The impact of stormwater discharges on freshwater, marine water and marine sediments and the implications for environmental management of the Pauatahanui Inlet, Porirua, New Zealand.

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ABSTRACT

A survey of Cu, Pb, Zn and Cr levels in sediment cores taken at four locations in the Pauatahanui Inlet has been undertaken in conjunction with a freshwater and marine water quality survey.

Levels of heavy metals in sediment were within the Australian and New Zealand Guidelines for Fresh and Marine Water Quality for the protection of Aquatic Ecosystems, [Interim Sediment Quality Guideline (ISQG) (high level of protection)]. Sediments in the vicinity of discharges from suburban catchments showed higher levels of Cu, Pb, Zn and Cr than those in the vicinity of rural catchments.

Levels of Cu, Pb and Zn in streams in the suburban catchments exceeded guideline levels for 99% species protection on occasions, and guidelines for Cu, Pb and Cd were exceeded in marine water. Elevated concentrations of heavy metals in marine and freshwater coincided with rainfall events and increased suspended sediment levels, indicating stormwater discharges as a contributing source of the contaminants.

Levels of N and P exceeded guideline trigger values in freshwater tributaries on occasions. There was no distinct difference between the rural and suburban catchments in terms of nutrient levels detected.

Levels of bacteria present (E-Coli and Enterococci) exceeded NZ guideline levels for contact recreation purposes after rainfall events.

Heavy metals in stormwater were attributed to transport sources. Control of these discharges will likely be ‘end of pipe’ in nature due to the diffuse nature of the heavy metal inputs, and the difficulties in controlling emissions from vehicles at source.

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ACKNOWLEDGEMENTS

This study was commissioned by the Wellington Regional Council (WRC), upon identification of the need for more data about the contaminants in the urban runoff which is discharging into the Pauatahanui Inlet. The significance of this information when identifying environmental pressures on the Inlet is clear. The reason for this study was a need for site specific information upon which to base policy, planning and environmental management decisions. I would like to take this opportunity to thank the WRC for supporting this research.

1. INTRODUCTION

The future environmental quality of the Pauatahanui Inlet depends on the foundations that are put in place today. Under the Resource Management Act (RMA) in New Zealand (NZ), environmental foundations are built by planners and environmental managers, based on the information about the environment obtained by scientists – ecologists, biologists, chemists, geologists and botanists to name a few.

The information presented over the following chapters will help satisfy a search for information. It will provide an insight into the impacts our activities, as humans, have on the world we live in. Some readers may make some changes to their lives that will help the environment.

The Pauatahanui Inlet receives untreated stormwater discharges from catchments which are under more and more pressure from development. Development surrounding the Inlet is at a stage where there are distinctly defined rural catchments, and distinctly defined urban catchments which flow into it, presenting an opportunity for comparative study of the catchments and the impacts they have on the water quality and sediments of the Inlet.

2. RESEARCH PURPOSE

2.1 MEETING THE NEED FOR INFORMATION

The Pauatahanui Inlet is a significant estuary in the Wellington Region. It is unique, has high ecological value (PCC 1999; WRC 1993; Department of Lands and Survey, 1986; NZ Wildlife service, 1984) and it is perceived to be under threat from the anthropogenic activities occurring within its catchment. It is therefore considered that the environmental quality of the Pauatahanui Inlet may be decreasing as a result of current human activities, and may be further compromised by those anthropogenic activities proposed in the catchment in the future.

The shape and existence Inlet is under threat, as sedimentation causes the Inlet to become more and more shallow. This is the subject of a study currently being undertaken by the WRC.

The research at hand concerns itself with contaminants other than silt, which is present in stormwater runoff. While there is a proven link (Snelder & Williamson, 1997) between suspended solids and many of the contaminants of concern (for example, many heavy metals are transported in the environment as they adsorb onto the particles that are washed off the land), this research targets the often invisible threat of trace elements and heavy metals. Problems associated with these invisible contaminants usually arise after the large scale earthworks and development have occurred and the threat of large scale sediment discharge has passed. This research focuses on the pollution from the roads, parking lots, rooftops and other impervious surfaces that are created and used by people.

It is generally considered that the stormwater discharging into the Inlet is contaminated to some degree, and this is a fair concern based on experiences elsewhere in New Zealand. For example, Auckland Regional Council has released a series of publications aimed at identifying and managing stormwater pollution, as a response to research showing significant contamination of sediment and water in the Auckland environment. Much of this contamination was linked to stormwater discharges (Glasby *et al* 1988, ARC 1998). A study of the sediments and waters of the Hatea River catchment in Whangarei also linked elevated levels of Cu, Pb and Zn to discharges from stormwater drains (Webster *et al*, 1998).

The extent of contamination from stormwater inputs, considered alongside the ecological sensitivity of the receiving environment, is yet to be absolutely pinpointed within the catchments of the Pauatahanui Inlet.

This area of concern is identified in the 'Pauatahanui Inlet Action Plan', a plan prepared by the Pauatahanui Inlet Advisory Group (August 2000). One of the concerns identified in this plan (issue 3.3) reads "All stormwater ends up in the Inlet untreated". Land use, and the downstream impacts it has, is also identified in the Plan as an area requiring further investigation (Pauatahanui Inlet Advisory Group, 2000).

2.2 SCIENTIFIC INFORMATION

Without scientific information, assessing the effectiveness of current management, and developing future environmental management objectives and plans for the Pauatahanui Inlet could be a guessing game.

Scientific information forms a crucial part of the management/planning decision-making process for regulatory authorities throughout the world. The WRC and Porirua City Council (PCC) (who are the relevant authorities in the Pauatahanui Inlet area) therefore need scientific information before they can determine what the environmental pressures on the Pauatahanui Inlet are. "Determining sources of contamination and the effects of this on the receiving environment is often considered a pivotal aspect if sustainable stormwater management is going to be implemented in the region" [Aitken, 1997].

On a more fundamental level in terms of the body sponsoring this research (WRC), the data will provide an indication to the WRC about whether the objectives in their Regional Policy Statement (RPS) and related regional plans are being met. This is a key aspect and part of the WRC's core 'business' in terms of the RMA 1991.

The information presented in this research will help regulatory agencies identify where their attention should be focussed, in terms of funding, management and monitoring. For example, if it is determined that a particular area is under threat from a particular contaminant, budgets can factor in the need for additional enforcement, monitoring and/or educational action to remedy the problem.

2.3 PRIOR RESEARCH

In 1980, Healy co-ordinated an environmental study of the Pauatahanui Inlet that presented results of an intensive monitoring programme undertaken between 1975 and 1977. Heavy metal analysis was carried out on the tissue of fish, birds, marine worms and vegetation, and in the sediments of the Inlet. At this time the results indicated a relatively unpolluted environment. No water samples were analysed for heavy metals or polycyclic aromatic hydrocarbons (PAH's), however nutrient analysis (organic carbon, nitrogen and phosphorus) were carried out on water and sediment samples. There have been no repeat studies of residues in birds, fish, worms or vegetation since 1980. As a component of the Healy study, Smith and McColl (1979) published the results of sediment monitoring in the Inlet. This research examined the total nitrogen, phosphorus, and organic carbon content of the sediments, and particle size distribution through sediment profiles to a depth of 20 cm in intertidal sediments.

A study by Glasby *et al* (1990) assessed the distribution of heavy metals in sediment in the Porirua Harbour. This study included samples taken from both Pauatahanui and Porirua Arms of the Porirua Harbour. The study showed that Co, Fe, Ni and Mn occurred in similar concentrations in both Inlets, while levels of Cu were slightly higher in sediment samples from the Porirua Arm. Levels of Pb and Zn were shown to be "notably higher" in the Porirua Arm when compared with the Pauatahanui Inlet. Lead and Zn, found in petrol and tyres on motor vehicles, were common contaminants found in stormwater runoff at this time (Pb is less common now with the removal of leaded fuels from the market). This study alerted authorities that urban runoff was influencing water and sediment quality in the harbour.

Berry *et al* (1997) conducted an investigation for the Wellington Regional Council and Porirua City Council entitled "Porirua Harbour Sediment and Shellfish Study". This research assessed the contamination of sediments and shellfish at 11 sites in both the Porirua Arm and Pauatahanui Inlet. Shellfish samples were analysed for heavy metals (Zn, Pb, Cu, Cd), PAH's and organochlorines and sediment samples for PAH's and organochlorines. The study showed that the levels of heavy metals and PAH's were highest at the mouth of the Porirua Stream, suggesting adverse impact on water quality as a result of urban run-off. Levels of organochlorines, commonly found in agrochemical, were highest in sediment samples from the mouth of the Pauatahanui Stream. This is indicative of impacts from the more rural catchment of the

Pauatahanui Stream.

A study by Botherway (1999) suggests that levels of Cu and Zn in the sediments of the Porirua Inlet are increasing, while Pb concentrations are decreasing. The basis for this suggestion is comparison of the results of Botherway, 1999, with those of Glasby *et al* 1990. Botherway identifies the source of this contamination as stormwater run-off from the surrounding catchment, and this would be consistent with the phasing out of lead based petrol in New Zealand. It was concluded that Cu and Zn should be detectable in water samples taken from some points of the inlet, particularly after rainfall events. This study did not assess any specific areas of the Pauatahanui Inlet, and it is noted that the Pauatahanui Inlet does not receive runoff from high density urban areas, the central business district or industrial areas, like the Porirua Arm of the Harbour does.

Research has identified that urban runoff/urban stormwater is likely to be the key source of much of the heavy metal and PAH contamination of the sediments in Porirua Harbour. This is particularly so given the high levels of some metals that have been found in sediments near the mouth of the Porirua Stream and in the Inlet adjacent to Porirua City. While this study focussed on the Porirua arm, it is reasonable to assume that, while the extent of contamination may be slightly less (due to the lack of industry and high density urban areas in the Pauatahanui catchment), similar problems may arise, or may already have arisen, in the Pauatahanui Inlet. This is because of the increased area of land now being used as roadways in the Pauatahanui Catchment, and the increasing density of traffic (linked to increased population) on roads along the Inlet margins.

In terms of data more specific to the Pauatahanui Inlet, the 1989 Environmental Impact report for the Future State Highway One Route (WRC, 1989) investigated the water quality in 4 of the 6 streams that feed into the Pauatahanui Inlet (Pauatahanui Stream, Duck Creek, Ration Stream, and Horokiri Stream). Analyses include oxygen levels, Biochemical oxygen demand (BOD-5), reactive phosphorus, nitrate, pH, turbidity, faecal coliforms and conductivity. Fish species present in the streams were also recorded. The results indicated that the environment was relatively unpolluted.

One particular reference drawn on in this research is a document recently prepared for the Wellington Regional Council entitled "The Pauatahanui Estuary and its Catchment: a literature summary and review" (Boffa Miskell, 2000). This document highlights current gaps in the research and areas where the Wellington Regional Council should be concentrating its monitoring efforts. In this report, it is identified that in the 25 years since the DSIR Study (Healy, 1980) there has been no intensive programme to monitor the environmental health of the Pauatahanui Inlet.

The Boffa Miskell report indicates that the problem of contaminated urban run-off and its potential adverse downstream effects has become a significant concern for many groups in the community. The report has identified that it is necessary to fill in some 'gaps' before a thorough prognosis for the Pauatahanui Inlet can be announced. This research will assist the WRC in 'filling the gaps'.

Contamination of the sediments of Pauatahanui Inlet by heavy metals was identified as a concern in a discussion document prepared by the Wellington Regional Council in 1993. (Rosier, 1993). This concern was put to rest to some degree by the findings of the study by Glasby *et al* in 1990. This study concluded that, while cobalt, nickel, iron, zinc, lead and manganese were found in the sediments, this is localised, and the areas affected ranged from uncontaminated to moderately contaminated (discussed in later chapters).

2.3.1 INLET ECOLOGY

Part of the reason why there is significant pressure on regulatory authorities to ensure the Pauatahanui Inlet is protected from contaminated stormwater runoff stems around the high ecological significance of the area. The Inlet is rated as a Site of National Significance on the Department of Conservation's Sites of Special Wildlife Interest (SSWI) database. It is the largest relatively unmodified estuarine area in the Southern part of the North Island of New Zealand.

There is considerable literature available detailing the ecological significance of the Pauatahanui Inlet. A summary of the key points from past ecological research is presented below;

- The inlet contains large areas of saltmarshes and sea grasses. It is the largest area of such habitat in the entire Wellington Region (the Wellington Region encompasses the area from Otaki, across to Akitio and south to Cook Strait). Saltmarsh vegetation provides shelter and habitat for birds, and helps stabilise the banks of the Inlet against erosion. They also produce organic matter. Species found in the saltmarshes include *Cotula coronopfolia* (Batchelor Buttons), *Juncus maritimus* (Jointed rush) and *Salicornia australis* (Glasswort) (Sheenan, 1988).
- The Inlet is home to large numbers of the copepod *Parastenhelia sp.*

Parastanhelia sp.. This is a shrimp like species (or meiofauna), and the Inlet has achieved national significance sure to the high densities of this species present. These organisms play an important role in estuarine ecology, as they stimulate bacteria growth, help break up detritus and form a part of the food chain (Sheenan, 1988).

- There is a high diversity of bird life present and the Inlet is an important feeding site and over-wintering site for migrating birds. Species include *Himanthopus leucocephalus* (Pied Stilt), *Haematopus unicolour* (Black Oystercatchers) and *Andrea novaehollandiae* (White Heron) (Sheenan, 1988).
- The Inlet contains approximately 43 species of fish, including permanent, transient and seasonal species (Sheenan, 1988).
- The Inlet is an important fish nursery area (Davis, 1987).

2.3.2 URBAN STORMWATER RUNOFF

As a precursor to the discussion about whether contaminated stormwater runoff is one of the main environmental pressures on the water quality in the Pauatahanui Inlet, it is necessary to discuss the issue of contaminated stormwater in general, including:

- its typical constituents,
- typical sources of contamination; and,
- effects on ecosystems.

What is stormwater and how does it get contaminated?

Stormwater runoff is one of the 'cogs' in the water cycle. It is a natural, environmental process which involves the atmosphere, soil, vegetation, streams, rivers, oceans and animals, including human beings and their activities.

A few hundred years ago, stormwater run-off did not pose such an environmental problem. Certainly, floods were caused, sediment was washed from the land, and there was temporary damage to the environment as a result. However, these were natural, land shaping events. It is the more sinister, and less visible concern brought about by our modern lifestyles and human activities which are now causing significant threat to many ecosystems and waterways throughout the world. Our lifestyles on the land are introducing contaminants into the water and sediments in quantities which the dependant aquatic ecosystems are unable to assimilate, digest or avoid.

Whenever it rains on a city, dust, litter and chemical contaminants such as heavy metals and various organic compounds are washed of the impervious streets, parking lots and roofs into efficient conveyance systems like kerbside drains, guttering and pipes and finally into waterways (Fergusson 1998, Jennings 1991, Strecker and Reininga 1999, Williamson 1995, Melville 1998, Morrissey 1997).

Furthermore, with the advent of these efficient systems to convey runoff into waterways, they become effective means of disposal (either intentionally or unintentionally) of all manner of contaminants. The kerbside drain, and the stormwater kerbside sump, form an integral part of urban waste disposal. Examples from the Wellington Regional Councils Pollution Response department include water from washing the car on the driveway, paint and waste from washing the paint brushes, waste oil, milk, and various unidentified substances that turn streams unusual colours and/or impact upon in-stream ecosystems.

Since the automobile was invented in the early 1900's, city development has been refitted and reformed to provide for vehicles. This has resulted in vast areas of impervious material such as asphalt or concrete, forming streets and car parks in our cities, towns and suburbs. [Fergusson, 1998]. The developing areas surrounding the Pauatahanui Inlet have this very matter in mind – conveyance of motor vehicles. In 1996, about 75% of the Porirua Population travelled to work in a car, truck or van (PCC, 1997). The infrastructure required to support this personal travel is vast.

As well as chemical pollution, the creation of large, impervious areas (e.g. the aforementioned streets, car parks, driveways and kerbside drains), which are linked to streams through efficient drainage networks increases peak flow and alters hydrological regimes in streams. This increases erosion and widens stream channels (Booth, 1990). This increased velocity in flow naturally means that more particles are carried along in the water, and the contaminants adhered to the particles are more likely to reach our waterways.

The nature of many of the contaminants found in stormwater run-off means that the impacts of the discharges are cumulative, for example the build-up of heavy metals over time in sediments. Morrissey (1997) suggests that this cumulative impact has potential to compromise the sustainability of our urban development. The concept of sustainability is discussed in coming pages.

The main contaminants which are found in urban runoff and identified in the literature are shown in Table 1, which is adapted from Fergusson (1998), however is the summary of conclusions from a large number of sources. The effects of these contaminants on the receiving environment are indicated.

Table 1. Main contaminants found in Urban Runoff

Constituent	Source of Urban Excess	Adverse Environmental Impact
Sediment/silt	■ Construction sites ■ Exposed soil (e.g. vegetation removal) ■ Eroding stream banks ■ Quarries ■ Roads ■ Agricultural runoff	■ Abrasion of fish gills ■ Adsorbs excess nutrients and chemicals and carries these in sediment to natural waterways ■ Blocks sunlight penetration of water ■ Covers substrate/smothers habitat ■ Sedimentation of waterways (blockage) ■ Reduction of aesthetic values
Organic matter	■ Organic litter (e.g. leaves, lawn clippings) ■ Food waste ■ Sewage ■ Animal waste ■ Soil/bank vegetation erosion	■ Algal blooms ■ Oxygen deprivation during decomposition
Inorganic matter	■ Litter	■ Non-biodegradable ■ Blockages ■ Leaching of toxic substances ■ Aesthetic impacts
Nutrients	■ Fertilisers/fertiliser runoff ■ Sewage discharges ■ Phosphate detergents ■ Soil erosion ■ Animal waste ■ Food waste ■ Soluble air pollutants	■ Deprives water of oxygen during decomposition, leading to eutrophication
Heavy Metals	■ Cars (tyre wear, brake lining wear) ■ Industrial discharges (waste and yard runoff) ■ Various chemicals ■ Sewage	■ Health effects on stream flora and fauna – toxic in low concentrations ■ Bioaccumulation to toxic levels ■ Persistent in the environment
Chloride	■ Pavement de-icing salts; ■ Landfill leachate	■ Soil sterilisation ■ Reduced growth of biota

Constituent	Source of Urban Excess	Adverse Environmental Impact
Bacteria/micro-organisms/ pathogens	■ Animal waste ■ Rubbish/litter ■ Sewage ■ Some industrial waste	■ Risk of disease
Oil/Hydrocarbons	■ Vehicles ■ Industrial sites ■ Food premises (cooking oil)	■ Deoxygenation of water ■ Aesthetic impact ■ Coating of surfaces ■ Toxic contamination – can contain PAH’s
PAH’s (Polyaromatic Hydrocarbons)	■ Combustion of organic material (e.g. vehicle emissions) ■ Oil, grease, tar, asphalt, bitumen	■ Bio-accumulation ■ Toxicity to aquatic organisms ■ Considered carcinogenic
Dioxins	■ Industrial waste ■ Air pollution	■ Considered carcinogenic
Organochlorines (E.g. DDT, PCB’s)	■ Pesticides; herbicides ■ Industrial wastes	■ Bio-accumulation ■ Carcinogenic ■ Persistent in the environment

Glasby *et al* (1988) notes that, in order of potential pollutant effects, metals of significant concern in the marine environment are lead, chromium, manganese, copper, mercury, zinc, cadmium, tin and nickel.

