law (Ward *et al.*, 1990). This has meant monitoring can be carried out on an *ad hoc* basis, resulting in disjointed data collection (Ward, 1991). The Environment 2010 Strategy (1996) points out that *"a lack of adequate environmental information can mean:* 4:51

- *delays to development activities;*
- *decisions that create high clean up costs;*
- *decisions that have irreversible or serious environmental consequences, and*
- *wrong priorities and misplaced resources."*

As the monitoring system connects the planning process to information processing, the achievement of objectives and policies will only be as effective as the quality of information received. Decision-makers require concise, accurate information factually representative of the problem or study. Consequently, better monitoring can lead to more effective:

- water quality management and control strategies;
- environmental and water policies;
- integrated resource planning;
- planning evaluation.

Information quality will also be affected by the use of variables, indicators and standards used in the monitoring process.

Decision-makers have the initial input to define specific or general monitoring objectives, influencing monitoring design. This step is necessary if the information gained from monitoring is to be of use to water managers in the control of nonpoint source pollution. Objective setting by decision-makers links social and institutional goals to water resource plans, confining the monitoring range to precipitate a desirable outcome. Decision-makers, policy makers or planners have an important part to play in preparing a comprehensive information base, as scientists alone cannot fulfil this task (Bosch, *et al.*, 1996).

6.6 FURTHER ASSESSMENT - ANALYSIS AND MODELLING

The information gained from any initial assessment should be interpreted, analysed and utilised to establish the interrelationships of nonpoint source pollutants and source control strategies. Building a model from specific components of a water quality problem allows recognition of the processes creating, modifying or degrading the aquatic habitat. Thus analysis and interpretation of a range of data may identify further information needs or reveal previously unrecognised relationships. For example, in Chapter 3 a tentative relationship between elevated phosphorous levels and the appearance of undesirable biological growths may provide the stimulation to implement further action towards attainment of a more desirable environment.

Analysis of environmental data may reveal nonpoint source contamination at an acceptable level to the community. However, the future effects of nonpoint source contaminants must also be guarded against if principles of sustainability are to be upheld. Ecosystems and landscapes sensitive to future changes should be identified so that future and present management activities can incorporate prevention plans concerning areas susceptible to nonpoint source pollutants. Future implications of nonpoint source contamination may be assessed by examining trends in data or extrapolating trends in human activities likely to contribute to nonpoint source pollution (e.g. increases in urbanisation, vehicle numbers, or construction).

The predominant method of assessing catchment or ecosystem changes is by comparison of past and present conditions (Montgomery *et al.*, 1995). For assessing trends in ecosystem stability, integrity or health, there are many useful methods involving parameters such as indicators, indices and/or other waterway variables. However, when trying to detect whether observed changes in ecosystem characteristics are natural and/or a result of human induced stress, few data sets give normative data or variances for a given system (Woodley *et al.*, 1993). This is often the case for the Christchurch aquatic assessment. Thus to obtain adequate data to reliably assess water quality, especially when considering ecosystem integrity, requires prior development of assessment objectives.

A selection of existing water quality models are also available to aid in the prediction or estimation of impacts of nonpoint source pollutants. Models can be independently developed to suit the specific water quality objectives or modified from existing models.

Models should be selected and evaluated based on an examination of objectives sought and the accuracy, scope, and form of available data, as well as the ecological resources that are affected by nonpoint source pollutants.

Common nonpoint source models are based on mass loading programmes that calculate runoff and pollutant levels for a particular land use or catchment. Models range from computer based simulations, for example, the Stormwater Management Model (SWMM) developed by the USEPA (House *et al.*, 1993), the Source Load and Management Model (SLAMM) from Pitt and Vourhees (Bannerman *et al.*, 1993), or Geographical Information Systems (GIS) incorporating runoff models like SLAMM; to statistical models, for example the Probabilistic Model of Stormwater Quality (PMBQ) from Tsanis, Xu and Marsalek (1994); or erosional models, for example the Universal Soil Loss Equation (USLE).

A simplistic model is often preferable when trying to model complex systems (Chen *et al*, 1993). Attempting to simulate the entirety of a complex system is time consuming and expensive and may lead to the formation of sophisticated models of no use to actual water quality management. While simple models can utilise existing information at reasonable costs, model validation is an important step in the modelling process and may require extensive additional data. Validation checks model accuracy and predictive capabilities, and ascertains if any important parameters have been neglected (House *et al.*, 1993). Model validation and model use may only be useful for a specific site, dependant on the chemical, biological and physical parameters used and pollutant source.

Since statistical information on pollutant characteristics is the commonly sought after objective of nonpoint source pollution modelling, a probabilistic approach in combination with mass balance data is an effective modelling approach. Such an approach can be applied to time series data (e.g. rainfall) to predict the variability of pollutant loadings on an event by event basis (House *et al.*, 1993).

Modelling can be attuned to suit monitoring based on resource allocations. This will be integral in defining monitoring capabilities within a set budget. Water quality monitoring and modelling are mutual techniques for evaluating nonpoint source pollution (Chen *et al.*, 1993). Both methods are capable of identifying the major factors affecting aquatic environments. Factors include sediment yields, temperature and flow regimes, nutrient cycling, habitat structures, and general water quality.

As water quality monitoring is a costly exercise, modelling provides a cost effective means of filling the gaps in monitoring programmes if sufficient information is obtainable. The usefulness of modelling as a water quality tool is validated by the predictive capabilities in the nonpoint source pollution field, particularly concerning stormwater runoff. For, example, Bannerman *et al.* (1993) found SLAMM to work well in simulating source-area runoff volumes when compared to measured volumes. Predictions of runoff quantities, sediment and chemicals generated by hydrological events, based on modelling catchment parameters, are also useful in risk evaluation. Modelling can be especially useful in determining probabilities of events.

6.7 PRIORITY SETTING - RISK ASSESSMENT

Past water quality policy development has been *ad hoc*, arbitrary, and reactive in part because of a lack of environmental prioritisation (MfE, 1996(a)). Risk assessment is desirable to anticipate environmental outcomes and initiate action to remedy affected areas or avoid degradation (Misra *et al.*, 1994). An assessment of the risk of adverse effects of the aquatic environment by anthropogenically-derived contaminants can establish long and short term risks, helping to further prioritise abatement strategies.

Determining the controls, practices and other remediation methods to be instituted or recommended will depend on an assessment of what contaminants to target and the circumstances of the waterway to be protected. An assessment of target or priority contaminants determines which abatement measure or suite of measures will best be employed to reduce or eliminate nonpoint source contaminants. Risk assessment, like other information tools, should be performed with consideration for the managerial goals and information needs of water quality objectives. Hence in reaching a decision about the appropriate course of action, not only will the risk of aquatic ecological degradation be considered by decision-makers but also the legal, regulatory, social, and political consequences.

Risk assessment models are often based on acute effects of a limited number of species in terrestrial systems (Misra *et al.*, 1994). However, the serious ecological problems amenable to remediation methods are caused by chronic, long-term, sublethal exposure (see Chapter 2.3). Ecological risk assessment is considered by some an important constituent of environmental assessments, as often regulatory standards provide insufficient information for decision-making (Suter, 1995).

Thorough risk assessment models will often require rigorous data on contaminant quantities and form, contaminants' spatial and temporal relationships, degree of biological uptake and output, characteristics of biological units and processes, and other extraneous toxicological data. Often information this in-depth is not readily available in the quantities and form necessary for comprehensive risk analysis.

Evaluating water quality degradation leads to identification of the sources of environmental pollutants, their disposal routes, and their continuity and quantity. Source identification leads to defining contaminant composition, matrix, usage, release, and emission. Data on these characteristics of contaminants may be easily obtained for point source pollutants but are rare for nonpoint source pollutants. Hence in estimating the risks from nonpoint sources, exposure and effects assessments are based on receiving water or urban stormwater data. In such cases, the variance of the contaminant can be important in exposure determination (Suter, 1995).

Risk assessments can be described by three phases (Misra *et al*, 1994; Suter, 1995, p808; MfE, 1996(a)). These are:

1. Pre-risk evaluation phase - hazard definition, identification of environmental problems.
2. Risk evaluation or analysis phase - scientific or technical risk evaluation, risk characterisation, risk ranking.
3. Risk management or post-risk evaluation phase - identify abatement options for risk reduction, rank risk reduction options.

While the ultimate goal of water quality protection may be ecological integrity, (physical , biological and chemical integrity) (USEPA, 1990; in Chen *et al.*, 1993), this goal may not be the mandate of the community. Rather, waterway attributes that facilitate aesthetic, recreational, or cultural uses may be preferentially valued over a healthier ecological environment. While community environmental values may be overlapping with water quality protection objectives, the motivation driving waterway restoration may have little to do with maintaining a balanced, adaptive, and integrated aquatic ecosystem.

Risk assessment models rarely integrate community values into assessment dimensions. Usually it is the role of the risk manager or decision maker to use ecological risk assessment findings to help obtain community goals. However, addressing community goals with broad based planning objectives may neglect certain community based issues or concerns. Incorporating or considering community environmental values in the decision-making or policy setting process is complicated by the range of values held by the community. Social surveys show public opinion in support of tougher environmental policies (Buhrs and Bartlett, 1993, p75). However, they do not indicate the support New Zealanders will lend to environmental policies aimed at sustainability.

Consideration of community based issues by an institution depends on whether an issue achieves agenda status. If environmental issues are to reach local government agendas, the special attention of the public or interest groups may be necessary (Buhrs and Bartlett, 1993, p20). Thus to adequately assess the risk of waterway degradation or to prioritise abatement methods, consideration of the community's needs and wants warrant attention in the initial assessment process.

6.8 LINKING NONPOINT SOURCE POLLUTION INTO PLANNING

Once an initial link to environmental goals is established, the role nonpoint source pollution plays in undermining those goals can be examined. This examination can then lead to reassessing established goals and defining new objectives that encompass the threat of nonpoint source pollution. Hence, providing comprehensive information on nonpoint source pollution may facilitate nonpoint source pollution achieving greater environmental management agenda status.

With greater recognition in a planning forum, objectives can be formulated to address nonpoint source pollution in line with waterway goals. Objective setting by decision-makers will also link social and institutional goals to water resource plans. Decision-makers, policy-makers or planners have an important part to play in preparing a comprehensive information base, as scientists alone cannot fulfil this task (Bosch *et al.*, 1996).

The examination of the information generated from the processes outlined above will take place in the planning process. This forum will provide a stronger focus on the economic and social issues not identified in this chapter. Once adequate information is generated the planning process will take the next progressive step to ameliorating nonpoint source water quality problems - abatement. Once strategies for nonpoint source pollution abatement are formulated by the planning process, the criteria for achieving abatement strategies can be introduced into the information collection and generation process. Thus continued feedback evolves, fuelling planning and policy objectives in attainment of sustainable resource use.

6.9 CONCLUSION

Recognition of a water quality problem through identifying and documenting nonpoint source pollution is the initial step to linking nonpoint source issues to environmental goals. This step is further serviced by monitoring, modelling and risk assessment to tighten the focus of the water quality problem so the best management option may be employed in amelioration. Monitoring should continue to be a dominant linkage between decision-making and information generation. This will provide feedback essential to both levels to move towards attaining a desired management objective.

Once recognition and understanding of nonpoint source pollution issues is attained, abatement strategies can be considered. Integrated information forms the basis for defining the effects of nonpoint source pollution, justifying nonpoint source abatement, and defining abatement priorities. These may help facilitate scientific, political, economic, social, fiscal, and institutional mechanisms that need to be resolved if nonpoint source abatement is to become a reality.

7.0 CONCLUSION AND RECOMMENDATIONS

This chapter presents the conclusions from the previous chapters and examines whether these conclusions have met the aims and objectives of this thesis. Recommendations are then made based on these findings.

Concern over the historical degradation of natural ecosystems and resources once thought of as inexhaustible, has led to a range of environmental management strategies over the past few decades. Many of these have lacked integration, continuity or a sound scientific basis, and as a result many natural ecosystems and resources are still in decline.

Christchurch, like many cities, must implement successful environmental strategies that maintain and enhance urban waterways if it is to maintain sustainable resources. Pollution of Christchurch's urban waterways by nonpoint source contaminants is one of the issues facing Christchurch authorities and public in the maintenance of their aquatic environment. This thesis investigates the origins and effects of nonpoint source contaminants. It also identified the information and management links needed to establish a strategy to help facilitate the obviation of urban nonpoint source contaminants.

Identification of the management and abatement strategies firstly required an examination of Christchurch's aquatic environment. Reviewing Christchurch aquatic environmental data has several purposes. One is to ascertain the state of Christchurch urban waterways, to determine the impact of nonpoint source contaminants. Another is to establish key nonpoint source contaminants so that the sources of these contaminants can be delineated. Based on the results of this review, further investigation into nonpoint source abatement may be justified.

Analysis of historical, biological and physico-chemical data in Chapter 3 identified several areas of degraded water quality. Focusing on freshwater reaches, biological data and contaminant concentration data suggest that a healthy aquatic ecosystem is not being maintained in some reaches. This conclusion is reinforced by the relationship between the percentage impervious area and number of trout in the Avon River. As impervious area increases trout numbers decline, implicating increased urbanisation as the cause of waterway degradation.

Establishing the causes of waterway impairment is difficult due to the complexity of the system. While nonpoint source contaminants can be considered one of the causes of waterway degradation, urbanisation also results in physical changes to the hydrology and geomorphology of the aquatic environment. However, the best indicator of waterway impairment in this study was the comparison of physico-chemical data with water quality criteria.

This comparison found that nutrients, heavy metals (copper, lead and zinc), and sediments to be the contaminants primarily responsible for deleterious effects in Christchurch's urban waterways. The contaminants derived predominantly from urban nonpoint sources are heavy metals and sediments.

Prioritising key contaminants identified as a concern to waterway integrity by incorporating a range of community waterway values may help meet waterway goals. A mechanism such as the one employed in this study simplifies the inherent complexities of nonpoint source contamination in urban waterways, providing an aid to decision making.

To further stimulate strategies that can be initiated to prevent nonpoint source pollution, a source identification and load assessment was undertaken. Zinc, as one of the priority contaminants, was selected for assessment. Tyres and zinc-clad roofing products were found to be the major sources of zinc in stormwater. The loads produced annually from these sources are estimated at 5.6 tonnes.

While not all sources of key nonpoint source contaminants identified in Chapters 3 and 4 were identified and quantified, the assessment of zinc outlines the difficulties of delineating and estimating loads from nonpoint sources. This assessment predominantly achieves the second objective of this thesis (i.e. develop an inventory of key nonpoint contaminants and estimate the relative contribution of these sources to the contamination of Christchurch waterways).

Gathering the information to quantify a nonpoint source contaminant is a complex and often unrewarding process. Often contaminant loading estimates are based on meagre data, due to secretive nature of suppliers of commercial products, or due to poorly known or undocumented quantities of contaminant in a product. Often equally unknown is the rates at which products containing contaminants emit contaminants into the environment.

This assessment indicates it is the more stable and voluminous forms of products that are the major environmental concern (e.g. roofs and vehicles). Policies and information strategies that single out these types of products and detail their characteristics or set strict environmental standards will help avoid significant adverse effects. An example of such a policy may incorporate nonpoint source contaminants into a hazardous substances register.

Using an integrative management approach may best facilitate incorporating information processes that identify pollution problems into decision-making processes thereby progress towards a greater range of abatement options. Through better abatement it is more likely that the management goals set for waterways will be attained.

Recognition of a water quality problem through comprehensive assessment of nonpoint source pollution is the initial step to linking nonpoint source issues to environmental goals. Monitoring, modelling and risk assessment are information processes that can be implemented to tighten the focus of the water quality problem so the best management option may be employed in amelioration.

An overall thesis conclusion is that through better identification and interpretation of nonpoint source pollution, a management response may be initiated that recognises nonpoint source pollution as an environmental problem deserving a greater status on the environmental agenda. Through greater awareness of the sources that threaten urban waterways, management and the public may work towards greater pollution prevention.

7.1 RECOMMENDATIONS AND FURTHER RESEARCH CONSIDERATIONS

Several recommendations and considerations for future research are identified within this study:

- More extensive and intensive monitoring of contaminants in waterways and stormwater is required to provide more comprehensive data for identifying pollution problems and for modelling and prediction purposes. Monitoring objectives for nonpoint source contaminants should include defining ecological condition, habitat and anthropogenic attributes limiting to ecological integrity, and to identify and locate the contaminants responsible for deleterious effects in the aquatic environment. Thus clear definition of objectives should be the priority step in developing a water quality monitoring programme

- Establish the causes and effects of change in hydrological regimes in urban Christchurch waterways.

- Further biological indicators indicative of urban streams need to be established. Also the development of physico-chemical indicators sensitive to New Zealand conditions are needed.

- Local authorities should recognise that public consultation is needed to further develop and refine schemes such as nonpoint source pollution abatement. This may involve the community defining what waterway degradation is in a social, cultural, ecological and aesthetic context. Thus, local authorities must gauge public perceptions of water quality whilst ensuring the beneficial uses of waterbodies, as determined by the public, are maintained. Hence future research must define what the public recognise as 'significant adverse effects' in urban waterways.

- Several sources of zinc are quantified in this study. However there are several sources of uncertainty in the load estimates from identified sources. Future research should address the sources of these uncertainties.

- To develop abatement strategies and facilitate optimum and cost effective resource use, the origins of nonpoint source contaminants need delineation. Several nonpoint contaminants of concern are identified in this study. Further research is required to delineate the sources of these contaminants and the potential contaminant loads derived from sources. Ecosystems and landscapes sensitive to future changes also should be identified so that future and present management activities can incorporate prevention plans concerning areas susceptible to nonpoint source pollutants.

- It is recommended that mechanisms that foster cooperation and coordination between agencies administrating urban and peri-urban resources be examined and implemented to ensure the abatement of nonpoint source pollutants over multi-jurisdictional regions is facilitated.

- To achieve proactive solutions to nonpoint source pollution abatement, a feasibility plan considering a range of pollution management techniques from the source to the waterway, needs to be researched.

GLOSSARY

Beneficial uses	The environmental values identified as in a waterbody "useful" to the community (e.g. recrreation, ecosystem potection, irrigation).
Benthic	Living on the bed of streams, rivers, lakes and the sea.
BOD	Biochemical oxygen demand. Oxygen consumed by the degradation of organic matter by organisms. Usually measured at 20°C and over 5 days (BOD_5).
Comparative Risk Assessment	A framework for assessing environmental risk issues and highlighting important differences among them that can help us establish priorities and focus limited time and money where they are most needed. (MfE, 1996).
Contaminant	Any substance (including gases, liquids, solids, and microorganisms) or energy (excluding noise) or heat, that either by itself or in combination with the same, similar, or other substances, energy or heat - (a) when discharged into water, changes or is likely to change the physical, chemical or biological condition of water; or (b) when discharged into land or air, changes or is likely to change the physical, chemical, or biological condition of the land or air into which it as discharged.
DIN	Dissolved inorganic nitrogen (NH_3 + NO_3).
Diurnal	During the day time.
DON	Dissolved organic nitrogen.
DRP	Dissolved reactive phosphorus (largely orthophosphate (PO_4).
Environment	Includes: (a) ecosystems and their constituent parts, including people and communities; (b) all natural and physical resources; (c) amenity values; and (d) the social, economic, aesthetic and cultural conditions which affect the matters stated in the paragraphs (a) to (c) of this definition or which are affected by those matters.
Guideline	Numerical concentration or narrative statement recommended to support and maintain a designated water use.
Green algae	Chlorophyta, such as *Chlorella* and *Hydrodictyon*

Heterotrophic	Organisms which require an external source of organic material as their source of carbon for growth; includes fungi and most bacteria.
Intrinsic value	Intrinsic value, in relation to ecosystems, means those aspects of ecosystems and their constituent parts which have value in their own right, including: (a) their biological and genetic diversity; and (b) the essential characteristics that determine an ecosystem's integrity, form, functioning and resilience.
Macrophytes	Large (aquatic) plants, such as the "oxygen weeds" (*Lagarosiphon, Elodea,* and *Egeria* as well as native charophytes.
NH_3	Ammonia. In water predominantly as the ammonium ion NH_4^+).
NO_3	Nitrate.
Periphyton	Plants, usually algae, which grow on objects such as stones, logs and other plants.
Phytoplankton	Planktonic plants.
Riparian	Found alongside steams and rivers.
Sewage fungus	Growths of bacteria and/or fungi responding to increased concentrations of organic material in the water.
TKN	Total Kjeldahl nitrogen (Organic nitrogen plus ammonia).
TON	Total organic nitrogen.
TN	Total nitrogen.
TP	Total phosphorus.

