The effects of human activities on stream water quality: Case studies in New Zealand and Germany

Paul Norman Doyle

Thesis submitted in partial fulfilment
of the degree of
Master of Applied Science

Earth and Oceanic Sciences Research Institute
Auckland University of Technology
Auckland, New Zealand

September 2005

Of all our natural resources, water has become the most precious…In an age when man has forgotten his origins and is blind even to his most essential needs for survival, water along with our other resources has become a victim of his indifference.

Rachael Carson, 1962: 39

Acknowledgements

I thank my supervisor, Professor Dr John Buckeridge, Director of the Earth and Oceanic Sciences Research Institute (EOS) at Auckland University of Technology (AUT), for his guidance, technical and moral support throughout this research project.

I also acknowledge the valuable help of Oliver Jost, an exchange student from the Wismar University of Technology, Business and Design (Hochschule Wismar), who worked with me from September to December 2000 and Eva Skinnars, an exchange student from Svenska Yrkeshögskolan University in Vasa, Finland, who worked with me in Wismar from May to August 2001.

I would also like to thank Neil Binnie, Dave Bryant, Dr Steve O'Shea, Dr John Robertson, Christine Sylvester, Barbara Jacomb, Christopher Whyburd, and Brid Lorigan of AUT, Auckland, for their advice and assistance with the procurement of equipment.

I am grateful for the technical and moral support I received from my supervisor in Germany, Professor Dr Manfred Sellner, Professor of Microbiology at the Wismar University of Technology, Business and Design (*Hochschule Wismar*). The help of Brigitte Schmidt, the technician at the university's Malchow Laboratories, was also invaluable.

Additionally, I would like to thank David Glover, Brent Evans and Phil White of the Auckland Regional Council, Michelle Kaczor and Sophie Heighway of the North Shore City Council, Klaus-Peter Haase of *Hansestadt Wismar* (the Wismar City Council), and Peter Bretschneider of Pro-wasser who provided advice, results and equipment.

Finally, cheers to my family and friends in New Zealand, Germany and Australia who put up with the ups and downs that the making of a thesis produces. Thanks to Hans for the use of his 'cupboard', and Trish and Brendan for proof reading. Special thanks go my wife, Susi, who was there for me on both sides of the world.

Abstract

Three case studies explore the effects of human activities on coastal streams and review measures to control the negative consequences of human activities. The first case study, an urban and a rural/forested stream in New Zealand, measured descriptors of water quality, including nutrients, dissolved oxygen and bacterial indicators of faecal contamination. The urban and rural catchments have stream-water qualities that fail to meet standards for fish life or bathing. Of the five sites studied, only one catchment, which had a substantial forest component (50%), had bacterial counts which meet the Australian Recreational Water-quality Guidelines for Secondary Contact (Faecal coliforms and enterococci, ANZECC, 2000) and the New Zealand Interim Guidelines for Freshwater Bathing (*Escherichia coli*, MofE, 2000). Only one site (which was downstream of a sediment-detention dam) had water clarity which met the Ministry of the Environment's (MofE, 1994) guideline for contact recreation.

The results from this New Zealand case study indicate that the absence of riparian vegetation altered the temperature, pH and dissolved oxygen regime, that livestock increased levels of nitrate, turbidity and bacteria indicators of faecal contamination and that urban land use increased peak flows, peak-flow turbidity and bacterial indicators of faecal contamination and decreased base flows.

The second case study, of a stream in the former *Deutsche Demokratische Republik* (East Germany), measured a similar suite of parameters and compared the German stream's 2001 water quality with records from 1991 (directly after the reunification of Germany). Measured levels of total nitrogen, nitrate, ammonium, phosphate and dissolved oxygen all showed significant improvements between 1991 and 2001. Stricter controls and regulations are thought to be the cause.

The final case study reviews plans for an urban residential development in the catchment of the New Zealand rural/forested stream. Degraded sections of the stream could actually be improved if the development is sensibly managed. However, the sensitive nature of the receiving environment (a marine reserve) requires that measures be taken to avoid or mitigate any deleterious effects. Plans by the relevant authority, the North Shore City Council, are a major step forward from the unsustainable development of the neighbouring catchment. Still, more needs to be done. Ten recommendations have been made to ameliorate the potential negative impacts of the development.

Statement of Originality

‘I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the qualification of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made in the references’.

………………………………… (signed)

………………….. (date)

Table of Contents

Acknowledgements .... **ii**

Abstract .... **iii**

Statement of Originality .... **iv**

Table of Contents .... **v**

List of Figures .... **ix**

List of Tables .... **xi**

Glossary .... **xii**

List of Abbreviations .... **xiv**

1 Introduction **1**

1.1 Effects of agricultural and urban land use on stream water quality 1

1.2 The need for region-specific studies 8

1.3 Thesis outline: three case studies 8

1.4 Aims and objectives of this study 10

1.5 Limitations 11

2 Case study one: A qualitative and quantitative comparison of the water quality of Awaruku (urban) and Vaughan (rural/forested) Streams, Auckland, New Zealand **12**

2.1 Historical setting 13

2.2 Future developments 17

3 Case study one: Physiography and climate **18**

3.1 Land use 18

3.2 Climate 18

3.3 Topography 19

3.4 Geology and soils 19

4 Case study one (NZ): Materials and methodology **20**

4.1 Site Selection 20

4.2 Catchment area and land use for each site 24

4.3 Preliminary evaluation and limitations 24

4.4 Sampling protocol 25

4.5 Monitoring time frame 26

4.6 Flow 26

4.7 Water clarity 27

4.8 Temperature 27

4.9 pH 28
4.10 Alkalinity 28
4.11 Salinity and electrical conductivity 29
4.12 Dissolved oxygen 29
4.13 Biochemical oxygen demand 29
4.14 Phosphate 30
4.15 Nitrate 30
4.16 Indicator bacteria 31
4.17 Coliform bacteria 31
4.18 Enterococci 32
4.19 Data analysis 32

5 Case study one (NZ): Results and analysis 35

5.1 Flow 35
5.2 Turbidity, clarity and suspended sediment 39
5.3 Temperature 45
5.4 pH 46
5.5 Alkalinity 48
5.6 Electrical conductivity 48
5.7 Dissolved oxygen 50
5.8 Biochemical oxygen demand 53
5.9 Phosphate 53
5.10 Nitrate 55
5.11 Coliform bacteria 56
5.12 Enterococci 59
5.13 Synopsis 60
5.14 Limitations 64

6 Case study two: A qualitative and quantitative comparison of the water quality of Köppernitz Stream, Wismar, Germany, between 1991 and 2001/2 65