Copper and zinc are the most significant heavy metals that are washed into stormwater systems in urban areas [Morrissey 1997]. Vehicles have been identified as one of the major contributors to stormwater pollution in Auckland, [Melville, 1998] and after soil erosion, vehicles are the greatest source of stormwater pollution in urban areas of the United States. [Fergusson 1998]. It is noted that the Pauatahanui Inlet faces both of these issues: erosion and pollution from vehicles.

Copper commonly comes from brake linings of vehicles, and zinc is released into the environment as tyres wear. These contaminants build up on or near the road until they are washed off by rainfall. A portion of the contamination may also become airborne.

Lead from leaded petrol is also likely to still be present in the environment (for example the sediments of the Porirua Inlet as identified by Botherway, 1999) despite the phasing out of leaded petrol in New Zealand, and is therefore likely to continue polluting the environment for many years to come. [Morrissey 1997], particularly if the sediments are disturbed.

Stormwater also appears to contribute to the poor microbiological quality of receiving waters. Bacteria present in stormwater can produce concerns for public health [Auckland Regional Council, 1992, Wellington Regional Council 2000a], and in some parts of the world, including New Zealand, this forces swimming beaches to close after rainfall events.

Why are we worried about the contamination of our stormwater?

A study by Pilotto *et al* (1998) into contamination of stormdrain and harbour sediments in Wellington showed that the highest contaminant levels were recorded in inner Wellington city stormwater systems. The contaminants of concern were identified as lead, zinc and copper. These were found to be the metals which are increased the most in the environment due to human activities. This report noted that "the proximity of the outlets of these drains to recreational areas should be of concern to local authorities". This study was carried out in the Wellington Harbour, which is south of the Pauatahanui Inlet.

The nature of some coastal receiving environments can lead to long term and insidious effects from stormwater discharges. Sheltered estuaries, harbours and lakes are likely to trap and accumulate particulate, which carries many of the pollutants (e.g. heavy metals and PAH's) found in stormwater runoff. [Snelder and Williamson, 1998]. Areas of the Porirua Harbour, including the Pauatahanui Inlet, are therefore at particular risk of serious pollution from stormwater discharges, as they are sheltered, low energy, estuarine systems.

In a report to the Wellington Regional Council, Berry (1996) noted that:

- The poorest water quality results in the region were recorded at sites near river mouths or stormwater outfalls draining urban areas;
- The sites with worst water quality in the Wellington Region were located in wharf areas of the Wellington Harbour, where it is suspected that stormwater entering the harbour is contaminated with sewage.
- On the Eastern side of the Wellington Harbour, the poorest water quality was at the mouth of a stream that received a variety of stormwater and emergency discharges.

Table 1 (previous page) gives an example of the impact that the various contaminants can have on the receiving environment, and presents a summary of the concerns. These concerns are heightened when there are sensitive species present in the receiving environment, or the receiving environment represents an area that is threatened and unique. The Pauatahanui Inlet is all three of these things, and this is discussed further below.

2.3.3 INDUSTRIAL DISCHARGES

Industry has been responsible for some serious water contamination in NZ the past. The Waiwhetu Stream (Lower Hutt, New Zealand) which had the dubious honour of being the most contaminated stream in New Zealand during the 1970's is testament to the damage that industrial discharges over a prolonged period can do. This damage includes significantly reduced water quality (affecting the number and diversity of species which are able to survive in the stream, potential water uses, and overall stream aesthetics) and sediments contaminated with levels of heavy metals so high that disturbance of the sediment results in further water quality degradation.

It is now generally assumed that wastes are no longer deliberately pumped directly into urban rivers and streams by industries. These discharges are now controlled by resource consents under the Resource Management Act 1991, and/or permitted activity rules in Regional Plans. Occasional discharges from industry do occur, but this is generally accidental or unintentional and generally due to lack of awareness about the fate of contaminants in the stormwater system. This is reflected in the findings of the Wellington Regional Council's Annual Incident Report 2000 [Hooper, 2000], which shows that approximately 30% of all complaints related to environmental issues in Porirua City were related to stormwater discharges during the 1999-2000 year.

The problem of contamination entering our waterways has not been completely solved with the dramatic reduction in industrial discharges. As the industrial discharges have been brought under control the "environmental effects of diffuse sources or contamination, such as stormwater, have come to the fore" (Morrissey, 1997). As this problem is now in the 'fore' every member of society may soon have to be accountable for the contamination entering our natural waterways.

3. THE STUDY AREA

3.1 PORIRUA HARBOUR

Porirua Harbour formed as a result of processes of erosion, seismic activity and glaciation, and is essentially a drowned river valley (Healy, 1980).

The Harbour is characterised by two distinctly different inlets, the Porirua Inlet (sometimes referred to as the "Onepoto Arm"), and the Pauatahanui Inlet. The Pauatahanui Inlet is the focus of this study.

3.2 PORIRUA ARM

The Porirua Arm is a tidal estuary approximately 4km long, and is fed by the Porirua Stream and numerous smaller tributaries that drain a catchment of about 70 km^2. The largely modified catchment extends into Johnsonville in the south and Paremata in the North. Porirua City lies along the southern and western sides of the Porirua arm of the Harbour.

3.3 PAUATAHANUI INLET

To the North and East of the Porirua Arm is the shallow estuary surrounded by rolling hill country which is known as the Pauatahanui Inlet.

The Pauatahanui Inlet is a tidal estuary, which, in comparison to the Porirua Arm of the same Harbour, is relatively unmodified. The Pauatahanui Inlet is larger than the Porirua Inlet, being about 3.5km long and 2km wide (Glasby *et al* 1990). The maximum depth in both inlets is approximately 3m.

Pauatahanui Inlet is characterised by 6 major sub-catchments. The 6 major streams draining these catchments are Pauatahanui Stream, Horokiri Stream, Duck Creek, Browns Stream, Ration Stream and Kahao Stream, draining a total catchment of approximately 100 km^2. The catchment extends as far as Paekakariki to the north and Haywards Hill to the east, and encompasses parts of the suburbs of Whitby, Paremata and Mana.

The Pauatahanui Inlet is somewhat unique, as any levels of contamination discovered will be sourced from rural, residential or transport land uses. There are no industrial discharges into the Inlet, or intense commercial/urban/industrial areas which discharge runoff (e.g. CBD's, industrial parks). Nor is there any discharge of municipal sewage – treated or untreated (there is some concern about 2 or 3 septic tank systems near the shores of the Inlet, however these are being addressed by the PCC and WRC, and effects are localised, [WRC pers.comm. 2000]). This unique situation is discussed further in later chapters.

A map of the catchment is included below as Figure 1.

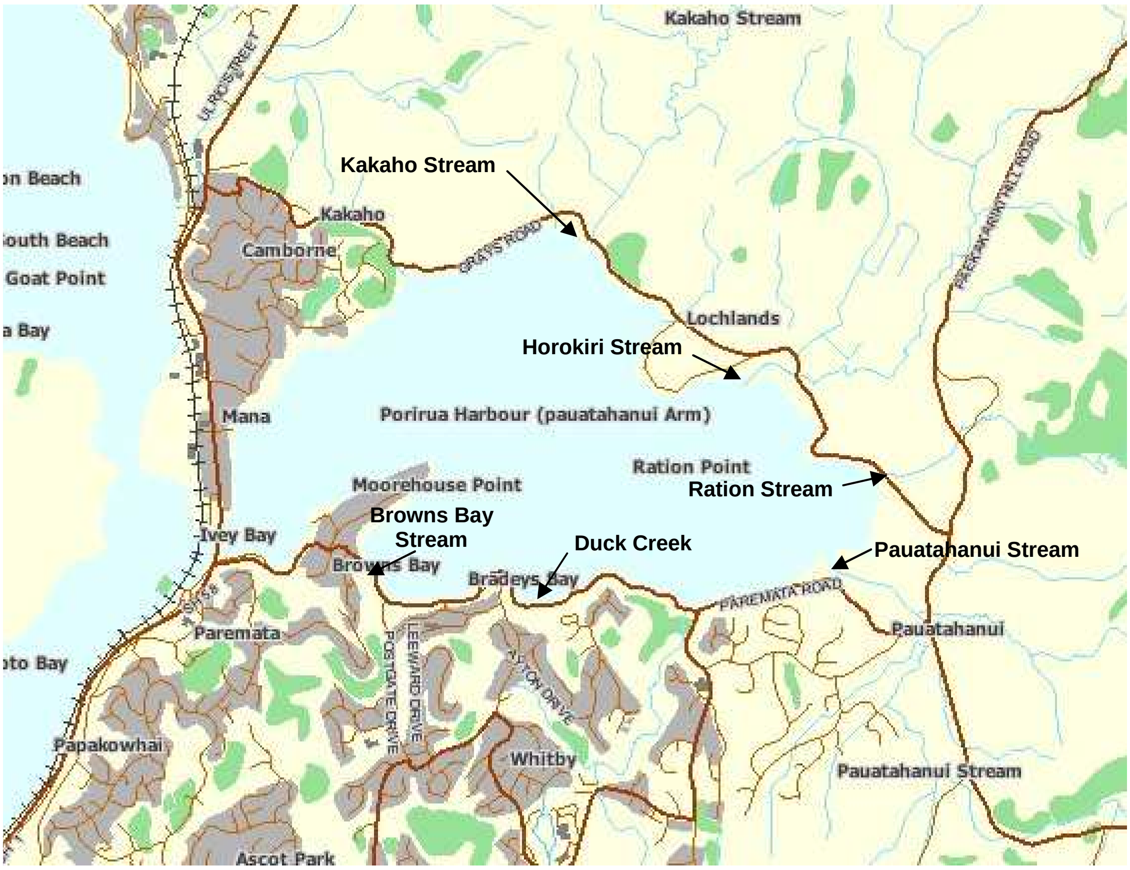

Figure 1. Location of the study area, Pauatahanui Inlet, New Zealand.

3.3.1 HISTORY OF PAUATAHANUI INLET

When Europeans first set foot in the area, bush extended to all shores of the Pauatahanui Inlet. In 1843 Samuel Brees, a NZ Company surveyor, recorded "Tawa, Pine and Rewa Rewa, Pukatea" on "gently undulating land" (Healy, 1980). Other species present at this time were Rimu, Rata, Hinau, Totara, Matai, Miro and Kahikatea. (Sheenan, 1988). The only areas noted to have been cleared at this time were around the shores of the Inlet, cleared by Maori for cultivation. At the time Samuel Brees made his observations, construction of the first roads in the area was well underway. In 1852, sawyers huts were evident in the lower part of the Horokiri Valley. In 1863, a steam driven sawmill was processing timber at Duck Creek. A number of other mills operated in the catchment (Healy, 1980). One mill still operates today in the Pauatahanui Stream catchment. The first school in Pauatahanui started in 1855 in the local hotel, with the first school buildings in the area erected in 1860 (One in Pauatahanui and one in Horokiri). The first church opened in 1857 (Sheenan, 1988).

Healy (1980) states that "by 1900 the process of settlement in Pauatahanui and Horokiri was to all intents completed. The bush had gone, and there had been 50 years of establishment and improvement of a stable group of family holdings."

As development continued, it was shaped more by motorised transport, which bypassed the need for local shops for a period. In more recent times, the modification/development that has occurred in the Pauatahanui Inlet catchment comprises predominantly of residential housing. Personal vehicles and public transport enable people to live in the area and commute to the city of Wellington to work, a social development of the last 25 years. Due to the increase in numbers of people living in the area, a small shopping area has again been established in Whitby. Three schools now meet the education needs of the children living in the area.

During development of the Porirua/Pauatahanui area, industrial activities became largely confined to the Porirua Basin, and did not spread to the catchment of the Pauatahanui Inlet. There is very little current activity in the catchment that could be termed industrial, and very little commercial activity that could impact on the environmental quality of the Inlet. Two 'industries' are located in the Pauatahanui Catchment – a timber mill, and a house moving yard.

3.3.2 POPULATION

Since the early 50's, more and more people have realised that the Pauatahanui area is a pleasant place to live, conveniently near to New Zealand's Capital City, Wellington. The result has been demand for housing, and this has placed, and continues to place, considerable pressure on the unique estuarine environment of the Pauatahanui Inlet (Healy, 1980).

In his study of the Inlet in 1980, Healy noted that "a demand for sections, real or created, resulted in large scale urban development".

The increasing population is shown in Figure 2 below, and Figure 3 shows the number of dwellings in the study area over the last 10-11 years. (The areas used for this analysis are those defined by statistics NZ for census purposes. A map of these areas is attached in Appendix 1).

As it is generally assumed that greater numbers of people result in greater actual and potential pollution, these Figures are important in terms of this research. The data in Figure 2 below shows that the population of the southeast catchments (Pauatahanui, Resolution, Discovery and Endeavour) increased significantly between 1990 and 1996. An even more dramatic increase was prevalent from 1996 to the latest census (2001).

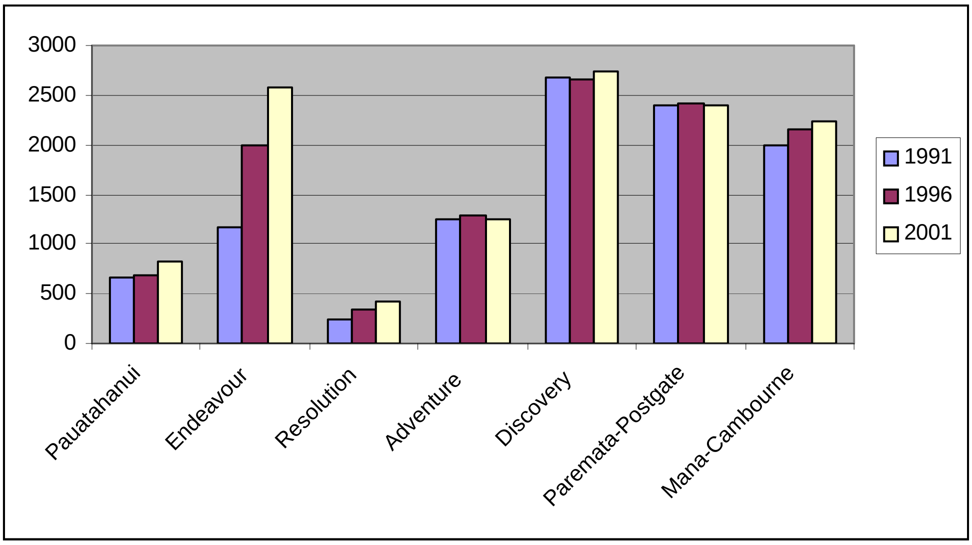

Figure 2. Usually resident population – Pauatahanui Inlet catchment, 1991-2001.

Figure 3 (below) also reflects the increasing population, and the added pressure this is placing on land resources. It shows that the number of dwellings in all areas has increased over the last 10 years, with by far the greatest increase occurring in the Endeavour area.

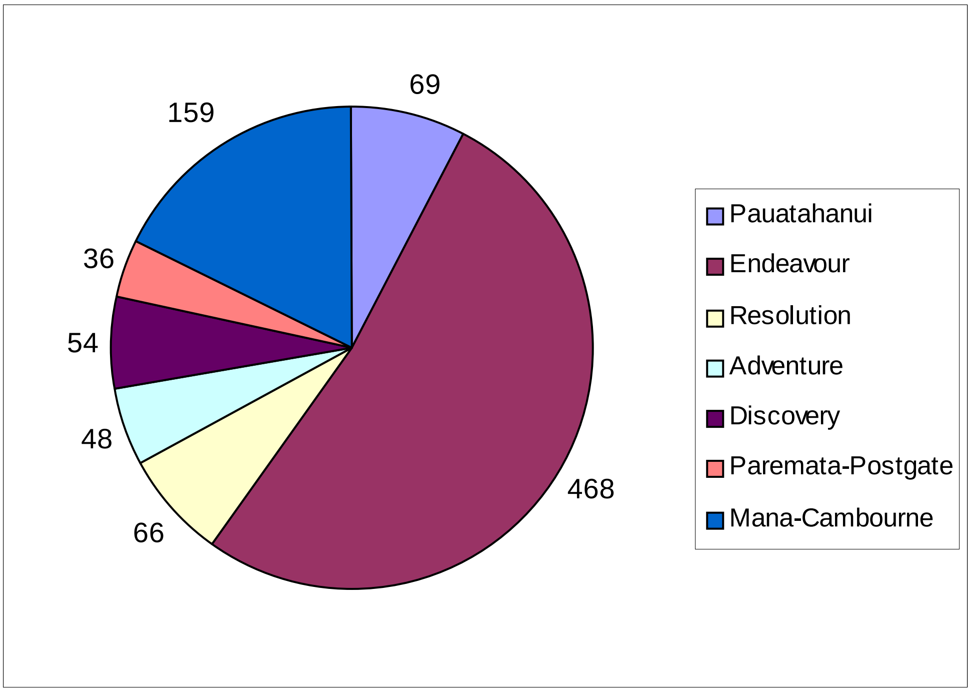

Figure 3. Increase in Total Dwellings (occupied & unoccupied) – Pauatahanui Inlet surrounding area, 1991-2001.