REFERENCES

Archibald, E.M. (1991). Urban Drainage as a Source of Contaminants to Drinking Water Supplies. *Protecting Drinking Water Quality at the Source, Conference Proceedings.* University of California Cooperelie External. California Water Resources Centre. No. 76.

ANZECC. (1992). *Australian water quality guidelines for fresh and marine waters.* Australian and New Zealand Environment and Conservation Council. Australia.

Baird, Amanda. (1992). *An overview of botanical information and recommendations for the management of the freshwater reaches of the Avon and Heathcote Rivers.* Canterbury Conservancy Technical Report Series 5, Department of Conservation, Christchurch.

Bannerman, R.T., D.W. Owens, R.B. Dobbs and N.J. Hornewer. (1993). Sources of pollutants in Wisconsin stormwater. *Water Science and Technology,* 28:3-5, pp 241-259. Great Britain.

Baudo, R., J.P. Gresy & H. Muntau. (1993). Freshwater sediment quality criteria: toxicity bioassessment. *Sediments: chemistry and toxicity of in-place pollutants.* pp 265-289, Lewis Publishers Inc., Boston.

Bradford, W.L. (1977). Urban stormwater pollutant loadings: a statistical summary through 1972. *Journal of World Pollution Control Federation,* pp 613-621.

BHP Steel. (1993). *Specifiers and Builders Guide.* BHP New Zealand Steel.

Bosch, O.J.H., W.J. Allen, J.M. Williams and A.H. Ensors. (1996). An Integrated Approach for Maximising Local and Scientific Knowledge for Land Management and Decision-Making in the New Zealand High Country. *Rangeland Journal,* 18: 1, pp 23-32.

Boyd, K.L. (1992). Public Education Approaches to Storm Water Quality Management. *Stormwater, Monitoring, Measurement and Management,* Water Environment Federation 65th Annual Conference and Exposition, pp 29-40. New Orleans.

Brandon, J.B., R. Noelwah, R. and F.K. Kosobud. (1994). Incentive based nonpoint source pollution abatement in a reauthorized clean water act. *Water Resources Bulletin,* 25, pp 781-791. American Water Resources Association. Minneapolis.

BRANZ. (1971). Galvanised Corrugated Steel Sheet and its Protection. *Building Information Bulletin,* 146. Building Research Association of New Zealand.

BRANZ. (1979). Protection of Galvanised Steel Sheet. *Building Information Bulletin,* 214. Building Research Association of New Zealand.

BRANZ. (1978). Atmospheric Corrosion of Metals. *Building Information Bulletin,* 203. Building Research Association of New Zealand.

BRANZ. (1986). Gutters and Downpipes. *Building Information Bulletin,* 251. Building Research Association of New Zealand.

BRANZ. (1996). Selecting Suitable Roof Cladding. *Build,* 40, pp 40-42. Building Research Association of New Zealand.

Brown, S., P. Mason and T. Snelder. (1996). *Runoff Quality in the Catchment of the Wigram Retention Basin.* NIWA Christchurch Consultancy Report No. CCC60510. Christchurch.

Bruce, A. (1953). *Report on biological and chemical investigation of the waters in the estuary of the Avon and Heathcote Rivers.* Unpublished Report for the Christchurch Drainage Board. Christchurch.

Buhrs, T., K.F.D. Hughey and R. Montgomery. (1996). *Integrated Environmental Management (IEM): A Working Definition.* Letter. Department of Resource Management. Lincoln University.

Canterbury Regional Council. (1992). *Managing Canterbury's water resources.* Positioning Paper 1. Canterbury Regional Council. Christchurch.

Canterbury Regional Council (1994). *A limited investigation of stormwater quality in the Avon-Heathcote catchment.* Canterbury Regional Council Technical Series. Christchurch.

Caldwell, L.K. (1990). *Between Two Worlds: Science The Environmental Movement And Policy Choice*. Cambridge University Press. Cambridge.

Chen, Y.D., S.C. McCutcheon, T.C. Rasmussen, W.L. Nutter and R.L. Carsel. (1993). Integrating Water Quality Modeling with Ecological Risk Assessment for Nonpoint Source Pollution Control. *Water, Science and Technology,* 28, pp 431-440. Great Britain.

Christchurch City Council. (1971). *Residential Urban renewal Plan.* Christchurch City Council. Christchurch.

Christchurch City Council.(1992(a)). *A biological re-evaluation of the Avon River catchment.* Christchurch City Council. Christchurch.

Christchurch City Council. (1992(b)). *Environmental monitoring for the proposed Avon-Heathcote estuary and River catchments and floodplain management plan.* Christchurch City Council. Christchurch.

Christchurch City Council. (1992(c)). *The estuary - where our rivers meet the sea.* Christchurch City Council. Christchurch.

Christchurch City Council.(1994(a)). *A biological re-evaluation of the Heathcote River catchment.* Christchurch City Council. Christchurch.

Christchurch City Council. (1994(b)) *Christchurch city surface water quality data.* Christchurch City Council. Christchurch.

Christchurch City Council. (1994(c)). *A limited investigation of stormwater quality in the Avon-Heathcote catchment.* Canterbury Regional Council Technical Series. Christchurch.

Christchurch City Council. (1995). *Proposed Christchurch City Plan.* Christchurch City Council. Christchurch.

Christchurch Drainage Board. (1980). *A Biological Survey of the Rivers in the Metropolitan Christchurch Area and Outlying Districts.* Christchurch Drainage Board. Christchurch.

Christchurch Drainage Board. (1988). *Heavy metals in the rivers and estuaries of metropolitan Christchurch and outlying areas.* Christchurch Drainage Board.

Clark, S.D. (1983). Legal and Institutional Framework for the Control of Nonpoint Sources of Pollution in Australia. Workshop on nonpoint sources of pollution in Australia: Proceedings. *Australian Water Resources Council, Conference Series,* No. 9, pp 190- 201. Aust. Government Pub. Service. Canberra.

Consumer Home and Garden. (1990). Which House Paints are the Best. *Consumer Home and Garden,* December, 1990, pp 7-10. Consumer Council, Wellington.

Crawford, T.J. (1991) The calculation of index numbers from wildlife monitoring data. *Monitoring for conservation and ecology.* (eds F.B.Goldsmith), pp 225-248 Chapman and Hall. London.

Crossley, J. (1990). Steel Challenge. *Architecture New Zealand,* November/December, 1990, pp 76-77. Associated Group Media Ltd, Auckland.

Dall, C.T. (1987). *Studies on faecal coliform bacteria in sediment of the Avon-Heathcote estuary, Christchurch, New Zealand.* Thesis, MAppSc, University of Canterbury, Lincoln College. Christchurch.

Dasgupta, P.H. (1995). Urban travel demand: a growing business but can it last. *Urban Transport and the Environment,* (ed. I.J. Sucharov), pp 89-98. Computational Mechanics Publications. Southhampton.

Elliott, A.H. (1996). Analysis of Potential Stormwater Quality Controls in Christchurch. Department of Natural Resources Engineering, Lincoln University. Lincoln.

Environment Canada. (1991). *A report on Canada's progress towards a national set of environmental indicators.* A State of the Environment Report No. 91-1. State of the Environment Reporting, Environment Canada. Ottawa.

Environmental Monitoring, Assessment, And Management. (1987) Edited by S. Draggen, J.J. Cohrssen & R.E. Morrison. Praeger Publishers. New York.

Fergusson, J.E., R.W. Hayes, T.S. Yong and S.H. Thiew. (1980). Heavy Metal Pollution by Traffic in Christchurch, New Zealand: Lead and Cadmium Content of Dust, Soil and Plant Samples. *New Zealand Journal of Science,* 23, pp 293-310.

Field, F., M. O'Shea and M.P. Brown. (1993). The Detection and Disinfection of Pathogens in Storm-Generated Flows. *Water Science and Technology,* 28(3-5), pp 311-315. Great Britain.

Geldolf, G.D. (1995). Adaptive Water Management: Integrated Water Management on the Edge of Chaos. *Water Science and Technology,* 32(1), pp 7-13. Great Britain.

Good, J.C. (1993). Roof runoff as a diffuse source of metals and aquatic toxicity in storm water. *Water Science and Technology,* 28:3-5, pp 317-321. Great Britain.

Grundy, K.J. (1996). Community Participation In Resource Management - Fact Of Fiction? Proceedings*: Resource Management: Issues, Visions, Practice, Symposium 5-8 July 1996,* p 62-73. Centre for Resource Management. Lincoln University, Canterbury.

Harrington, L. (1985). Management of nonpoint pollution. *Journal of Soil and Water Conservation,* 40:1, pp 26-29.

Harrison, D. (1991). California's Nonpoint Source Pollution Control Programme. *Protecting Drinking Water Quality at the Source,* Proceedings of a Conference. University of California. Water Resources Centre, No. 76. California.

Haskell, B.D., B.G. Norton and R. Costanza. (1992). What is Ecosystem Health and Why Should We Worry About It? *Ecosystem Health: New Goals for Environmental Management.* (eds Haskell, B.D., B.G. Norton and R. Costanza). Island Press. Washington.

Hellawell, J.M. (1986) *Biological indicators of freshwater pollution and environment management.* Elsevier Applied Science Publishers, London.

Hellawell, J.M. (1991) Development of rationale for monitoring. *Monitoring for conservation and ecology.* (ed. G.B. Goldsmith), pp 1-14. Chapman and Hall.

Herrmann, R., J. Daub, J. Forster and T. Striebel. (1994). Chemodynamics of trace pollutants during roof and street runoff. *Water Science and Technology,* 29(1-2), pp 73-82. Great Britain.

Hicks, D.M. (1993). *Sedimentation and Erosion in the Avon-Heathcote Catchment.* NIWA Freshwater Miscellaneous Report No.27. Christchurch.

Hoffman, E.J., J.S. Latimar, C.D. Hunt, J.L. Mills and J.G. Quinn. (1985). Stormwater runoff from highways. *Water, Air and Soil Pollution,* 25, pp 349-362.

Hogwood, Brian W. and Lewis A. Gunn (1984). Evaluation. *Policy Analysis for the Real World.* Oxford: Oxford University Press.

Holdgate, M.W. (1979). A Perspective of Environmental Pollution. Cambridge University Press, Great Britain.

Howe, R.S. (1985). The Politics of Nonpoint Source Pollution Control: A local Perspective. *Journal of Soil and Water Conservation,* 40(1), p 107.

House, M.A., J.B. Ellis, E.E Hendricks, T. Hvitved-Jacobsen, J. Seager, L. Lijklema, H. Aalderink and I.T.Clifforde. (1993). Urban drainage - impacts on receiving water quality. *Water Science and Technology,* 27(12), pp 117-158.

Huang, X., I. Hlhan and N.K. Aras. (1994). Emissions of trace elements from motor vehicles: Potential marker elements and source composition profile. *Atmospheric Environment,* 28(8), pp 1385-1391. Elservier Science. Great Britain.

Hudgens, R.D. and R.B. Bustamante. (1993). Toxicity and the Disposal of Engine Coolants. *Engine Coolants Testing: Third Volume, ASTM STP 1192,* (ed R.E. Beal), pp 149-164. American Society for Testing Materials, Philadelphia.

Hurst, P., A. Hay and N. Dudley. (1991). The Pesticide Handbook. Journeyman Press. London.

Irwin, F.H. (1991). An Integrated Framework for Preventing Pollution and Protecting the Environment. *Environmental Law,* 22, pp 2-76.

James, R. and K. Whitman. (1995). Stormwater monitoring and pollutant source identification and control in the Santa Clara Valley, California, USA. *Journal of Water Management* 42(11-13), pp 495-501.

Jenkins, D. and L. Russell. (1994). Heavy Metal Contribution of Household Washing Products To Municipal Wastewater. *Water Environment and Research,* 66(6), pp 805-812.

Karr, J.R. (1986). Biological Monitoring and Environmental assessment: A Conceptual Framework. *Environmental Management,* 11(2), pp 249-256.

Karr, J.R. (1992). Ecological Integrity protecting Earths Life Support Systems. *Ecosystem Health: New Goals for Environmental Management,* (eds. R. Costanza, B.G. Norton, B.D. Haskell), pp 223-237. Island Press. USA.

Keddy, P.A.(1991) Biological monitoring and ecological prediction: from nature reserves management to national state of the environment indicators. *Monitoring for conservation and ecology.* (ed. F.B. Goldsmith), pp 249-267. Chapman and Hall. London.

Knox, G.A. and A.R. Kilner. (1973). *The ecology of the Avon-Heathcote estuary.* Unpublished Report to the Christchurch Drainage Board, The Estuarine Research Unit, University of Canterbury. Christchurch.

Kussell, G. and T. Clarkson. (1995). Benzene emissions from motor vehicles in New Zealand. *Water and Atmosphere,* 3(4), pp 13-16. NIWA.

Lamb, R.C. (1981). *From the banks of the Avon: The story of a River.* A.H. & A.W. Reed Ltd., Christchurch.

Laxen, D.P.H. and R.M. Harrison. (1977). The highway as a source of water pollution: an appraisal with the heavy metal lead. *Water Research,* 11, pp 1-11. Pergamon Press. Great Britain.

Lee, F.L. and Anne Jones-Lee. (1993). Water quality impacts of stormwater-associated contaminants: Focus on the real problem. *Water Science Technology* 28:3-5, pp 231-240. Great Britain.

Lee, F.L. and Anne Jones-Lee. (1994). Stormwater Runoff Management: are Real water Quality Problems Being Addressed by Current Structural Best Management Practices? *Public Works,* November, 1994, pp 53-72.

Lennet, D.R. and M.T. Barbour. (1994). Using benthic macroinvertebrate community structure for rapid, cost-effective, water quality monitoring: Rapid bioassessment. *Biological Monitoring of Aquatic Systems,* (eds. Stanford L. Loeb and Anne Spacie), pp 187-216. CRC Press, INC., USA.

Linforth, S., L. Vorreiter, J. Constandopoulos and S. Biddulph. (1994). Sources and Effects of Major Pollutants in Sydney Stormwater. *Water Down Under,* 3, pp 335-340.

Makepeace, D.K., D.W. Smith and S.J. Stanely. (1995). Urban Stormwater Quality: Summary of Contaminant Data. *Critical Reviews in Environmental Science and Technology,* 25(2), pp 93-139. CRC Press, Inc.

Mancini, J.L. and A.H. Plummer. (1986) Urban Runoff and Water Quality Criteria. *Proceedings.*

Manhood, T.W. and G. Zukovs. (1993). A Comprehensive Stream Study. *New Techniques for Modelling the Management of Stormwater Quality,* Proceedings of the Stormwater and Water Quality Management Modelling Conference. Lewis Publishers. USA.

Marsalek, J. (1990). Evaluation of Pollutant Loads from Urban Nonpoint Sources. *Water Science and Technology,* 22(10-11), pp 23-30. Great Britain.

Mellanby, K. (1975) Biological methods of environmental monitoring. *Measures in monitoring the environment* (eds W. Fletcher & J. Lenthan), pp 1-13. Blackie & Sons Ltd. Glasgow.

Milne, C.D.A. (1992). Resource Management Act 1991. in: Royal Forest and Bird Protection Society of New Zealand. (1992). *Handbook of environmental law.* Edited by C.D.A. Milne. Royal Forest and Bird Protection Society of New Zealand.

Memon, P.A. (1993). *Keeping New Zealand Green: Recent Environmental Reforms.* GP Print Ltd., Wellington.

Ministry of Agriculture and Fisheries. (MAF). (1989). *Fisheries survey of the Heathcote River.* New Zealand Freshwater Fisheries Report No. 125. MAF.

Ministry of Agriculture and Fisheries. (MAF). (1992). *Fisheries survey of the Avon River.* New Zealand Freshwater Fisheries Report No. 137. MAF.

Ministry for the Environment/Department of Statistics (1991). *Reporting the State of the Environment. SER Information Paper No.2.* Wellington.

Ministry for the Environment. (1992). *Guidelines for the control of undesirable growths in water.* Ministry for the Environment. Wellington.

Ministry for the Environment. (1996(a)). *Comparative Risk Assessment.* Ministry for the Environment. Wellington.

Ministry for the Environment. (1996(b)). *A Proposed Methodology for Deriving Aquatic Guideline Values for Toxic Contaminants.* Ministry for the Environment. Wellington.

Ministry for the Environment. (1996(c)). *Environment 2010 Strategy.* Ministry for the Environment. Wellington.

Ministry of Transport. (1996). *Environmental Externalities: Land Transport Pricing Study.* Ministry of Transport.

Misra, V., F.N. Jaffery and P.N. Viswanathan. (1994). Risk Assessment of Water Pollutants. *Environmental Monitoring and Assessment,* 29, pp 29-40. Kluwer Academic Publishers. Netherlands.

Mitchel, B. (1990). *Integrated water management.* Belhaven Press. London.

Montgomery, D.R., G.E. Grant and K. Sullivan. (1995). Watershed analysis as a framework for implementing ecosystem management. *Water Resources Bulletin,* 31(3), pp 369-385. American Water Resources Association.

Morgan, S.W.K. (1985). Pollution control in the zinc industry. In *Zinc and its Alloys and Compounds,* pp 147-153. Ellis Horwood Ltd. Publishers. Chichester.

National Institute of Water and Atmospheric Research (NIWA). (1993) *The effects of urbanisation on the invertebrate fauna of the Avon and Heathcote Rivers.* New Zealand Freshwater Miscellaneous Report No. 36, Canterbury Regional Council.

New Zealand Meteorological Service. (1980). Summary of Climatological Observations. *New Zealand Meteorological Service Miscellaneous Publication 177.*

NIWA. (1995). The Intertidal Zone: Benthic Ecology and the effects of Grain Size. *Water and Atmosphere,* 3(3), pp 17-19. National Institute of Water and Atmospheric Research. Wellington.

NIWA. (1996). *Runoff Quality in the Catchment of the Wigram Retention Basin.* Consultancy Report No. CCC60510.

Novotny V.H. (1988). Diffuse (Nonpoint) Pollution: A Political, Institutional, and Fiscal Pollution. *Journal of the Water Pollution Control Federation,* 60 (8), pp 1404-1413.

Novotny, V. and J. Goodrich-Mahoney. (1978). Comparative assessment of pollution loadings from nonpoint sources in urban land use. *Progress in Water Technology,* 10(5-6), pp 775-785. Pergamon Press. Great Britain.

Novotny, V. and G. Chesters (1981) *Handbook of nonpoint pollution.* Van Nostrand Reinhold Company.

Novotny, V., H. Sung, R. Bannermann and K. Baum. (1985). Estimating nonpoint pollution from small urban watersheds. *Journal of Water Pollution Control Federation,* 57, pp 339-347. The Federation, Washington.

Novotny, V.H., W.G. Wawrzyn, J Bachhuber, S. Grant, K. Windstrup and R. Schonter. (1993). Sources and the delivery of sediments contaminated by toxic metals to the North Avenue dam, Milwakee, WI, USA. *Water Science Technology* 28, pp 103-115. Great Britain

Novotny, V.H. (1992). Control of Water Quality in Urban Runoff: Efficiencies and Cost. *Stormwater, Monitoring, Measurement and Management,* Water Environment Federation 65th Annual Conference and Exposition, pp 41-61. New Orleans.

Ontario Ministry of the Environment. (1992). *Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario.* Ontario Ministry of the Environment.

Pitt, R., M. Lalor, R. Field and M. Brown. (1995). The investigation of source area controls for the treatment of urban stormwater contaminants. *Water Science Technology* 28, pp 271-282. Great Britain

Pitt, R., R. Field, M. Lalor and M. Brown. (1995). Urban stormwater toxic pollutants: assessment, sources, and treatability. *Water Environment and Research,* 67(3), pp 260-275.

Prey, J. (1994). On site controls for urban stormwater pollution. *Public Works,* June, 1994, pp 52-53.

Pyziak, T. and D.W. Brinkman. (1993). Recycling and Refining Used Lubricant Oils. *Journal of the Society of Tribologists and Lubrication Engineers,* May, pp 339-346.

Quek, U. and J. Forster. (1993). Trace metals in roof runoff. *Water, Air, and Soil Pollution,* 68, pp 373-389. Kluwer Academic Publishers, Netherlands.

Reinelt, L.E. and A. Grimvall. (1990). Estimation of nonpoint source loadings with data obtained from limited sampling programs. *Environmental Monitoring and Assessment,* 21, pp 173-192. Kluwer Academic Publishers. Netherlands.