6.1 Location 65
6.2 Historical setting 66
6.3 Climate 69
6.4 Topography 69
6.5 Geology and soils 69
6.6 Land use 70

7 Case study two (Germany): Method 71
7.1 Previous study: 1990 & 1991 73
7.2 Catchment areas and land use for each site 74
7.3 Parameters measured 74
7.4 Suspended sediments 74
7.5 Oxidation-reduction potential (Redox) 75
7.6 Phosphate 75
7.7 Nitrogen 75
7.8 Bacteria: total cultivatable colonies at 22°C 76
7.9 Toxicity: fluorescent bacteria 76
7.10 Macro-invertebrate survey 76
7.11 Data analysis 76
8 Case study two (Germany): Results and analysis 77
8.1 Flow 77
8.2 Suspended sediment 79
8.3 Temperature 79
8.4 pH 80
8.5 Alkalinity 81
8.6 Conductivity 82
8.7 Dissolved oxygen 83
8.8 Oxidation-reduction potential 85
8.9 Biochemical oxygen demand 86
8.10 Phosphate 87
8.11 Nitrogen 88
8.12 Bacteria: cultivatable colonies at 22°C 93
8.13 Toxicity: fluorescent bacteria test 94
8.14 Macro-invertebrates 94
8.15 Synopsis of results 94
8.16 Limitations 96
9 Comparison of New Zealand streams and German stream 98
9.1 Flow 98
9.2 Temperature 98
9.3 pH and alkalinity 98
9.4 Conductivity 99

9.5 Dissolved oxygen 99
9.6 Phosphate 99
9.7 Nitrogen 99
9.8 Synopsis 100
9.9 Limitations 100
10 Case study three — The proposed residential development at Long Bay, New Zealand: Expected water quality impacts; review of current and planned policies to minimise these; and extra measures required 101
10.1 Review of findings of case studies one and two 101
10.2 The vulnerability of the marine reserve 103
10.3 The Long Bay residential development and its anticipated effects........ 104
10.4 Comprehensive catchment plans 106
10.5 Measures must be taken before development 106
10.6 Ensure on-site erosion and sediment controls are used........ 110
10.7 Maintain stormwater and contaminants at pre-development levels 111
10.8 Other important objectives 116
10.9 Methods to ensure the above measures happen 118
10.10 Synopsis 121
11 Conclusions 123
12 References 127
Appendix I: New Zealand methodology details........142
Appendix II: Tables of raw data from New Zealand........149
Appendix III: Tables of raw data from Germany........154
Appendix IV: Long Bay Structure Plan: Land Use Strategy........161

List of Figures

Figure 1: Idealised catchment with permeable and impermeable surfaces........................2
Figure 2: The relationship between vegetation and erosion..4
Figure 3: Sources of sediments from urban and rural land uses 5
Figure 4: Some effects of sediment in aquatic systems 6
Figure 5: Sediment smothering the low-intertidal zone south of Awaruku Stream..........6
Figure 6: The process of eutrophication...7
Figure 7: Location of Awaruku and Vaughan Streams...12
Figure 8: The causes of urban sprawl 14
Figure 9: How planning around the car and urban sprawl reinforce each other 15
Figure 10: Metropolitan urban limit in the Long Bay area 16
Figure 11: Average rainfall per month for Long Bay 18
Figure 12: Aerial photograph of the Long Bay area 21
Figure 13: Upper Awaruku site...21
Figure 14: Mid Awaruku site 22
Figure 15: Lower Awaruku site 22
Figure 16: Mid Vaughan site 23
Figure 17: Lower Vaughan site...23
Figure 18: The clarity tube in action 28
Figure 19: Equipment at the NSCC laboratory 31
Figure 20: Systems diagram of the process of data analysis...33
Figure 21: Mean base flow per hectare for each site 36
Figure 22: Box plot of peak flows per hectare during storm events 37
Figure 23: Boxplot of peak flows for the mid Awaruku and mid Vaughan site 38
Figure 24: ARC gaugings graph for the lower Vaughan site...39
Figure 25: Box plot of dry weather clarity-tube reading..40
Figure 26: Damage by livestock in the catchment of the lower Vaughan site.................41
Figure 27: Mean clarity-tube readings for rainfall event samples 42
Figure 28: Turbidity of mid Vaughan and mid Awaruku Stream sites............................45
Figure 29: Box plot of pH at all sites 47
Figure 30: Fluctuations in stream pH at the mid and lower Awaruku sites.....................47
Figure 31: Box plot of dissolved oxygen concentration at each site...............................50
Figure 32: Dissolved oxygen levels at lower and mid Awaruku sites 52
Figure 33: Box plot of ortho-phosphate levels at all sites..54

Figure 34: Box plot of nitrate at all sites 56
Figure 35: Location of Wismar in Europe 65
Figure 36: Catchment of the Köppernitz 66
Figure 37: Sources of phosphate loading in freshwaters in Germany 67
Figure 38: Changes in land use per day in Germany 68
Figure 39: Mean monthly rainfall and temperature estimates for Wismar 69
Figure 40: Upper Köppernitz sampling site 71
Figure 41: Sampling sites: mid Köppernitz, lower Köppernitz and Mündung 72
Figure 42: Positions of sampling sites on the Köppernitz 73
Figure 43: Mean temperature for all sites on the Köppernitz 79
Figure 44: Mean electrical conductivity measurements at sites on the Köppernitz 82
Figure 45: Mean dissolved oxygen levels at all sites on the Köppernitz 83
Figure 46: Mean measured dissolved oxygen levels for 1991 and 2001 84
Figure 47: Mean dissolved oxygen readings of the Köppernitz from 1990 and 1991. 85
Figure 48: Mean oxidation-reduction potential readings from 2001 86
Figure 49: Mean biochemical oxygen demand for the Köppernitz for 1990 and 1991 86
Figure 50: Mean measured biochemical oxygen demand for the Köppernitz 87
Figure 51: Mean phosphate readings of the Köppernitz for 1990 and 1991 88
Figure 52: Mean measured phosphate level from 1991 for the Köppernitz 89
Figure 53: Mean measured total nitrogen levels at sites on the Köppernitz 90
Figure 54: Mean nitrate readings of the Köppernitz for 1990 and 1991 90
Figure 55: Mean ammonium readings of the Köppernitz for 1990 and 1991 91
Figure 56: Mean measured ammonium levels of the Köppernitz from 1991 92
Figure 57: Mean nitrite readings of the Köppernitz for 1990 and 1991. 92
Figure 58: Boxplot of total bacterial colonies for the Köppernitz, 2001 93
Figure 59: Calculated peak flow in Vaughan Stream for flood events 104
Figure 60: Total suspended sediment yield from Vaughan catchment 105
Figure 61: Ineffective sediment dam, Vaughan catchment 111
Figure 62: On-site storm water attenuation tank 112
Figure 63: Integrated household water system 113
Figure 64: Rain garden design 113
Figure 65: Turf blocks and porous paving 114
Figure 66: Stormwater detention tank 114
Figure 67: Enviropod mesh filters and a sand filter unit 115

Figure 68: Swale 115
Figure 69: Painting drain inlets to inform the public of the fate of influents...............120