From the Figures presented above, it can be confirmed that the population in the catchment is growing, and that the area of the catchment occupied by suburban dwellings is increasing to accommodate this population. The main population growth has been in the Endeavour and Resolution areas – an extension of what was known in 1980 as Whitby Village (and is still known by this name locally). The same conclusion is easily drawn when visiting the area, and this is demonstrated in photographs 1-3 below.

Photo 1. Suburban development in progress, Whitby, 2000.

Photo 2. View across Pauatahanui Inlet to the 'southern' (suburban) side of the Inlet, 2000.

Photo 3. View across the Pauatahanui Inlet to the 'northern' (rural) side of the Inlet, 2000.

3.3.3 LAND USE

Over the last 20 years, much of the land use in the southern sub-catchments has changed from agricultural, and in some places, forest, to suburban/residential. This is demonstrated in Figure 4 below, which shows the expansion of the urban area in the southern catchment since the 1970's.

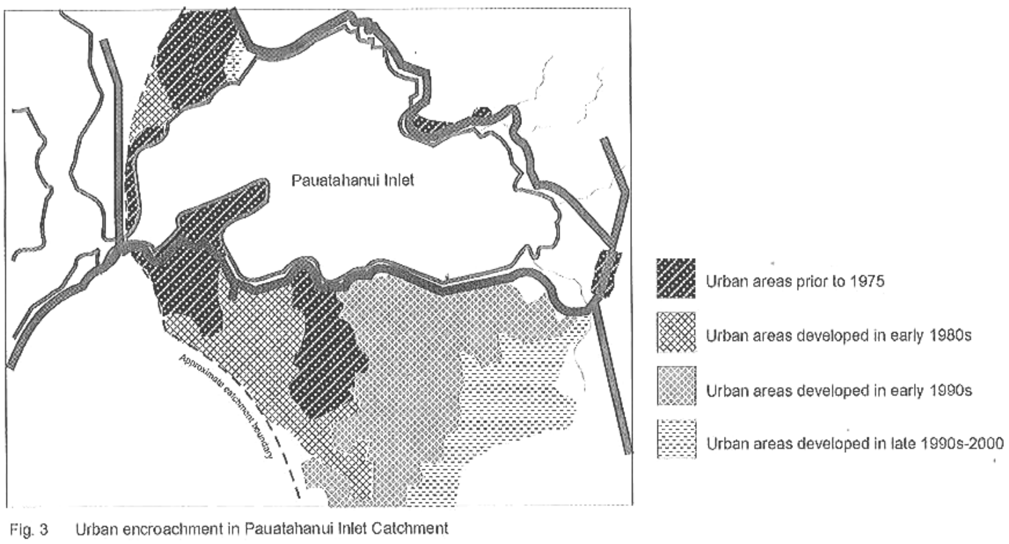

Figure 4. Expansion of Urban areas in the Pauatahanui Inlet Catchment. Source: Wellington Regional Council, 2000.

When the land is initially cleared, and/or landscaped for subdivision, increased run-off volume and increased sedimentation are frequently the immediate concerns. An example of the scale of subdivision developments in the catchment is shown in Photo 4 below. The change in land use, however, impacts upon the Inlet permanently, as the nature of the runoff from these now developed areas, inhabited by humans, is altered. As mentioned earlier, it is this runoff which is focused upon in this research.

Photo 4. Subdivision development, Whitby, 2000.

As is clearly demonstrated in the map in Figure 4, and in photos 2 and 3 above, the northern catchments of the inlet still drain predominantly rural areas (photo 3), and are, incidentally, zoned rural in the Porirua City Plan. The catchments on the southern side of the Inlet (photo 2) drain the residentially zoned areas of Whitby, Discovery, Adventure, Resolution and part of Pauatahanui.

A map (from Healy, 1980) of the catchments is included below as Figure 5.

Comparison of the two ‘sides’ to the study area is made in following chapters, with particular focus on the Duck Creek (residential) and Horokiri (rural) catchments.

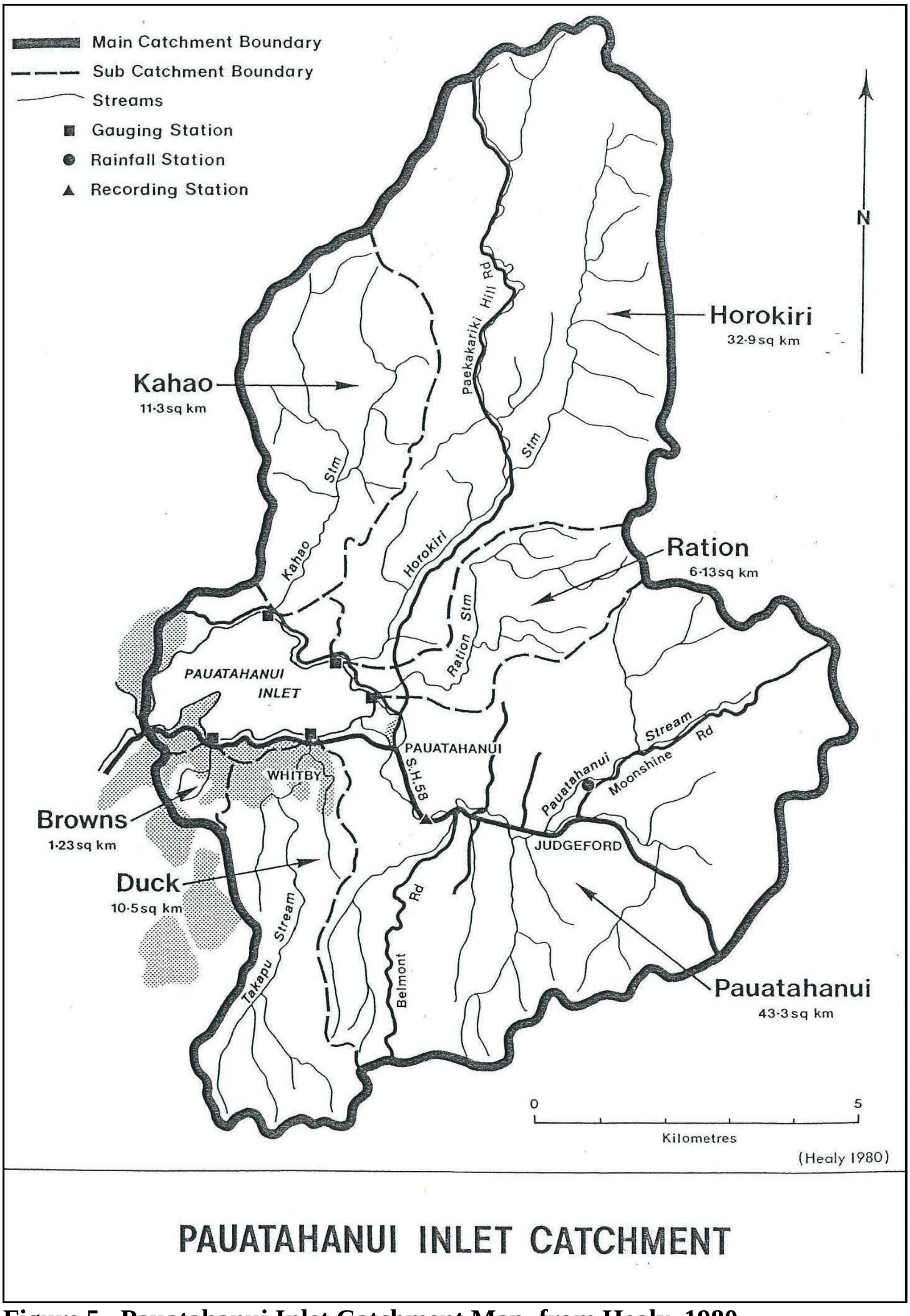

Figure 5. Pauatahanui Inlet Catchment Map, from Healy, 1980.

3.4 THE RURAL CATCHMENTS

3.4.1 HOROKIRI STREAM

Horokiri Stream has a catchment of approximately 45km^2. It enters the northern side of the Pauatahanui Inlet. The stream drains a catchment that is predominantly rural - consisting of larger farms, and smaller lifestyle holdings that have a range of uses including orcharding, horse riding and stabling facilities and small hobby farms. Land cover in the catchment is mainly pasture, with some gorse and scrub. The Paekakariki Hill Road follows the Horokiri stream through the upper and middle catchment (see Appendix 2). This road does not receive heavy traffic in significant volumes as it is unsuitable for trucks. Grays Road crosses the Horokiri Stream near its mouth, and receives occasional heavy traffic, however this is not the preferred route.

Glasby *et al* (1990) notes that rural catchments of the Porirua Harbour have been substantially top dressed with fertiliser in the past.

3.4.2 KAHAO, RATION AND PAUATAHANUI STREAMS

Kahao Stream drains a small catchment (11.3 km^2), which is agricultural in nature. There are no major roads running through this catchment, and the upper part of the stream is in native bush cover.

Ration Stream drains a small, low-lying pastoral catchment. The Pauatahanui Golf Course is located in the higher part of the catchment, and there are some large areas of riparian vegetation which have been retained. The lower part of the stream forms part of the saltmarsh area where it meets the Pauatahanui Inlet. This saltmarsh is managed as Department of Conservation Reserve.

The upper Pauatahanui Stream catchment is rural in nature, with the Haywards Hill road and Moonshine Road passing through the catchment. There are 2 main branches to the stream. The area has been subdivided into 10 acre blocks and there are large areas of lifestyle holdings. Poultry, alpaca and pig farming occur in the rural part of the catchment. Closer to the mouth of the stream, residential development is encroaching on the catchment as Whitby extends to the east. The stream mouth forms a major part of the saltmarsh area at the eastern end of the Inlet.

3.5 THE SUBURBAN CATCHMENTS

3.5.1 DUCK CREEK

Duck Creek drains a small catchment of about 11 km^2 and is located on the southern side of the Inlet. There are two branches to Duck Creek. The eastern branch runs through pasture and a pine plantation. The western branch runs through urban areas, and two man-made lakes near the Whitby shopping village, before joining the eastern branch at the Golf Course. From here the Creek is bordered by the Duck Creek Golf Course until it reaches a small saltmarsh (Department of Conservation Reserve), and then the Inlet. The stream receives discharges of stormwater from the residential area. The features in the lower Duck Creek catchment are shown in Figure 6 below.

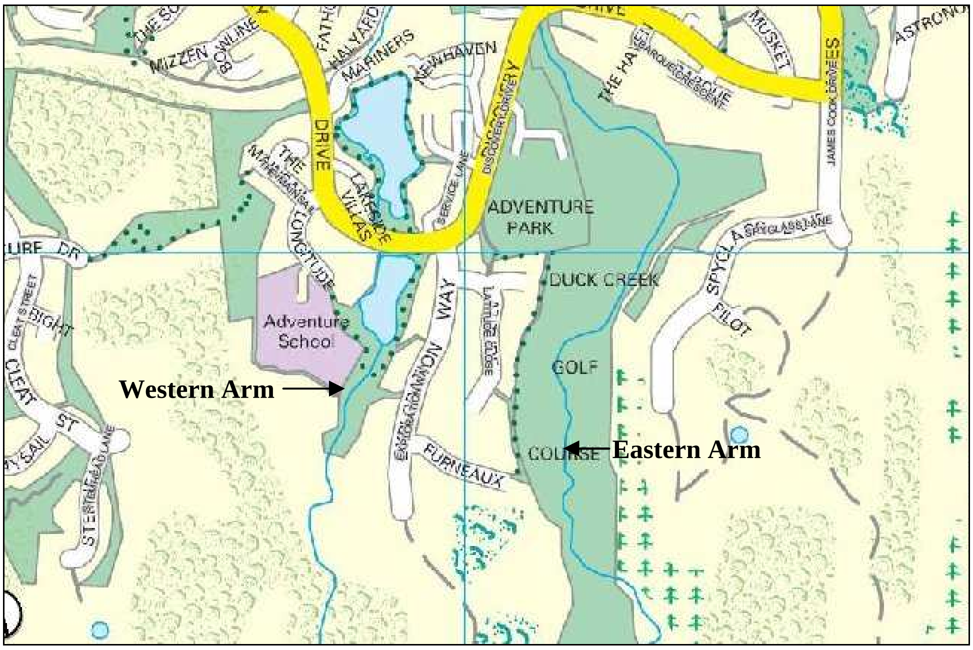

Figure 6. The two arms of the upper Duck Creek catchment.

Continued subdivision/residential development is occurring in this catchment at the present time, and in the report by the Wellington Regional Council in 1989, it was noted that 'on-going housing development is a major feature of the catchment' (WRC, 1989).

Residential development of this catchment started in the 1960's at the western end of the Inlet, and has spread eastwards towards Pauatahanui since this time.

The man-made lakes near the shopping village likely serve as silt retention basins to some extent.

In 1990, Glasby *et al* noted that "Vegetation cover in Duck Creek catchment is grassland with bracken, fern and scrub. Land in this catchment is used for recreational purposes." In the 10 years since this report by Glasby *et al* was written, housing has become the predominant land use in the Duck Creek catchment.

3.5.2 BROWNS BAY STREAM

This is the smallest sub-catchment feeding into the Inlet, being only $1.23km^2$. Nearly the entire catchment is suburban in nature, and has been in suburban land use for a number of years. There are two branches to the stream in the upper catchment, which meet half way down the catchment in the suburban area and flow to the inlet.

4. OBJECTIVES

All stormwater currently ends up in the Pauatahanui Inlet untreated. The objective of this research is to identify whether this is a cause for concern at the present time, whether it has been a concern in the past, and to project forward into the future and identify whether this may lead to environmental concerns for future generations.

This study explores the impact stormwater run-off from the surrounding land may be having on the water and sediment chemistry in the Pauatahanui Inlet. It also looks at concentrations of heavy metals, nutrients and trace elements in water. Some physiochemical and biological parameters in water are also assessed. This leads on to a discussion of the possible environmental impacts that stormwater run-off may have, now and in the future, on the Pauatahanui Inlet.

Findings of field research are presented along with a discussion about other studies of the Pauatahanui Inlet. Where applicable, the results are compared with the relevant New Zealand Guidelines for Water Quality. These guidelines provide the information necessary to enable the potential adverse impacts of certain levels of contamination to be identified.

This research contributes to the understanding of the current environmental pressures on the Pauatahanui Inlet, and helps identify the specific pressures unique to the area in terms of stormwater quality.

The information presented may be used to guide future efforts in pollution control and minimisation, and will provide information to be used in the decision making processes for environmental management and planning for the current day, and future of the Pauatahanui Inlet.

In terms of contribution to science, the findings will aid in directing future research efforts.

As a result of this study, regulatory authorities will be more adequately informed, and this will enable them to develop management strategies to let people continue to enjoy the Pauatahanui Inlet today, without compromising the ability of future generations to do the same.

5. METHODOLOGY

5.1 WATER QUALITY SAMPLING

Water quality sampling was undertaken on 5 occasions at 8 freshwater sites and 6 marine water sites during March and April 2001. Sampling was timed to coincide with rainfall events on 3 occasions, during which surface runoff was observed. On two occasions sampling was undertaken when no runoff was occurring (i.e. after prolonged dry weather). Repeat sampling was made at exactly the same location on each visit.

Water sampling sites are shown in Figure 7, and described below in Table 2.

Table 2. Description of Water sampling sites

Site	Site Number	Description
1	BR1	Browns Stream at Mouth
2	INL1	Inlet 1 – Browns Bay, Pauatahanui Inlet
3	DC1	Duck Creek Upper - @ Furneaux Drive
4	DC2	Duck Creek Lower - @ Golf Course
5	INL2	Inlet 2 - 50m off shore out from Duck Creek
6	PA1	Pauatahanui Stream at Mouth
7	HO1	Horokiri Stream, Upper – Paekakariki Hill Road
8	INL3	Inlet 3 – Pauatahanui Settlement end of Inlet.
9	RA1	Ration Stream at Paekakariki Hill Road
10	HO2	Horokiri Stream at mouth (Grays Road)
11	INL4	Inlet 4 – 50m off shore from Horokiri Stream
12	KA1	Kahao Stream at mouth
13	INL5	Inlet 5 – 50m off shore from Kahao Stream
14	INL6	Inlet 6 – Below Paremata Bridge

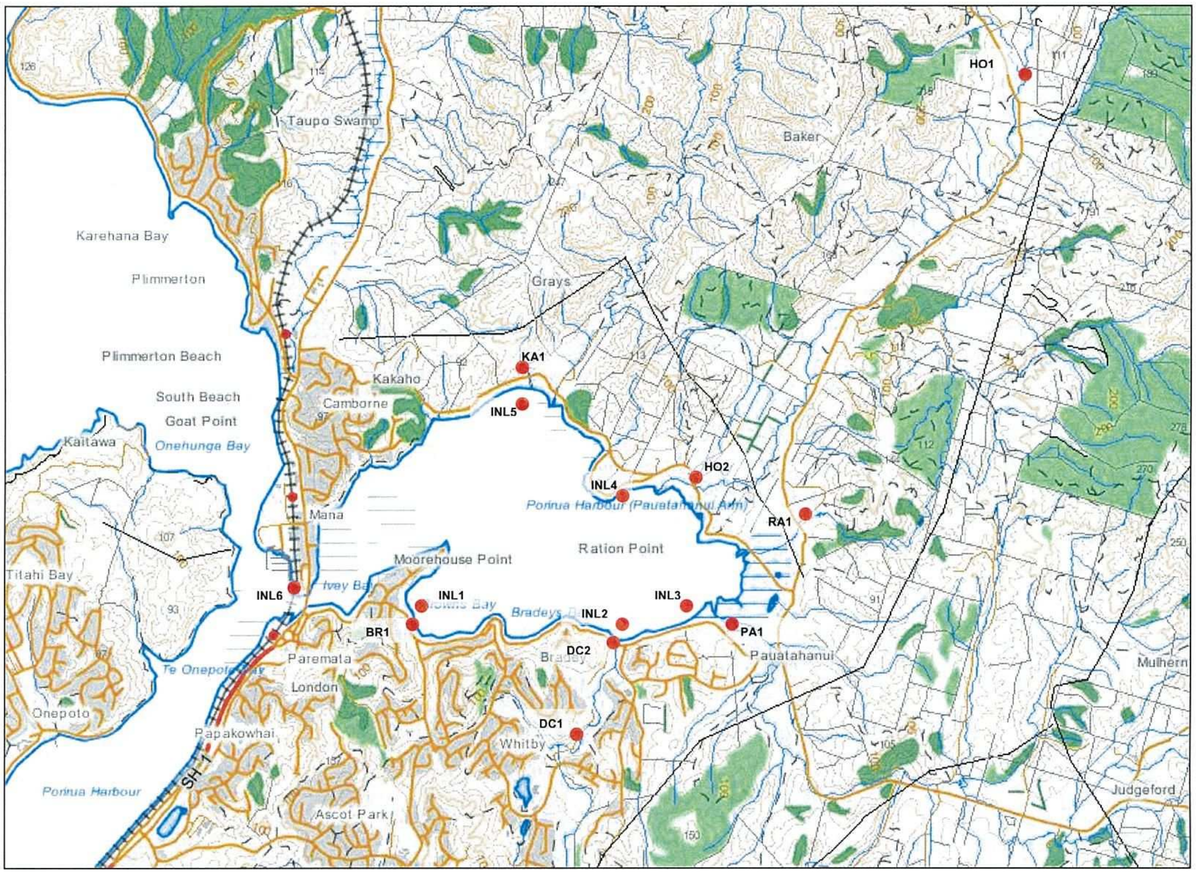

Figure 7. Water Quality Sampling locations – Pauatahanui Inlet

The water sampling sites were situated near to the mouths of the 6 streams feeding the Inlet to enable some discussion of the impacts of specific streams on the water quality to be made, and also to provide data that may be useful when analysing sediment core samples for various heavy metals.