Reinelt, L.E., R.R. Horner and R. Castensson. (1990). Nonpoint Source Water Pollution Management: Improving Decision-Making Information Through Water Quality Monitoring. *Journal of Environmental Management,* 34, pp 15-30. Academic Press Limited.

Richards, W.L. (1990). Protection of steel from atmospheric corrosion. *New Zealand Engineering,* April 1, 1990, pp 19-20. Technical Publications. Wellington.

Rogers, P. and A. Rosenthal. (1988). The Imperatives of Nonpoint Source Pollution Policies. *Journal of the Water Pollution Control Federation,* 60(11), pp 1912-1921. The Federation. Washington.

Roesner, L..A. and M.A. Hobel. (1992). Stopping stormwater pollution at its source. *Public Works,* December, 1992, pp 55-56.

Royds Garden. (1993). *The Avon, Heathcote Rivers and Avon-Heathcote Estuary: Water Quality/Ecology Overview.* Report Prepared for the Canterbury Regional Council.

Sanford, D.C. (1983). Legal and Institutional Framework for the Control of Nonpoint Sources of Pollution in Australia. Workshop On Nonpoint Sources Of Pollution In Australia: Proceedings. *Australian Water Resources Council, Conference Series,* No. 9, pp 190- 201. Aust. Government Pub. Service. Canberra.

Sartor, J.D., G.B. Boyd and F.J. Agardy. (1974). Water pollution aspects of street surface contaminants. *Journal of Water Pollution Control Federation,* 46:3, pp 458-467. The Federation. Washington.

Singh, A.K., M.F. Gin, F. Ni and E.R. Christensen. (1993). A Source-Receptor Method for Determining Nonpoint Sources of PAHs to the Milwaukee Harbour Estuary. *Water Science and Technology,* 28(8-9), pp 91-102. Great Britain.

Slunder, C.J. and W.K. Boyd. (1971). *Zinc: Its corrosion and resistance.* Zinc Development Association, London.

Smith, D.G. (1986). *Heavy Metals in the New Zealand Aquatic Environment: A Review.* Water and Soil Miscellaneous Publication No. 160.

Snelder, T. & S. Trueman. (1995). *Environmental impacts of urban stormwater runoff.* ARC Technical Publication No. 53, NIWA. Auckland.

Snelder, T., A. Schwarz, G. Macky, M. Taylor and R. Greenaway. (1995). Christchurch City Waterways Aquatic Vegetation Management: Strategic Overview. Consultancy Report No. CCC60505, by NIWA and Boffa Miskel for the Christchurch City Council. Christchurch.

Spellerberg, I.F. (1991) *Monitoring ecological change.* Cambridge University Press. Cambridge.

Steven, Jenny (1990). *Environmental quality monitoring - analysis of a survey of public agencies.* Canterbury: Centre for Resource Management, Lincoln University.

Stotz, G. (1990). Decontamination of highway surface runoff in the FRG. *The Science of the Total Environment,* 93, pp 507-514. Elsevier.

Suren, K. (1993). *The Effects of Urbanisation on the Invertebrate Fauna of the Avon and Heathcote Rivers.* New Zealand Freshwater Miscellaneous Report No. 36, NIWA. Christchurch.

Suter, G.W. (1995). Introduction to Ecological Risk Assessment for Aquatic Toxic Effects. In G.M. Rand (ed.), *Fundamentals of Aquatic Toxicology: Effects, Environment and Risk Assessment.* Taylor and Fransis. Washington.

Thomas, P.R. and G.R. Greene. (1993). Rainwater quality from different roof catchments. *Water, Science and Technology,* 28:3-5, pp 291-299. Great Britain.

Thomson, B. & J. Davies. (1992). *Interpretation of organochlorine and hydrocarbons contaminants in the Avon and Heathcote River and estuary systems.* Institute of Environmental Health and Forensic Science. Christchurch Science Centre.

Thompson, D.G. (1983). Nonpoint source pollution mitigation - A catchment management activity. Workshop on nonpoint sources of pollution in Australia: Proceedings. *Australian Water Resources Council, Conference Series,* No. 9, pp 190- 201. Aust. Government Pub. Service, Canberra.

Tsanis, I.K., P. Xu and J. Marsalek. (1994). Estimates of Toxic Contaminant Mean Concentrations and Loads from Runoff Water Quality Data. *Journal of Great lakes Resources,* 20(2), pp 435-442. International Association of Great Lakes Resources.

USEPA. (1983). *Results of a nationwide urban runoff program (NURP).* Environmental Protection Agency, Water Planning Division, Washington D.C., USA.

USEPA. (1986). *Quality Criteria for water 1986.* United States Environmental Protection Agency. Washington.

Usher, M.B.(1991) Scientific requirements of a monitoring programme. *Monitoring for conservation and ecology.* (1991) (eds G.B.Goldsmith), pp 15-30. Chapman and Hall.

Van Rossem, J. (1992). Fresh and geothermal water. in: Royal Forest and Bird Protection Society of New Zealand. (1992). *Handbook of environmental law.* Edited by C.D.A. Milne. Royal Forest and Bird Protection Society of New Zealand.

Wanilista, M.P. & Y.A. Yousef. (1995). *Storm water management.* John Wiley & Sons. Canada.

Ward, Jonet C. (1990). *Environmental Indicators for State of the Environmental reporting. Information Paper No. 21.* Canterbury: Centre for Resource Management. Lincoln University.

Ward, Jonet C. (1991). *Integrated Environmental Monitoring. Information Paper No. 37.* Canterbury: Centre for Resource Management, Lincoln University.

Ward Jonet C. and Simon J. Hedley (1994). *Monitoring The New Zealand Coastal Policy Statement: A preliminary assessment . Information Paper No. 51.* Canterbury: Centre for Resource Management. Lincoln University

Ward, J. & J. Talbot. (1988). *Water quality management. Information Paper No. 8.* Canterbury. Centre for Resource Management, Lincoln College and University of Canterbury.

Ward, R.C., J.M. Loftis and G.B. McBride. (1990). Design of Water Quality Monitoring Systems. Van Nostrand Reinhold. New York.

Water Quality Centre. (1988). *Research Findings of the Water Quality Centre 1981 to 1988.* Water quality Centre, Department of Scientific and Industrial Research, Publication No. 14. Hamilton.

Watson, J. (1989). *Along the Hills.* The Caxton Press. Christchurch.

Weeks, C.R. and J.A. Crockett. (1993). Urban stormwater pollution and abatement. Workshop on nonpoint sources of pollution in Australia: Proceedings. *Australian Water Resources Council, Conference Series,* No. 9, pp 190- 201. Aust. Government Pub. Service, Canberra.

Wenger, R.B., Y. Rong and H.J. Harris. (1990). A Framework for Incorporating Stream use in the determination of Priority Watersheds. *Journal of Environmental Management,* 31, pp 335-350. Academic Press Limited.

Whipple. W, Jr., B.B. Berger, C.D. Gates, R.M. Ragan and C.W. Randall. (1975). Characterisation of Urban Runoff. *Water Resources and Research,* 14(2), pp 370-372.

Wilber, W.G. and J.V. Hunter. (1977). Aquatic Transport of Heavy Metals in the Urban Environment. *Water Resources Bulletin,* 13(4), pp 721-734. American Water Resources Association.

Williamson, R.B. (1986a). Urban stormwater quality I. Comparison of three New Zealand Catchments. *New Zealand Journal of Marine and Freshwater Research,* 19, pp 413-427. Dept. of Statistics and Scientific Research. Wellington.

Williamson, R.B. (1986b). Urban stormwater quality II. Comparison of three New Zealand Catchments. *New Zealand Journal of Marine and Freshwater Research,* 20, pp 315-328. Dept. of Statistics and Scientific Research, Wellington.

Williamson, R.B. (1993). *Urban runoff data book.* Water Quality Centre Publication No. 20, NIWA. Hamilton.

Williamson, R.B. and R.J. Wilcock. (1994). *The distribution and fate of contaminants in estuarine sediments.* Unpublished Report for the Auckland Regional Council. National Institute for Water and Atmospherics, Hamilton.

Wilson, P.S. and T.K. Harris. (1991). Integrated Environmental Pollution Control. *Environmental Law,* 22, pp i-xxi.

Woodley, S., J. Kay and G. Francis (1993). *Ecological Integrity and the Management of Ecosystems.* St Lucie Press, Deleray Beach, Florida.

APPENDICES

A 1. RESOURCE MANAGEMENT ACT 1991: Section 5(2)

Section 5(2) defines "sustainable management" as enabling communities to provide for there social, economic and cultural well-being and for their health and safety while:

(a) sustaining the potential of physical and natural resources (excluding minerals) for the reasonable foreseeable needs of future generations: and

(b) safeguarding the life-supporting capacity of air, water, soil and ecosystems; and

(c) avoiding , remedying or mitigating any adverse effects of activities on the environment.

A.2 ENVIRONMENTAL REVIEW OF CHRISTCHURCH URBAN WATERWAYS

A 2.1 BIOTA OF THE URBAN CHRISTCHURCH AQUATIC ENVIRONMENT

To examine the health of the urban Christchurch aquatic ecosystem as suggested by authors such as Karr (1986) or Helawell (1986) requires a complex and tasking study of biological integrity. Such an undertaking would necessitate far greater spatial, temporal and diagnostic data on ecosystem attributes and functions than is currently available.

Instead this review will examine current information on species populations and diversity for fish, macroinvertabrates, macrophytes, and physio-chemical environmental data. Environmental information will help illuminate current and future problems in the aquatic environment.

A 2.1.1 Fish

Fisheries data in the Christchurch urban region are essentially limited to the Ministry of Agriculture and Fisheries (MAF) surveys of the Avon, Heathcote and Styx Rivers, surveyed from 1989 to 1992.

Being the first comprehensive fisheries surveys of Christchurch urban waterways these documents serve as baseline data and a measure of environmental conditions. Without spatial and temporal data from previous years it is difficult to assess any environmental trends on integrity, quality or health. Only tentative general conclusions about aquatic environmental health can be made based on community composition and diversity. These conclusion can be further tested when more data becomes available.

Figure 2.1 gives an indication of fish stocks in two metropolitan influenced rivers (Avon and Heathcote Rivers) and one urban and rurally influenced river (the Styx). The Avon and the Styx Rivers show similar trends but the Heathcote is distinctive by its lack of brown trout and larger percentage of bullies.

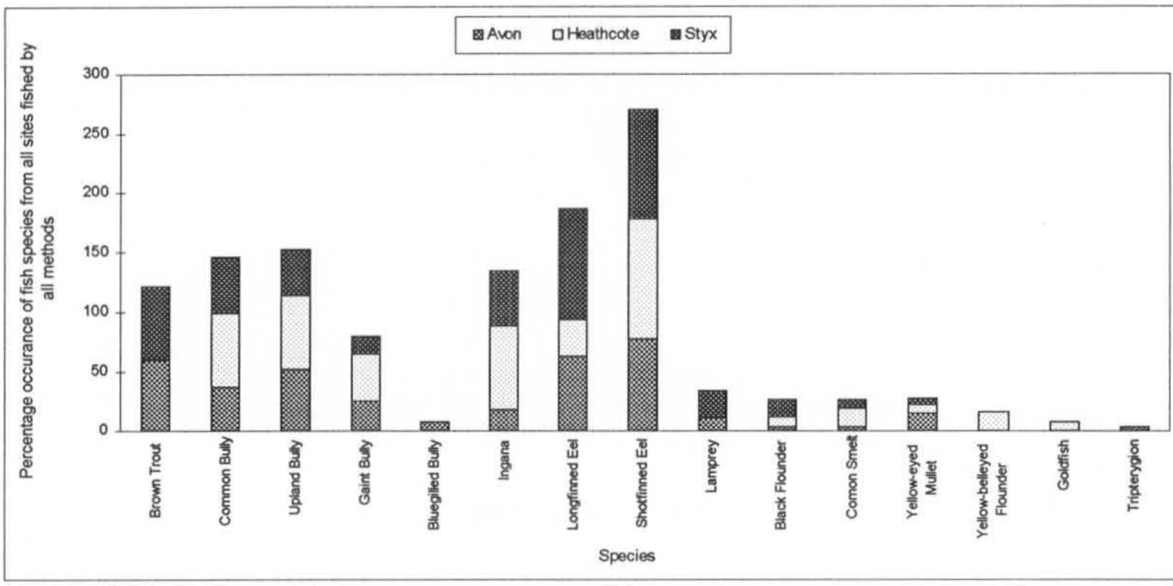

Figure A 2.1. Percentage fish occurrence, by species, for 3 Christchurch rivers, 1992 (MAF, 1992).

The water quality of the Avon and Heathcote Rivers during surveying was reported to apparently have few problems. Exceptions were Haytons and Addington drains which have low species diversity possibly due to pollution.

MAF concluded that the Avon River is still a outstanding trout fishery for an urban river, although comparison to other urban rivers is not made. However, several factors were highlighted as ongoing and potential problems concerning trout and other fish populations.

Riparian areas that provide favourable fish habitats are lacking. This problem is currently being addressed by the Christchurch City Council (CCC). Riparian management education and changes are being stimulated, particularly where private land owners are concerned.

The most serious threat to fisheries alluded to in the MAF surveys concerns hydrological and geomorphological effects of urbanisation in the catchments. Shrinking wetted areas due to reduced water levels (baseflow) have been observed. Urbanisation could be the cause of reduced baseflow due to the loss of infiltration due to impermeable surfaces. Precipitation is then more readily discharged via the storm drainage system directly into the rivers increasing flood levels.

Hydrological features of the urban environment are interconnected to geomorphological changes. These have been observed in the form of increased siltation from urban runoff. This affects fisheries by covering clean gravel substrate suitable for spawning and feeding, clogs gills, and reduces visibility and temperature (Williamson, 1993). The Heathcote in the non-tidal reaches contains a high proportion of silt/clay and fine sand fractions predominantly due to loess washed from the neighbouring hills (Christchurch Drainage Board (CDB), 1981). This may explain the low trout numbers in the Heathcote River.

Also of concern is the stunted growth of trout in the headwaters of the Avon, the main habitat of trout at the time of survey (Figure A 2.2). The authors suggest that suppressed growth as well as the disappearance of fish from certain reaches could be due to pollution incidents, such as sediment loading from construction, or municipal swimming pool discharges.

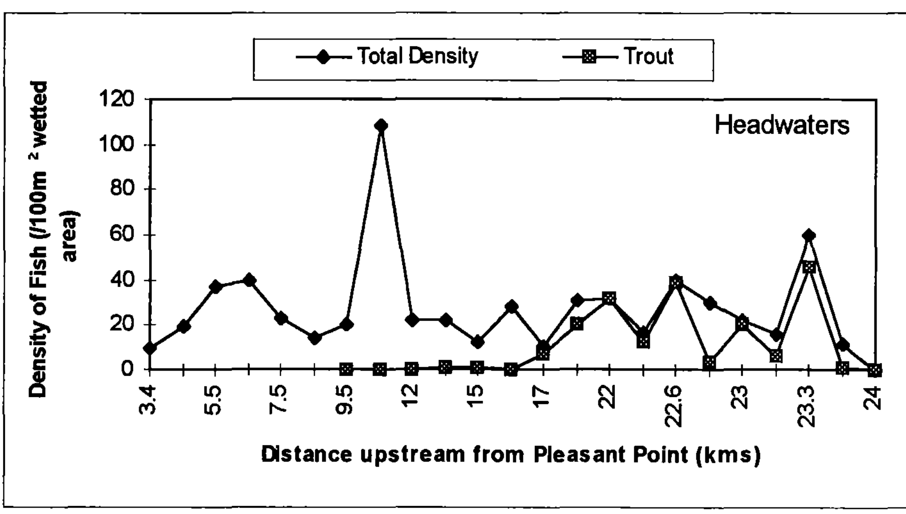

Figure A 2.2. Comparison of trout densities to total fish densities for the Avon River (MAF, 1992).

A 2.1.2 Freshwater Invertebrates & Macrophytes

Four surveys comprise the body of data on Heathcote and Avon River's macroinvertebrates: the CBD 1980 biological survey; the CCC's biological re-evaluations of the Avon River (1992(a)) and the Heathcote River (1994(a)); and Suren's comparison of the Avon and Heathcote's invertebrate fauna (1993).

Suren's investigation compared macroinvertebrates of the Avon and Heathcote Rivers with those of similar rural waterways, while the CCC (1992(a)) surveyed benthic macroinvertebrates, converted the data to comparative/diversity indices, and compared these with a previous survey.

Diversity was found to be less in the Avon catchment than its rural counterparts, but there was an increase in the number of taxa present over time (although this may be due to sampling differences). Some taxa were also no longer represented in biological re-evaluations, possibly indicating a change in conditions.

Most index values were found to be lower than previously. Investigations concluded that slower water velocity, reduced baseflow, increased silt content (compared to rural streams), modified stream channels, vegetation reductions, and increased nutrient levels exerted a strong influence on community composition and diversity. This is analogous with observations made in the fisheries surveys.

One or a combination of these effects may be the cause of the succession of certain aquatic species. Change in the caddis fly species is a good example of this. In the Avon River five species of caddis representative of swift currents and low siltation have been replaced by species preferring slower currents and possibly being pollution tolerant. The Heathcote River has experienced a similar succession.

Increases in filamentous green algae in the Avon and the drains of the Heathcote River were also associated with low diversity. Suffocating macrophytes and exposed substratum, increases in the plants is possibly associated with the appearance of 2 new species of caddis fly. It also could indicate slower water velocities and increased nutrients.

Associations of benthic ecology with different land uses were noted by Suren (1993) in the Addington Drain region. Elevated nutrients, bacteria and sediments are possibly related to the low number of taxa found. This may indicate that aquatic invertebrates respond to local as well as regional conditions.

Native macrophyte species of the Avon and Heathcote have largely been eliminated (Baird, 1992). There exists no native community gradient. Only small groups at best represent native flora. CCC (1992 (a)) found that the abundance and distribution of aquatic macrophytes has changed since the earlier CDB surveys. Whatever the distribution of macrophytes, Suren (1993) postulates that that macrophyte species composition was not likely to have a great effect on invertebrate fauna. Thus changes in invertebrate fauna over the 1979 to 1991 period may be due to urban impacts such as stormwater runoff or reduced baseflow.

A 2.2 ESTUARINE BIOTA

A 2.2.1 Fish

Little monitoring has been done to attest to the stability of fish populations in the estuary. There does appear to be abundant fish of the more common variety, but there may be some doubt if the estuary is providing favourable conditions for freshwater migratory fish such as inanga.

The feeding habits of fish show a wide range of food sources utilised, from detritus to other fish. Changes through siltation, contamination, riparian landscaping, and adventive flora threaten these habitat features effecting the balance of fish and other organisms.

A 2.2.2 Invertebrate

Knox and Kilner (1973), Knox (1992) and Royds Garden (1993) describe the distribution of estuarine invertebrates.

Fauna of the estuary are primarily distributed due to salinity as some are freshwater derived, others saltwater derived. Diversity decreases in the freshwater environment due to the changing salinity and the finer substrate.

Cockles are the dominant species in terms of biomass, followed by another bivalve and species of gastropod and polychaetes. These dominant species occupy key roles in the ecosystem, particularly as a food source for species on higher trophic level. Through the digestion of detritus, microflora and microorganisms these organisms convert nutrients and organic matter from the rivers and Bromley Sewage Works. Possible problems include an apparent decline in numbers of cockles and pipis around the sewage outflow area. Also cockle sizes are found to be smaller in some areas, such as Humphreys Drive, but whether this is due to cockles developing in an area on their tolerance limits or because of pollution is uncertain.

Several species occurring in the estuary have been described as pollution tolerant, existing in an oxygen depleted environment and occasionally in low salinities. The most tolerant species is comprised exclusively of oligochaetes (e.g. *Tubifex sp.*). Other tolerant fauna include mud-flat crab *Helice crassa* and mud-flat snail *Amphibola crenata*. Some of these species are more abundant due to the great number of microflora and microorganisms available for digestion, boosted by the nutrient output of the Bromley Sewage Works and rivers.