List of Tables

Table 1: Catchment area, land use and location of each site 24
Table 2: Mean rainfall event turbidity for all sites...43
Table 3: Median clarity and turbidity for all sites..44
Table 4: Mean stream temperature for all sites...45
Table 5: Peak stream temperatures for four sites from ARC data 46
Table 6: Mean conductivity for all sites...49
Table 7: Mean dissolved oxygen levels from ARC data..50
Table 8: Median faecal coliform counts for each site. 57
Table 9: Median faecal coliform counts for 16 North Shore streams............................57
Table 10: Median faecal coliform counts for Awaruku stream 58
Table 11: Median Enterococci count at each site..59
Table 12: Median Enterococci counts for 16 North Shore streams 59
Table 13: Median Enterococci counts for Awaruku stream...60
Table 14: Synopsis of catchment factors that appeared to affect water quality.............62
Table 15: Summary table of New Zealand data..63
Table 16: Land use and total catchment areas for sites on the Köppernitz....................74
Table 17: Stream flows per hectare at three sites on the Köppernitz.............................78
Table 18: Electrical conductivity readings on the Köppernitz.......................................82
Table 19: Summary table of German results..97
Table 20: Comparison of New Zealand and German Stream data...............................100
Table 21: Yield of contaminants from Vaughan catchment 104
Table 22: Recommendations for the Long Bay Development.....................................122

Glossary

Alkalinity: Alkalinity measures a sample's ability to accept protons (hydrogen ions). Water with a high alkalinity is well buffered against acids.

Base flow: Defined in the NZWQN as less than median flow

Benthic: Bottom dwelling

Biological oxygen demand (BOD): BOD measures how much oxygen a one-litre sample of water uses up over a period of time. BOD indicates the amount of organic pollutants and oxidising chemicals in a sample. Generally the demand, or use, of oxygen is measured over an arbitrary five-day period.

Black disk clarity: A method of measuring clarity, used for the New Zealand Ministry of Health's guidelines for recreational water quality (MoE 1994). See also "Clarity tube".

Clarity: The maximum distance humans can see submerged objects in the water

Clarity tube: One-meter long transparent tube used to read water clarity

Coliform bacteria: A bacteria found in faeces. However, the relationship between total coliforms and faecal contamination is tenuous, because some of the genera also originate from the soil, vegetation and industrial effluents (Kumar 1998). Total coliform counts are therefore only useful as indicators of the extent of organic matter in the stream.

Conductivity: Conductivity is a measure of how well electricity conducts through the water. See also **salinity.**

Dissolved oxygen (DO): Amount of oxygen dissolved in water. Solubility decreases with temperature. DO varied diurnally due to photosynthesis.

Enterococci: A bacteria used to indicate faecal contamination. Enterococci were found to be significantly correlated to gastrointestinal disease in freshwaters in a major EPA study (EPA 1986) and are used in the EPA guidelines for freshwater recreational use. Enterococci can come from non-faecal sources, so results must be analysed cautiously.

***Escherichia coli* (*E. coli*)**: The coliform bacteria most specific for faecal contamination (MofE 1999b). *E. coli* are unlikely to multiply in water (MofE 1999b) and are used by the Ministry of the Environment (MofE 1999a) as the guideline for freshwater recreational use. However, the ministry has reservations about these guidelines, since, although they are internationally accepted, they are based on a small number of studies. The EPA (1986) also uses *E. coli* for recreational freshwater standards.

Faecal coliforms: Also known as thermotolerant coliforms, they are a sub-group of the coliforms. Faecal coliforms are more specific to the faeces of warm-blooded animals than total coliforms; however, they can have different die-off rates to pathogens (Kumar 1998) and multiply in waters (MofE 1999b). The term "faecal coliforms" is a misnomer since they can come from other environmental sources (EPA 1986).

Flow: The rate at which water passes a point in the stream. Measured in cubic meters per second (m^3s^{-1}) or litres per second (Ls^{-1})

Gewässergüteklasse: German stream classification system. The table below shows the classes (LAWA 1990).

I	I-II	II	II-III	III	III-IV	IV
Unpolluted to very lightly polluted	Lightly polluted	Moderately polluted	Critically polluted	Heavily contaminated	Very heavily contaminated	Excessively contaminated

LC_{50} value: Lethal concentration-50, i.e. the concentration of a chemical that will kill 50% of a species

LT_{50} value: Lethal temperature-50, i.e. the temperature that will kill 50% of a species

Nitrate: See **Nitrogen**

Nitrogen: Nitrogen is found in proteins. It cycles between organisms and the forms nitrite, nitrate, ammonia and nitrogen gas. Proteins initially break down to form ammonia. This is converted to nitrite in a process called nitrification under the appropriate conditions by *Nitrosomonas* baceria. *Nitrobacter* then oxidise the nitrite to form nitrate. Denitrifying bacteria convert nitrate to nitrogen gas in a process called denitrification. Denitrification functions in oxygen poor environments and is not likely to play a large role in the streams studied.

pH: A measure of the concentration of hydrogen ions. Specifically, it is the negative log (to the base 10) of the hydrogen ion concentration. Because it is a negative logarithmic scale, a solution with a pH of six has 10 times the concentration of hydrogen ions a solution with a pH of seven. A value of seven is considered neutral with values lower than this acidic and higher than seven basic or alkaline.

Phosphate: See **Phosphorus**

Phosphorus: A mineral which is mainly found as phosphate, either inorganically or organically in biochemicals like DNA, RNA, phospholipids and ATP. Phosphates can be found singly (orthophosphate), in linear strings (polyphosphate), or in cyclic or branched linear structures (metaphosphate). In aquatic systems, the bioavailable phosphorous is orthophosphate plus easily desorbed phosphate (Webster *et al.* 2001).

Phosphate is poorly soluble and sorbs readily to particles (Webster *et al.* 2001).

Riparian zones: Area beside the stream which has direct interactions with the stream. The width of this zone varies, depending on the particular interaction being considered.

RMA: New Zealand Resource Management Act (1991). The Act controls the use of land, air and water and attempts to minimise the impact of human activity.

Salinity: The amount of dissolved salts in the water. Conductivity is related to salinity. As salinity increases, conductivity also increases. Salinity in waters is influenced by closeness to the sea, rainfall, and geology.

Suspended sediment: Particles of minerals or organic matter that are suspended in the water column. These particles scatter and absorb light, making the water less clear.

Turbidity: An arbitrary measurement of light scattering at 90°

List of Abbreviations

AD: *Anno Domini* (Latin for "in the year of the Lord", i.e. years after Christ)

ANOVA: Analysis of variance model

ANZECC: Australian and New Zealand Environment and Conservation Council

APHA: American Public Health Association

ARC: Auckland Regional Council, the regional authority for the area studied in New Zealand

ARGF: Auckland Regional Growth Forum

ATP: Adenosine triphosphate. ATP serves as the major energy source within the cell.