Marine water samples from the Inlet were taken within one hour either side of high tide to minimise the influence of tidal flows/flushing on water quality and to minimise variance between the samples.

Freshwater samples were taken from points above the tidal influence wherever possible to enable the most accurate representation of run-off from the land. The sites chosen were located at the mouths of the 6 main streams draining sub-catchments into the Inlet, plus two upstream sites. One upstream site was in Duck Creek, where the stream enters the golf course and the other in the upper reaches of the Horokiri Stream.

Standard grab methods were employed for all samples, using bottles provided by the Wellington Regional Council Laboratory (Telarc Registered). Marine water samples were taken at a depth of approximately 1.25 metres and obtained via wading.

pH was measured in the laboratory using an Orion 420A pH meter fitted with a Schott Blue Line 17 pH electrode.

Freshwater and seawater samples for trace metal analysis were collected in 250ml acid washed polyethylene bottles and preserved at the time of collection by acidifying to pH of less than 2 using HNO_3. The samples were digested and preconcentrated using APHA Method 3030 E and analysed by flame AA for Cd, Cr, Cu, Fe, Mn, Pb & Zn using a Shimadzu AA-670 atomic absorption/flame emission spectrophotometer. Detection limits were 0.005 mg/L for Cd, 0.01 mg/L for Cu, 0.03mg/L for Fe & Zn and 0.05 mg/L for Cr, Mn & Pb.

Salinity was measured using an Orion model 160 conductivity meter (using the instrument's Salinity mode).

E-Coli was determined using APHA Method 9213 D and enterococci was determined using APHA Method 9230 C.

5.2 SEDIMENT CORES

Four sediment cores were taken from the inlet. The sites of these cores are shown in Figure 8. As shown in the Figure 8, the sites were located to the east and west of the points where Duck Creek and Horokiri Stream discharge into the Inlet.

Cores were taken at low tide from the intertidal zone using PVC tubing. Core depths varied depending on the thickness of the softer sediment, and were taken to a depth of 0.3m – 0.5m. The cores were split into two lengthways down the centre. Once half of the core was retained for reference purposes. The other half was sub-sampled every 30mm and analysed for Pb, Zn, Cu and Cd.

The sediment samples from the core splits were oven dried at 50 deg C and sieved through a 1mm stainless steel sieve to achieve a uniform sample. The < 1mm portion of sample was sub-sampled and digested using EPA Method 3010A and analysed by flame AA for Cr, Cu, Pb & Zn using a Shimadzu AA-670 atomic absorption/flame emission spectrophotometer.

5.3 HISTORICAL DATA

A variety of sources were used to obtain data about the history of the Pauatahanui Inlet. The Wellington Regional Council incident database and photo archives were used to obtain data on past pollution incidents and land uses in the catchments. Porirua City Council archives were a source of information. Publications from the 70's and 80's were useful sources of land use data, as was the GIS systems operated by the WRC.

Healy (1980) contained valuable information and references. Much of the detail on the early European settlement of the area was gained from this publication.

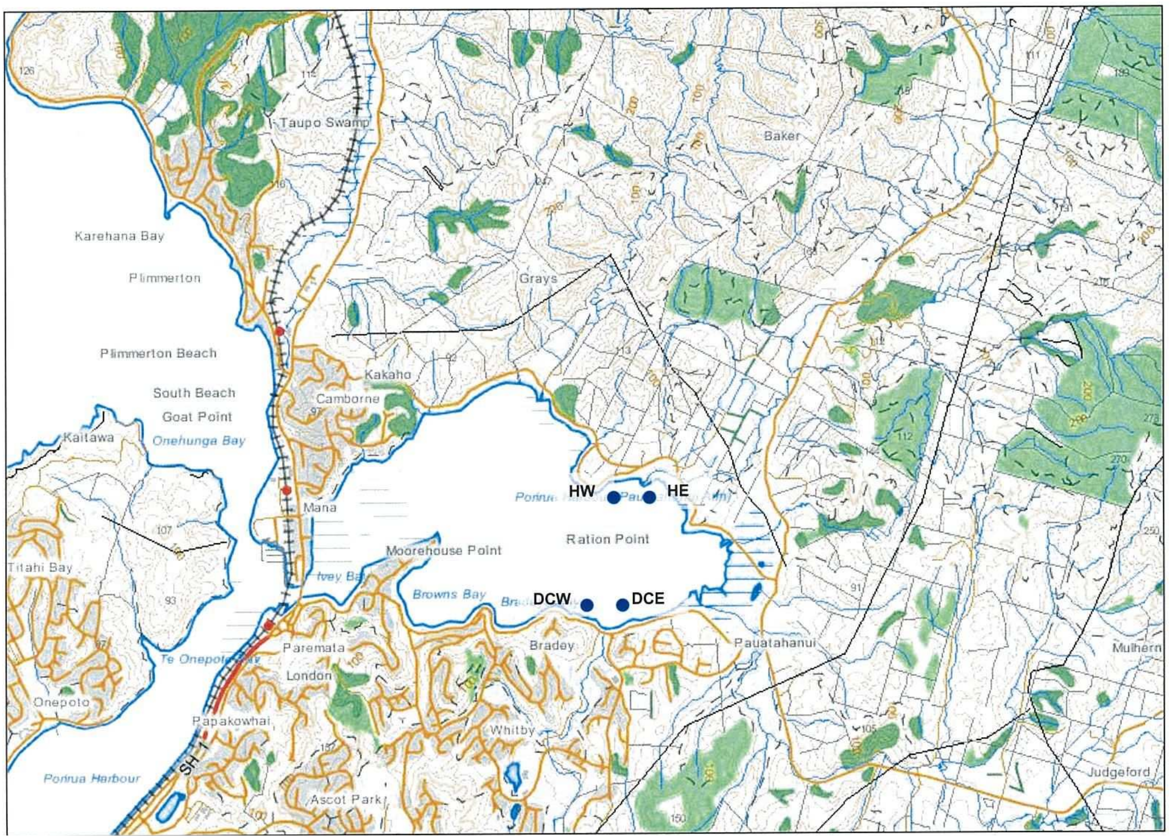

Figure 8. Sediment Sampling locations – Pauatahanui Inlet

6. RESULTS

6.1 HEAVY METALS IN WATER

Table 3 below shows the maximum concentrations of various heavy metals in water samples taken from the streams feeding in to the Inlet. This is relevant because water quality management in streams will have impacts upon the down-stream estuarine ecosystem. The maximum level is used in order to present the most conservative approach to determine exceedances of guideline values.

Table 4 shows the maximum heavy metal concentrations in the marine water of the Inlet itself, and again, maximums are used.

Table 3. Maximum Heavy Metal Levels in Freshwater (μg/L) over 5 sampling runs, Feb-May 2001 - Comparison with New Zealand & Canadian Guideline Levels.

	BR1	DC1	DC2	HO1	HO2	KA1	PA1	RA1	Detection Limit	NZ Guideline 99% species protection [a]	NZ Guideline 80% species protection [a]	Canadian Guideline Water, Aquatic Life [b]
Cr	-	-	-	-	-	-	-	-	0.1	0.01(CrIV)	40.0(CrIV)	1.0(CrIV)
Cu	30.0	-	-	-	-	-	-	-	10	1.0	2.5	2-4
Pb	-	70.0	-	-	-	-	-	-	50	1.0	9.4	1.0-7.0
Zn	190	-	-	-	-	-	-	-	30	2.4	31.0	30.0
Mn	650	-	50	30	-	160	550	230	30	1200	3600	-
Fe	2200	110	560	510	1500	440	1400	1200	30	-	-	300
Cd	-	-	-	-	-	-	-	-	5	0.06	0.8	0.017

(- = below detection limit)

a. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Trigger values for toxicants at alternative levels of protection. Australia New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, October 2000.

b. The Canadian Environmental Quality Guidelines, Fresh Water: Aquatic Life. Canadian Council of Ministers of the Environment, 1999, updated 2001.

6.1.1 ZINC

Zinc (Zn) was detected in 3 samples. All samples containing Zn above the detection limit were from the Browns Bay Stream, taken after rainfall (2 March, 27 March and

3 April). Concentrations of Zn in the Browns Bay stream exceeded the NZ Guideline levels, the maximum level recorded being 30µg/L. More detailed examination of the results (see Appendix 2) revealed that this occurred on three occasions. The three exceedances occurred during the three 'wet weather' sampling runs. This is consistent with discharges of contaminated stormwater.

6.1.2 LEAD

Lead (Pb) was detected in only 2 samples – upper Duck Creek (DC2) and INL 3, both on 3 April 2001. Concentrations of Pb in the upper Duck Creek site exceeded guideline levels, at 70µg/L (the guideline level for 80% species protection is 9.4µg/L). The April sampling run was undertaken during moderate rainfall.

6.1.3 MANGANESE

Manganese (Mn) was detected on all sampling occasions in Browns Bay Stream and the Pauatahanui Stream. It was also detected in lower Duck Creek during wet weather runs, and in Ration stream on 1 March, 2 March and 27 March. At no time however were the guideline levels for Mn exceeded.

6.1.4 IRON

Iron (Fe) levels were highest in Browns Bay Stream, which is consistent with the observation of iron oxide bacteria (orange staining) on the stream bed on all sampling occasions. The highest level of Fe at any site was 2.5mg/L (INL2, 27 March 2001). There are no NZ guidelines for Fe in freshwater. The maximum concentrations of iron detected at all sites except DC1 (Upper Duck Creek) exceeded the Canadian guidelines for Fe. This exceedance is treated with caution, as it may be explained by naturally high Fe levels in soils around the Inlet, or iron-organic matter complexes. It is also noted, upon more detailed examination of the results (Appendix 2) that the levels detected at each site are reasonably consistent across all sampling occasions, with slight increases in concentration recorded at most sites after wet weather.

6.1.5 COPPER

Copper (Cu) was detected at 0.03mg/L in Browns Bay stream on 2 March 2001. This was the only freshwater site to record Cu, exceeding the guideline levels. This occurred on one occasion, after rainfall. Copper was found at various sites in the Inlet itself (saltwater), and appeared to coincide with turbid waters/stirred up sediments. This is consistent with the analysis method, which was a sample digest and included the sediment.

6.1.6 CHROMIUM

Chromium was not detected in any freshwater sample.

6.1.7 CADMIUM

Cadmium was not present in freshwater samples.

Table 4 below examines the maximum levels of heavy metals in the marine water of the Inlet.

Table 4. Maximum Heavy Metal Levels in Marine Water (μg/L) over 5 sampling runs, Feb-May 2001 - Comparison with New Zealand & Canadian Guideline Levels.

	INL1	INL2	INL3	INL4	INL5	INL6	Detection Limit	NZ Guideline 99% species protection [a]	NZ Guideline 80% species protection [a]	Canadian Guideline Water, Aquatic Life [b]
Cu	10.0	10.0	10.0	-	10.0	10.0	10	0.3	8.0	-
Pb	-	-	140	-	-	-	50	2.2	12.0	-
Zn	-	-	-	-	-	-	30	7.0	43.0	-
Mn	-	-	-	-	-	-	50	-	-	-
Fe	1500	2500	1800	1000	1300	250	30	-	-	-
Cd			6.00	5.00	6.00	6.00	5	0.07	36.0	0.12

(- = below detection limit)

a. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Trigger values for toxicants at alternative levels of protection. Australia New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, October 2000.

b. The Canadian Environmental Quality Guidelines, Water: Aquatic Life. Canadian Council of Ministers of the Environment, 1999, updated 2001.

Guidelines for Cu were exceeded at all sites except INL 4. Examination of the results & field notes shows that these exceedances occurred during sampling runs where quite turbid/discoloured water was noted in the Inlet. This was particularly evident on the 27 March sampling run where considerable wave action (waves were noted to be approximately 1m in height and breaking on the southern bays) in the Inlet had stirred up bottom sediments. During this sampling run, all sites except INL4 recorded elevated levels of copper. This is consistent with the findings of Webster *et al* (2000) that Cu was one of the most mobile heavy metals in sediments under estuarine conditions. There is evidence that turbid conditions mobilise Cu present in surface sediment. Turbid conditions could stir up the sediment and oxidise sulphide compounds of Cu which are immobilised below the sediment surface under calm conditions, Webster *et al* (2000).

Levels of Pb at INL3 exceeded guidelines on the 3 April 2001 sampling run. This sampling occasion occurred after significant rain, and considerable runoff had occurred. Levels of Cd also exceeded guideline levels at INL 3, 4, 5 and 6 on this sampling run. Lead and Cd tend to have similar demand behaviour in water.

6.2 NUTRIENTS IN WATER

6.2.1 NITROGEN

Nitrogen levels were highest in Browns Bay Stream, and at the upper Horokiri Stream site. Levels ranged from 120 to 1800μg/l in the freshwater samples, and 110 to 600μg/l in marine water samples.

In Figure 9, the N levels in the Duck Creek and Horokiri Streams are compared. All sites demonstrated that after rainfall, nitrogen levels increased. Levels in the upper Horokiri (HO1) were significantly higher than at the lower Horokiri site (HO2), and the impacts of rainfall and runoff on N levels were more marked at this site.

6.2.2. PHOSPHORUS

Phosphorus levels were highest at most sites on 27 March sampling run, when turbid water was noted throughout the inlet and its contributing streams, and significant disturbance of sediments in the Inlet had occurred.

Figure 10 illustrates the comparison in P levels between the urban, Duck Creek catchment and the rural Horokiri catchment. DC1, DC2 and HO1 showed elevated levels of P after rainfall, however HO2 demonstrated results which appeared opposite to this.

The tables below (Table 5 and Table 6) compare the results obtained in this study with the current NZ guidelines (there are no Canadian guidelines for N or P).

Table 5. Range of Total Nitrogen and Phosphorus Levels in Freshwater (μg/L) over 5 sampling runs, Feb-May 2001 - Comparison with New Zealand Guideline Levels.

	BR1	DC1	DC2	HO1	HO2	KA1	PA1	RA1	Detection Limit	NZ Guideline [a]
N	830-1800	150-900	270-1000	250-1800	120-720	220-460	230-510	460-880	-	614
Exceedances	5	2	3	3	1	0	0	2		
P	53-160	31-67	28-120	8-78	24-130	14-120	34-58	70-92	0.008	33
Exceedances	5	4	4	3	2	3	5	5		

Exceedances = Number of exceedances of guideline levels

a. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Trigger values for physical and chemical stressors, lowland rivers. Australia New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, October 2000.

Levels of nitrogen in the Browns Bay Stream exceeded guideline trigger values on all sampling occasions. DC1 and HO2 also recorded levels in excess of guidelines on 3 occasions. Some of the levels recorded were three times the guideline level, indicating an external source of nitrogen.

Levels of phosphorus were above guideline levels at all sites on occasions, with the Browns Bay Stream, Pauatahanui Stream and Ration Stream exceeding guidelines on all five sampling occasions.

Table 6. Range of Total Nitrogen and Phosphorus Levels in Marine Water (μg/L) over 5 sampling runs, Feb-May 2001 - Comparison with New Zealand Guideline Levels.

	INL1	INL2	INL3	INL4	INL5	INL6	Detection Limit	NZ Guideline [a]
N	210-450	350-600	230-510	230-360	120-590	110-200	-	300
Exceedances	3	5	2	1	1	0		
P	BDL-140	39-130	BDL-140	17-86	11-39	BDL	0.008	30
Exceedances	2	5	1	3	2	0		

Exceedances = Number of exceedances of guideline levels

a. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Trigger values for physical and chemical stressors, estuaries, South east Australia (no guideline available for estuaries in New Zealand). Australia New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, October 2000.

BDL = Below Detection Limit

The levels of phosphorus detected in the Inlet itself were above guideline trigger values for all sites except INL6 on occasions. INL6 is the entrance to the inlet – and is subject to greater flushing and clean water inflow from the open sea. The levels of phosphorus in the inlet reflect the elevated levels present in the streams entering the estuary. It is also possible that direct discharge from the land to the Inlet accounts for some of the nutrients present.

Septic tanks are often the source of excess nutrients in surface water systems. There are very few septic tanks in the immediate catchment of the Pauatahanui, and the Wellington Regional Council actively monitors all systems. A number of systems which were not operating effectively were identified in the late 1990's, and these were repaired to the satisfaction of the Council (WRC pers comm.). While still a potential source of nutrient enrichment, septic tanks are unlikely to be a major contributor to the levels recorded in this study.

Healy (1980) assessed the inputs of N & P from streams into the Pauatahanui Inlet. While most results are presented as monthly total input, the study does note that the Pauatahanui Stream carried 0.01-0.05 μg/L reactive Phosphorus and levels of N in this stream ranged from 1000μg/L to 5μg/L. Seasonal variations were noted, with higher levels recorded in water winter when rainfall is higher, and plant uptake of nutrients is lower.