A 2.3 REVIEW OF PHSICO-CHEMICAL DATA IN THE AVON-HEATHCOTE CATCHMENT

A 2.3.1 Heavy Metals

A 2.3.1.1 Heavy Metals in the Sediments of the Avon and Heathcote Rivers

The most extensive study undertaken of heavy metal concentration in river sediments was undertaken by the Christchurch Drainage Board (1988) in 1981-82, with additional surveying by the CCC in 1992. Total copper, chromium, cadmium, lead, nickel, and zinc were analysed for in the <2 mm fraction of river sediments. Elliott (1995) compared these results along with others from minor studies with the Ontario sediment quality guidelines (Appendix 3). Findings include:

- Lead exceeded LEL for much of the Avon River, with Riccarton Main Drain exceeding the SEL guideline.
- Lower reaches of the Heathcote River studied in the early 80's showed very high lead levels. Dunbar, Curletts, Haytons, and Ballantine Drains exceeded the LEL guideline for lead.
- Zinc exceeds LEL guideline for most of the Avon River except Wai-iti Stream.

- Zinc exceeds LEL guideline for most of the Heathcote River exceptions being the Cashmere Stream. The Curletts Drain shows levels in excess of SEL guideline.
- Cadmium exceeded the LEL guideline in Taylors Drain.
- The copper LEL guideline was exceeded in St Albans Creek, Waimari Stream, Dudley Creek, Clarkson, Addington, Riccarton, and Taylors Drains in the Avon catchment, and Curletts Drain and lower reaches of the Heathcote River in the Heathcote River.
- Some of the loop area of the Heathcote River has shown reduced metal contamination from comparison of 1980-81 and 1991 studies.

Comparison of metal concentrations with the sediment quality guidelines reveals several 'hotspots' of elevated metal levels. There appears to be no general distribution pattern to the non-tidal reaches of the two catchments. The exceptions being elevated levels near stormwater outlets and within close proximity to some industrial regions. Noticeably these include Addington Drain, Riccarton Main Drain, and Curletts Drain.

Comparing 1981-82 survey data with the 1992 data indicates that conditions in the lower Avon River were stable for most metals, the exception being lead. An appreciable increase in all six metals was noted at Mackenzie Avenue, most probably associated with a large stormwater outlet in this area.

A 2.3.1.2 Heavy Metals in the Sediments of the Avon-Heathcote Estuary

Several studies have measured heavy metal concentrations in the estuarine sediments, the most comprehensive being the 1981-82 Christchurch Drainage Board (1988) study and the subsequent 1991 Christchurch City Council (1992) study. The 1981-82 CBD (1988) study made 17 transects of the estuary testing the entire sediment fraction for total heavy metal concentration for other 300 sites. In 1991 only 13 sites were sampled for correlation with the 1981-82 study. Six heavy metals were tested for copper, chromium, cadmium, lead, nickel, and zinc.

NOAA guidelines for freshwater and marine sediments can be used (Appendix 3) for evaluation of heavy metal levels. The NOAA low effect range (ER-L) reflects the level of effect in 10% of observed biota while the medium effect range (ER-M) demonstrates an effect on 50% of biota. Basic findings are:

- Only two sites exceeded the NOAA ER-L for lead and zinc. Sites were located near the mouth of the Heathcote River in fine substrate.
- All other metal are well below guideline ER-L levels.
- The 1991 data show a general rise metal concentration from the 1983 data. This could have been due to sampling and analysis differences.
- Comparison with the relatively unpolluted Saltwater Creek estuary shows that up to 40% of tidal flats have been affected by effluent from various discharge sources. The most significant contaminants being lead followed by zinc, chromium and copper.

A 2.3.1.3 Heavy Metals in Estuarine Biota

Two studies have investigated heavy metal content in estuarine biota. The 1980-81 CBD (1988) study tested for six metals in cockles, mudflat snails and two species of wading bird. To update this survey CCC (1992(b)) analysed limited cockle samples for the same heavy metals. Findings include:

- Smaller shellfish contain higher metal concentrations than larger shellfish.
- Mudflat snails did not appear to be adversely affected by increased chromium, nickel, lead and zinc compared with their counterparts in Saltwater Creek estuary.
- Lead was the only metal to show a relationship between the amount accumulated in the snail and present in the substrate.
- Cockles near outflows or river outlets were generally smaller and contained significantly more copper, lead, zinc than their counterparts further away from outflows. Cockles sampled around Humphreys Drive registered an increase in lead content between the two studies.
- Comparison of the concentration of metals in the livers of oystercatchers in the Avon-Heathcote Estuary and Salt Water Creek Estuary shows oystercatchers of the Avon-Heathcote estuary to have higher copper and zinc concentrations.
- The concentrations of heavy metals measured in cockles and mudflat snails fall within the guidelines for human consumption. One exception was the mudflat snails in the Humphreys Drive vicinity. These only marginally exceeded the guidelines for human consumption.

A 2.3.1.4 Heavy Metals in the Water Column

Heavy metal concentrations were determined in the surface waters from selected sites in the Avon River, Heathcote River and Avon-Heathcote Estuary by the CCC (1992(b)) (Figures A 2.3 - 2.8). Comparing heavy metal concentrations with USEPA guidelines (1986) for acute and chronic criteria at 50 mg/l hardness and the Australian marine guidelines (ANZWE, 1992) for estuarine samples findings include:

- Curletts Road Drain, Haytons Drain and Halswell Junction Road Basin all exceed USEPA acute and chronic criteria for zinc and for several copper samples.
- Lead concentrations above USEPA acute criteria were detected at Haytons Road Drain and Halswell Junction Road Basin.
- The outfall from Ponds 5 and 6, and the City Drain exceeded Australian marine guidelines and USEPA acute criteria for lead and Australian marine guidelines for copper.
- Charlesworth Drain exceeded Australian marine guidelines for zinc.

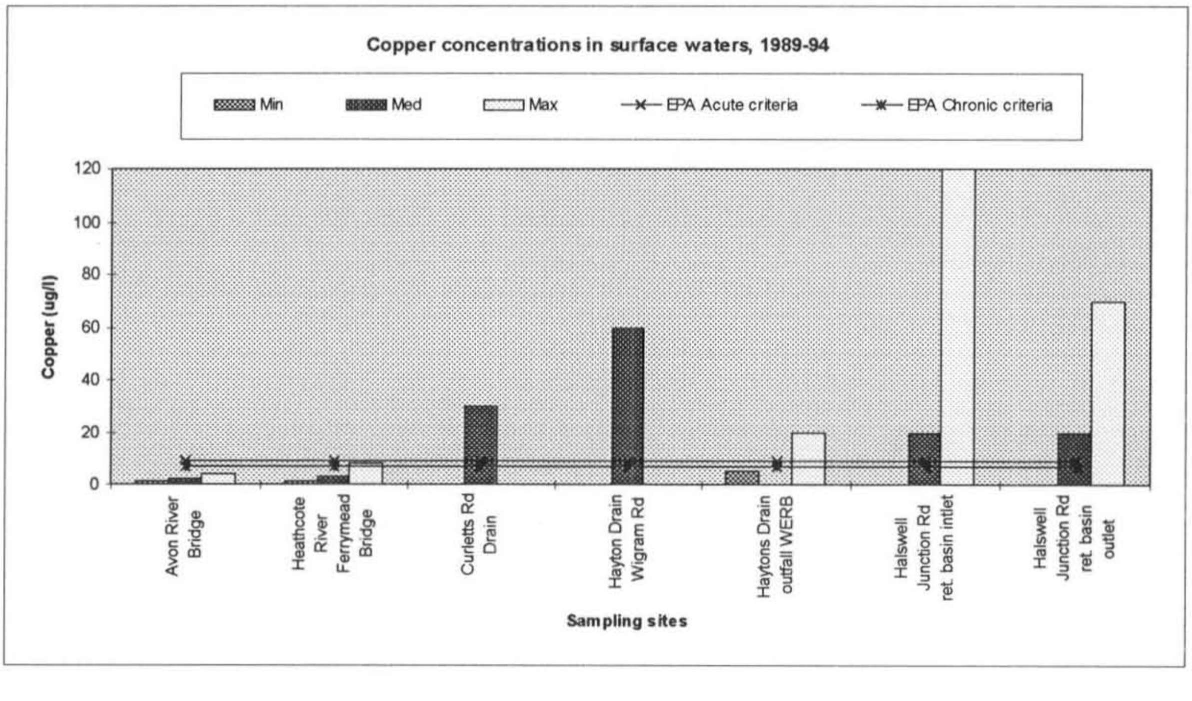

Figure A 2.3. Comparison of copper concentrations in Christchurch baseflow with USEPA criteria (see Appendix 3 for criteria).

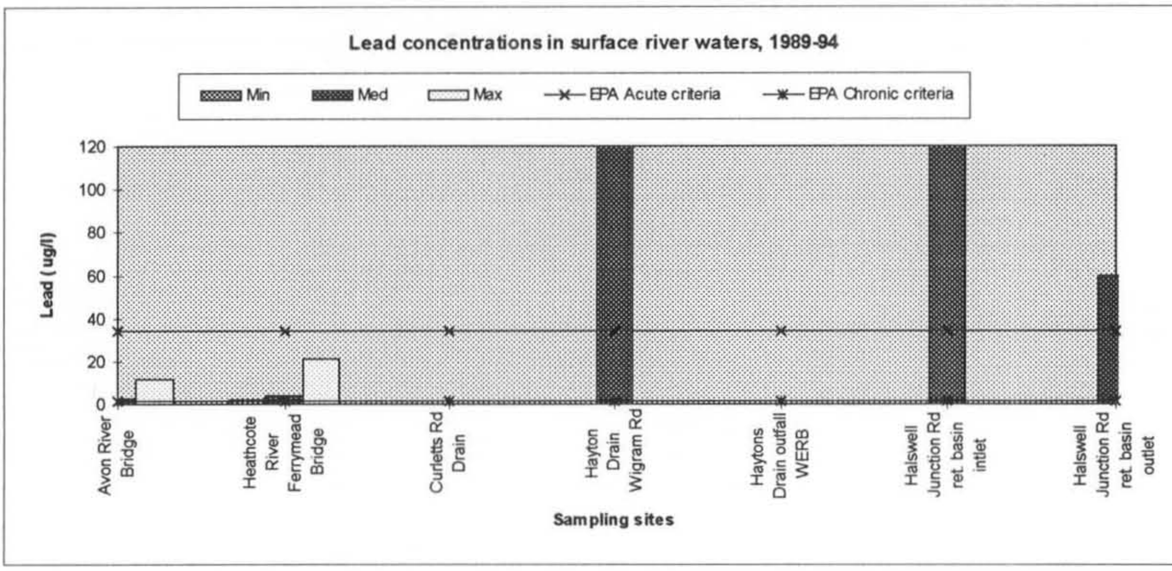

Figure A 2.4. Comparison of lead concentrations in Christchurch baseflow with USEPA criteria (see Appendix 3 for criteria).

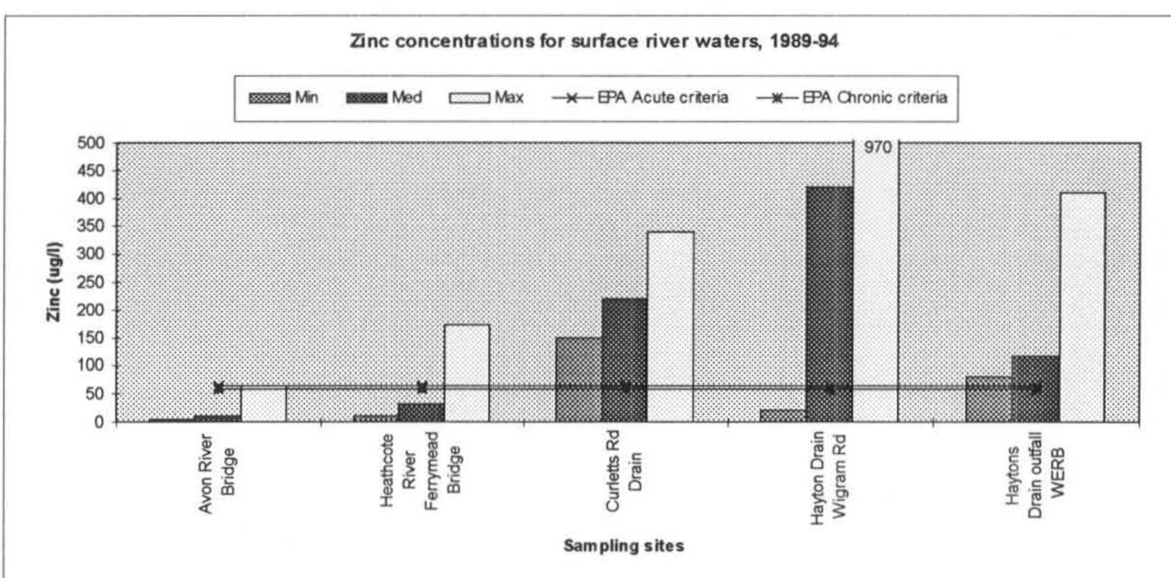

Figure A 2.5 Comparison of zinc concentrations in Christchurch baseflow with USEPA criteria (see Appendix 3 for criteria).

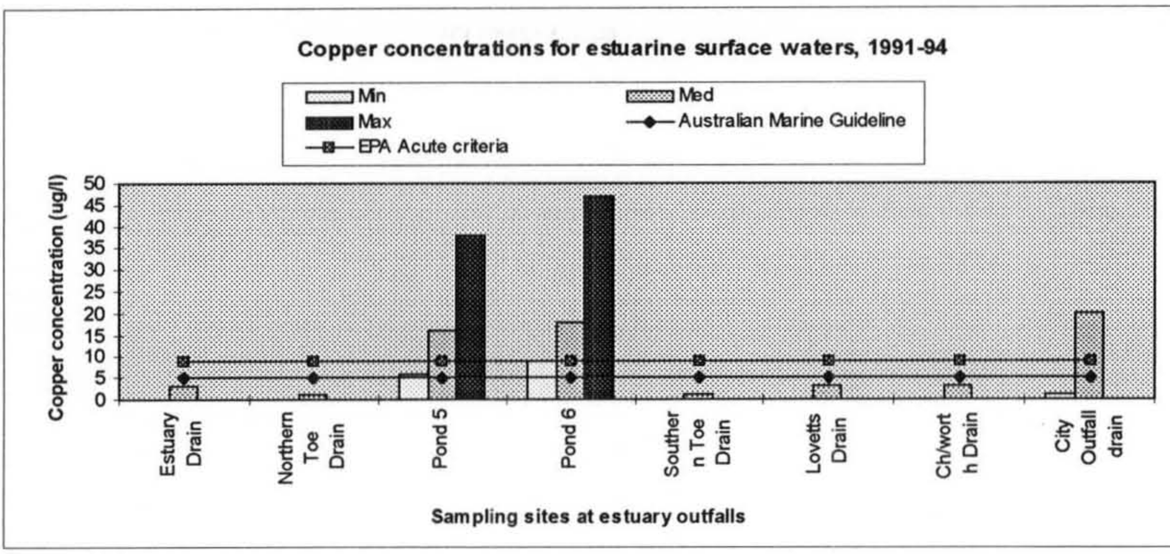

Figure A 2.6. Comparison of copper concentrations in Christchurch estuary waters with USEPA criteria (see Appendix 3 for criteria).

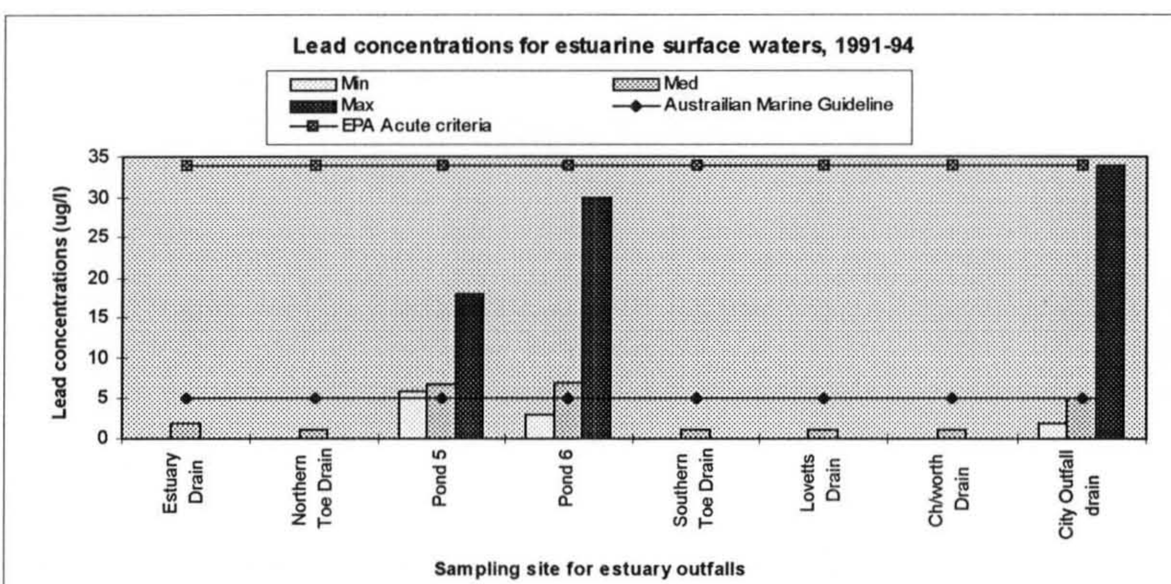

Figure A 2.7. Comparison of lead concentrations in Christchurch estuary waters with USEPA criteria (see Appendix 3 for criteria).

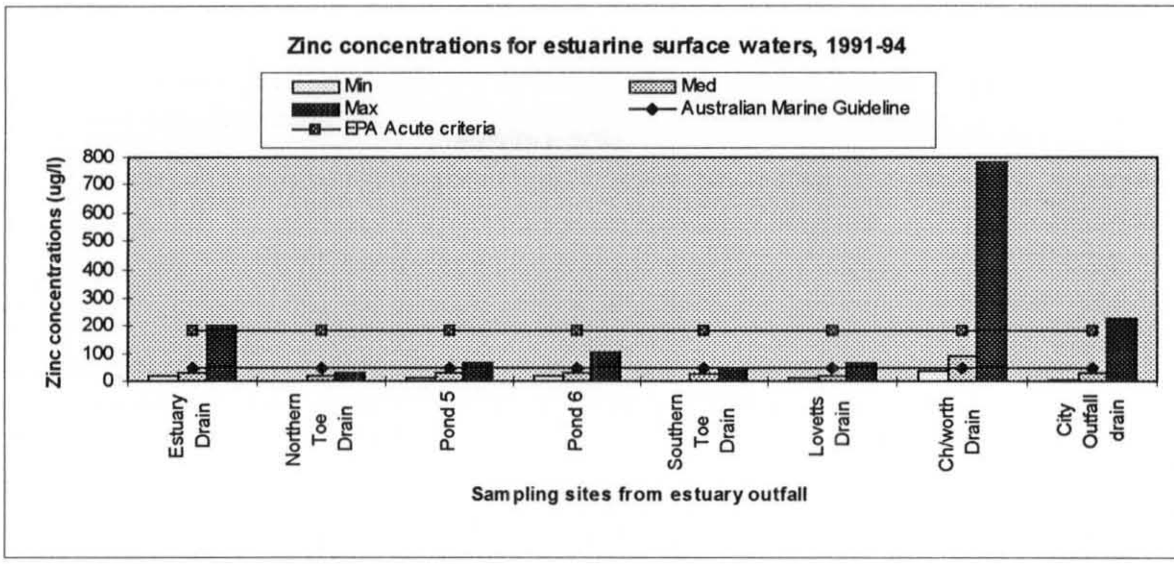

Figure A 2.8. Comparison of zinc concentrations in Christchurch estuary waters with USEPA criteria (see Appendix 3 for criteria).

A 2.3.1.5 Heavy Metals in Stormwater

The CRC (1994) took stormwater samples during three storms from 5 subcatchments in the Avon-Heathcote catchment. Sites sampled include Haytons Road Drain, Riccarton Main Drain, Valley Road, Bowenvale, and Milnes Drain. Six metals were analysed for and are compared with USEPA acute and chronic criteria for dissolved metals at 50 mg/l hardness, observations include:

- Quality of stormwater varied with land use.
- Zinc was detectable in all sampling, most sites exceeding USEPA acute criteria. The highest excesses occurred near industrial areas. Rural and hill-residential areas did not exceed the USEPA acute criteria
- Concentrations of lead were below detection limits. However, detection levels are above USEPA acute criteria for surfaces waters, resulting in inconclusive sampling.
- Copper concentrations were barely detectable (above a 20 *u*g/l detection limit), although Port Hill sites did register levels above USEPA acute criteria.