AUT: Auckland University of Technology

BGR: *Bundesanstalt für Geowissenschaften und Rohstoffe* (German Federal Institute for Geology and Resources)

BMVEL: *Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft* (German Federal Ministry for Consumer Protection, Food and Agriculture)

BOD: Biological oxygen demand

BOD_5: 5-day BOD

BP: Years before present

BRD: *Bundesrepublik Deutschland* (Federal Republic of Germany)

C°: Degree celcius

$CaCO_3$: Calcium carbonate

C_{BD}: Clarity as measured using the black disk

cfu (colony forming units): The number of bacteria in the sample that have formed colonies

cm: Centimetres

cm/s: Centimetres per second

COD: Chemical oxygen demand

C_T: Clarity, as measured using the clarity tube

DIN: *Deutsches Institut für Normierung* (German Institute for Standardisation)

DDR: *Deutsche Demokratische Republik* (East Germany)

DO: Dissolved oxygen

DNA: Deoxyribonucleic acid

ECBCC: East Coast Bays City Council, Auckland, New Zealand

E. coli: *Escherichia coli*

EEC: European Economic Community

e.g.: *Exempli gratia* (Latin for "for example")

EOS: Earth and Oceanic Sciences Research Institute

EPA: United States Environment Protection Authority

ESI: Engineers and Surveyors Institute

et al.: *Et alii* (Latin for "and others")

etc: *Et cetera* (Latin for "and so on")

EU: European Union

Fe^{2+}: Iron (II) ion

$g/day/cm^{-2}$: Grams per day per square centimetre

GIS: Geographic Information System

ha: Hectares

ISO: International Organisation for Standardisation

K: Degrees Kelvin

KCl: Potassium chloride

km^2: Square kilometres

LAWA: Länderarbeitsgemeinschaft Wasser, Berlin, Germany

LBSP: Long Bay Structure Plan

LC_{50} value: Lethal concentration-50, i.e. the concentration of a chemical that will kill 50% of a species

LINZ: Land Information New Zealand

LK: Lower Köppernitz site

Ls^{-1}: Litres per second

L/sec/ha: Litres per second per hectare

LT_{50} value: Lethal temperature-50, i.e. the temperature that will kill 50% of a species

m^3s^{-1} or **m^3/s:** Cubic meters per second

M: Mündung site on the Köppernitz

MF: Membrane filtration, a method of measuring bacterial concentrations

mFC: Medium to enumerate faecal coliforms

mg/l: Milligrams per litre

$mgCaCO_3/l$: Milligrams of calcium carbonate per litre

mgN/l: Milligrams of nitrogen per litre

$mgNH_4/l$: Milligrams of ammonium per litre

mgO_2/l: Milligrams of oxygen per litre

mgP/l: Milligrams of phosphorus per litre

micro-S/cm: MicroSiemens per centimetre

MK: Mid Köppernitz site

MKp: Mid Köppernitz site previous: site used in 1990/91 study

mm: Millimetres

MPN: Most Probable Number, a method of measuring bacterial concentrations

MofE: Ministry of the Environment, New Zealand

mV: Millivolts

n: Number of measurements

N: Nitrogen

NA: Not Applicable

NH_4^+: Ammonium ion

NIWA: National Institute of Water and Atmospheric Research, New Zealand

nm: Nanometre

NO_2^+: Nitrogen dioxide ion (nitrite ion)

NO_3^-: Nitrogen trioxide ion (nitrate ion)

NSSC: North Shore City Council, the local authority of the area studied in New Zealand

NTU: Neothelmic Turbidity Unit, the standard unit for turbidity

NVDPC: Northern Virginia Planning District Commission

NZ: New Zealand

NZWQN: New Zealand Water Quality Network

O_2: Oxygen

OECD: Organisation for Economic Cooperation and Development

P: Phosphorus

pers. com.: Personal communication

PO4 and PO_4: Phosphate

Redox: Oxidation-reduction potential

RMA: New Zealand Resource Management Act (1991)

RNA: Ribonucleic acid

SHMAK: Stream Health Monitoring Assessment Kit

spp.: Species (plural)

WBGU: *Wissenschaftlicher Beirat Globale Umweltveränderungen* [German Advisory Council on Global Change]

WHC: Whaingaroa Harbour Care Society

WTW: *Wissenschaftlich-Technische Werkstätten* — a company which makes measuring devices

UK: Upper Köppernitz site

UN: United Nations

µS/cm: MicroSiemens per centimetre

1 Introduction

A river is the report card for its watershed.
Alan Levere, Connecticut Dept. of Environmental Protection

With an expanding global population (UN, 2003) and increasing consumption rates (UN, 2002), humans are converting more land from natural and low intensity uses to urban, industrial or high intensity agricultural uses (Stoel, 1999; Larson, 2002; UN, 2002). When such changes in land use occur in a stream catchment, the stream's flow regime (Hollis, 1975; Sala and Inbar, 1992), water quality (Herlihy *et al.,* 1998; Buck *et al.*, 2004) and biodiversity (Lenat and Crawford, 1994; Roy *et al.,* 2003) often are adversely affected.

Biodiversity warrants further explanation because its significance is frequently underestimated. Even "simple" stream invertebrates are vital to the survival of fish species (Wallace and Webster, 1996). The invertebrate could be a food of the fish, or a food of its prey, etc. The invertebrate may also play an important role, directly or indirectly, in controlling parasites and other disease-causing organisms, maintaining habitats or perhaps oxygen levels. We effect changes in biodiversity at our peril[1].

Streams are of value to humans as sustainers of biodiversity and providers of fresh water, food and amenity. Furthermore, environmental ethicists such as Singer (1979) and Naess (1973), and many indigenous cultures would argue that stream ecosystems have intrinsic value.

Given the worth of stream ecosystems, it is important to assess the effects of human actions on them and implement policies which ensure that our actions are sustainable. This thesis (1) assesses the impact of urban and agricultural land uses on stream water quality using two case studies and (2) critiques policies in place to mitigate and avoid deleterious effects on stream environments.

1.1 Effects of agricultural and urban land use on stream water quality

Many studies have shown urban and rural land uses change flow regimes (e.g. Hollis, 1975; Bosch and Hewlett, 1982; Sala and Inbar, 1992; Booth and Jackson, 1997) and reduce water quality (e.g. review by Cooper, 1993; Paul and Meyer, 2001).

---

[1] Some anthropogenic changes can be positive, e.g. native plantings on farmland.

1.1.1 Changes in the flow regime

Clearing forested land for agriculture causes increases in mean stream flows, mainly due to reductions in transpiration (Bosch and Hewlett, 1982).