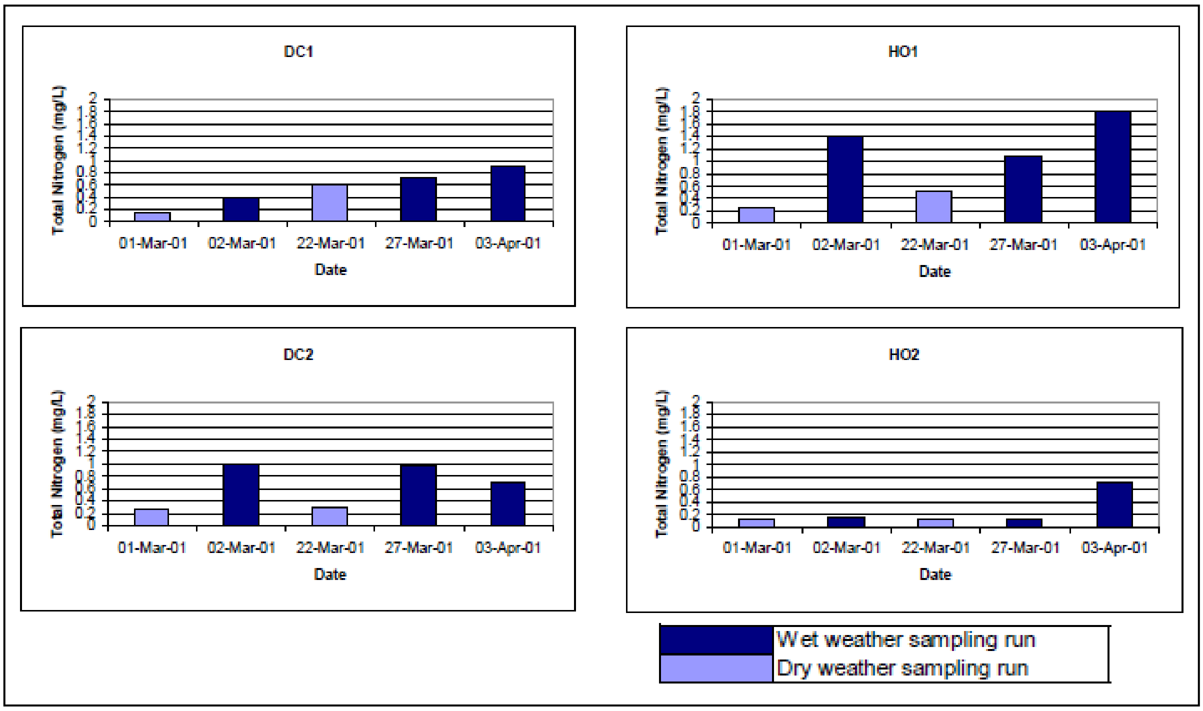

Figure 9. Comparison of Nitrogen levels in the Horokiri Stream (rural catchment) and Duck Creek (urban catchment).

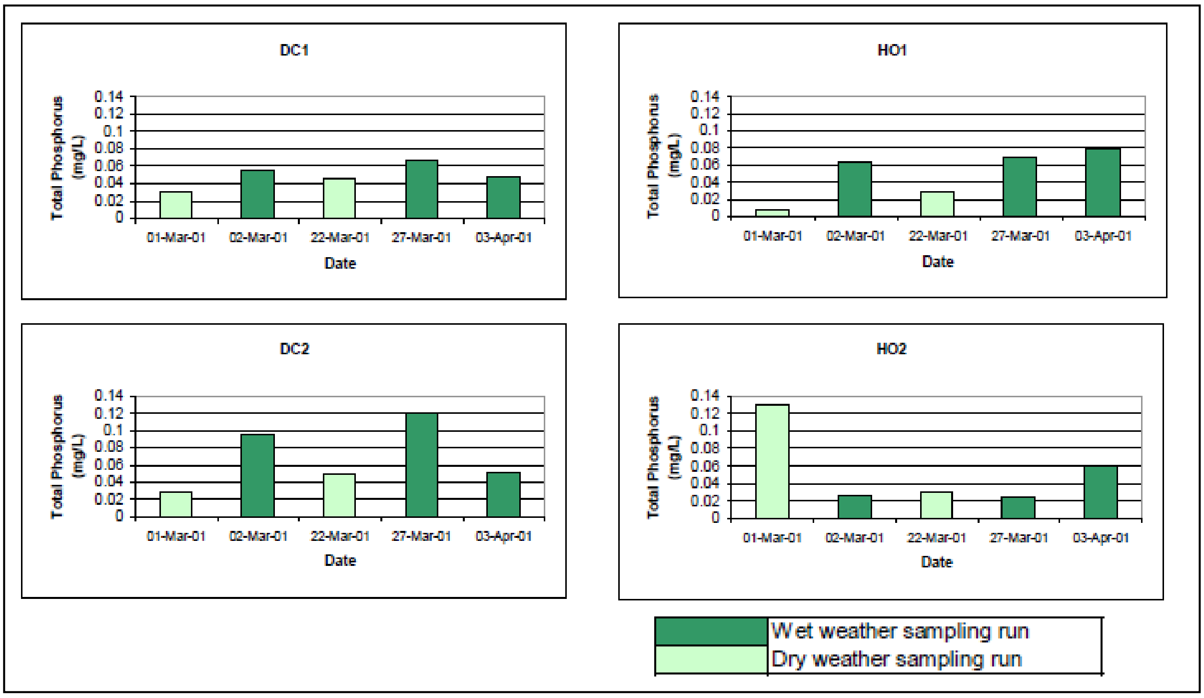

Figure 10. Comparison of Phosphorus levels in the Horokiri Stream (rural catchment) and Duck Creek (urban catchment).

6.3 PHYSIOCHEMICAL PROPERTIES - WATER

The range of suspended solids, salinity and pH identified in the samples at all sites is included in Table 7 and Table 8. Suspended solids are linked to levels of heavy metals (as these adhere to suspended particles), while salinity was analysed to help determine the influence of mixing on sampling sites.

Table 7. Physiochemical Parameters, range in Fresh Water over 5 sampling runs, Feb-May 2001 - Comparison with New Zealand & Canadian Guideline Levels.

	BR1	DC1	DC2	HO1	HO2	KA1	PA1	RA1	Detec-tion Limit	NZ /Aust Guideline	Canadian Guideline Water, Aquatic Life [c]
Susp. Solids (mg/L)	8-23	2-7	2-18	2-24	2-14	3-10	15-19	5-12	2		-
Salinity (μS/m)	BDL-0.3	BDL	0.1-0.7	BDL	0-0.2	0.1-21.5	0.3-7.3	BDL	0.1	0.3-0.35(µS/m) [b]	-
pH	6.9-7.0	7.2-7.4	7.0-7.5	7.5-7.7	7.2-7.7	7.6-8.9	7.1-7.3	7.1-7.4	n/a	7.2-7.8 [a]	6.5-9.0

a. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Default Trigger values for physical and chemical stressors in New Zealand for slightly disturbed ecosystems. Australia New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, October 2000.

b. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Default Trigger values for physical and chemical stressors in South East Australia (no NZ values available) for slightly disturbed ecosystems. Australia New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, October 2000.

c. The Canadian Environmental Quality Guidelines, Water: Aquatic Life. Canadian Council of Ministers of the Environment, 1999, updated 2001.

BDL. Below Detection Limit

Table 8. Physiochemical Parameters, range in Marine Water over 5 sampling runs, Feb-May 2001 - Comparison with New Zealand & Canadian Guideline Levels.

	INL1	INL2	INL3	INL4	INL5	INL6	Detec-tion Limit	NZ/Aust Guideline Estuaries	Canadian Guideline Water, Aquatic Life
Suspended Solids(mg/L)	4-66	9-120	4-120	8-40	9-78	3-25	2	-	-
Salinity(μS/m)	34.7-36.2	19.3-36.2	28.3-36.1	35.1-36.3	33.9-36.2	36.0-36.2	0.1	-	-
pH	8.0-8.1	7.8-8.1	8.0-8.1	8.0-8.1	8.0-8.1	8.0-8.2	n/a	7.0-8.5 [a]	7.0-8.7 [b]

a. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Default Trigger values for physical and chemical stressors in South East Australia (no NZ values available) for slightly disturbed ecosystems. Australia New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, October 2000.

b. The Canadian Environmental Quality Guidelines, Water: Aquatic Life. Canadian Council of Ministers of the Environment, 1999, updated 2001.

BDL. Below Detection Limit

It is clear that the DC2 (mouth of Duck Creek), KA1 (mouth of Kahao Stream) and PA1 (lower Pauatahanui Stream) sampling sites were subject to salt water influence on some sampling occasions. This is therefore taken into account when assessing the results at these sites. It is also apparent that the salinity in some areas of the Inlet was reduced on sampling occasions due to freshwater inflows. This is expected in an estuarine environment.

6.4 BACTERIA LEVELS

Levels of up to 10,000CFU/100ml **enterococci** were found in freshwater samples, with saltwater samples demonstrating significantly lower levels.

E-coli showed a similar pattern, with levels up to 23000CFU/100ml found in the freshwater sites.

Bacteria counts were highest after rainfall, and particularly high when waters were turbid. The results of bacteria sampling are shown in Table 9 and Table 10 below.

Table 9. Bacteria levels, range in Freshwater over 5 sampling runs, Feb-May 2001 - Comparison with New Zealand Guideline Levels (CFU/100ml).

	BR1	DC1	DC2	HO1	HO2	KA1	PA1	RA1	NZ Guideline[a]
E-Coli	1400-17100	100-1200	258-23000	300-10200	500-9000	340-4400	240-1140	230-4400	273
Enterococci	600-9200	160-7000	132-8000	156-10000	236-7800	266-2200	230-980	490-3700	n/a

a. Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas, Ministry for the Environment, June 2002. Freshwater Interim Guidelines, Alert/Amber mode II (single sample).

Table 10. Bacteria, range in Marine Water over 5 sampling runs, Feb-May 2001 - Comparison with New Zealand Guideline Levels. (CFU/100ml)

	INL1	INL2	INL3	INL4	INL5	INL6	NZ Guideline[a]
E-Coli	<2-1000	6-320	<2-2800	0-17	2-195	<2-12	n/a
Enterococci	<2-1600	8-740	1-500	2-40	2-138	<2-48	136

a. Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas, Ministry for the Environment, June 2002. Freshwater Interim Guidelines, Alert/Amber mode (single sample).

E-Coli is the preferred indicator for freshwater systems, while Enterococci is the preferred indicator in marine water.

6.5 SEDIMENT CORES

Figure 11, Figure 12, Figure 13 and Figure 14 below show photographs of the 4 core splits that were retained for reference purposes, and a description of each core. The cores from the Northern side of the Inlet were far less varied through the profile when compared to those on the Southern side.

Figure 15 illustrates the metals concentrations with depth in the sediment cores.

Results show that the sediments at the Duck Creek West site contain the highest levels of zinc, lead, copper and chromium. Levels of zinc, lead and copper at this site were on average twice those found at the other 3 sites.

Photo	Depth (mm)	Description
	0-5	Fine light grey silt layer.
	5-40	Grey colour. Fine to medium gran size, silt and sand particles. Occasional pebble (to about 10mm diameter). Cockles present, up to 20mm diameter in size.
	40-110	Brownish grey colour. Medium to coarse grain size with some larger pebbles (to 20mm diameter). Shell fragments present. Evidence of iron staining (orange-brown pockets).
	110-200	Brown silt with pockets of grey sand. Medium to coarse texture. Abundant shell fragments, some intact shells present. Cockle shells present, to 35mm diameter size. Pebbles to 30mm diameter.
	200-240	Fine brown silt. Small amount of grey sand (medium particle size). No shell fragments, no pebbles.
	240-242	2mm thick distinct layer of dark brown fine silt.
	242-265	Fine brown silt. Small amount of grey sand (medium particle size). No shell fragments, no pebbles.
	265-290	Medium to coarse grey sand. Small shell fragments present. No pebbles.
	290-350	Coarse grey sand. Small pockets of medium-fine brown sandy silt. Large pebbles/stones present – to 350mm in size. Abundant shell fragments.

Figure 11. Duck Creek East core – photo and description.

Photo	Depth (mm)	Description
	0-5	Fine grey silt layer.
	5-40	Fine- medium grey brown Small pebbles (to 4mm diameter) Small shell fragments (<1mm).
	40-60	Coarse grain size. Grey in colour. Small shell fragments present. Pebbles present, to 10mm in diameter.
	60-180	Very coarse grain size. Compacted gravels. Pebbles to 50-60mm in diameter, abundant. Shell fragments, some large (cockle shells). Some pockets of fine grey coloured silt
	180-260	Large, abundant pebbles with fine grey silt and some coarser particles. Small shell fragments. Pebbles up to 30mm in diameter.
	260-335	Fine grey silt with some coarser grey sand particles. Few pebbles, to 15mm diameter. Evidence of iron staining. Shell fragments and patches of brown, coarse-medium sand present.

Figure 12. Duck Creek West core – photo and description.

Photo	Depth (mm)	Description
		
	0.5	Very fine light grey silt layer, with whole cockle shells present, some shell fragments, and some sticks/organic matter.
	5-130	Fine light grey silt. Pockets of brown coloured silt. Shell fragments – mainly cockle shells.
	130-350	Dark grey fine silt with abundant large shell fragments. One large, intact, bivalve (60mm diameter). Other large shells present, also up to 60mm diameter. Small fine shell fragments also abundant.

Figure 13. Horokiri Stream East core – photo and description.

Photo	Depth (mm)	Description
	0-90	Fine grey-brown silt. Occasional small shell fragment.
	90-150	Grey fine-medium silt. Few shell fragments.
	150-210	Less compacted grey fine-medium silt. Shell fragments abundant.
	210-410	Dark grey fine silt with patches of brown silt. Some organic matter (sticks) which is breaking down (black in colour).
	410-500	Medium – coarse brown grey silt. Occasional small shell fragment. Evidence of some iron staining.

Figure 14. Horokiri Stream West core – photo and description.

6.5.1 HEAVY METALS IN SEDIMENT

Sediment leaching under estuarine conditions

Metal behaviour in estuarine conditions was researched in a study by Webster *et al* (2000). This was based on sediments from the Hatea River and estuary, and involved assessing the rate at which various metals leached under various salinities, at a pH similar to the estuary. It was noted that Fe (not studied in this research for sediment cores) and Pb were the least mobile metals. Manganese and Cu were considered to be the most mobile, while Cr and Zn were also noted as being considerably less mobile than copper or manganese.

This may explain why Cu was detected on occasions (particularly when the sediment was stirred up) in the water samples taken from the Inlet, but was not significantly high in the sediment cores. Copper also complexes strongly with organic matter so may be carried in the water in this form. Chromium and Zn were detected in the water samples, and Pb was detected in marine water at low levels on only one occasion, however these feature more strongly in the sediment core samples.

Glasby *et al* (1990) noted that Cr was higher in sediments of the Pauatahanui Inlet when compared to the Porirua Inlet, and this was thought to possibly reflect the differences in sediment origin. Despite the higher levels in the Pauatahanui inlet, it was noted that all samples taken by Glasby *et al* were in Index of Geoaccumulation[1] (Igeo) class 0 (uncontaminated).

The findings of this study are consistent with the study by Glasby *et al* (1990), which found levels of Zn were higher in sediment at the mouth of the Duck Creek Stream (Igeo class 2, moderately contaminated) than other areas in the Pauatahanui Inlet.

In order to facilitate further discussion about the levels of heavy metals in the sediment of Pauatahanui Inlet, a summary of the data gathered is presented in Table 11. This table shows the mean, minimum and maximum level of heavy metals for each core. It also shows the current New Zealand Guidelines (The Australian and New Zealand Guideline for Fresh and Marine Water Quality for the protection of

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[1] NOTE: Igeo is used to compare the current heavy metal concentration with pre-European background levels, and was introduced by Muller (1979), and also used by Stoffers *et al* (1986a). This formula for calculating the Igeo class was not applicable to the research done in this study, as it is based on the <20 microgram fraction of the sediment (This study focussed on the <100 microgram fraction).

aquatic ecosystems, ANZECC, 2000), and the current Canadian Sediment Quality Guidelines for the protection of aquatic life. Figure 15 shows trace metal concentrations in sediment as a function of depth in the cores studied.

The results obtained by Glasby *et al* (1990) are presented in Table 12 and also compared to the guidelines.

Table 11. Heavy Metal Levels in Sediment, March 2001 - Comparison with New Zealand and Canadian Guideline Levels. Levels shaded grey = maximum level detected in Inlet during survey.

Site	Mean	Min	Max	NZ ISQG LOW [a] mg/kg	NZ ISQG High [b] mg/kg	Canada ISQG [c] mg/kg	Canada PEL [d] mg/kg
CHROMIUM							
DCW	10.0	7.3	12.0	80	370	37.3	90
DCE	8.2	5.5	9.8				
HW	7.2	6.5	8.2				
HE	6.2	4.4	7.6				
COPPER							
DCW	7.0	4.6	9.1	65	270	35.7	197
DCE	3.3	1.9	4.8				
HW	4.4	3.0	5.1				
HE	3.5	2.6	3.9				
LEAD							
DCW	22.4	15.0	37.0	50	220	35	91.3
DCE	10.3	5.5	16.0				
HW	8.4	6.2	11.0				
HE	7.5	5.4	9.4				
ZINC							
DCW	59.6	38.0	69.0	200	410	124	271
DCE	34.2	23.0	47.0				
HW	39.2	30.0	48.0				
HE	34.7	26.0	41.0				

a. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality for the protection of aquatic ecosystems, Interim Sediment Quality Guideline (ISQG) Low (Trigger Level). Australia New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, October 2000.

b. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality for the protection of aquatic ecosystems, Interim Sediment Quality Guideline (ISQG) High. Australia New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, October 2000.

c. The Canadian Sediment Quality Guidelines for the protection of aquatic life, Interim Sediment Quality Guideline (ISQG). Canadian Council of Ministers of the Environment, 1999, updated 2001.

d. The Canadian Sediment Quality Guidelines for the protection of aquatic life, Probable Effect Level (PEL). Canadian Council of Ministers of the Environment, 1999, updated 2001.

Table 12. Heavy Metal Levels in Sediment, Glasby *et al*, 1990- Comparison with New Zealand and Canadian Guideline Levels. Results of 30 samples taken from Pauatahanui Inlet.