A 2.3.2 Organics

A 2.3.2.1 Organics in the Water Column

Several organochlorines and hydrocarbon contaminants have been analysed in water, sediment and biota of the Avon-Heathcote catchment. Thompson and Davies (1994) provide an interpretation of the results based on comparison with known guidelines (where guidelines exist. This information is summarised in Table A 2.1.

Dieldrin appears to be the only organic contaminant detected in the water column in levels of concern.

Chlordane, dieldrin and DDT were measured in estuarine sediments at levels above recommended guidelines (Table A 2.1). Use of these compounds has been discontinued in New Zealand. Comparison of DDT content in cockles from samples taken in 1973 to sampling in 1993, found that there is approximately a 5 fold reduction in levels (Elliot, 1995). Trends for the Manakau Harbour over the period 1987-92 indicated little change in DDT concentrations in shellfish (Williamson and Willcock, 1994). Some monitoring of these compounds is still recommended.

The effects of PCP are relatively unknown. Levels detected in cockles in the estuary are thought to be at levels suitable for human consumption. PCP levels detected in the Avon River water column for Fendalton Avenue are comparable to levels detected from industry discharges overseas. This implicates point source discharges or illegal discharges as being the sources responsible.

PAH's were detected at elevated levels in the estuary, particularly in the sediments close to river/estuarine channels. Guidelines for PAH's are not well established and the effects are uncertain. Levels lower than those recommended by the Australian water quality guidelines were found to have adverse effects on fish (Williamson and Wilcock, 1994). Observed sublethal effects at sediment concentrations commonly found in urbanised estuaries are under study. Continued use of fossil fuels will ensure sustained delivery of PAH's into the aquatic environment. As many of these compounds are carcinogenic this could be cause for concern.

Concentrations of organic compounds found in the estuary have been associated with sediments at the mouth of the Avon and Heathcote Rivers and along river-associated estuarine channels, particularly at the intersection of the rivers (Thompson and Davies, 1994). Implications are that the rivers may be a major source of organic compounds.

COMPOUND	AREAS DETECTED	POSSIBLE EFFECTS	POSSIBLE SOURCES
Heptachlor & Heptachlor Epoxide	Not detected	None	Timber treatment Pesticides, insecticides
Endrin	Detected in the estuary	Possible cumulative effect with dieldrin	Agricultural sprays
Dieldrin	Water: Avon River mouth, Heathcote River mouth, Haytons Drain Sediment: Avon R. mouth, Heathcote R. mouth, estuary-Plover St.	Chronic effects - affects sensitive life stages or organism functions	Agricultural sprays
DDT	Sediment: Avon R. mouth, Heathcote R. mouth, estuary-Plover St.	Chronic effects - affects sensitive life stages or organism functions	Agricultural sprays
Chlorodane	Sediment: Avon R. mouth, Heathcote R. mouth, estuary-Plover St.	Chronic effects - affects sensitive life stages or organism functions	Timber preservation
Poly Chlorinated Bipynel (PCB's)		None known	Electrical supply industry
Lindane	Waters: Avon R. Wainoi Rd.	None. Possibly an anomalous result	Agricultural sprays
Pentachlorophenol (PCP)	Water: Avon R. Fendalton Rd. Sediment: Estuary- 4 samples Biota: all cockle samples	Uncertain No effect for human consumption of shellfish	Electrical conductivity Timber preservation
Polycyclic aromatic hydrocarbons (PAH's)	Sediment: most estuary sites	Levels did not exceed guidelines but effects are uncertain	Fossil fuels
Alkane Hydrocarbons	Sediment: Estuary Biota: most cockles	Uncertain - probably low impact	Hydrocarbons

Table A 2.1 Organic compounds in the Christchurch aquatic environment.

A 2.3.2.2 Organics in Stormwater

CRC (1994), in a limited stormwater investigation, was surprised to find that no organic contaminants were detected higher than the limit of detection. Some higher levels were expected due to the concentrations of organic compounds detected in the groundwater of the Avon and Heathcote catchments (1,1,1-trichloroethane, 1,1-dicloroethane, dichloromethane, xylene, and ethylbenzene).

A 2.3.3 Nutrients

A 2.3.3.1 Nutrients in the Water Column

The Christchurch City Council (1994(b)) has tested for nutrients on a monthly to bi-monthly basis since 1989. Kilner and Knox (1973) also studied nutrient levels in the rivers and the estuary.

Higher conductivities have suggested increased nutrient levels in Christchurch waterways (CCC, 1992(a)). The Heathcote River generally has higher DRP levels than the Avon River (Figure A 2.9 and 2.10) with DRP concentrations in both rivers increasing downstream. This is most likely a result of oxidation pond effluent moving upstream with the tide (*pers comm.* Dr A.H. Elliott), although Robb (CCC, 1992(a)) suggests that increases in the Avon River may be because of a release of residual industrial wastes in the Heathcote River and effluent from farmland near the estuary.

Comparing DRP levels with the recommended concentration of DRP for limiting biological growths (15-30 mg/m^3; MfE, 1992), indicates the Heathcote River to be in excess of the recommended DRP levels for most sites (Figure A 2.10). Addington Main Drain, Riccarton Drain, Dudley Creek, and Horseshoe Lake also exceed this guideline.

Median ammoniacal nitrogen values for the Heathcote show a similar relationship to DRP levels (see Figure A 2.10 - A 2.12), Haytons Drain having the highest levels. In the Avon catchment Dudley Creek and Horseshoe Lake have the highest ammoniacal nitrogen concentrations (Figure A 2.11).

Excessive nutrient levels in the Haytons Drain area have been attributed to the fertiliser works situated in this subcatchment (Brown, Mason and Snelder, 1996).

Nitrate levels in the Heathcote River exceed the recommended MfE (1992) guidelines for limiting biological growths (40-100 mg/m^3) for all sites except Haytons Drain (Figure A 2.14). Sites at Templetons Road and Springs Lodge noticeably have the highest levels of nitrate. These locations are spring fed and reflect high nitrate concentrations in the groundwater, also contributing to the low dissolved oxygen in these locations.

Most sites on the Avon River exceed the recommended low flow average value for nitrate. This is again perhaps a reflection of high groundwater nitrate. Groundwater as a source of nitrates is reiterated by Elliott (1995) with a comparison nitrate loads in stormwater runoff with baseflow, indicating nitrogen is entering urban streams from other sources than urban runoff.

In the Avon-Heathcote estuary a huge contribution of nutrients comes from the oxidation ponds in comparison to the rivers (CCC, 1992(b)), although the CCC (1992(b)) study did take stormwater into account.

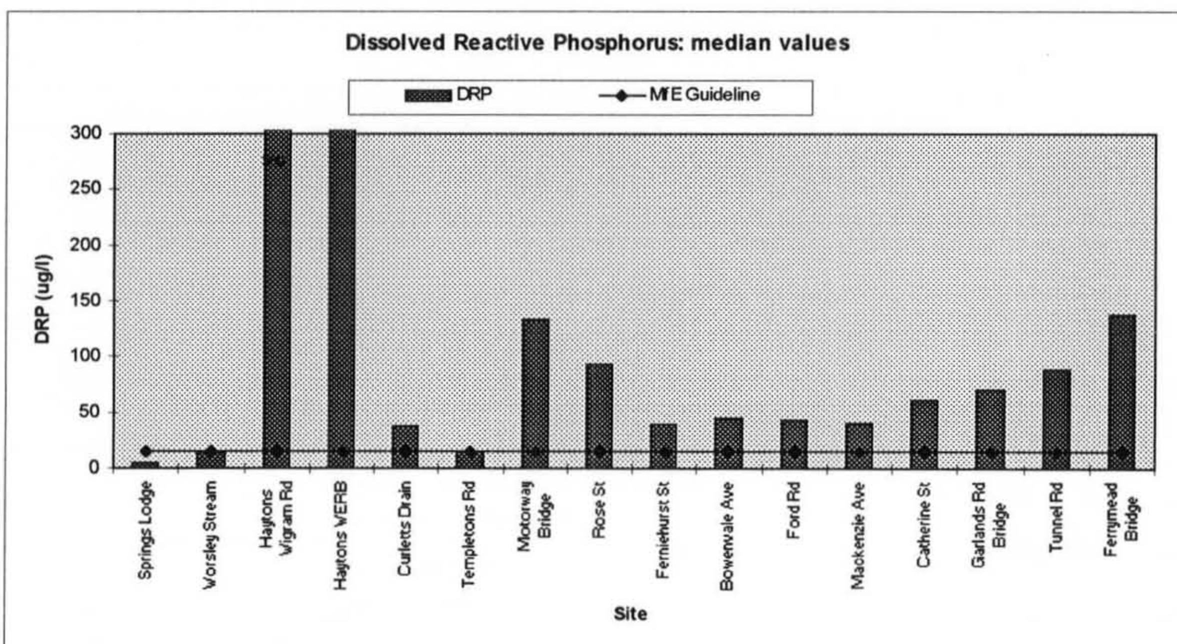

Figure A 2.9. Dissolved reactive phosphorus levels in the baseflow of the Avon River. Data from CCC, 1994(b) (see Appendix 3 for guideline).

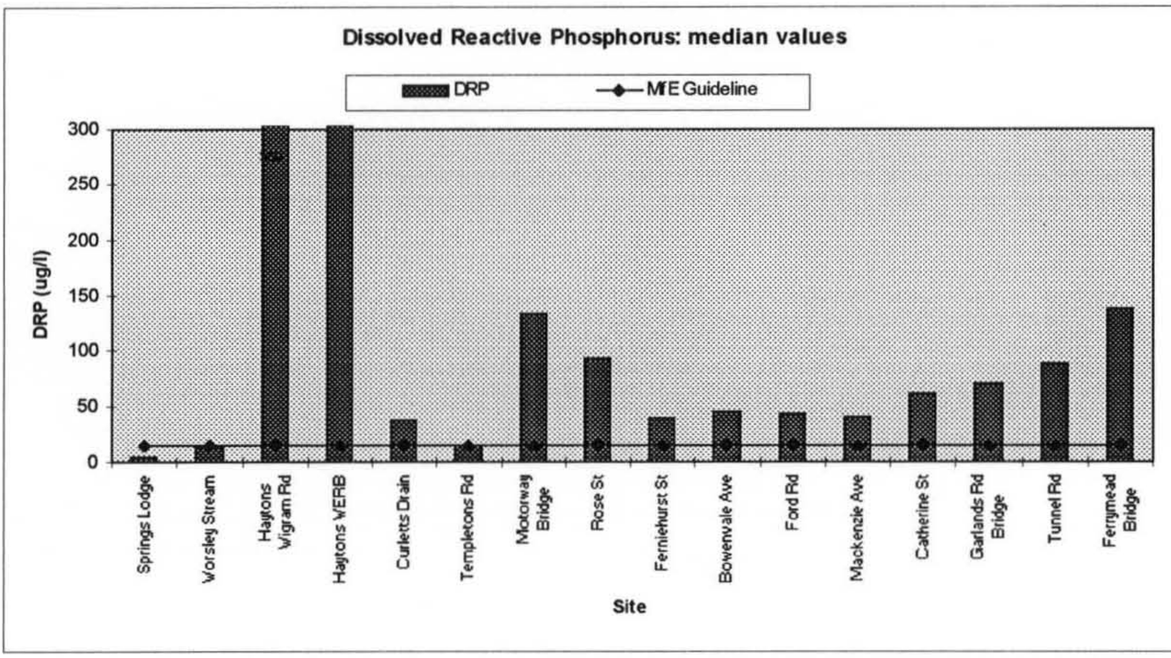

Figure A 2.10. Dissolved reactive phosphorus levels in the baseflow of the Heathcote River. Data from CCC, 1994(b) (see Appendix 3 for guideline).

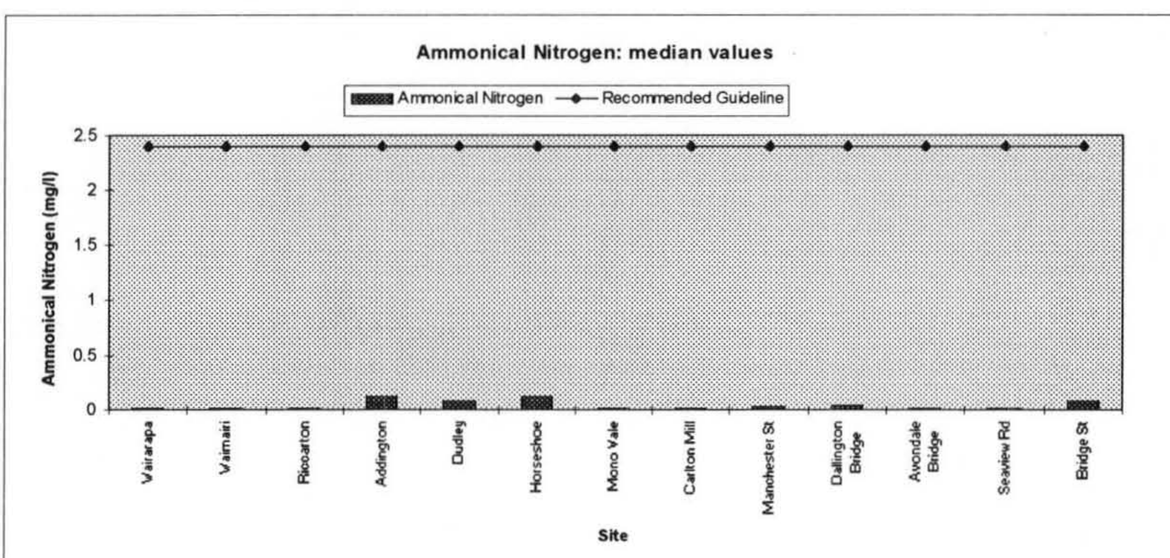

Figure A 2.11. Ammoniacal nitrogen levels in the baseflow of the Avon River. Data from CCC, 1994(b) (Guideline from ANZEC, see Appendix 3).

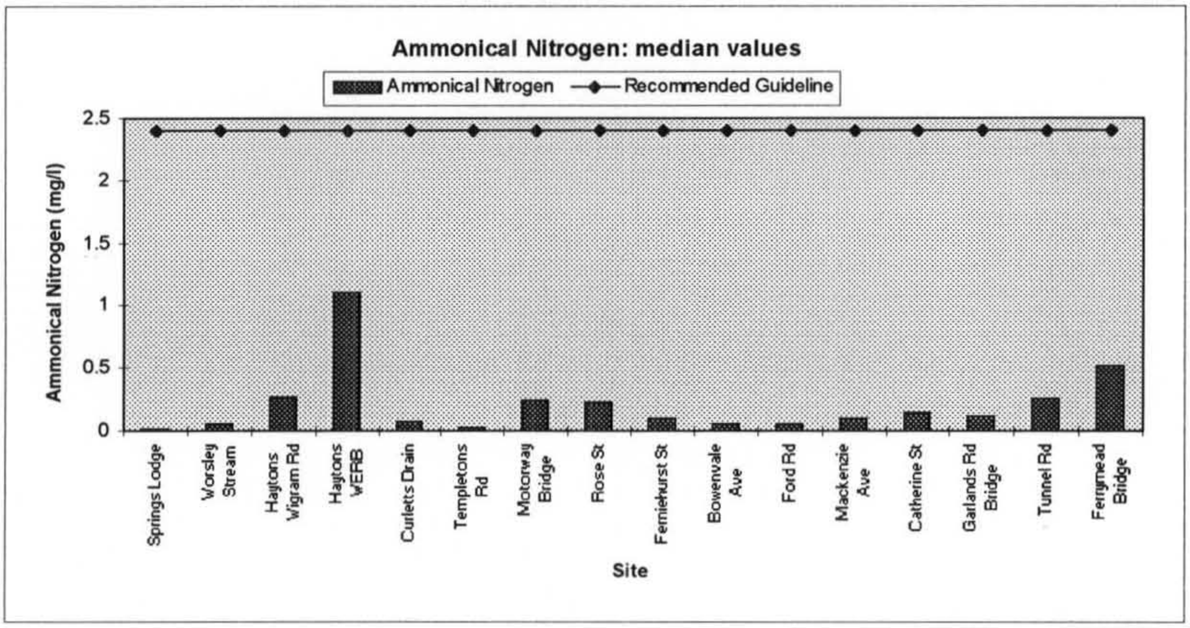

Figure A 2.12. Ammoniacal nitrogen levels in the baseflow of the Heathcote River. Data from CCC, 1994(b) (Guideline from ANZEC, see Appendix 3).

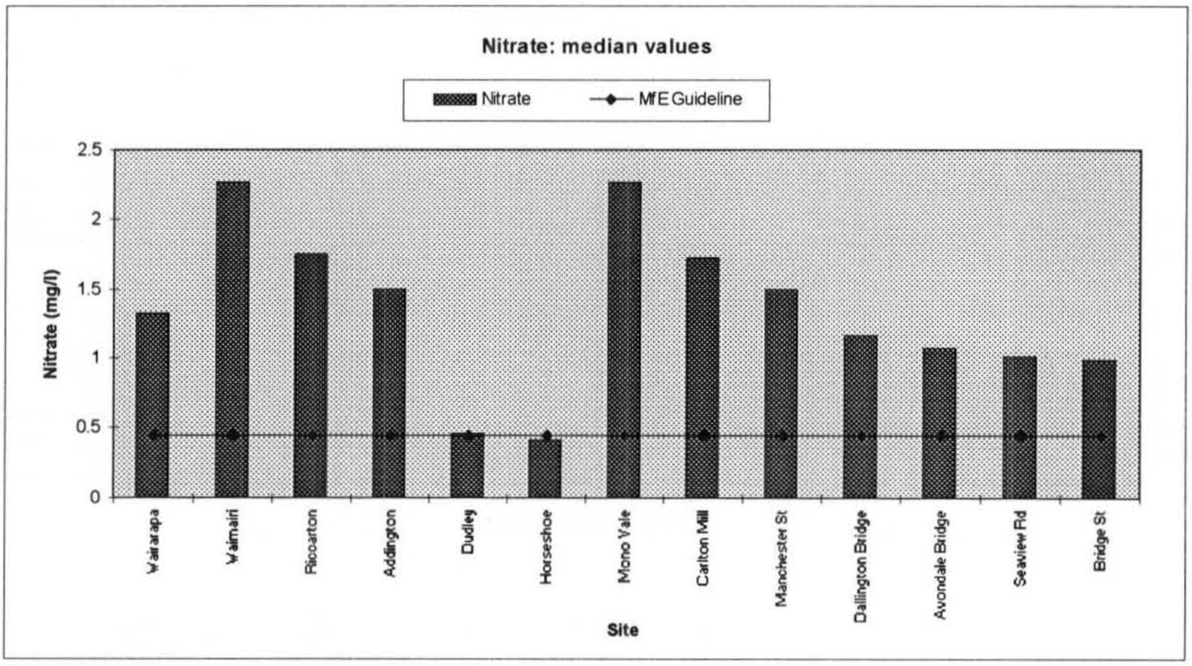

Figure A 2.13. Nitrate levels in the baseflow of the Avon River. Data from CCC, 1994(b).

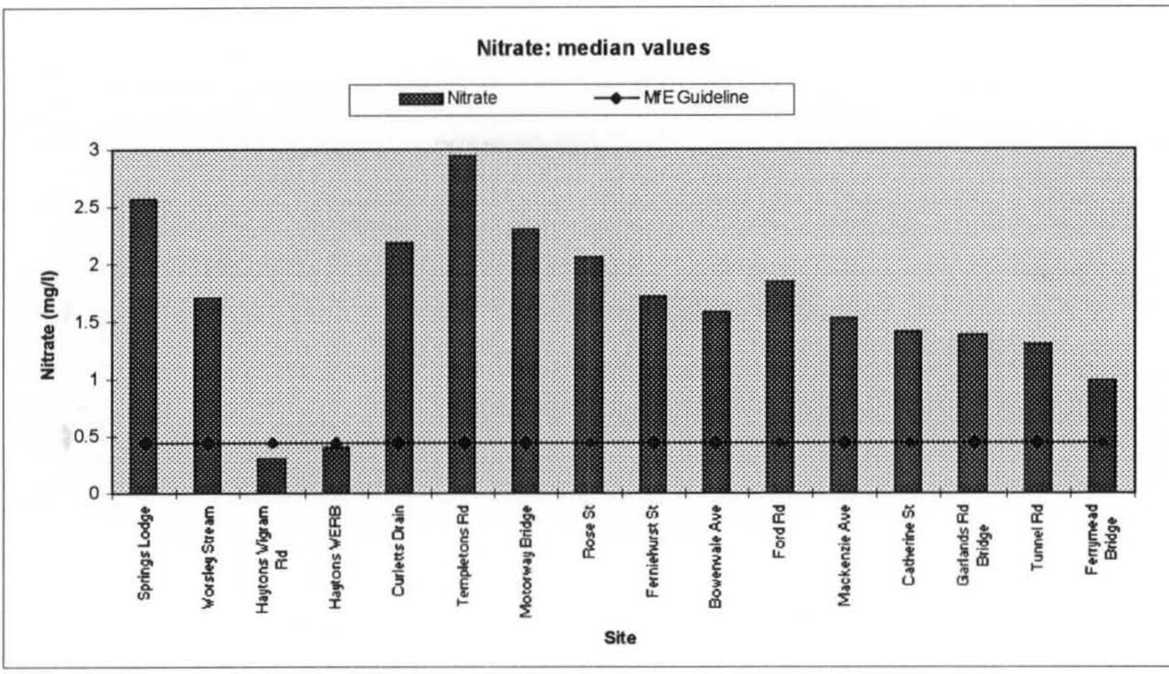

Figure A 2.14. Nitrate levels in the baseflow of the Heathcote River. Data from CCC, 1994(b).