Urbanisation causes even greater changes in flow regimes. In natural catchments, a good deal of the rainfall is absorbed by the soil, recharging the water table and reducing runoff (Figure 1–left). Roofs, paving and other impermeable barriers prevent this filtering of rainwater into the soil and thus increase runoff volumes (Figure 1–right). Efficient drainage systems are then required to deliver the extra runoff to streams, thereby eliminating vegetative interception, which would naturally slow the runoff (Hollis, 1975). Due to these higher runoff volumes, which are quickly delivered to streams, peak flows in urban areas are far higher than equivalent non-urban areas (Hollis, 1975; Sala and Inbar, 1992; Booth and Jackson, 1997). This effect can be quite dramatic: The Auckland Regional Water Board (1983a) has calculated that for a 10km^2 catchment, a change from rural land use to urban land use with 20% impervious surface would reduce the lag time between a storm and the resulting flood peak from two hours to 20 minutes. It also estimated that a basin with 50% impervious surface could have two-year floods with peak flows that are almost four times greater than in farmed catchments.

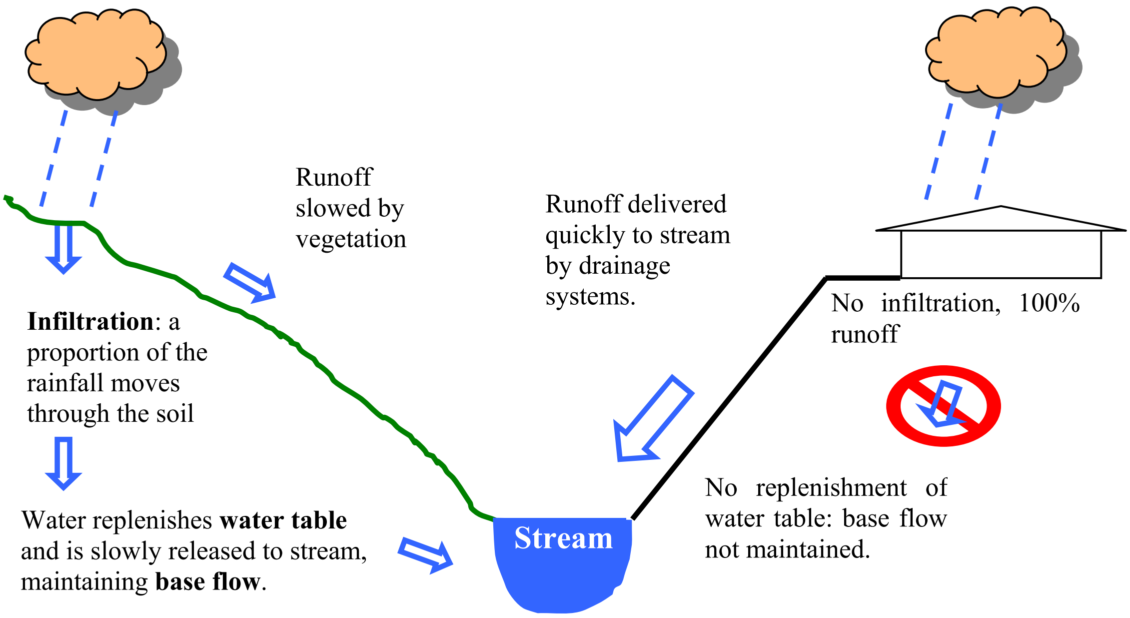


Figure 1: Idealised catchment cross-section with permeable vegetated surfaces on the left and impermeable surfaces on the right.

Not surprisingly, these high flows cause erosion of the stream bed, which removes habitat areas for biota, enlarges the stream's channel and also increases turbidity as the eroded sediment travels through the stream (Booth and Jackson, 1997; Pizzuto *et al.*, 2000). Flooding and bank erosion are a concern for nearby residents, and these concerns are often translated into protective action. This action usually entails the straightening and widening of the stream, which increases the gradient and decreases drag. In addition, channels are often surfaced with concrete or caged rocks (gabions), which further reduces drag and erosion.

Unfortunately, these solutions to flooding bring their own problems. The channelled and lined stream resembles a drain and residents will be less likely to care for it. Such streams have been described as ecological deserts, since microhabitats are lost and higher velocities during peak flows sweep many species away (Wilding, 1996). Additionally, channel straightening and lining or piping of the stream and its tributaries adds to the initial problem: flooding downstream is further increased. In natural streams, peak flows would be held back by obstructions in the channel and also (during flood events) slowed down and stored in the flood plain. This deceleration spreads out the peak (it is said to be “attenuated”).

The effect artificial drainage systems have on both speeding up the delivery of runoff to the stream and speeding the flow in the stream should not be underestimated. The Auckland Regional Water Board (1983a) has calculated that even a rural catchment could have its mean annual flood increased by 1.7 times if it had complete storm-water sewering.

Conversely, during long dry spells, streams with a high proportion of paved surfaces in their catchments can suffer from reduced base flows (Klein, 1979; Hengeveld and De Vocht, 1982). The water table, which supplies the stream during dry periods, will have poorer replenishment rates in paved areas (see Figure 1).

This low flow has adverse effects on the stream environment, including increased sedimentation, higher pollution concentrations (due to reduced dilution), greater variability in temperature, pH and dissolved oxygen (as smaller water volumes are less able to buffer temporal changes) and reduced streambed habitat area (Klein, 1979; MofE, 1998; Wood *et al.*, 1999).

1.1.2 Water quality: pollutants and altered temperature and pH regimes.

Water quality refers to the physical and chemical condition of the stream water which enables it to sustain a healthy biotic community and meet human needs. Agricultural and urban land uses have been found to alter water quality by polluting streams with sediments, nutrients, faecal bacteria and a host of other contaminants. The problems begin when vegetation is cleared, especially if the soil is exposed.

Soils that are covered in well-established vegetation usually lose very little sediment during rainfall (Figure 2).