Heavy Metal	**Mean**	**Min**	**Max**	**NZ ISQG LOW** [a]	**NZ ISQG High** [b]	**Canada ISQG** [c]	**Canada PEL** [d]
Chromium	38	19	101	80	370	37.3	90
Copper	29	20	66	65	270	35.7	197
Lead	36	27	47	50	220	35	91.3
Zinc	133	97	241	200	410	124	271

a. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality for the protection of aquatic ecosystems, Interim Sediment Quality Guideline (ISQG) Low (Trigger Level). Australia New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, October 2000.

b. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality for the protection of aquatic ecosystems, Interim Sediment Quality Guideline (ISQG) High. Australia New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, October 2000.

c. The Canadian Sediment Quality Guidelines for the protection of aquatic life, Interim Sediment Quality Guideline (ISQG). Canadian Council of Ministers of the Environment, 1999, updated 2001.

d. The Canadian Sediment Quality Guidelines for the protection of aquatic life, Probable Effect Level (PEL). Canadian Council of Ministers of the Environment, 1999, updated 2001.

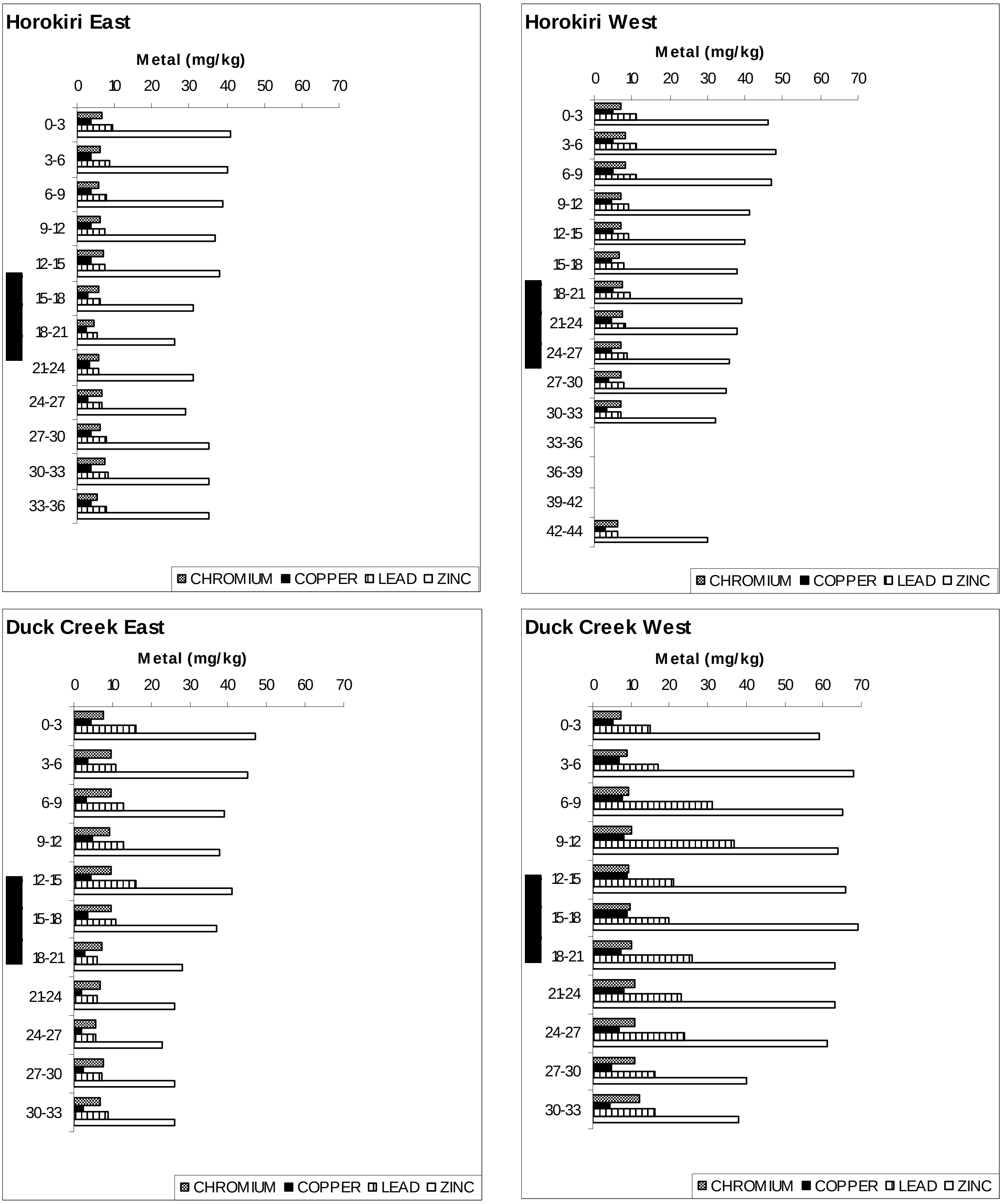

Figure 15. Trace metal concentrations in sediment as a function of depth in cores from east and west of the Horokiri Stream and Duck Creek discharge points, in the Pauatahanui Inlet.

6.5.2 CHROMIUM

In comparison to other sites, levels of Cr in the sediment were slightly higher in the core from the Duck Creek West site. The results at the Duck Creek East site were also slightly higher than those found at the outlet of the Horokiri Stream. Levels of Cr at the Duck Creek west site also increase with depth.

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (the NZ Guidelines) for the protection of aquatic ecosystems recommend an Interim Sediment Quality Guideline (ISQG) low (trigger) level of 80 mg/kg dry weight Cr, while the high ISQG level determined is 370 mg/kg dry wt. The maximum level of Cr in the sediment sampled during this study was 12 mg/kg dry weight, which is well below the ISQG determined in the Guidelines.

The Canadian Sediment Quality Guidelines for the Protection of Aquatic Life specify an interim sediment quality guideline (also ISQG) of 37.3 mg/kg and a 'Probable Effects Level" (PEL) of 90.0 mg/kg for Cr. The levels found in this study are also well below the Canadian guidelines.

The results of the study by Glasby (1990), also indicate that the levels of Cr in the sediments throughout the Inlet are within the guideline levels for Cr, however of note is the maximum level of Cr detected which exceeds the NZ ISQG–low guideline trigger value. Also exceeded by the maximum levels of Cr found in the 1990 study were the Canadian ISQG and PEL.

There did not appear to be any distinct correlation between changes in the core profile and levels of Cr in any core. Chromium levels were reasonable consistent with depth, increasing slightly in more recently deposited sediments in all cores.

6.5.3 COPPER

Copper was almost twice as high in the Duck Creek West core than in the other cores taken. Based on the study by Brown (1999), Cu is reasonably mobile under saline conditions, and less likely to remain in the oxidised surface sediment. At depth, Cu is immobilised as copper sulphide.

NZ Guideline ISQG-low level for Cu is 65 mg/kg dry weight, and the high level is 270 mg/kg. Even adopting the 'low' level for the sensitivity of the Pauatahanui Inlet ecological environment, the levels of Cu recorded in the sediments studied are still well below guideline levels (maximum 9.1 mg/kg).

The maximum level of Cu detected in the 1990 sampling by Glasby *et al* is around the NZ ISQG-low trigger level, and in excess of the Canadian ISQG. The maximum Cu level at this time was well below the NZ ISQG-high trigger level, and the Canadian PEL.

There did not appear to be any distinct correlation between changes in the core profile and levels of Cu in any core, with Cu levels being reasonably consistent with depth, increasing slightly in more recent sediments.

6.5.4 LEAD

Lead levels were highest in the Duck Creek West core. There is evidence in this core that levels of Pb may be decreasing over time, however in other cores there is no such evidence. Lead was highest in the Duck Creek West sediment core, and perhaps provides the best indication of the influence of motor vehicles on contaminant levels. Levels of Pb at the other 3 sites were not high.

The maximum level of Pb (37.5mg/kg) detected during this research, and the maximum recorded by Glasby *et al* (1990) (47mg/kg) was below the NZ ISQG-low trigger level, however in excess of the Canadian ISQG. Naturally, the NZ guideline is given more weight in these circumstances.

In the Duck Creek West core, higher concentrations of Pb were recorded at depths between 60mm to 260mm in comparison to other depths in the core. This also appeared to be the case in the Duck Creek East core, though less marked, at depths between 60mm and 180mm. The two cores from the Horokiri side of the Inlet recorded more consistent Pb levels throughout the core.

6.5.5 ZINC

Levels of Zn at the DCW site were approximately double those at all other sites, even the site to the east of Duck Creek (DCE site) which is located in the same bay of the Inlet.

The most likely cause for this is the influence of flow in the inlet. In light of the results for all metals, it is reasonable to assume that the point to the west of Duck Creek is an area where sediments are likely to settle out after flowing down Duck Creek. These results are consistent with previous research that demonstrates that heavy metals adhere to sediment particles and areas where suspended solids settle out are likely to have higher levels of heavy metal contamination.

Despite the levels at DCW being higher than the other 3 sample sites, it is noted that the NZ Guideline ISQG-low level for Zn is 200 mg/kg dry weight, and the high level is 410 mg/kg. The maximum level of Zn found in the sediment was 69 mg/kg dry weight (DCW). This suggests that there is no immediate threat to aquatic ecosystems from the current levels of Zn in sediment at these sites. However again, it is apparent that there is an 'external' source of Zn contributing to levels in sediment at DCW, and probably at other sites in the southern bays of the Inlet.

Levels of Zn were also well below the Canadian Guidelines (ISQG 124 mg/kg and PEL 271 mg/kg).

Maximum levels of Zn were within the NZ guidelines for this research, however of note is that the results from Glasby *et al* exceeded the NZ guideline (ISQG-low trigger level). The Canadian ISQG was also exceeded by results of the 1990 study.

There did not appear to be any distinct correlation between changes in the sediment composition through the profile and concentrations of Zn in any core.

6.5.6 COMPARISON – GLASBY *et al* & CURRENT STUDY

On average, the results of both this study and the study undertaken by Glasby *et al* in 1990, complied with the NZ ISQG-low trigger values. Some of the maximum results in the 1990 study did reach the trigger levels in the guidelines.

The study undertaken in 1990 by Glasby *et al* was more extensive than this study, and focussed on the surface sediments. The 30 sampling sites were distributed throughout the Inlet, and it is likely that more areas that receive suspended solids deposition were encountered during the 1990 study. The study carried out as part of this research was different to the 1990 study in that sediment cores taken as part of this research are able to indicate the trend in deposition of contaminants in the sediment over time.

7. DISCUSSION

7.1 A NOTE ON DETECTION LIMITS

The detection limits used in this study, in many cases, are higher than the trigger guideline level. It is likely that in some circumstances the trigger guideline level may have been exceeded, however this has gone undetected.

It is considered that the detection limits in this study are low enough to give a reasonable indication of whether there is an environmental problem in the Inlet.

7.2 HEAVY METALS IN PAUATAHANUI INLET

Increases in heavy metal concentration in water samples (from the tributaries of suburban catchments and in the Inlet itself) coincided with episodes of rainfall. This is consistent with mobilisation of particles as a result of runoff, and the knowledge that heavy metals absorb on to these suspended particles and are transported in the environment. This is further demonstrated as levels of suspended solids in the samples were also higher on these occasions.

When these suspended particles, with their absorbed heavy metals, reach low energy situations, they cease to be carried along and are able to settle out (deposit) on the substrate. This is demonstrated in the results of analysis of the sediment core samples.

The presence of higher levels of heavy metals in the Duck Creek West core in comparison to other cores indicates that there will be other (untested) sites in the Inlet that receive deposition of heavy metal laden particles.

Potentially ‘at risk’ areas will likely be in locations where sediment naturally settles out of the water column (e.g. sheltered embayments and low ‘energy’ areas). Water quality results indicate that these areas are more likely to be in the vicinity of the Browns Bay Stream, and the Pauatahanui Stream, both of which recorded heavy metal concentrations which exceeded guideline levels on occasions. Some potential deposition areas may have been partly demonstrated in the results obtained by Glasby *et al* (1990), which presented results from 30 surface sediment samples taken from the Pauatahanui Inlet. This study found four areas within the inlet which had higher zinc levels in sediment (presented as Igeo Class) when compared to other sites.

Heavy metal concentrations in sediment cores did not exceed interim sediment quality guidelines for NZ for lead, zinc, copper and chromium. A comparison with Canadian interim sediment quality guidelines also showed that the levels were below these. However, the presence of heavy metals in water and sediments cannot be overlooked for the reason that it indicates a potential problem. In the case of zinc in particular, the concentrations in sediment appear to be increasing, with higher levels found in more recently deposited sediments. As the area of residential land use increases throughout the Inlet, it is anticipated that this trend will continue.

The presence of higher levels of metals in the Duck Creek West sediment core indicates that heavy metal contaminated suspended solids are settling out in the Inlet at this point. This is further emphasised by the water samples taken from the Inlet and the contributing streams, and by the study undertaken by Glasby *et al* (1990) which found elevated levels of zinc in this area when compared to other parts of the Inlet. In this core, lead levels appear to have decreased in recent times, which coincides with the removal of leaded petrol from the market. Zinc levels however were higher in the surface sediments, and the rate of deposition of this contaminant on the substrate of the Inlet in this area appears to be increasing over time.

As previously discussed, the land use in the southern catchments of the Pauatahanui Inlet is residential, with small areas of rural use. The sources of the contaminants found in the Duck Creek cores (east and west) will therefore be ‘residential’ in nature. In a study by Tom Snelder (NIWA, 1995), it was estimated that in urban catchments, vehicles contributed 40% of the zinc contamination present in stormwater, 100% of lead contamination, 50% of copper contamination and 50% of suspended solids contamination. It is significant to note that levels of lead and zinc were notably higher in the cores from the residential ‘side’ of the inlet, which reflects the greater influence transport has on the stormwater discharging to this side of the Inlet.

Vehicles are therefore likely to be the main source of stormwater contamination in the southern catchments. There is evidence in the Duck Creek West core that levels of lead may be decreasing over time, now that lead based fuels are no longer used in NZ. There is, however, no such evidence in the other 3 cores. This is most likely because there is still lead present in the environment from these times, particularly as lead is absorbed onto particles in the environment, and these particles may take some time to reach waterways. While possibly co-incidental, lead concentration appeared to increase in coarser sediments at depths around 60mm to 180/200mm in the Duck

Creek cores. This may indicate that there was a comparatively high input of lead into the Inlet at this time. Based on sedimentation rates of 3mm/year estimated by Healy (1980), this would have occurred approximately 20 years ago.

Other residential sources of heavy metal contamination could be paint residue entering the stormwater system, house cleaning, and discharges from galvanised iron roofs. It is possible that some other activities may lead to isolated incidents of contamination which could affect heavy metal levels in sediments. For example, the Wellington Regional Council Pollution Response Department reported a small number of incidents involving paint residues being water blasted from homes and entering the inlet via stormwater. Whether these residues were of leaded paint is not known (WRC pers. comm.).

Chromium may be related to use of tanalised timber (treated with CCA – Copper, Chromium & Arsenic) in building in the urban areas. Levels of chromium at the Duck Creek west site increase with depth. This may also indicate that chromium inputs into the Inlet were greater in the past, which would be consistent with the steady development in the past in terms of inputs from tanalised timber.

Based in this information, and that presented in the other studies cited, it is fair to assume that the amount of heavy metal contamination that would enter the Inlet would increase as a result of further urbanisation of the catchment.

Due to the rural nature of the northern sub-catchments, the discharges from the Horokiri, Kahao and Ration streams are unlikely to be of large concern at the current time in terms of the potential for accumulation of heavy metals in the sediment, and heavy metals contamination of marine and fresh water. Water quality results have indicated however that some nutrient enrichment may be occurring. Riparian zones on these streams would help to reduce this.

The results of this study indicate that any proposal to alter the zoning of the northern catchments from Rural to Residential should be carefully considered. Proposals to allow more intensive subdivision or improvements to roads which may result in higher traffic volumes should also be carefully considered, and in the event that this occurs, attention should be paid to mitigation measures for contaminated runoff.

As an example of mitigation measures, examination of the results has revealed that heavy metal concentrations in water are linked to episodes with higher suspended sediment. This is consistent with the behaviour of metals in the water, absorbing on to suspended particles. Settling basins have been demonstrated to be effective at reducing heavy metal concentration, as they settle out the sediment and adsorbed metals, retaining them in situ. This is discussed further in section 6.7.

The guideline levels used in this study have been set by the ANZECC based on protection of 99% of the species present in the ecosystem. The exceedance of these guidelines, which this study has demonstrated is occurring in freshwater and marine water in the Inlet on occasions, indicates that loss of species is likely to be occurring throughout the Inlet and its tributaries, based on current levels of heavy metal contamination.

To take this one step further, a loss of biodiversity may be occurring in the Pauatahanui Inlet and its catchment as a result of the contaminated stormwater inputs identified in this study.

7.3 NUTRIENTS & PHYSIOCHEMICAL STATUS OF PAUATAHANUI INLET

Nitrogen levels exceeded NZ guidelines for freshwater quality on at least one occasion at all freshwater sites except Kahao Stream and Pauatahanui Stream, with phosphorus levels exceeding guidelines at all sites on at least 2 of the 5 sampling occasions. Nitrogen and phosphorus were also exceeded at many of the marine water sites on a number of occasions.

This clearly indicates that nutrient enrichment of the waterways is a concern in terms of the health of the receiving ecosystem, and the nutrient levels identified may be placing stress on the species present (or which would normally be present) in the Inlet, and in the tributaries of the catchment.

The study by Healy (1980) demonstrated that N & P levels increase in winter when rainfall is higher and plant uptake is lower. Seasonal variations are not presented in this study, and the time after rainfall was probably not long enough to pick up any nutrients leaching into streams through groundwater (i.e. this study detected nutrients inputs from surface flows only).

Nutrient enrichment is not restricted to the rural catchments, so the source cannot be attributed entirely the agricultural sector. While the solution to nutrient enrichment in the rural catchments often lies in riparian management, sources of nutrients in the urban catchments are many and varied (from garden fertiliser, to car washing detergent, to dog faeces), and therefore less easily managed.

Management of the nutrient inputs in to the Inlet and its tributaries will therefore require an approach tailored to the inputs specific to the land use.

7.4 BACTERIA

Bacteria levels (enterococci and e-coli) were consistently high in fresh and marine water after periods of rainfall. Results were above bathing water quality guideline levels.