A 2.3.3.2 Nutrients in Stormwater

The CRC (1994) took stormwater samples during three storms from 5 subcatchments in the Avon-Heathcote catchment. Sites sampled include Haytons Road Drain, Riccarton Main Drain, Valley Road, Bowenvale, and Milnes Drain. Total phosphorus, total Kjeldahl nitrogen (TKN), dissolved reactive phosphorus, ammoniacal nitrogen, and nitrite-nitrogen were measured.

Total phosphorus levels were generally within the typical range for urban areas (200-420 mg/m^3; Williamson, 1993). DRP average concentrations exceeded MfE (1992) guidelines (see Appendix 3) for all sites, with Port Hills rural and residential areas recording the highest levels. DRP was also measured in the stormwater at Wigram Retention Basin (Brown et al., 1996). Concentrations were well in excess of MfE guidelines for limiting biological growths, much of this being attributed to the Ravensdown Fertiliser Company.

TKN and nitrate-nitrogen levels have a similar pattern to phosphorus. All 5 areas measured by the CRC exceed the MfE (1992) guideline limiting biological growths for nitrate-nitrogen in stormwater flow (100 mg/m^3).

Ammoniacal nitrogen generally falls within typical range for storm water flow (25-250 mg/m^3; Williamson, 1993) with only the industrial area of Hornby exceeding the average.

No clear patterns are indicated by the nutrient contents from these stormwater sampling events apart from the apparent contribution from rural areas.

A 2.3.4 Pathogens

Faecal coliform and *E.coli* numbers have been measured by the CCC (1992(b), 1994(b)) since the 60's. Recently sampling on a regular basis has taken place since 1989 for the Heathcote River and since 1991 for the Avon river. The CRC also have sampled localities within the Avon-Heathcote catchment particularly in the estuary.

A 2.3.4.1 Pathogens in the Rivers

Faecal coliform levels are generally higher in the Heathcote River than the Avon River. Concentrations decline in the saline reaches of the rivers. Die-off in saline waters is far greater than in freshwater due to factors such as organic toxins (Kilner and Knox, 1973), bactophage attack, sedimentation, and dilution.

Most fresh water sites exceed the Health Department guidelines for contact recreation (200 FC/100 ml, 126 *E.coli*/100 ml). One exception was the spring fed headwaters of the Heathcote River.

Highest median levels occurred at Haytons Drain and Curletts Road Drain, Heathcote catchment and Dudley Creek, Avon catchment. These areas are connected to rural subcatchments and probably have elevated bacterial levels due to runoff from animal wastes. Curletts Road drain's bacterial levels have declined in the 1993-94 sampling period compared to 1991-92. Increased residential and commercial interests in the area may be responsible for this decline.

The number of bacteria in stormflow has been indicated by intensive sampling (winter 1989-92) on the Heathcote River after several periods of heavy rainfall. Faecal coliform levels ranged from 220-9200 per 100 ml averaging 4800 per 100 ml. Median faecal colifom levels for low flow in the Heathcote River are approximately 840 per 100 ml, probably lower considering this figure includes some runoff from rainfall. This is a 570% increase in faecal coliform levels during storms.

A 2.3.4.2 Pathogens in the Estuary

Median faecal coliform and *E.coli* levels do not generally exceed Health department guidelines for contact recreation.

Bacterial levels show a marked decrease in recent years compared to levels reported by Kilner and Knox (1973). This is primarily through better sewage treatment at the Bromley Sewage Farm, and industry and residential localities being connected to the sewage farm in the interim.

A 2.3.5 Sediment

A 2.3.5.1 Sediment in the Rivers

Suspended solids data for the Avon-Heathcote catchment have been regularly sampled by the CCC (1992(b), 1994(b)). Hicks (1993) reports on sediment sources in the Avon and Heathcote Rivers.

The Heathcote River carries much higher sediment baseflow concentrations than the Avon River (Figure A 2.15 and A 2.16). The Heathcote River's greater sediment concentrations is predominantly due to sediment sourced from the adjacent Port Hills.

Sediment sources in the Avon catchment also are dependant on geological conditions and connections to the rural hinterland, but the largest cause for concern has been bankside erosion (CCC, 1992(a)). Although bank erosion is a natural process it can be accelerated in the urban environment due to vegetation removal and drainage modifications. Bank erosion is usually undesirable in the urban environment. The Avon and Heathcote Rivers have seen a number of projects aimed at increased bankside stability, with the more recent projects taking into account environmental aspects of the riparian zone. Stability projects include the use of stabilising materials and native fauna that easily blend in with the riverbank environment.

The Avon and Heathcote Rivers have no sites in which median concentrations exceed the concentration guideline for suspended solids (50 mg/l, from Makepeace, 1995; Figure A 2.15 and A 2.16).

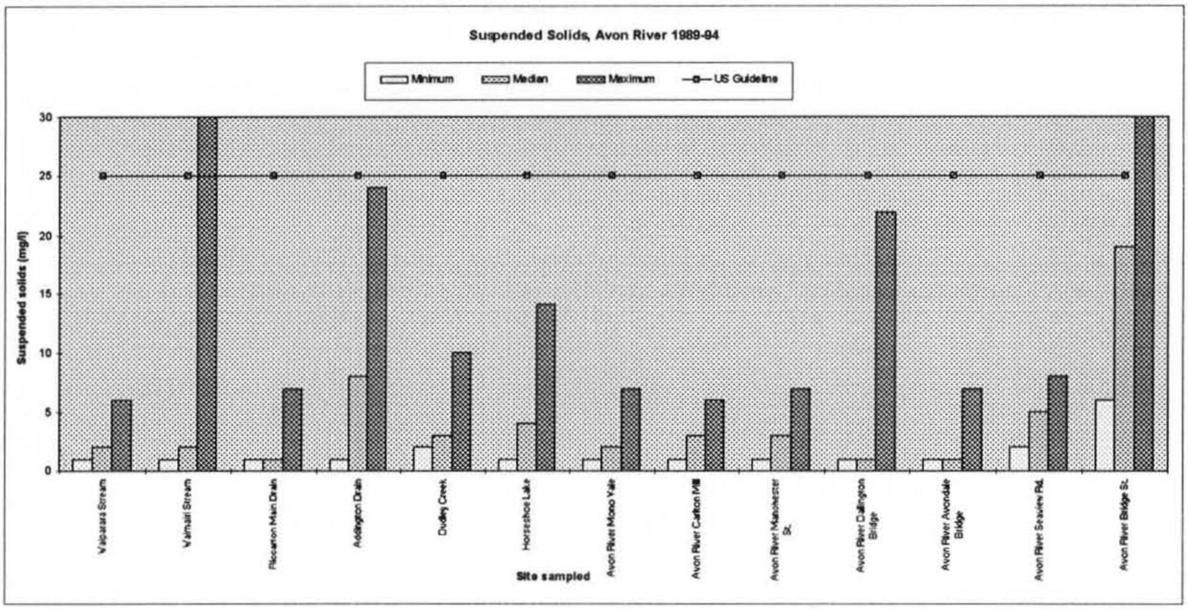

Figure A 2.15. Suspended Solids and guideline (Makepeace, 1995), Avon River 1989-94. Data from CCC, 1994(b).

Biological surveys in the Avon-Heathcote catchment have shown some effects due to sedimentation (Suren, 1993; CDB, 1988; Royds Garden, 1993). Specifically, high sediment levels have been suggested as a probable cause of reduced invertebrate diversity in the Avon River and reduced invertebrate and fish diversity in the Heathcote River. Poor water clarity and substrate conditions due to sedimentation were limited to specific sites in the rivers, although poor substrate composition is a more widespread problem in the Heathcote River. Suren (1993) found approximately 70% silt content in the Heathcote River compared to less than 25 % in non-urban catchments. Sites with sediment problems are reflective of slower water velocities (Royds Garden, 1993). Sites include Haytons Drain and Addington Drain.

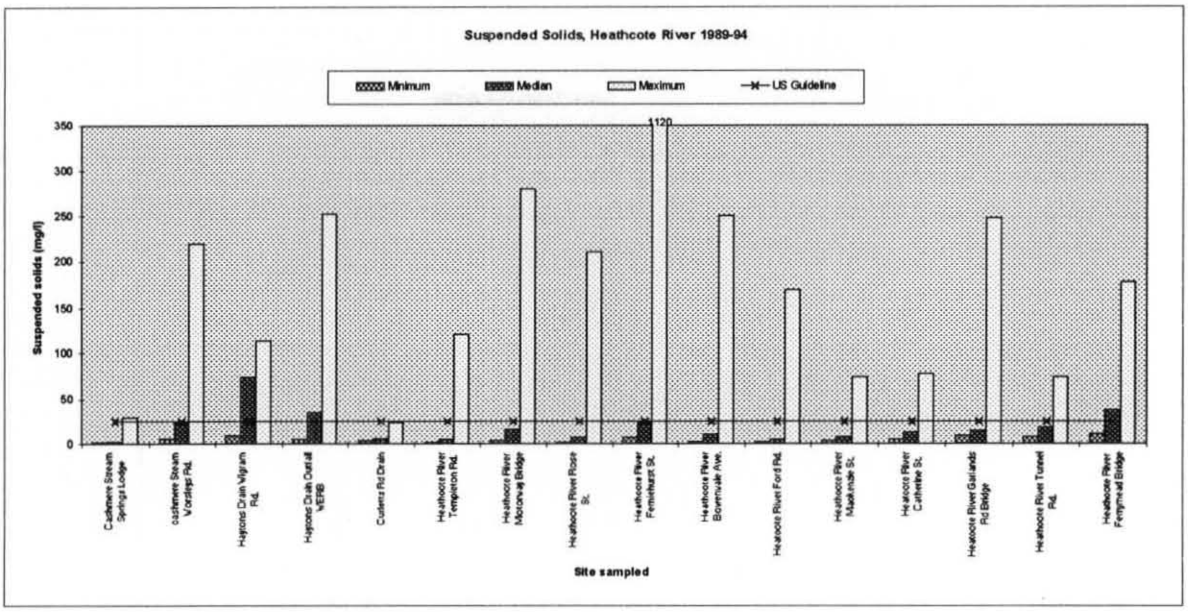

Figure A 2.16. Suspended solids and guideline (Makepeace, 1995), Heathcote River 1989-94. Data from CCC, 1994(b).

A 2.3.5.2 Sediments in the Avon-Heathcote Estuary

Sediments have a transition from fine silt/clay at the river mouths to sand at the estuary mouth. The Heathcote River mouth has siltier mudflats than the Avon River mouth. Mudflats retaining moisture for longer and contain far more organic material and nutrients than sand banks. The resulting high internal bacteria population (NIWA, 1995) results in depletion of oxygen in the mud substrate.

The effects of sediment loading on the estuary from the rivers are uncertain. Sedimentation particularly of fine grained material is generally increased by urbanisation, but whether this inhibits the estuary biota or plants is unlikely. Sediment can adversely affect suspension feeding bivalves and some polychaete worms and with decreased water clarity photosynthetic organisms productivity can be reduced (NIWA, 1995). These conditions may be accelerated by *Spartina*. More likely though is that contaminants associated with fine sediments in the estuary would be the cause of detrimental effects on estuary organisms.

A 3. AQUATIC CRITERIA AND GUIDELINES

Water Quality Parameter	**Guidelines for Sediments (FW: Fresh Water; M: Marine)**			
Heavy Metals	**NOAA ER-L[1] FW/M (mg/kg)**	**NOAA ER-M[2] FW/M (mg/kg)**	**Ontario MoE 1989 FW (mg/kg) Lowest Effect Level**	**Servere Effects Level**
Cadmium			**1.0**	**10.0**
Chromium			**31**	**111**
Copper	**70**	**390**	**16**	**110**
Lead	**35**	**110**	**31**	**250**
Nickel			**31**	**90**
Zinc	**120**	**270**	**110**	**820**
Notes: [1] ER-L Effects Range Low: 10% of studies demonstrate an effect [2] ER-L Effects Range Medium: 50% of studies demonstrate an effect				

Table A 3.1. Guidelines for the protection of aquatic ecosystems from heavy metals in sediment. From Snelder and Trueman, 1995; Ontario MoE, 1992.

Water Quality Parameter	**Surface Water Guidelines**			
Heavy Metals - Surface Metals	**EPA FW Acute Criteria[1], 1986 (mg/l)**	**EPA FW Chronic Criteria[3], 1986 (mg/l)**	**Australian[2], 1992 (mg/l)**	
	50-300 mg/l $CaCo_3$	**50 mg/l $CaCo_3$**	**Freshwater[3]**	**Marine[3]**
Cadmium	**0.0036**	**0.00066**		
Chromium	**0.98[3]**	**0.12**	**0.010**	**0.050**
Copper	**0.009-0.050**	**0.0065**	**0.002-0.005**	**0.005**
Lead	**0.034-.331**	**0.0013**	**0.001-0.005**	**0.005**
Nickel	**0.16**	**0.056**	**0.015-0.150**	**0.015**
Zinc	**0.181-0.800**	**0.059**	**0.05-0.50**	**0.050**
Notes: [1] Wanielista & Yousef, 1995 [2] Australian & New Zealand Environmental Council, 1992 [3] USEPA, 1986				

Table A 3.2. Guidelines for the protection of aquatic ecosystems from heavy metals in surface waters.

Water Quality Parameter	Surface Water Guideline (mg/l)	Notes
Ammonia	**0.08-2.5 (dependant on temperature and pH)[♦]**	**For Christchurch waterways ammonia of 2.4 is used corresponding to a median pH of 7.5 at 5 °C**
Dissolved Reactive Phosphorous (DRP)	**< 0.015 - 0.030[α]**	
Dissolved Inorganic Nitogen (DIN)	**< 0.040 - 0.100[α]**	**level needed to significantly effect periphyton biomass**
Nitrate NO_3-N	**< 0.040 - 0.100[α]**	
Nitrite	**< 0.1 - 1.0[α]**	
Suspended solids (SS)	**25 - 100**	**or < 10% change in seasonal average (may also use 5 - 25 NTU[β])**
Notes: [α] From MfE, 1992 [β] From Makepeace, 1995 [♦] USEPA, 1986		

Table A 3.3. Nutrient guidelines for limiting undesirable biological growths in freshwater, and suspended solid guideline.

Water Quality Parameter	Low Flow			Storm Flow		
	Low	**Average**	**High**	**Low**	**Average**	**high**
Suspended Solids	**7 g/m^3**	**14 g/m^3**	**23 g/m^3**	**50 g/m^3**	**170 g/m^3**	**470 g/m^3**
TP	**30 mg/m^3**	**55 mg/m^3**	**90 mg/m^3**	**200 mg/m^3**	**420 mg/m^3**	**1120 mg/m^3**
DRP	**4 mg/m^3**	**8 mg/m^3**	**20 mg/m^3**	**13 mg/m^3**	**40 mg/m^3**	**70 mg/m^3**
NH_3-N	**30 mg/m^3**	**55 mg/m^3**	**130 mg/m^3**	**25 mg/m^3**	**100 mg/m^3**	**250 mg/m^3**
NO_3-N	**265 mg/m^3**	**450 mg/m^3**	**3600 mg/m^3**	**375 mg/m^3**	**800 mg/m^3**	**1500 mg/m^3**
TN				**1300 mg/m^3**	**2500 mg/m^3**	**4250 mg/m^3**
TKN	**460 mg/m^3**	**570 mg/m^3**	**830 mg/m^3**	**1100 mg/m^3**	**1900 mg/m^3**	**3200 mg/m^3**

Table A 3.4. Recommended guidelines for low and storm flow of nutrients and suspended solids in urban runoff. From Williamson, 1993. Based on the 10, 25 and 75 %-ile for New Zealand and overseas data. Not an effects guideline.

4.0 CONTAMINANT RANKING DATA

RIVER REACHES	Cu	Pb	Zn	DRP	Sediment	Nitrate
Haytons Drain	9.3	48	137.3	797.6	57.1	0.7
Curletts Drain	22	36	204	47.3	8.5	2.12
Heathcote - Main	61.0	73.1	167.0	318.1	35.9	1.79
Riccarton Drain	20.4	367.5	251.3	19.8	1.5	1.78
Addington Drain	51.3	172.2	410.5	29.2	9.2	1.68
Waimairi Stream	14.2	164.5	132.1	6.1	3.1	2.39
Dudley Creek	24.3	224.5	366.3	51.4	3.8	0.56
Avon - headwaters	25.1	100.1	184.7	5.3	2.2	2.53

Table A 4.1. Means for contaminant data sets in baseflow (mg/l), 1989-95, 1988 sediment data for metals (mg/kg).

FRESHWATER REACH	Cu	Pb	Zn	DRP	Nitrate	SS	TOTAL
Haytons Drain	0.0	0.6	0.6	1.2	1.2	1.2	7.2
Curletts Drain	0.4	0.4	0.4	0.8	0.8	0	6.4
Heathcote - Main Stem	1.6	1.6	1.6	3.2	3.2	3.2	20.7
Riccarton Drain	1.1	2.2	1.1	0.0	2.2	0	9.1
Addington Drain	1.1	1.1	1.1	0.0	2.2	0	5.9
WaimairiStream	1.1	1.1	1.1	0.0	2.2	0	9.8
Dudley Creek	1.3	1.3	1.3	2.7	2.7	0	14.6
Avon - headwaters	1.6	1.6	1.6	0.0	3.2	0	14.3
TOTAL	8.2	9.9	8.8	7.9	17.7	4.4	

Table A 4.2. Ranking of contaminants and freshwater reaches for urban Christchurch.

FRESHWATER REACH	METALS	INTRINSIC ECOLOGICAL	RECREATION	AESTHETICS	RANK
Heathcote Catchment					
Haytons Drain	Cu	0	0.7	0.5	0.0
	Pb	0.5	0.7	0.5	0.6
	Zn	0.5	0.7	0.5	0.6
Curletts Drain	Cu	0.5	0.3	0.5	0.4
	Pb	0.5	0.3	0.5	0.4
	Zn	0.5	0.3	0.5	0.4
Heathcote - Main	Cu	0.5	1.7	1.5	1.6
	Pb	0.5	1.7	1.5	1.6
	Zn	0.5	1.7	1.5	1.6
Avon Catchment					
Riccarton Drain	Cu	0.5	0.7	1.5	1.1
	Pb	1	0.7	1.5	2.2
	Zn	0.5	0.7	1.5	1.1
Addington Drain	Cu	0.5	0.7	1.5	1.1
	Pb	0.5	0.7	1.5	1.1
	Zn	0.5	0.7	1.5	1.1
Waimairi Stream	Cu	0.5	1.7	0.5	1.1
	Pb	0.5	1.7	0.5	1.1
	Zn	0.5	1.7	0.5	1.1
Dudley Creek	Cu	0.5	1.7	1	1.3
	Pb	0.5	1.7	1	1.3
	Zn	0.5	1.7	1	1.3
Avon - headwaters	Cu	0.5	1.7	1.5	1.6
	Pb	0.5	1.7	1.5	1.6
	Zn	0.5	1.7	1.5	1.6

Table A 4.3. Ranking values for metals for urban Christchurch.