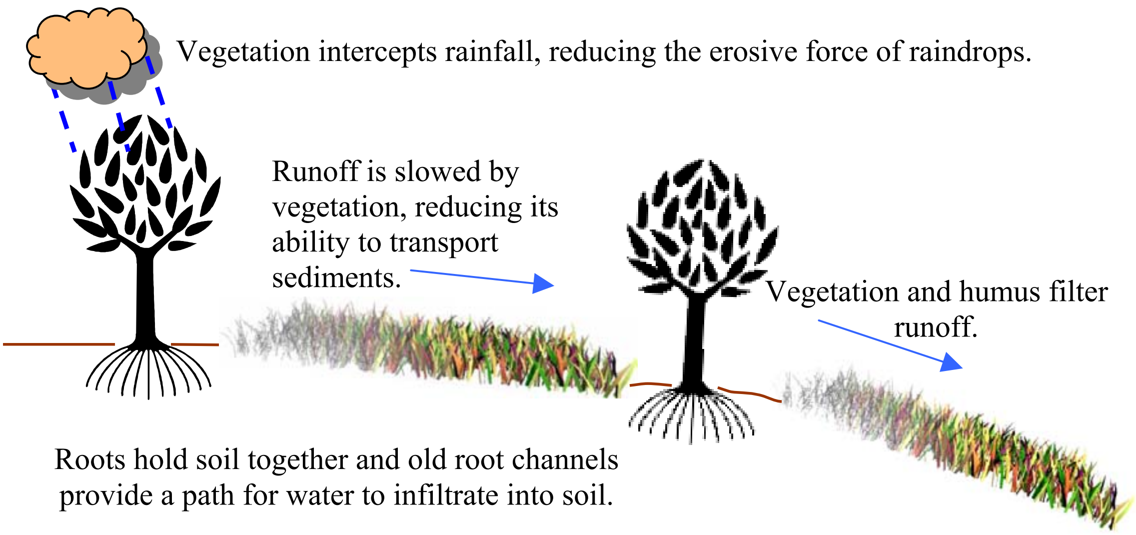


Figure 2: The relationship between vegetation and erosion

Removing or reducing the vegetative cover can result in extremely high loads of suspended sediments. Handyside (1995) suggests an indicative annual yield of sediment from earthworks on North Shore City, New Zealand, of 16,800 tonnes/km^2/year, compared to 50 tonnes/km^2/year for established land uses (pasture or residential). Additionally, the increased stream flows seen in urban areas cause channel erosion, which widens, straightens and smoothes the channel (Pizzuto *et al.,* 2000). In some cases, eroded channel material contributes more sediment to the receiving environment than earthworks (Handyside, 1995; Trimble, 1997).

Increased sediment loads are not limited to urban land uses. Figure 3 summarises how both urban and rural land uses can increase sediment loads in streams.

Increased sediment loads cause myriad problems (summarised in Figure 4). Benthic organisms and their habitats become smothered when sediments settle (Winterbourn, 1986; Boulton *et al.,* 1997; Jowett and Boustead, 2001). This is especially intense when freshwater enters the marine environment (e.g. near stream mouths, see Figure 5) due to the flocculating effect salt has on clay particles. Sediments can also clog fish gills and feeding mechanisms on filter feeders (Wood and Armitage, 1997; Ellis *et al.*, 2002), reduce the visual range of aquatic animals (Rowe and Dean, 1998; Richardson *et al.,* 2001a), and limit photosynthetic productivity (reviewed in Ryan, 1991), thereby altering the community structure of the water body. Moreover, sediments can act as a carrier of other pollutants, such as heavy metals, pathogens and phosphates, which adsorb to the surface of particles (WBGU, 1999). Settled sediments can release these pollutants in a relatively quick flux if the sediment is re-suspended and there is a change in the salt or oxygen concentration, the redox potential or pH levels of the water (Hounslow, 1995; WBGU, 1999).

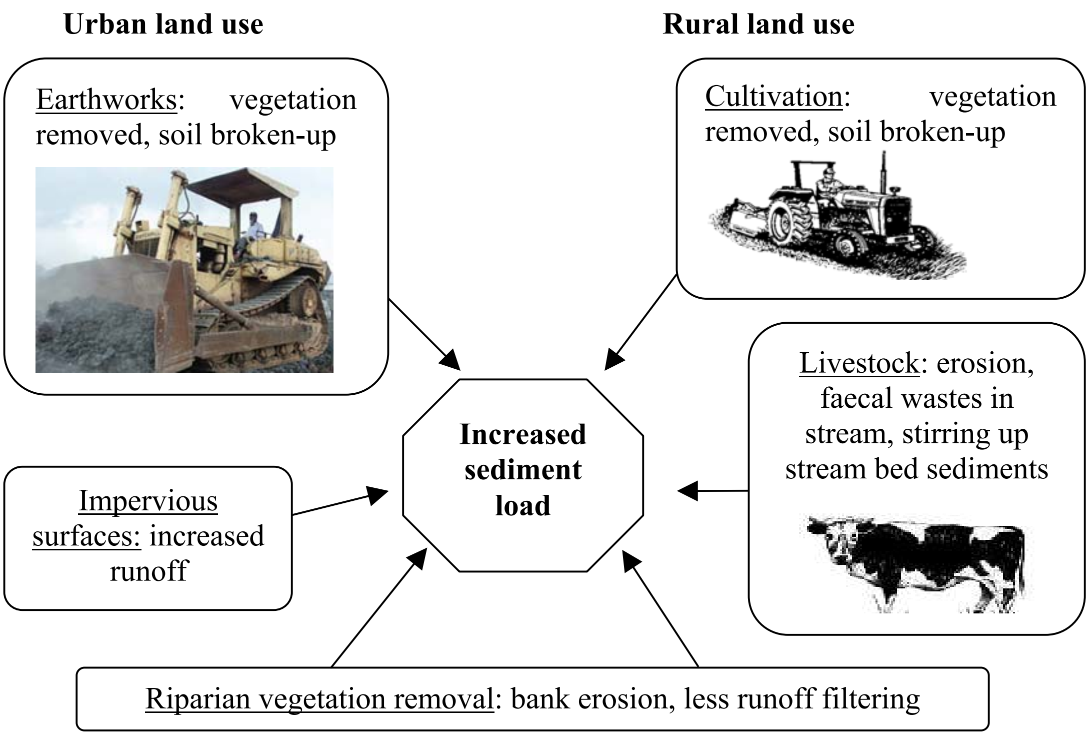


Figure 3: Sources of sediments from urban and rural land uses

The amount of phosphorus in streams can also be influenced by fertilisers and animal wastes. The concentration in streams has been correlated to the amount of fertiliser applied (McColl, 1978). Cooper and Thomsen (1988) found that catchments of improved pasture transfer about 15 times as much phosphorus to streams as forested catchments.

The other main nutrient, nitrogen, can also be found in human and non-human wastes and fertilisers. Nitrogen fixation from legumes is another source. It is not surprising then, that Cooper and Thomsen (1988) found catchments of improved pasture transfer about three times as much total nitrogen to streams as forested catchments.