Contaminated stormwater flows would have played a part in the elevated levels, however it is noted that bacteria counts increase with turbid conditions, as they adhere to substrate particles and become dislodged when the water is disturbed.

There is insufficient data to determine whether there is direct sewage discharge to the Inlet, however the results are low enough to indicate that in the streams studied, there were no excessively high bacteria counts which would be consistent with a sewage discharge.

7.5 IMPLICATIONS FOR MANAGEMENT OF THE INLET

When we compare the levels of heavy metal contamination in the Pauatahanui Inlet to other estuaries in New Zealand, we find that Pauatahanui is relatively unpolluted. The Hatea estuary in Whangarei, the estuaries of the Auckland Harbour, and the Wellington Harbour are facing considerable higher levels of contamination than the Pauatahanui Inlet. However, this comparison needs qualification and it is emphasised that:

- The Pauatahanui Inlet does not receive, and has never received, significant industrial discharges, or overflow discharges of municipal sewage.
- The source of contamination is residential – and the area of residential land use in the catchment is increasing rapidly, as more and more people seek the pleasure of living somewhere like Pauatahanui Inlet.
- Receiving environments of this nature are very rare in this part of New Zealand, and there is high ecological sensitivity in this case.

Due to the lack of industrial or municipal discharges into the inlet, it is fair to conclude that the majority of the heavy metal contamination entrained in stormwater runoff is sourced from motor vehicles. There will be small quantities that are attributable to other sources – for example there is a possibility that some heavy metal contamination comes from galvanised iron roofs or treated timber used in building.

For this reason, when we assess the current land use in the Pauatahanui Catchment and the proposed future developments in the catchment in conjunction with the ecological sensitivity of the receiving environment, we can conclude that the future of the Inlet is threatened by contamination in stormwater runoff from urban areas.

As we watch as other estuaries in New Zealand become more and more degraded through discharges of an industrial nature, municipal sewage, and contaminated stormwater, Pauatahanui Inlet presents itself as more and more pristine. However, if we continue to compare the Pauatahanui Inlet with some of the more heavily contaminated systems, we are unlikely to see the problem until it is too late. This is why comparison with the ANZECC guidelines is invaluable. These guidelines enable a fair assessment of the contamination levels in the Inlet to be made.

It appears that that the biggest threat in terms of heavy metal contamination of the Inlet is transport.

Until the day arrives when contamination from vehicles can be controlled at source, the most cost effective mechanism of avoidance, remedy or mitigation of the adverse effects of the discharges of stormwater contaminated with wastes from vehicles, will be located at the end of the pipe, or at some point after the water has left the roadway. This can be incorporated in roading design for new roads, however retrofitting these methods to existing roads is also able to occur. There will be added benefits of these 'end of pipe' solutions, in terms of other contaminant discharges (e.g. silt control), however the remainder (e.g. silt generation) are able to be addressed by dealing with the problem at source. Section 6.7 discusses stormwater management options.

More detailed monitoring of the streams during rainfall events could aid in isolating the particular stormwater catchments of concern, and provide an indication of the priority areas. However, worthy of comment is the significant cost of this monitoring in terms of time and analysis, and number of samples required. For example, it may be more suitable to direct this cost into installation of more sediment retention basins on more stormwater outlets to address current, and potential future contamination. These are all questions for regulatory authorities to consider.

7.5.1 WHO IS RESPONSIBLE FOR STORMWATER MANAGEMENT IN NEW ZEALAND?

Management of stormwater discharges is covered by the RMA 1991 in New Zealand, and responsibility for carrying out the RMA 1991 falls on the shoulders of Regional and Local Councils (Territorial Authorities).

The RMA 1991 recognises that land use has a major impact on the surrounding environment, and gives Regional Councils the responsibility for controlling land use for "the maintenance and enhancement of the quality of water in water bodies and coastal water" [sec 30 (c)] [White, 1992]. Regional Councils also have the responsibility to control land use to avoid and mitigate natural hazards [30 (c) (4) RMA 1991].

Territorial Authorities have control over actual or potential effects of the use, development or protection of land, and the power to restrict subdivisions where "damage from inundation of any source" could possibly be suffered or accelerated or worsened [s106(1)(a)&(b)]. Because stormwater is related to both land and water resources, control of it needs to be addressed with regional and district planning. [White, 1992].

Sections 12 (coastal marine area), 13 (river beds), 14 (water use) and 15 (discharges of contaminants) of the RMA 1991 are managed by regional councils, usually with Resource consents [Wellington Regional Council, 1999]. The Building Act (1991) and the Local Government Act (1974) can be used to control urban development in terms of infrastructure, while sections 9 (land-use activities) and section 11 (subdivisions) are the parts of the RMA 1991 which fall under the jurisdiction of Territorial Authorities (Barrell, 1997).

The Wellington Regional Council (WRC) has three regional plans that contain rules about stormwater discharges. These are:

- The Regional Coastal Plan (Operative June 2000)
- The Regional Plan for Discharges to Land (Operative December 1999)
- The Regional Freshwater Plan (Operative December 1999)

The Regional Plans discuss stormwater management, and a key tool identified in pollution prevention is environmental education. As discussed earlier, however, the impact of education on the attitudes towards vehicle use is limited.

The Porirua City Council (PCC) has control of stormwater while it is in the stormwater system and before discharge to a natural waterway. Once the ‘contamination’ enters a natural watercourse, or the Coastal Marine Area (e.g. the Pauatahanui Inlet), responsibility then falls on the WRC. The WRC can also control source discharges of contaminants before they reach a stormwater system, as these are classified in many cases as a discharge to land in a manner that may enter water (WRC pers. Comm. 2000.) .

It is clear that this complex situation therefore calls for a joint approach to this problem, at least by the WRC and the PCC.

Other organisations with a role to play in the management of the Inlet may include the Department of Conservation (DoC) and the Ministry of Fisheries, as DoC manages a number of reserves in the area, and the Ministry of Fisheries has an interest in the impact on fish life and fisheries stocks. There are also a number of local interest groups.

This co-operative approach has been occurring. An example of this is the document entitled “Integrated Management of the Pauatahanui Inlet” which was published in

1995 by the WRC, PCC, DoC and MAF Fisheries. In this document it is noted that "The risk to the Inlet from the multiplicity of management agencies has declined and should not pose a problem in the future".

This document addresses the management of the Inlet in general, hence the involvement of the DoC and MAF. Stormwater management forms a part of the overall management of the Inlet, and falls under the jurisdiction of the Regional and City Council. It is one aspect of a large and complex system.

7.6 SUSTAINABLE URBAN STORMWATER MANAGEMENT

The literature on urban stormwater runoff indicates that the way in which stormwater runoff from non-point sources (predominantly transport) is currently managed in NZ (and many other countries in the world) is unsustainable. The research at hand demonstrates that this is also likely to be the case at Pauatahanui. To understand why this is so, we must first understand what 'sustainable' means.

7.6.1 WHAT IS SUSTAINABLE?

'Sustainable' is a word that has many definitions in the literature, and its definition and significance has been widely discussed in conjunction with a number of natural resource management problems. While global reports, such as Agenda 21 (1991), the World Conservation Strategy (1980) and the Brundtland Report (1987) address environmental sustainability on a global scale, there is little information regarding what sustainability means in terms of localised areas – such as a stormwater catchment. Smith *et al* (1993) suggests that sustainability may be achieved when the "co-existence of ecological diversity and urban development has been reached". This appears to compliment the Resource Management Act 1991, which has the purpose of promoting the sustainable management of natural and physical resources, prescribing for the "use, development and protection of natural and physical resources, in a way, or at a rate, which enables people and communities to provide for their social, economic and cultural wellbeing and for their health and safety" [Ministry for the Environment 1991]. As this thesis discusses a resource management issue in New Zealand, the RMA definition is the one to be used throughout this research.

Under the RMA, all people are responsible for the generations of the future, and ensuring their wellbeing and health and safety.

7.6.2 IS CURRENT MANAGEMENT OF THE INLET SUSTAINABLE?

The key findings of this study are consistent with other literature that demonstrates stormwater runoff from transport sources is a main cause of contamination of water and sediment.

It must be acknowledged that urban development will have some adverse effects on the environment, and that even the best management of stormwater cannot eliminate all of the adverse outcomes. White (1992) and Strecker and Reininga (1999), identify that the only way to guarantee that the effects of urban development on sensitive receiving environments can be avoided, is to prevent stormwater discharges occurring. This may involve elaborate stormwater treatment systems, or may mean that development cannot be permitted in sensitive areas.

It is also acknowledged that control of non-point urban stormwater pollution at its source, in particular emissions from motor vehicles, will be nearly impossible. In the foreseeable future the phasing out of vehicles is highly unlikely. For this reason, end of pipe treatments may be the most favourable option, coupled with education and awareness programmes (Author unknown, 1996). This will at least enable the generations of today to minimise the problem.

The information presented has indicated that significant levels of contaminants are present in the sediments of Pauatahanui Inlet. This was the case in 1990 (Glasby *et al*), and appears to be the case today. It can therefore be expected that contamination will increase in conjunction with future development of the sub-catchments of the Pauatahanui Inlet. Further contamination from existing developments can also be expected, and the net effect is compounding levels of contamination.

Left unchecked, in the face of increasing urbanisation of the catchment, the levels of pollution entering the Inlet from stormwater are likely to rise. Comparison of current contamination levels with ANZECC guidelines suggests that this will impact upon the ecological diversity of the inlet, and in some areas, may already be doing so. This in turn may limit the enjoyment and use of the inlet for future generations.

7.7 SCIENCE AND PLANNING

This study has been based on the results of five sampling runs, and the findings of a sediment investigation. In the terms of some investigations, this one may be slightly more advanced than some initiated, however, interpretation of the results must consider that:

- The research did not cover seasonal, or diurnal variations.
- It presented a 'snap shot' in time.
- The detection limits of equipment used were, in some cases, higher than the guideline levels to which the results were going to be compared.

While data collection was limited, analysis in relation to other prior research shows that the measurements were not outside those predicted and therefore there is no reason to doubt the findings of this study. Bearing in mind the limitations identified, this research still presents valuable information to the authorities responsible for managing the Pauatahanui Inlet.

Our regulatory agencies need to know, as precisely as possible, where the main environmental problems lie. Which catchments are the problematic ones? Are there any characteristics which suggest point source contamination? These are just two of the questions that should be asked before a decision on the method, means and magnitude of a pollution prevention or clean-up is instigated.

The Australian and New Zealand Guidelines for Fresh and Marine Water, which are used in this research, have been developed around a 'critical effect' level. Because it is most desirable to prevent adverse effects occurring before the event, they have developed threshold levels that are lower than the level at which effects are known to occur. The severity of the potential impact (e.g., irreversible damage, or a persistent pollutant) is used to determine the threshold, or trigger value. These are the guideline levels presented alongside the data in Tables 3-12.

In the presentation of the results of the research undertaken, the maximum levels of contamination found in the Inlet during the 5 sampling runs are presented. This is a very conservative approach. The guidelines themselves are very conservative, plus the use of the maximum (instead of say, the average) is even more conservative.

This conservative approach (in both the guidelines and this study) stems from the knowledge that in some systems, it only takes one 'dose' of the maximum concentration to efficiently dispatch some species from an ecosystem.

Knowledge of the extent of the problem at hand, its precise location, and the nature of the contaminants involved enables the planning agencies to make more informed decisions, which will result in better environmental management.

The monitoring undertaken as part of this research will enable the Council to make some important decisions. These decisions stem around where to direct future resources (people and finance) in terms of avoiding, remedying and mitigating the effects of runoff on Pauatahanui Inlet.

7.8 STORMWATER MANAGEMENT OPTIONS

This section briefly discusses the options available for management of stormwater in the Pauatahanui Inlet.

7.8.1 PLANNING AND REGULATORY METHODS

Planning and regulatory methods to manage stormwater include;

- Land use zoning.
- Controls on discharges and activities (e.g. point source discharges from industry or the use and storage of hazardous substances) through resource consents or district and regional plans.
- Urban design initiatives.
- Enforcement of resource consent conditions and regional/district plan provisions.

Land use zoning, discharge controls (resource consents and Regional Plan performance standards) and enforcement provisions are in place in the Wellington Region, and Porirua City, and apply to management of the Pauatahanui Inlet. There is also the opportunity for urban design initiatives, and subdivision design initiatives which emphasise stormwater management, in particular contamination.

7.8.2 EDUCATION

Education of the public and private sector about how their household or business can contribute to pollution, and alternative means which are better for the environment, can be very successful. Mechanisms are varied and usually offer a combination of approaches. They include posters, radio & newspaper advertisements, seminars, brochures, and labelling stormwater drains.

A variety of educational programmes have been run in and around the Pauatahanui Inlet, from region-wide programmes instigated by the WRC (e.g. the 'Drains to Streams campaign), to those specifically focussed on the Pauatahanui Inlet. The success of these educational programmes is often difficult to monitor, however it is fair to say that general awareness in the community has been increased as a result.

7.8.3 SOURCE CONTROLS

Catch pits (in stormwater sumps) have proven to be effective at trapping particles of greater than 250µm in size (Jarret & Godfrey, 1988). These require proper management (cleaning out the sediment and maintenance of the outlet) to ensure that the trapped sediments are not re-mobilised during high storm flows, and have an added sediment control benefit.

Auckland City Council, and other Councils in the Auckland Region have been trialling methods including:

- More frequent street sweeping to pick up particles and debris.
- More regular cleaning of catch pits.
- Retrofitting of filter bags in the catch pit outlets.

The success of these trials will be known soon.

Stormwater collection and re-use is another option. A study by Watercare Services Ltd (1996) into future water supply options in Auckland noted that directing stormwater for non-potable uses would be expensive due to the infrastructure required. However their report further noted that there may be scope to provide the required infrastructure with new subdivision developments.

The Watercare Services report also investigated the potential for the use of household tanks for domestic water supply, which would in turn reduce the amount of run-off into stormwater drains. Such collected water could be used for gardens and toilet flushing if the appropriate plumbing was installed on a dwelling. Concerns about the potential for airbourne contaminants to contaminate this water supply were highlighted. However, this option should not be discounted in Pauatahanui Inlet, which often experiences water shortages and hosing restrictions in summer. The Pauatahanui area experiences less air pollution than parts of Auckland (WRC, 2000).

Reduction in the area of impervious surfaces in a catchment is another method of reducing the amount of runoff entering the stormwater system, and subsequently, waterways. This requires the integration of stormwater issues into initial design of subdivisions/roads, or alternatively, retrofitting/redesigning with stormwater in mind. Considerations include the soil infiltration and rainfall characteristics and availability of land for such purposes (ARC 1998). In the Whitby area, some consideration has been given to this aspect of stormwater control. Two man-made lakes are present in the western arm of Duck Creek, near the shopping centre, and these act as sediment retention ponds. However, the results of this study indicate that there is still a problem in this catchment, and it is noted that a considerable amount of runoff will enter this stream downstream of the ponds, and in the eastern arm.

Riparian vegetation plays a number of roles which enhance the in stream environment and mitigate the effects of stormwater runoff. These include filtering sediment from overland flow, denitrification of groundwater prior to entering streams and buffering effects of stream bank erosion. The appropriate width of a riparian margin depends on the nature of the site (ARC 1998).

All new high use roads in the Auckland Region have been required to implement suitable stormwater quality treatment measures, since 1992. A favoured approach has been the integration of overland flows through grassed swales and batters, and the construction of ponds or wetlands above discharge points (ARC 1998). The regulatory framework is in place to enforce similar measures on any major roading developments in the Pauatahanui catchment.

7.8.4 STRUCTURAL SOLUTIONS

Common stormwater treatment devices include (source ARC 1998):

- Ponds & Wetlands

There are various types of ponds that can be used to provide protection from increased peak flows and stormwater quality benefits. In terms of maintenance of stormwater quality, all ponds rely on removal of suspended sediment via provision of a low energy environment where suspended sediment will settle.

- Bioretention

Bioretention relies on vegetation cover and landscaping to improve stormwater quality. Examples include;

- Vegetative filter strips (strips of dense vegetation or grass which slow overland water flows resulting in sediment deposition and filtering)
- Grass Swales, which are open, grassed drains. These allow soakage and filtering to occur.

- Sand filtration beds, which rely on filtration of the stormwater through a sand filter.
- Infiltration trenches are rock filled trenches which fill with stormwater and then empty via soakage of the water into surrounding soil. Limitations include soil type and porosity
- Oil separators collect hydrocarbons that float on the surface of the water, though are not usually suitable for general stormwater treatment as by the time the oil reaches the device, it can be emulsified or coated on sediment.
- Coarse sediment traps are usually installed prior to a final treatment to catch the larger particles. These work well where there is limited room available for treatment.
- A variety of proprietary filter devices (e.g. wool filters & filter cloths) are available for various circumstances.

The above are a few examples, and should this method be considered, the most appropriate method would need to be investigated. There will be site, soil, location and topographical constraints on the placement of structural stormwater management systems, however there is scope for such mechanisms to be installed in the Pauatahanui Inlet.

The significant advantage of structural systems, which are effectively ‘end of pipe’ solutions, is that they are able to mitigate the effects of contamination of stormwater from vehicle sources, whereas often policy, education and source controls are unable to do so.