FRESHWATER REACH	CONTAMINANT	INTRINSIC ECOLOGICAL	RECREATION	AESTHETICS	RANK
Heathcote Catchment					
Haytons Drain	DRP	1	0.7	0.5	1.2
	SS	1	0.7	0.5	1.2
	Nitrate	1	0.7	0.5	1.2
Curletts Drain	DRP	1	0.3	0.5	0.8
	SS	0	0.3	0.5	0.0
	Nitrate	1	0.3	0.5	0.8
Heathcote - Main	DRP	1	1.7	1.5	3.2
	SS	1	1.7	1.5	3.2
	Nitrate	1	1.7	1.5	3.2
Avon Catchment					
Riccarton Drain	DRP	0	0.7	1.5	0.0
	SS	0	0.7	1.5	0.0
	Nitrate	1	0.7	1.5	2.2
Addington Drain	DRP	0	0.7	1.5	0.0
	SS	0	0.7	1.5	0.0
	Nitrate	1	0.7	1.5	2.2
Waimairi Stream	DRP	0	1.7	0.5	0.0
	SS	0	1.7	0.5	0.0
	Nitrate	1	1.7	0.5	2.2
Dudley Creek	DRP	1	1.7	1	2.7
	SS	0	1.7	1	0.0
	Nitrate	0	1.7	1	2.7
Avon - headwaters	DRP	0	1.7	1.5	0.0
	SS	0	1.7	1.5	0.0
	Nitrate	1	1.7	1.5	3.2

Table A 4.4. Ranking values for nutrients and suspended sediments for urban Christchurch.

A 5.0 ZINC LOADING ESTIMATES

A 5.1 ROOFING

A 5.1.1 Christchurch Residential Galvanised Roofing Area

A 5.1.1.1 Roof

To aid in the calculation of zinc loads generated from runoff a survey of some Christchurch's residential and industrial areas was performed to ascertain the state and type of materials composing Christchurch roofs. This information is used in calculations below and the survey is detailed in Appendix 6.

Standard New Zealand House: Floor Plan = 95 m^2 (Honey and Buchanan, 1992)
Garage: Floor Plan = 15 m^2 (*pers comm* Bill Ash, BRANZ)
Total Area: Floor Plan = $\underline{110\ m^2}$

Number of private dwellings in Christchurch, 1996 = $\underline{112900}$ (estimated from 1991 figures, CCC, 1995)

Roof Angle for galvanised roofs = 20° - 25°, take average roof angle of 22.5° (*pers comm* Bill Ash, BRANZ)

For a simple gable roof the roof area = floor plan + 15% floor plan (for angle) + 1% over-extension:

$$= 110\ m^2 + 16.5\ m^2 + 1.1\ m^2$$
$$= \underline{130\ m^2}$$

- Total roofing area for residential Christchurch = $112900 \times 130\ m^2$

$$= 14677000\ m^2$$
$$= \underline{1467.7\ ha}$$

The Christchurch residential roof survey yielded a figure of 59.7% of roofs composed of galvanised steel (galvanised steel is the term used to represent zinc coated products protected by a zinc coating only as opposed to an alloy of zinc and another metal), 66.2% of these are protected by paint. This corresponds well with Dept. Statistics (1981; cited Honey and Buchanan, 1992) figure of 61.3% of residential roofs being galvanised steel.

The survey also found that 71% of Christchurch's residential roofs are steel based products. Crossley (1990, pp 76) reported that 70% of the residential market (New Zealand wide) uses steel roofing products.

- Total galvanised roofing area = 1467.7 ha x 0.651

  = $\underline{9554 \times 10^3\ m^2}$

- Total exposed galvanised roofing area = 1467.7 ha x 0.651 x 33.8% (% of unpainted galvanised roof)

  = $\underline{3229 \times 10^3\ m^2}$

A 5.1.1.2 Gutter

For residential guttering x-sectional area of gutters range from 6000 mm^2 to 21875 mm^2 (BRANZ, 1986). For average New Zealand house of 100 m^2 roof drainage area requires a gutter of approximately 10000 mm^2

Perimeter of average eaves gutter for 10000 mm^2 = 290 mm (based on typical standard profiles)

Plan area of a typical roof = 100 m^2 x 0.85 = 85 m^2 (100 m^2 - 15% due to roof angle, from section A 4.1.1 above)

Length of gutter for 100 m^2 roof = 4 x $\sqrt{85}$ m^2

= 36.88 m

Assuming a large percentage of galvanised gutters are unpainted on the inside the estimated surface exposed for corrosion = 36.88 m x 0.290 m

= 10.7 m^2

From the Christchurch roofing survey (Appendix 6) 64.3% of guttering was galvanised steel. Due to the uncertainties in whether guttering is painted or not, it will be assumed that 20% are afforded some form of protection, for the 122900 roofs in Christchurch.

Estimated total area of exposed galvanised guttering = 10.7 m^2 x 122900 x 64.3%x 20%

= <u>169 x 10^3 m^2</u>

A 5.1.2 Zinc Load Estimates From Christchurch Residential Roofs

A 5.1.2.2 Method 1. Corrosion Rate

Life span of zinc coated products: 50 years in low rainfall, rural atmosphere (BRANZ, 1979), 15 year warranty, minimum durability requirement (BHP, 1993; BRANZ, 1996)

Use an average life span of 32.5 years, reasonable for a moderate urban coastal atmosphere.

Average zinc coating on roofing products = 275 g/m^2 for Galvsteel (BHP, 1993)

= <u>137.5 g/m^2</u> for one side (exposed)

Corrosion rate for 32.5 years: 137.5 g/m^2 / 32.5 = <u>4.23 g/m^2/year</u>

= 11.6 mg/m^2/day (BRANZ show for a rural atmosphere a figure of 17 mg/m^2/day)

- Estimated zinc corrosion from Christchurch residential roofs based on this corrosion rate and the exposed galvanised area (Section A 5.1.1.1)

= 4.23 g/m^2/year x 3229000 m^2

= 13.66 x 10^6 g/year

= <u>13.66 tonnes/year</u>

- Assume 5% of this not connected to stormwater drainage due to leaks and unconnected roofing:

$$= 13.66 \text{ tonnes/year} - 5\%$$

$$= \mathbf{12.48\ tonnes/year}$$

A 5.1.2.2 Method 2 - Average Concentration

Roof runoff concentrations for zinc from several roofing types are listed in Table 5.1. These values were obtained from a literature search. The most appropriate concentration to use for an estimate of the loads from Christchurch roofs, found from the literature review, is the urban runoff concentration (1200 μg/l) from Greene and Thomas (1993). Measured in a dry Australian climate, this concentration is the most comparable to Christchurch conditions and roofing material. By comparison, acid rain is an important factor in the studies in the northern hemisphere. This results in accelerated corrosion and increased mobility of zinc. Also zinc concentrations are at an appreciable level in the atmosphere in those studies. Quek and Forster (1993) found rainwater concentrations around 105 μg/l. On the other hand rainwater collected by Greene and Thomas (1993) was practically free from zinc contamination, suggesting minimal airborne contribution.

Data obtained from ESR on zinc concentrations from 35 New Zealand schools generally show zinc concentrations from galvanised steel roofs to be lower than indicated by overseas studies. The zinc concentration data from the schools has been interpolated so that for a given percentage paint cover a zinc concentration can be obtained (Appendix 6). As this data is indicative of New Zealand conditions and provides a larger sampling range, it will be used for residential and industrial roofing load calculations.

Zinc concentration for galvanised steel roof (from Appendix 7.2) = 0.40 mg/l

Area of galvanised steel roofing for residential Christchurch (from Section 5.1.1.1)

$$= 9555 \times 10^3 \text{ m}^2$$

Mean Christchurch rainfall = 648 mm/ year (New Zealand Meteorological Service, 1980)

15% reduction in roof runoff due to roof angle = $9555 \times 10^3 \text{ m}^2 - 15\% = 8123 \times 10^3 \text{ m}^2$

Roof runoff = 0.648 m x 8123 x 10^3 m^2 = 5263704 m^3 = 5.264 x 10^9 l/year

- Estimated total zinc in runoff = 5.264 x 10^9 l/year x 0.40 mg/l
  = 2.105 x 10^9 mg/year
  = 2.10 tonnes/year

- Assume 5% of this not connected to stormwater drainage due to leaks and unconnected roofing:
  = 2.10 tonnes/year - 5%
  = **2.00 tonnes/year**

A 5.1.3 Christchurch Industrial Galvanised Roofing Area

A survey similar to the residential survey found that 62.2% of roofs are of galvanised material and 75% of these are unpainted.

Industrial floorspace was reported to be 3792000 m^2 in 1994 (CCC, 1995)

Assume that 25% of this is double storeyed, plan area = 2844000 m^2 = 284 ha

Assume total roof area to be at an angle of 22.5° and 1% overlap = 3299 x 10^3 m^2

Estimated unpainted galvanised industrial roofing area = 3299040 m^2 x 62.2% x 75%
= 1539002 m^2

A 5.1.4 Zinc Load Estimates From Christchurch Industrial Roofing

A 5.1.4.1 Method 1 - Corrosion Rate

For 275 g/m^2 Galvsteel corrosion rate over 32.5 years (from Section 4.12.2)
= 4.23 g/m^2/year

Estimated zinc corrosion from Christchurch industrial roofs = 4.23 g/m^2/year x 1539002 m^2

= 6509979 g/year

= 6.51 tonnes/year

- Assume 5% of this not connected to stormwater drainage due to leaks and unconnected roofing:

  = 6.51 tonnes/year - 5%

  = 6.18 tonnes/year

A 5.1.4.2 Method 2 - Average Concentration

Zinc concentration for galvanised steel roofs (from Appendix 7) = 0.90 mg/l

Area of galvanised steel roofing for residential Christchurch (total area x 62.2%)

= 2052×10^3 m^2

Mean Christchurch rainfall = 648 mm/ year (New Zealand Meteorological Service, 1980)

15% reduction in roof runoff due to roof angle = 2052×10^3 m^2 - 15% = 1744×10^3 m^2

Roof runoff = 0.648 m x 1744×10^3 m^2 = 1130243 m^3 = 1.130×10^9 l/year

- Estimated total zinc in runoff = 1.130×10^9 l/year x 0.90 mg/l

  = 1.130×10^9 mg/year

  = 1.13 tonnes/year

- Assume 5% of this not connected to stormwater drainage due to leaks and unconnected roofing:

  = 1.13 tonnes/year - 5%

  = 1.07 tonnes/year

Guttering not taken into account due to the unknown number of industrial buildings.

5.1.5 Zinc Load Estimates From Christchurch Guttering

From above corrosion rate for 275 g/m^2 galvanised steel = 4.23 g/m^2/year

Estimated zinc corrosion from Christchurch residential gutters

= 4.23 g/m^2/year x 460260 m^2

= 1946902 g/year

= 1.95 tonnes/year

- Assume 5% of this not connected to stormwater drainage due to leaks and unconnected roofing:

= 1.95 tonnes/year - 5%

= **1.85 tonnes/year**

A 5.2 AUTOMOTIVE

Chapter 5.3.2 details the automotive parts that are capable of dispersing zinc into the environment. It is a difficult task to accurately asses the loads attributed to automotive parts due to the infinite variety of vehicles, and the large number of compounds used to fuel and maintain them. The load analyses below uses available information to estimate zinc loads from automotive parts. Once this is achieved there still remains the problem of how much of the estimated load is likely to find its way into the aquatic environment, usually via stormwater drainage.

A large percentage of the particulate material derived from vehicles is entrapped at the roadside, with 95% of street refuse found within 1m of the curb (Novotny and Chesters, 1981). The effect of the curb on dust and dirt particles has been demonstrated by Shaheen (1975, cited Novotny and Chesters, 1981). The question now is how much zinc is left by the roadside, accessible to stormwater flow?

Several studies have demonstrated the percentage of zinc accumulated in roadside dirt (e.g. 397 $\mu g/g$ for residential land use; Novotny and Chesters, 1981), but often fail to demonstrate the percentage of metals left on roads as a result of vehicle emissions. Previous studies of lead found the density of lead fallout decreases with distance from the road (emission point) (Day, 1977; Laxen and Harrison, 1977). One study finding that 42% of lead was lost from the road (Laxen and Harrison, 1977). However, this was based on data from lead emitted predominantly from exhaust emissions.

Cadle and Williams, (1978) and Malmquist (1983; cited Santa Clara Valley Nonpoint Source Pollution Program, 1992) found that most zinc from tyres settles on or near the road. No data has been found on the distribution of zinc emitted from tyres near or on the roadside so for the purposes of this study it will be assumed 80% zinc remains on the road. A similar assumption is made for dust from brake linings. For oil and coolant, it is assumed that all leaks from vehicles are contained within the vicinity of the road so it is assumed that 100% of this is washed into the stormwater drainage system.

A 5.2.1 Tyres

Average passenger car tyre lasts 30000 kms, from new (*pers comm* Dunlop Tyres)

Average passenger car tyre will shed 12.95 g of ZnO from new to warrant of fitness standard (Ministry of Transport, 1995)

Christchurch in 1991 had approximately 151600 cars. With a 2% increase per annum in 1996 the car population would approximately be 166760 (CCC, 1995)

Average kilometres travelled by cars in Christchurch = 17000 kms/car (CCC, 1995)

Tyre life = 30000 kms / 17000 kms/year = <u>1.76 years</u>

ZnO produced per tyre = 12.95 g / 1.76 years = <u>7.36 g/year</u>

For 166760 Christchurch cars (4 tyres each car) annual distribution of ZnO

= 7.36g/year x 4 x 166760

= <u>4.91 tonnes/year</u>

- Approximately 80% of this accumulates roadside, so assume 80% is washed into receiving waters:

  = 80% x 4.91 tonnes/year

  = 3.04 tonnes/year ZnO

- There is 80.38% Zn in ZnO, thus the weight of zinc = 3.04 x 80.34%

  = **2.44 tonnes/year**

Check No. 1:

Approximate tyre wear ≅ 1 cm/25000 km (Santa Clara Nonpoint Source Program, 1992)

Average tyre diameter ≅ 65 cm

Average tyre width ≅ 15 cm

Surface area of tyre = 3063 cm^2

Reduce for tyre tread: approximately 30% spacing = 3063 x 30%

surface area = 2144 cm^2

Volume over 1cm wear over 25000 = 2144 cm^3

Average tyre density ≅ 1.07 g/cm^3 (Santa Clara Nonpoint Source Program, 1992)

ZnO composition of tyre = 0.7% (Ministry of Transport, 1995)

Weight of 1 cm wear over 25000 km = 2294 g/rubber/tyre

For 17000 kms (average vehicle distance covered in Christchurch) wear

= 2294 g x 17000 kms / 25000 kms

= 1560 g/tyre/year

Zinc emitted per tyre per year = 0.7% x 1560 g/tyre/year = 10.9 g/tyre/year

For 166760 Christchurch cars, 4 tyres each car, annual distribution of ZnO

= 10.9 g x 4 x 166760

= 7.28 tonnes/year

- Approximately 80% of this accumulates roadside, so assume 80% is washed into receiving waters :

  = 80% x 7.28 tonnes/year

  = **5.82 tonnes/year**

- There is 80.38% Zn in ZnO, thus the weight of zinc = 5.82 x 80.34%

  = **4.68 tonnes/year**

Check No. 2:

Tyre wear = 0.125 g/vehicle/km (Novotny *et al.*, 1991)

Tyre wear for 166760, 4 tyred vehicles over 17000 kms = 354 tonnes.rubber/year

ZnO composition of tyre = 0.7% (Ministry of Transport, 1995)

Total zinc emitted from Christchurch passenger car tyres = 354 tonnes/year x 0.007

= <u>2.48 tonnes/year</u>

- Approximately 80% of this accumulates roadside, so assume 80% is washed into receiving waters :

  = 80% x 2.48 tonnes/year

  = **1.98 tonnes/year**

- There is 80.38% Zn in ZnO, thus the weight of zinc = 1.98 x 80.34%

  = **1.59 tonnes/year**

All estimates are within the same order of magnitude, but it would seem the initial analysis uses Christchurch specific data and would therefore provide the most realistic estimation.

A 5.2.2 Coolant

It is estimated that 25 - 50% of coolant ends up in the environment (Hudgen and Bustamante, 1993).

Assume 37.5% of coolant ends up in the stormwater system.

Concentration of zinc in cooling systems:

- 14 μg/g (Shaheen, 1975; cited Santa Clara Nonpoint Source Program, 1992), at a density of 1000 g/l = 14 mg/l
- 200 mg/l, maximum concentration (Hudgen and Bustamante, 1993).

Average coolant capacity in a motorcar = 6 litres, recommended that coolant be changed every 3 years (*pers comm* Shantha Mannapperuma)

Estimated volume of coolant entering the stormwater system per year = 6 litres per 3 years

= 2 l/year x 0.375

= 0.75 l/year/vehicle

for 166760 Christchurch vehicles = 0.75 x 166760

= <u>125070 l/year</u>

Use average content of zinc in coolant = <u>14 mg/l</u> (Shaheen, cited Santa Clara Valley Nonpoint Source Pollution Control Program, 1992)

- Estimated weight of zinc in coolant entering the aquatic environment

= 125070 l/year x 14 mg/l

= 1751 g/year

= 1.75 kg/year

A 5.2.3 Oil

After several telephone conversations with Christchurch mechanics it was estimated that approximately 50% of vehicles have obvious oil leaks but only 10% of these would be called major. A major oil leak was defined as a vehicle losing around 250 ml of oil per month. However the range of oil estimated by Christchurch mechanics ranged from 60% to 5%. This estimation was dependant on the type of service facility a mechanic worked in.

Estimated that 10% of cars have oil leaks, for 166760 Christchurch vehicles = 16676 leaking vehicles

Estimated volume of oil that the average vehicle leaks = 0.25 l/month = 3 l/year

Volume of oil from leaks = 16676 x 3 litres

= 50028 l/year

Zinc concentration 1: Average zinc concentration of oil = 890 mg/l (Huang *et al.*, 1994)

Concentration of zinc in used oil = 550 μg/g (Pyziak and Brinkman, 1992)

Assume a density of oil = 850 kg/m^3 (Santa Clara Nonpoint Source Program, 1992)

Zinc concentration 2: Hence zinc concentration of oil = 468 mg/l

Take average zinc concentration in oil from 1 and 2 = 679 mg/l

- Estimated zinc from engine oil leaks entering the aquatic environment

= 50028 l/year x 679 mg/l

= **34.0 kg/year**

A 5.2.4 Exhaust Emissions

Zinc produced from 49 vehicles tested for 30 minutes (idling): 10000 ng/filter/car - catalyst

12000 ng/filter/car - noncatalyst

- particle size measured =<10 μm (Huang *et al.*, 1994)

Assume 11000 ng of zinc produced in 30 minutes = 528 μg/day

Number of days Christchurch vehicles spends on the road travelling at a velocity of 50 km/hour = 17000 (km/year) /50 (km/hr) x 166760 cars = 56698400 hours

= 2362433 days

Estimated emissions of zinc for 1996 = 2362433 x 528 = 1247.4 g/year

= **1.2 kg/year**

Fergusson (1980) found 62% lead concentration in soil to lie within 10 m of the road. However, not all the lead deposited from vehicles within 50-100 m is accountable for. The amount deposited ranges from 6% to 48%. Therefore 3.7% and 29.8% of the lead emissions lie within 10m of the road. Thus an average figure is approximately 17%. Zinc emitted from exhausts has a similar distribution pattern to lead (see Figure A 6.1), thus it is estimated that 17% lies within 10 m of the road. Assuming most of this finds it way into the stormwater drainage system then:

- the approximate amount of zinc washed into waterways from vehicle exhausts:

= 62% x 17% x 1.2 kg/year

= **0.2 kg/year**

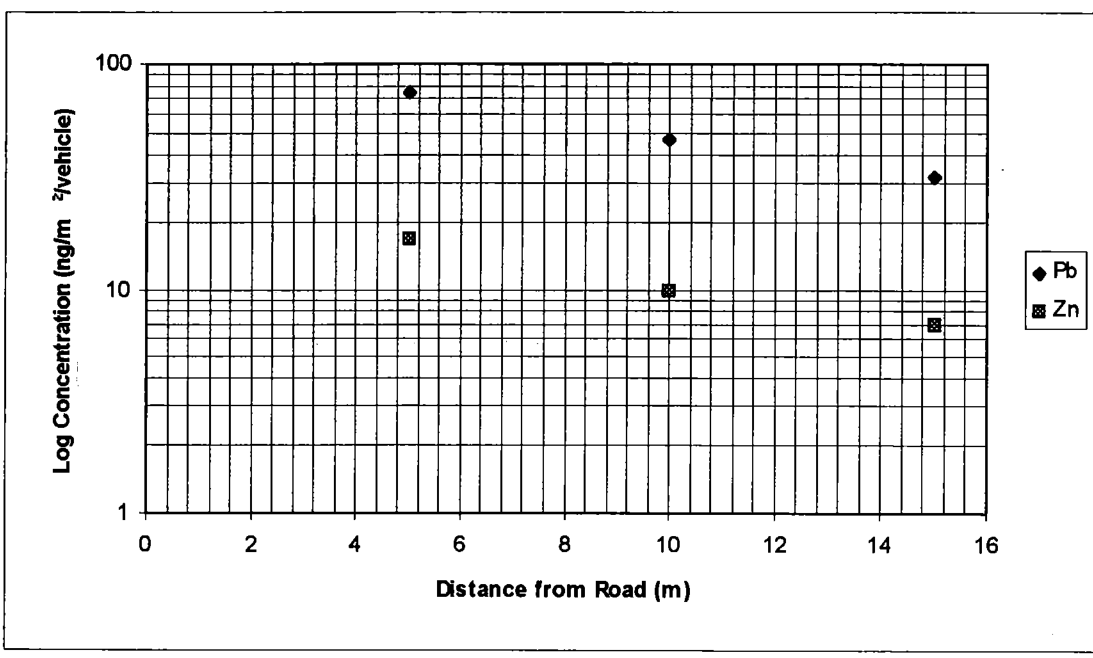

Figure A 5.1. Zind and lead concentrations distributed at the margins of a roadway. Both metals show a similar distribution pattern. Data from Ministry of Transport, 1996.