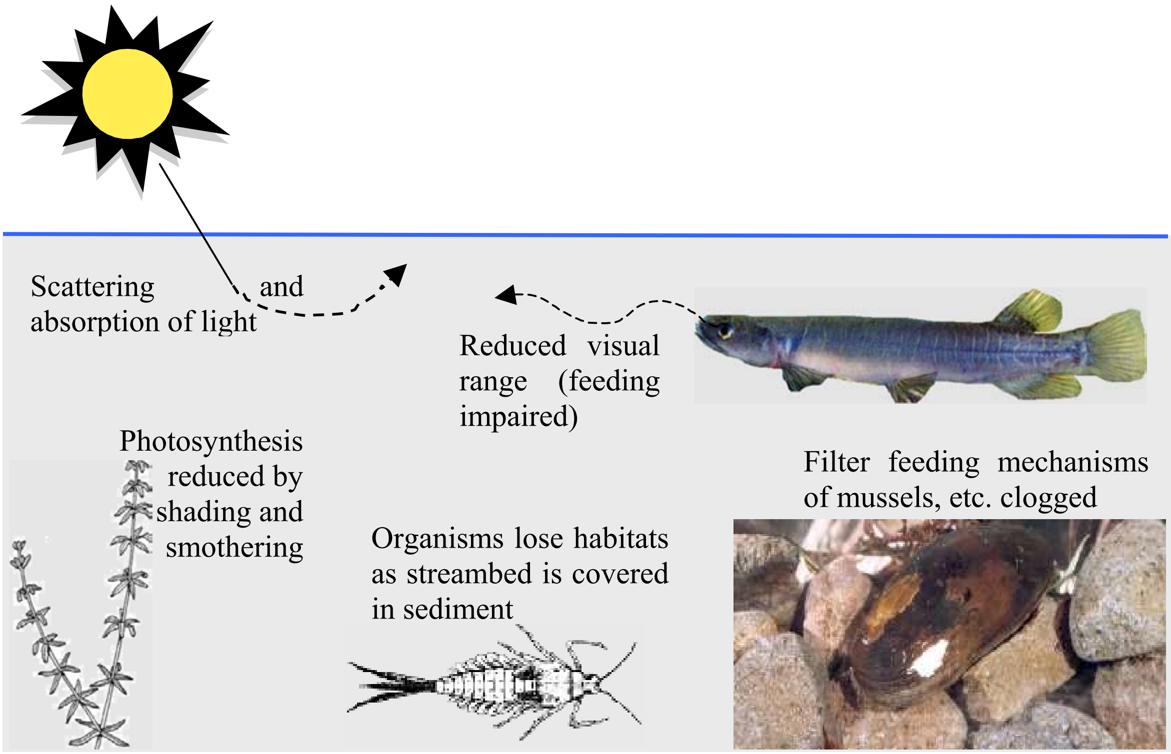


Figure 4: Some effects of sediment in aquatic systems

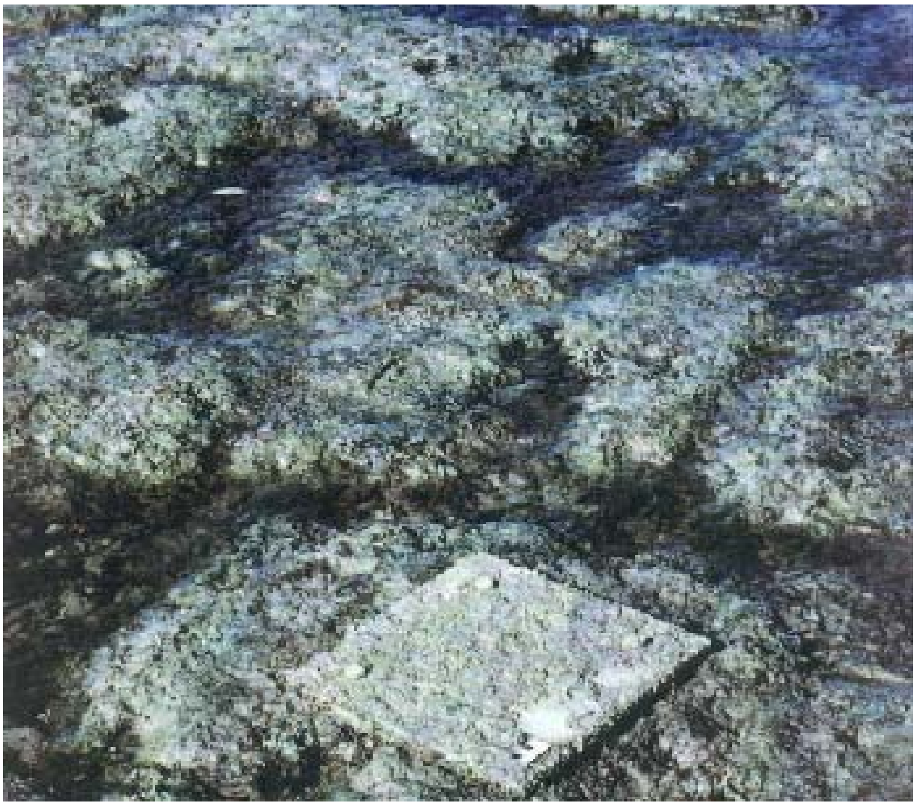


Figure 5: Sediment smothering the low-intertidal zone south of Awaruku Stream mouth, Long Bay, Auckland (March 7, 1998; Plate #3, southernmost transect). Photograph: J. Buckeridge

Elevated levels of nitrogen and phosphorus can cause cultural eutrophication (Figure 6), leading to critically low levels of dissolved oxygen, especially at night (Cooper, 1993).

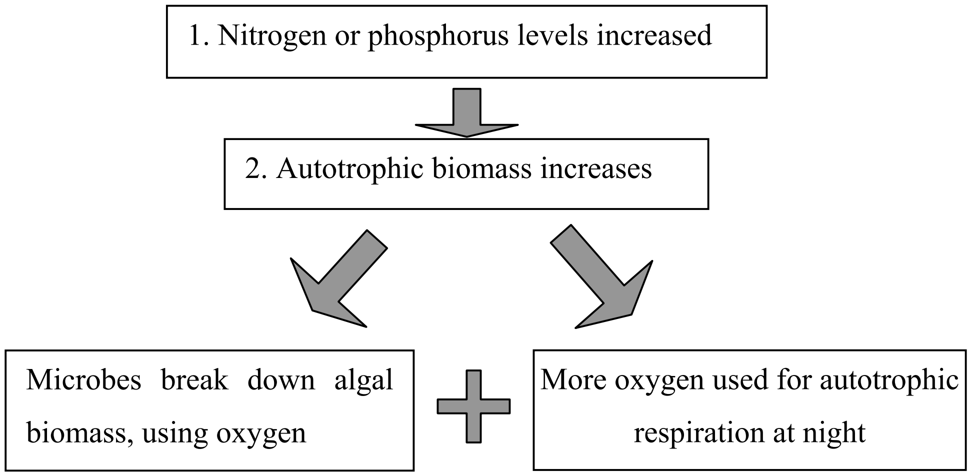


Figure 6: The process of eutrophication

Certain species of nitrogen (nitrate and ammonia) can be toxic (Kumar, 1998) and/or use up oxygen as they are oxidised in the water (i.e., nitrate and ammonium).

Another pollution problem associated with urban and agricultural land uses is faecal contamination. Human wastes contain bacteria (causing, for example, typhoid), viruses (e.g. the hepatitis A virus), Protozoa (e.g. *Giardia sp*.) and Helminthoidea (e.g. hookworms). Human diseases can be transmitted when infected faecal matter enters a person's mouth, sinuses or open wounds. Some pathogens, e.g. hookworm, may even infect through the skin (Kumar, 1998).

The wastes of animals other than humans may also be a source of such pathogens, and although human wastes are generally held to pose a greater health risk than the wastes of other animals, there is little or no epidemiological evidence to support this (Sinton *et al.,* 1998). Faecal bacteria have been found in elevated levels in urban and rural streams (Uunk and van de Ven, 1986; Paul and Meyer, 2001; Buck *et al*., 2004).