8. CONCLUSIONS

- Guideline levels for heavy metals (for 99% species protection, Ministry for the Environment, New Zealand) in freshwater are being exceeded in the Pauatahanui Inlet on occasions. These guideline levels have been set based on protection of 99% of the species present in the freshwater ecosystem s feeding into the Inlet. Exceedance of these guidelines indicates to the authorities responsible for the management of the Inlet and its catchments that loss of species is likely to be occurring based on current levels of heavy metal contamination. This further suggests that here may be a loss of biodiversity in the Inlet and its catchment as a result of contaminated stormwater discharges.
- Guideline levels for heavy metals (for 99% species protection, Ministry for the Environment, New Zealand) in marine water are also being exceeded in the Pauatahanui Inlet on occasions. Exceedance of these guidelines again indicates to the authorities responsible for the management of the Inlet that loss of marine species is likely to be occurring, based on current levels of heavy metal contamination. This further suggests that here may be a loss of biodiversity in the Inlet as a result of contaminated stormwater discharges.
- Heavy metals of concern in both fresh and marine water include copper, chromium, zinc and manganese. Iron levels were also exceeded however the sources of this may be natural.
- Levels of Nitrogen and Phosphorus exceeded the guideline (MfE) trigger values for physical and chemical stressors in both marine and freshwater on a number of occasions, at almost all sites studied. This suggests that the levels present will be impacting upon the ecology of the fresh and marine water environment, and indicates that some management should focus upon minimising the inputs of nutrients into the Inlet and its tributaries. This applies to both the urban and rural catchments, however management techniques will need to be tailored for the different land use areas, given the different nutrient inputs present.
- Sediment cores taken from 4 sites in the Inlet have suggested that the inputs of heavy metals have varied over time. The Duck Creek West core recorded the highest levels of all heavy metals. This core was located in an area of the inlet where it is apparent sediment from the nearby Duck Creek settles out and deposits on the bed of the Inlet. It is likely that there are other low energy areas in the Inlet where similar deposition is occurring, particularly in the vicinity of streams discharging from the suburban sub-catchments.
- The results of the core sampling are consistent with findings of other studies

demonstrating that heavy metals absorb onto suspended particles, and their concentration is likely to be higher in areas where the particles settle out. This suggests that stormwater treatment mechanisms which reduce the amount of suspended particles entering the Inlet (e.g. sediment retention basins/settling ponds), and means of reducing the velocity of stormwater flows to reduce the amount of particles which become mobile, would be appropriate at this site. Such mechanisms would work in partnership with mitigating the other significant concern facing the Inlet: increasing sedimentation filling the inlet and lowering water levels.

- After rainfall events, contaminants absorbed on suspended solids particles are being washed from the suburban zone into the Inlet. The discharge also carries nutrients and bacteria into the Inlet.
- It is most likely that vehicles are the main source of heavy metal contamination. This presents a problem for which the solutions are difficult to determine, however a number of options do exist for regulatory authorities.
- Riparian vegetation will help to reduce the nutrient inputs into the Inlet and the streams of its sub-catchments.

The WRC is the regulatory authority to whom it is likely the responsibility for management of, or co-ordination of management of the Pauatahanui Inlet will fall. The WRC has demonstrated a significant commitment to environmental management of the Inlet by commissioning this research, among other examples, which will provide them with a valuable insight into the problem and potential problems of contaminated stormwater discharges into this unique and valuable ecosystem.

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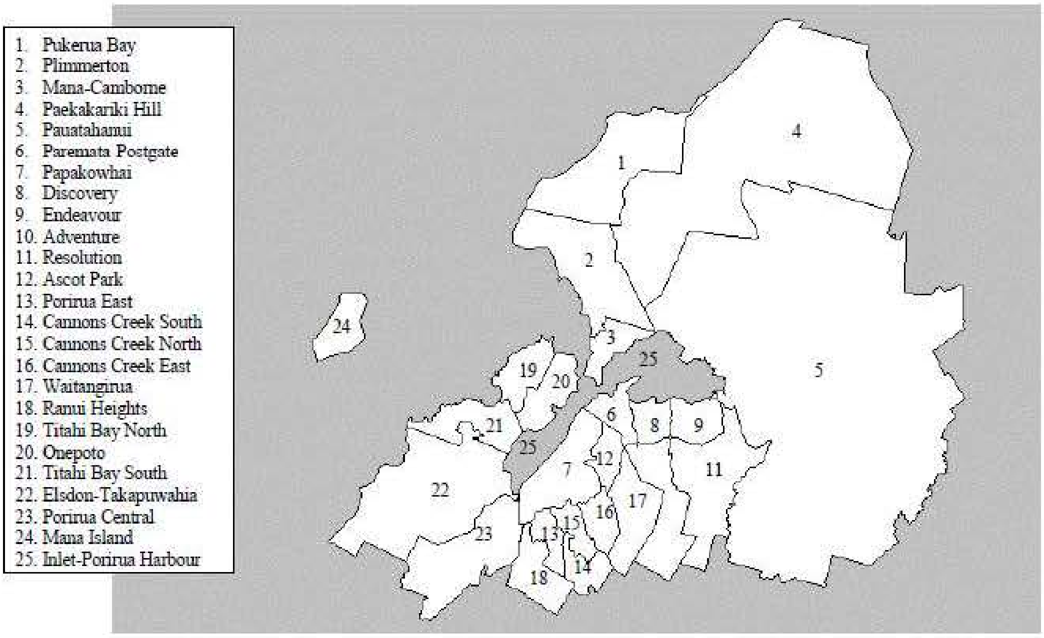
APPENDIX 1
STATISTICS NEW ZEALAND, MAP OF TERRITORIAL AREAS

PORIRUA CITY AREA UNITS

AS DEFINED BY STATISTICS NEW ZEALAND



APPENDIX 2
WATER QUALITY DATA TABLES

Table 1. Cadmium mg/L

Site	1 MAR 2001	2 MAR 2001	22 MAR 2001	27 MAR 2001	3 APR 2001
BR1	<0.005	<0.005	<0.005	<0.005	<0.005
DC1	<0.005	<0.005	<0.005	<0.005	<0.005
DC2	<0.005	<0.005	<0.005	<0.005	<0.005
HO1	<0.005	<0.005	<0.005	<0.005	<0.005
HO2	<0.005	<0.005	<0.005	<0.005	<0.005
KA1	<0.005	<0.005	<0.005	<0.005	<0.005
PA1	<0.005	<0.005	<0.005	<0.005	<0.005
RA1	<0.005	<0.005	<0.005	<0.005	<0.005
INL1	<0.005	<0.005	<0.005	<0.005	<0.005
INL2	<0.005	<0.005	<0.005	<0.005	<0.005
INL3	<0.005	<0.005	<0.005	<0.005	**0.006**
INL4	<0.005	<0.005	<0.005	<0.005	**0.005**
INL5	<0.005	<0.005	<0.005	<0.005	**0.006**
INL6	<0.005	<0.005	<0.005	<0.005	**0.006**

Table 2. Chromium mg/L

Site	1 MAR 2001	2 MAR 2001	22 MAR 2001	27 MAR 2001	3 APR 2001
BR1	<0.05	<0.05	<0.05	<0.05	<0.05
DC1	<0.05	<0.05	<0.05	<0.05	<0.05
DC2	<0.05	<0.05	<0.05	<0.05	<0.05
HO1	<0.05	<0.05	<0.05	<0.05	<0.05
HO2	<0.05	<0.05	<0.05	<0.05	<0.05
KA1	<0.05	<0.05	<0.05	<0.05	<0.05
PA1	<0.05	<0.05	<0.05	<0.05	<0.05
RA1	<0.05	<0.05	<0.05	<0.05	<0.05
INL1	-	-	-	-	-
INL2	-	-	-	-	-
INL3	-	-	-	-	-
INL4	-	-	-	-	-
INL5	-	-	-	-	-
INL6	-	-	-	-	-

Table 3. Copper mg/L

Site	1 MAR 2001	2 MAR 2001	22 MAR 2001	27 MAR 2001	3 APR 2001
BR1	<0.01	**0.03**	<0.01	<0.01	<0.01
DC1	<0.01	<0.01	<0.01	<0.01	<0.01
DC2	<0.01	<0.01	<0.01	<0.01	<0.01
HO1	<0.01	<0.01	<0.01	<0.01	<0.01
HO2	<0.01	<0.01	<0.01	<0.01	<0.01
KA1	<0.01	<0.01	<0.01	<0.01	<0.01
PA1	<0.01	<0.01	<0.01	<0.01	<0.01
RA1	<0.01	<0.01	<0.01	<0.01	<0.01
INL1	<0.01	<0.01	**0.01**	**0.01**	**0.01**
INL2	<0.01	<0.01	**0.01**	**0.01**	<0.01
INL3	<0.01	<0.01	**0.01**	**0.01**	<0.01
INL4	<0.01	<0.01	<0.01	<0.01	<0.01
INL5	<0.01	<0.01	<0.01	**0.01**	<0.01
INL6	<0.01	<0.01	<0.01	**0.01**	<0.01

Table 4. E Coli CFU/100ml

Site	**1 MAR 2001**	**2 MAR 2001**	**22 MAR 2001**	**27 MAR 2001**	**3 APR 2001**
BR1	6000	7100	1400	15600	17100
DC1	1200	100	106	100	100
DC2	258	18900	400	23000	2000
HO1	412	10200	300	7400	5100
HO2	900	4900	500	3400	9000
KA1	340	1140	870	4400	2700
PA1	240	1140	420	1140	480
RA1	230	310	720	1200	4400
INL1	<2	32	4	1000	0
INL2	12	6	226	160	320
INL3	<2	5	4	2800	5
INL4	2	3	21	17	0
INL5	10	2	5	195	4
INL6	<2	5	4	12	10

Table 5. Enterococci CFU/100ml

Site	1 MAR 2001	2 MAR 2001	22 MAR 2001	27 MAR 2001	3 APR 2001
BR1	1250	7800	600	9200	2200
DC1	160	7000	200	2000	500
DC2	132	8000	400	3700	1900
HO1	156	10000	200	9300	7200
HO2	236	4700	600	4800	7800
KA1	266	1180	420	2200	1500
PA1	240	980	230	700	660
RA1	490	3000	2800	1500	3700
INL1	<2	58	10	1600	16
INL2	10	8	96	160	740
INL3	<2	1	2	500	31
INL4	6	14	40	22	2
INL5	32	3	6	138	2
INL6	<2	20	3	14	48

Table 6. Total Iron mg/L

Site	1 MAR 2001	2 MAR 2001	22 MAR 2001	27 MAR 2001	3 APR 2001
BR1	2.2	1.5	1.4	0.82	1.3
DC1	0.07	0.05	0.04	0.04	0.11
DC2	0.23	0.43	0.24	0.56	0.32
HO1	0.11	0.51	0.07	0.14	0.43
HO2	0.76	<0.03	0.91	1.5	0.13
KA1	0.15	0.07	0.44	0.19	0.36
PA1	1.3	1.4	0.34	0.58	0.4
RA1	1.2	0.96	0.86	1.2	0.86
INL1	0.76	<0.03	0.91	1.5	0.13
INL2	0.69	0.17	0.54	2.5	0.18
INL3	0.22	0.03	0.04	1.8	0.22
INL4	0.28	0.78	0.14	1.0	0.34
INL5	0.25	1.3	0.14	0.29	0.59
INL6	<0.03	<0.03	0.03	0.25	0.09

Table 7. Total Manganese mg/L

Site	1 MAR 2001	2 MAR 2001	22 MAR 2001	27 MAR 2001	3 APR 2001
BR1	**0.65**	**0.35**	**0.53**	**0.12**	**0.32**
DC1	<0.03	<0.03	<0.03	<0.03	<0.03
DC2	<0.03	**0.05**	<0.03	**0.04**	**0.04**
HO1	<0.03	**0.03**	<0.03	<0.03	<0.03
HO2	<0.03	<0.03	<0.03	<0.03	<0.03
KA1	<0.03	<0.03	**0.16**	<0.03	<0.03
PA1	**0.55**	**0.33**	**0.05**	**0.12**	**0.03**
RA1	**0.23**	**0.12**	<0.03	**0.03**	<0.03
INL1	<0.05	<0.05	<0.05	<0.05	<0.05
INL2	<0.05	<0.05	<0.05	<0.05	<0.05
INL3	<0.05	<0.05	<0.05	<0.05	<0.05
INL4	<0.05	<0.05	<0.05	<0.05	<0.05
INL5	<0.05	<0.05	<0.05	<0.05	<0.05
INL6	<0.05	<0.05	<0.05	<0.05	<0.05

Table 8. Lead mg/L

Site	1 MAR 2001	2 MAR 2001	22 MAR 2001	27 MAR 2001	3 APR 2001
BR1	<0.05	<0.05	<0.05	<0.05	<0.05
DC1	<0.05	<0.05	<0.05	<0.05	**0.07**
DC2	<0.05	<0.05	<0.05	<0.05	<0.05
HO1	<0.05	<0.05	<0.05	<0.05	<0.05
HO2	<0.05	<0.05	<0.05	<0.05	<0.05
KA1	<0.05	<0.05	<0.05	<0.05	<0.05
PA1	<0.05	<0.05	<0.05	<0.05	<0.05
RA1	<0.05	<0.05	<0.05	<0.05	<0.05
INL1	<0.05	<0.05	<0.05	<0.05	<0.05
INL2	<0.05	<0.05	<0.05	<0.05	<0.05
INL3	<0.05	<0.05	<0.05	<0.05	**0.14**
INL4	<0.05	<0.05	<0.05	<0.05	<0.05
INL5	<0.05	<0.05	<0.05	<0.05	<0.05
INL6	<0.05	<0.05	<0.05	<0.05	<0.05

Table 9. pH

Site	**1 MAR 2001**	**2 MAR 2001**	**22 MAR 2001**	**27 MAR 2001**	**3 APR 2001**
BR1	7.0	6.9	7.0	6.9	6.9
DC1	7.4	7.3	7.3	7.3	7.2
DC2	7.5	7.1	7.2	7.0	7.2
HO1	7.7	7.6	7.7	7.5	7.5
HO2	7.6	7.7	7.4	7.2	7.5
KA1	8.4	8.8	7.6	8.0	8.9
PA1	7.1	7.2	7.2	7.3	7.3
RA1	7.3	7.2	7.1	7.1	7.4
INL1	8.0	8.1	8.1	8.0	8.1
INL2	8.0	8.1	8.0	8.0	7.8
INL3	8.1	8.1	8.0	8.0	8.0
INL4	8.1	8.1	8.1	8.0	8.1
INL5	8.1	8.1	8.1	8.0	8.1
INL6	8.1	8.2	8.1	8.0	8.1

Table 10. Salinity

Site	1 MAR 2001	2 MAR 2001	22 MAR 2001	27 MAR 2001	3 APR 2001
BR1	0.3	0.1	0.2	<0.1	0.1
DC1	<0.1	<0.1	<0.1	<0.1	<0.1
DC2	0.7	0.1	0.1	0.1	0.4
HO1	<0.1	<0.1	<0.1	<0.1	<0.1
HO2	<0.1	<0.1	<0.1	0.2	<0.1
KA1	21.5	0.1	11.5	16.7	0.2
PA1	7.3	4.3	2.1	8.6	0.3
RA1	<0.1	<0.1	<0.1	<0.1	<0.1
INL1	36.2	35.9	35.6	34.7	35.8
INL2	33.1	36.2	32.2	33.4	19.3
INL3	36.1	36.0	34.9	35.6	28.3
INL4	36.3	35.8	35.1	35.2	36.0
INL5	34.8	36.2	35.3	33.9	35.6
INL6	36.1	36.2	36.0	36.2	36.1

Table 11. Total Nitrogen (mg/L)

Site	1 MAR 2001	2 MAR 2001	22 MAR 2001	27 MAR 2001	3 APR 2001	GUIDELINE lowland river*
BR1	0.96	1.2	0.83	1.4	1.8	0.614
DC1	0.15	0.39	0.61	0.7	0.9	0.614
DC2	0.27	1.0	0.29	0.96	0.7	0.614
HO1	0.25	1.4	0.51	1.1	1.8	0.614
HO2	0.12	0.14	0.12	0.13	0.72	0.614
KA1	0.46	0.29	0.33	0.22	0.38	0.614
PA1	0.51	0.40	0.29	0.27	0.23	0.614
RA1	0.58	0.53	0.65	0.46	0.88	0.614
INL1	0.43	0.23	0.42	0.45	0.21	
INL2	0.60	0.45	0.35	0.51	0.44	
INL3	0.23	0.28	0.38	0.51	0.30	
INL4	0.26	0.36	0.23	0.26	0.23	
INL5	0.28	0.59	0.23	0.12	0.18	
INL6	0.12	0.20	0.11	0.12	0.13	

Table 12. Total Phosphorus mg/L

Site	1 MAR 2001	2 MAR 2001	22 MAR 2001	27 MAR 2001	3 APR 2001
BR1	0.072	0.067	0.053	0.12	0.16
DC1	0.031	0.056	0.045	0.067	0.048
DC2	0.028	0.095	0.049	0.12	0.051
HO1	0.008	0.063	0.03	0.07	0.078
HO2	0.13	0.026	0.03	0.024	0.061
KA1	0.024	0.014	0.056	0.12	0.067
PA1	0.036	0.058	0.05	0.059	0.034
RA1	0.07	0.076	0.07	0.092	0.071
INL1	0.059	<0.008	0.081	0.14	0.022
INL2	0.13	0.052	0.067	0.12	0.039
INL3	<0.008	<0.008	<0.008	0.14	0.029
INL4	0.017	0.045	0.017	0.086	0.034
INL5	0.014	0.011	0.039	0.06	0.025
INL6	<0.008	<0.008	<0.008	<0.008	<0.008

Table 13. Suspended Solids mg/L

Site	1 MAR 2001	2 MAR 2001	22 MAR 2001	27 MAR 2001	3 APR 2001
BR1	11	11	8	11	23
DC1	3	2	4	3	7
DC2	2	18	8	7	13
HO1	24	<2	9	2	2
HO2	2	2	3	14	4
KA1	9	3	10	-	9
PA1	16	17	15	-	19
RA1	5	5	9	-	12
INL1	45	4	66	-	9
INL2	63	12	120	-	9
INL3	16	4	120	-	5
INL4	15	40	8	-	24
INL5	15	78	10	-	9
INL6	5	3	5	-	25

Table 14. Zinc mg/L

Site	1 MAR 2001	2 MAR 2001	22 MAR 2001	27 MAR 2001	3 APR 2001
BR1	<0.03	**0.10**	<0.03	**0.19**	**0.12**
DC1	<0.03	<0.03	<0.03	<0.03	<0.03
DC2	<0.03	<0.03	<0.03	<0.03	<0.03
HO1	<0.03	<0.03	<0.03	<0.03	<0.03
HO2	<0.03	<0.03	<0.03	<0.03	<0.03
KA1	<0.03	<0.03	<0.03	<0.03	<0.03
PA1	<0.03	<0.03	<0.03	<0.03	<0.03
RA1	<0.03	<0.03	<0.03	<0.03	<0.03
INL1	<0.03	<0.03	<0.03	<0.03	<0.03
INL2	<0.03	<0.03	<0.03	<0.03	<0.03
INL3	<0.03	<0.03	<0.03	<0.03	<0.03
INL4	<0.03	<0.03	<0.03	<0.03	<0.03
INL5	<0.03	<0.03	<0.03	<0.03	<0.03
INL6	<0.03	<0.03	<0.03	<0.03	<0.03