A 5.2.5 Brake Pads

Approximately 130 g of brake dust are emitted every 17000 kms per vehicle (Santa Clara Valley Nonpoint Source Program, 1992)

Total brake dust emitted for 166760 Christchurch vehicles = 166760 x 130 g

= 21683543 g/year

Mass of zinc in brake linings = 124 μg/g (Shaheen, 1975; cited Santa Clara Valley Nonpoint Source Program, 1992)

Estimated zinc emissions from brake linings 1996 = 21683543 g x 124 μg/g
= 2688.8 g/year
= <u>2.7 kg/year</u>

- Approximately 80% of this accumulates roadside, so assume 80% is washed into receiving waters :
  = 80% x 2.7 kg/year
  = **2.2 kg/year**

Check.

Total brake dust emitted for 166760 Christchurch vehicles = 8 mg/km (Malmquist, 1983)

Estimated dust emissions from brake linings 1996 = 8 mg/km x 17000 km x 166760
= 22679360 g/year

Estimated zinc emissions from brake linings 1996 = 22679360 g x 124 μg/g
= 2812.2 g/year
= <u>2.8 kg/year</u>

- Approximately 80% of this accumulates roadside, so assume 80% is washed into receiving waters :
  = 80% x 2.8 kg/year
  = **2.3 kg/year**

This correlates well with previous result. However it is not entirely independent as similar calculation and figures for dust generation are used.

A 6.0 CHRISTCHURCH RESIDENTIAL & INDUSTRIAL ROOF FIELD SURVEY

To estimate zinc loadings from residential and industrial roofs it is necessary establish the current protective condition and types of roofing materials used in urban residential Christchurch. Some data on the percentage of zinc-based roofing products is available (e.g. Department of Statistics (1981) found that 65.1% of Christchurch roofs were composed of galvanised steel (galvanised steel or galv-steel is the common name given to corrugated roofing iron used on many New Zealand roofs)), but little data exists on the protective condition of roofs.

The protective condition of a roof is determined by whether a roof has an adequate protective coating over the metal surface.

It is unknown whether a coated roof will yield zinc in runoff. Many paints have a portion of zinc in their make up (e.g. some roof paints are advertised as having zinc oxide as a constituent for protection against ultra violet rays) possibly adding to zinc loads in runoff. All samples from roofs researched in this study had zinc (see Section 5.2), although it is possible that the zinc was derived from galvanised steel gutters and even galvanised pipes. Galvanised steel gutters are generally unpainted on the drainage surface with many totally unpainted.

The survey thus had several objectives:

- establish the percentage of unprotected residential and industrial roofs;
- establish the percentage of galvanised steel gutters;
- check the quantity of zinc coated roofing materials with figures given in the literature. These are:
    - 65.1% of Christchurch roofs are built with galvanised steel (Department of Statistics, 1981; cited Honey and Buchanan, 1992) and;
    - 70% of the New Zealand residential market uses steel roofing products (Crossley, 1990).

A 6.1 METHODOLOGY

A 6.1.1 Residential

Christchurch was established well over a century ago and therefore has a wide variety of ages and types of housing. To sample a cross-section of Christchurch housing:

- 4 areas were defined based on housing ages (Table A 6.1), selected from a plan of segregated housing ages obtained from a CCC report on housing renewal (1971).
- A quadrant (1 km^2) from each age class is selected by listing quadrant numbers from a standard CCC map, and then randomly selecting quadrant numbers.
- The data was then gathered by starting from the randomly selected quadrants and surveying several streets around the quadrant until approximately 200 houses per quadrant had been recorded.

Chosen Representative Quadrant	Age Class	No. Houses Christchurch In Age Class	Chosen Location
D20	< 1945	45000	Linwood
J14	1946 - 1965	36000	North Beach
O9	1966 - 1980	19000	Hoon Hay
H4	> 1980	22900	Avonhead
Notes: Quadrants from Christchurch Handimap, 1993			

Table A 6.1. Roof survey areas, ages and number of dwellings.

The following data was collected:

- roof material;
- paint coverage (rated from excellent to poor rankings based on paint condition an dcoverage, and the percentage paint cover approximated to the nearest 5%);
- gutter material; and
- additional comments on garage material and protective condition and if roofs were unconnected to the stormwater drainage system.

A 6.1.2 Industrial

Concentration of industry in one area with a little or no integrated residential housing and a long history of being industrial were the main selection parameters for an industrial location. The survey concentrated on the Sockburn industrial estate as well as peripheral Middleton industries. Roof types and conditions were recorded by observation similar to the residential section of the survey.

A 6.2 RESULTS AND DISCUSSION

A 6.2.1 Residential

Results for the Christchurch residential roof survey are tabulated below (Table A 6.2 and A 6.3). Also presented are the weighted average data.

Location (Age)	No. Houses Surveyed	Weighted Average No. Houses Surveyed	% Galv-Steel Roofs	% Of Galv-Steel Roofs Paint Cover	% Of Steel Roofing Products	% Of Galv-Steel Gutters
Linwood (<1945)	195	318	69.2	65	83.6	67.7
North Beach (1946-65)	243	255	46.5	40	51.9	73.3
Hoon Hay (1966-80)	210	134	58	90	77.1	63.8
Avonhead (>1980)	221	162	63.8	90	71.5	43.8
Average			58.8	70	70.6	62.2
Weighted Average			**59.7**	**66.2**	71	**64.3**
Notes: Weighted averages are based on the number of houses in each age class (Table A 6.1)						

Table A 6.2. Results of Christchurch residential roofing survey.

Comparison of the percentage of galvanised steel roofs obtained by survey (59.7%) with the Department of Statistics 1981 census figure (61.3%) shows a reasonable parity. The survey also showed a similar number of steel products (all other zinc coated products discluding galvanised steel) used in roofing in Christchurch (71%) than estimated for New Zealand wide (70%).

The other zinc coated products used in roofing in residential Christchurch, such as pressed pre-painted tiles, chip coated tiles, and pre-painted coloursteel, were generally observed to be in good condition. One reason for this is that these products made up a large proportion of materials used on new houses. Thus it is reasonable to assume that zinc loading in roof runoff is largely generated from galv-steel roofs. Galv-steel roofs have a much larger range of wear than other roofing materials.

The number of houses for 5 categories of roofing condition are shown in Table A 6.3. These categories are based on the state and coverage of paint and oxidation of the roof (i.e. patches of rust). Most housing surveyed falls into the 'good' category, but a proportionately high number of houses also are in the 'poor' category. Houses with 'poor' roofing conditions are likely to be the main generators of zinc in roof runoff due to the lack of paint protection.

AREA	ROOFING CONDITION				
	EXCELLENT • No paint deterioration • Recent to newly painted	GOOD • Visible oxidation of paint • Very minor flaking	MODERATE • Paint consistently oxidised • Visible flaking in patches	DETERIORATING • Areas of total paint loss • Most paint flaking or peeling	POOR • Large % of paint loss • All paint peeling or flaking • Possible patches of rust • Never painted
Linwood	5.2	35.5	24.4	11.1	23.7
Hoonhay	5.0	72.7	11.6	5	58
Nth Beach	8.8	31.9	22.1	15.9	21.2
Avonhead	24.8	45.4	10.6	2.8	16.3
% 0f Galv-steel Roofs	11.0	426.4	17.2	8.7	16.8
Notes: Roofing conditions based on paint condition and coverage					

Table A 6.3. Results of Christchurch residential roofing survey by percentage- roofing conditions for galv-steel roofs.

Only a small proportion of garages were observed in this survey, so no estimate will be made on percentage of materials used and their condition, except to say the condition of garage roofs often were reflected by the condition of the house roof. Many new houses have garages built into the house.

Add-ons to houses or houses which were not well maintained often had areas of roof not connected to the stormwater drainage system. While it is impractical to quantify this based on survey observations it is probable that 5% of roof runoff does not enter the stormwater drainage system.

A 6.2.2 Industrial

In the industrial component of the survey a total of 53 roofs were observed. The percentage of these composed of galvanised steel is 62.2%, with only 25% of these had paint cover. Numbers of roofs based on the observed conditions from excellent to good are: excellent = 2, good = 5, moderate = 4, deteriorating = 12 and poor = 10. The total fraction of steel based roofing products was 85%, which is substantially greater than the New Zealand residential market. This is to be expected as many of the buildings surveyed in the industrial location are of warehouse design requiring broad sheeted building products for cost effective construction.

A 7.0 SCHOOL ROOF SURVEY

A literature review of zinc loads from roof runoff yielded little data. In light of this lack of information, New Zealand research bodies were contacted in the hope that some monitoring of a nature useful to this investigation might have been undertaken.

The Institute of Environmental Science and Research Limited (ESR) found they had concentration data from various school water tanks as part of drinking water quality control checks. In all over 35 schools were sampled in 1995. However, without data on the type and condition of the roofing material from which zinc has originated an estimate of zinc loads from Christchurch roofs is impractical.

To obtain the necessary data on roofing materials and condition of roofing materials a simple survey was sent to all schools. The survey had the aim of establish the concentration of zinc for a given galvanised steel roof with for a certain roof condition. Thus the objectives were to:

- providing information comparable to the Christchurch residential roof survey;
- establish school roof types and condition of roofs, and gutter type;
- establish zinc concentrations that correlate to the roofing conditions in the Christchurch field survey.

A 7.1 METHODOLOGY

Design of the school roofing postal survey was structured in such a way as to be applicable to the Christchurch roofing field survey. Load calculations based on the Christchurch residential roof survey provided estimates of zinc loads from galv-steel roofing based on a percentage paint cover. However, Christchurch roofs were also described in terms of roof condition based on the five categories: excellent, good, moderate, deteriorating, and poor.

Questions have been formatted so that a person with minimal knowledge of the roof in question could answer. Guides to questions and a summary of what the survey was trying to achieve accompanied the survey form. To help establish this aim survey questions were formulated to be consistent with the Christchurch field survey, thus the 5 categories to describe roof conditions was used.

This survey also seemed like a good opportunity to establish if gutters contributed significantly to the zinc load, as previous studies have indicated (Bannermann *et al.,* 1993). Thus a question on gutter material was also included. To check if zinc concentrations in the drinking water were elevated due to galvanised water tanks an added question on the make-up of water tanks was also included.

A 7.2 RESULTS AND DISCUSSION

From the 35 schools surveyed 28 responded. Their responses are recorded in Table A 6.1. The majority of roofs are galv-steel (21 in all), with 2 roofs being coloursteel and several being composites of both. One roof is plastic. The majority of gutters are also galv-steel. Several are plastic and 3 schools have copper gutters.

The condition of roofs varied from poor to excellent, with the majority of roofs falling in the good to excellent range (Table A 6.1). Two roofs are unpainted. The number of years since roofs were last painted ranged from newly painted to painted over 10 years ago.

All schools contained measurable zinc in the data from ESR. For the zinc data to complement the Christchurch field survey, data on the school roofing paint condition and coverage was needed. To determine roof conditions, survey correspondents were asked to assign roofs a paint condition based on five categories: excellent, good, moderate, deteriorating and, poor. These categories were used rather than numerical values because it was unlikely that correspondents would be able to estimate a numerical value for paint coverage consistent with the Christchurch field survey, and with other survey correspondents. It also likely that survey response would have been affected by a question based on a numerical descriptor. Thus descriptive terms that correspondents were likely to identify with were used. School roofing conditions, descriptions and the average zinc concentration for each category are shown in Table A 7.2.

To ascertain zinc concentration likely to be yielded from Christchurch galv-steel roofs, Christchurch roof conditions (from Appendix 6.2) are correlated with the corresponding average zinc concentration for the same roof condition (Table A 7.2).

SCHOOL	ZINC[1] (mg/l)	ROOF MATERIAL	ROOF CONDITION	GUTTER	LAST PAINTED
Taipa	1.3	Galv	P	Galv	10
Glen Murray	0.12	Galv/CS	G	G/Al/Cu	2
Te Kohanga	0.17	Galv	G	Galv	5
Kaihere	0.14	Galv	G	Galv/CS	2
Beachlands	0.35	Galv	E	Galv/P	8
Clevedon	0.25	Galv/CS	G	P	4
Hira	0.19	Galv	G	Galv	3
Oparure	0.18	Galv	M	P	6
Mataroa	0.21	Galv	G	Galv/P	7
Coatsville	0.05	Galv	G	P	2
Kaukapakapa	0.08	Galv/Cs	E/G	Galv/P	2
Glenham	0.28	plastic	G	Galv	U
Limehills	0.08	Galv/CS	E/M	Cu	7
Mataura Is	0.09	Galv	P	Galv	14
Orepuki	0.14	Galv	E	P	3
Otapiri	0.21	Galv	M	Galv	5
Otatara	0.5	Galv	D	Galv	10
Pahia	0.11	Galv	E	CS	5
Rimu	0.11	Galv	E	Galv	U
Te Tipua	0.03	CS	E	P	2
Tokanui	0.18	Galv	G	Galv	6
Tuturau	0.33	Galv	E	Galv	5
Waimahaka	0.72	Galv	D	Galv	8
Waimumu	0.35	Galv	M	P	7
Wallacetown	0.33	Galv	G	Galv/P/Cu	7
Woodlands	0.09	CS	E	Galv	6
Mahana	0.17	Galv	E	Cs	5
Matakana	0.13	Galv	G	Galv	2

Notes: Materials -: Galv = Galv-steel, CS = Coloursteel, P = Plastic, Al = Aluminium, Cu = Copper
Conditions -: E = Excellent, G = Good, M = Moderate, D = Deteriorating, P = Poor
U = Unpainted
[1] **Concentration data from ESR.**

Table A 7.1. Results of school roofing survey.

The totals for each galv-steel roof condition category (Appendix 6.2) are summed with the corresponding zinc concentration category in Table A 7.2. These are then totalled and averaged to find the average runoff concentration. Concentrations from composite roofs (e.g. Galv-steel/ coloursteel (Galv/Cs)) and composite roof conditions (e.g. E/G; see Table A 7.1) are disregarded in the averaging due to their ambiguity.

Christchurch residential and industrial roofs yield an average runoff concentration of approximately 0.40 mg/l and 0.90 mg/l respectively.

DESCRIPTION OF PAINT COVER	CONDITION OF ROOF	[1]% OF CHRISTCHURCH GALV-STEEL ROOFS		AVERAGE ZINC CONCENTRATION
		Residential	Industrial	
No paint deterioration Recent to newly painted	Excellent	11.0	6	0.18
Visible oxidation of paint Very minor flaking	Good	46.4	15.2	0.16
Paint consistently oxidised Visible flaking in patches	Moderate	17.2	12.1	0.24
Areas of total paint loss Most paint flaking or peeling	Deteriorating	8.7	36.4	0.61
Large % of paint loss All paint flaking or peeling Possible patches of rust	Poor	16.8	30.3	1.3
Notes: [1] From Christchurch field survey, Table A 6.3 and Section A 6.2.2				

Table A 7.2. Average zinc concentrations from galv-steel roof runoff for excellent to poor roofing conditions, based on data from 20 New Zealand schools, and number of houses surveyed in those conditions in the Christchurch field survey.

There are several sources of error in these results. The largest is likely to come from correlating roof conditions defined by correspondents in the school roof survey with the conditions from the Christchurch field survey. There may be a large variation in the actual condition of galv-steel roofs, not delineated by this survey. The use of the decriptors, 'excellent' to 'poor', leaves a margin for error in defining roof conditions. Correspondents may have had difficulty in representing roof conditions with 5 decriptors, and as a result the correlation of Christchurch field survey data may lose continuity.

There are also uncertainties in the concentration data. The zinc concentration data from school water tanks are only a one off sample. This raises some doubt to the validity of these concentrations being truly representative of the amount of zinc being washed off school roofs. Zinc concentrations may vary dependent on the amount of rainfall, antecedent dry periods, and the atmospheric environment. Ideally a number of samples would be taken from each tank to establish a mean concentration representative of roof runoff for several conditions. It may be for one of these reasons that the Mataura Island school zinc concentration is very low when a much higher concentration would be expected for a roof in the 'poor' category (see Table A 7.1). For this reason this concentration value is disregarded in determining the average zinc concentration values for Table 7.2. The average zinc concentration for the 'excellent' category of roof condition is higher than the 'good' category. This discrepancy may be due to several factors. Zinc concentration from gutters may be in the same order as the zinc concentration from roof runoff. The water level and tap locations in the water tanks from which samples were taken may influence concentrations. However, the other roof condition categories indicate that zinc concentrations increase with deteriorating roof condition.

Some further features of the results are:

- Roofs with plastic guttering, reported to be in excellent condition, and relatively recently painted, were found to generate measurable zinc (from Table A 6.2 Clevedon, Oparure and Coatsville). Galv-steel roofing material can be shown to generate zinc concentrations comparable to, if not greater than those reported coming from gutters in overseas studies (e.g. Bannermann *et al.*, 1993; Good, 1993)
- Coloursteel roofs had the lowest range of zinc concentrations, but if fitted with galv-steel gutters zinc concentrations are notably higher.
- Guttering is shown to significantly contribute to zinc concentrations in roof runoff. This is validated by a one sample from a school fitted with a plastic roof and galv-steel gutters containing measurable zinc. Previous studies observations have also observed zinc contribution from gutters (Bannermann *et al.*, 1993).
- The type of water tanks samples were collected from was also established through the survey. This was to check if water tanks are made from galv-steel. However, as none are (most are concrete, two are polythene) this will not effect zinc concentrations.

ROOFING SURVEY

Please answer the questions concerning only that roofing which is connected to the drinking water tank.

Question 1. **Please tick the appropriate box.**

Which material is the roof composed of?

Galvanised Iron. ☐ Chip-coated Tiles ☐

Coloursteel. ☐ Concrete Tiles. ☐

Other. ☐ Please specify. ______________________________

Question 2.

When was the roof last painted? **Please tick the appropriate box.**

Less than 1 year ago. ☐ 5 to 6 years ago. ☐

1 to 2 years ago. ☐ 6 to 7 years ago. ☐

2 to 3 years ago. ☐ 7 to 10 years ago. ☐

4 to 5 years ago. ☐ More than 10 years ago. ☐

Unpainted ☐

Question 3.

Which material is the gutter composed of? **Please tick the appropriate box.**

Galvanised Iron. ☐ Plastic. ☐

Coloursteel. ☐ Aluminium. ☐

Question 4.

How would you describe the condition the roof is in? **Please tick the appropriate box.**

Excellent. (No paint deterioration, recent to newly painted) ☐

Deteriorating. (Most paint flaking or peeling, areas of paint loss) ☐

Good. (Visible oxidation of paint, very minor flaking) ☐

Poor. (Considerable paint loss, most paint flaking or peeling, possible rust patches) ☐

Moderate. (paint consistently oxidised, flaking in patches ☐

Question 5.

Which material is the water tank composed of?

Concrete. ☐ Other. ☐ Please specify. ____________________

THANK YOU FOR COMPLETING THIS SURVEY

☺