In addition to sediments, nutrients and faecal contaminants, a plethora of other pollutants enter streams from agricultural and urban activities. These include pesticides, heavy metals and organic compounds. However, this thesis will concentrate on sediment, nutrient and faecal pollution.

While urban and agricultural land use in stream catchments can have the above deleterious effects on water quality, the effect can be compounded if riparian (stream-side) vegetation is removed. Numerous studies have found that riparian buffer strips intercept pollutants and, in many cases, take them in or allow their decomposition (Reviewed by Peterjohn and Correll, 1984; Wilson and Imhof, 1998). For instance, Lowrance *et al.* (1984) found that nitrogen volumes passing through riparian forests decreased by 65%. They concluded this was due to the uptake of nutrients into forest biomass, accumulation of sediments on the forest floor and denitrification.

Riparian vegetation also provides shade for the stream. Stream sections lacking riparian shading have been found to have higher maximum temperatures and greater temperature fluctuations (Quinn *et al.,* 1992; Harding and Winterbourn, 1995; Storey, 1995; Quinn *et al.,* 1997; Leung, 1999). In addition, the reduced shading can allow increased photosynthesis and therefore higher primary producer biomass. Respiration by these primary producers and decay of their biomass can lead to reduced oxygen levels, especially at night. Higher water temperatures in unshaded sections compound this problem, because oxygen solubility decreases as temperature increases. Respiration rates also rise with increasing temperature. Wilcock *et al.* (1998) and Storey (1995) both found that streams with little riparian vegetation tended to have lower dissolved oxygen levels than streams with forested riparian zones.

1.2 The need for region-specific studies

While numerous studies have been undertaken on the effects of agricultural and urban land use on stream water quality and flow regimes, no universal model has been produced which can accurately predict the effects of such land uses in different catchments (Hollis, 1975; Bosch and Hewlett, 1982; Sala and Inbar, 1992; Cooper, 1993; Booth and Jackson, 1997; Herlihy *et al.,* 1998; Paul and Meyer, 2001; Buck *et al.*, 2004). The effects of land use vary considerably between catchments due to differences in physiography and climate. Quinn and Stroud (2002) found major differences in the effects of agricultural land use on water quality (sediment and nutrient levels) between a hill-country site in the Waikato region of New Zealand and other North Island regions. They concluded that flawed predictions would result if findings of land-use impacts on water quality were transferred between regions with different geologies, soils, topographies or rainfalls, and that region-specific studies are required to predict the effect of land use.

1.3 Thesis outline: three case studies

1.3.1 Case studies one and two: Assessment of land use effects

This thesis contains two case studies of streams from disparate environments. Although the case studies investigate the general effects of urban and agricultural land uses on streams, the particular aim is to provide assessments of land use effects specific to the catchments studied, so that these catchments may be better managed.

The case study sites were chosen to provide valid comparisons between land uses. To make fair comparisons between land uses in small studies, physiography and climate must be similar in each area studied (Quinn and Stroud, 2002). This can be achieved by comparing neighbouring catchments or by examining the same catchment before and after land use change (Quinn and Stroud, 2002).

The first case study, in North Shore City, New Zealand, uses neighbouring catchments, as have a number of other studies (Dons, 1987; Fahey and Marden, 2000; Quinn and Stroud, 2002), to compare an urban residential and a rural/forest stream. Urban residential development is planned for the rural/forest stream, and both streams drain into a marine reserve. Little was known about the water qualities of these streams before this study began in 2001.

Several theses have been written on water quality in the Auckland region recently (e.g. Storey, 1995; Wilding, 1996; Leung, 1999); however, these studies concentrate on macroinvertebrate communities and only one, Leung (1999), involved the streams investigated in this case study. The range of physico-chemical parameters studied by Leung, and the number of measurements made at each site (four), was also limited. Although several reports have been written recently which include one or both of the streams in this present study (Beca Steven, 1999; Green *et al.,* 2000; North Shore City Council, 2000a; Kingett Mitchell, 2001a & 2001b), most have undertaken little or no water-quality testing, with the exception of the North Shore City Council (2000a) report, which sampled five events in the urban stream.

In the second case study, a stream in Wismar city, in the former *Deutsche Demokratische Republik* (DDR, East Germany) is studied. Environmental controls in the DDR were weak. Since the fall of the East German regime in 1989/90, the region has been the subject of far stricter environmental controls, as well as extensive road and housing developments. This study compares the 2001 water quality of a stream with its condition directly after the fall of the DDR (1990–1991) and is the first study in the greater Wismar region to do so. This method of comparing catchments before and after changes has also been used in a number of other studies (e.g. Sala and Inbar, 1992; Trimble, 1997; McKergow *et al.,* 2003). However, as it requires lengthy studies or historical data, it is used less frequently than other comparative methods. Differences in water quality between upstream agricultural areas of the stream and downstream urban

areas are also investigated. Such longitudinal comparisons have also been conducted by Hogg and Norris (1991), Harding *et al.* (1999) and Perdaki and Mason (1999).
With the exception of the 1990 and 1991 water quality measurements from the Wismar City Council (unpublished), no other water-quality testing has taken place in the German stream.
These studies also afforded the rare opportunity to compare the water qualities of very disparate stream systems. By comparing the water qualities of the German and New Zealand streams, further evidence could be given for the need of region specific studies. As previous knowledge of water quality in the streams investigated was limited, these studies also serve to provide base-line water quality data for the three streams.

1.3.2 Case study three: policies to avoid and mitigate deleterious land-use effects

The third case study of this thesis reviews the possible effects of a proposed urban residential development in the catchment of the New Zealand rural/forest stream and reviews policies to ameliorate any potential deleterious effects. This study is novel in that it uses results from water-quality analysis of the stream in case study one, as well as modelling from other studies (Beca Steven, 1999; Green *et al.,* 2000), to critique a development concept put forward by the local council. As well as highlighting positive aspects of the local council plan, further measures are suggested which could make development of the area more sustainable.

1.4 Aims and objectives of this study

Through these case studies, this thesis aims to:

- Determine land use effects on stream water quality in two areas.
- Assess the effectiveness of measures designed to ameliorate the negative effects of human activities.

These aims will be achieved through the following six objectives:

- Establish baseline water-quality data for the three coastal streams studied.
- Compare the water quality of stream sections draining urban, rural and forested catchments.
- Compare the 2001 water quality of an East German stream with records from the stream shortly after the fall of the East German regime.
- Compare the 2001 water quality of a German stream now with the New Zealand streams studied.

- Review the possible effects of a proposed urban development in the catchment of one of the New Zealand streams.
- Review policies for the mitigation or elimination of any potential negative effects from the development in that catchment.

1.5 Limitations

This study concentrates on the freshwater environment, although mention is made of the effects of poor stream-water quality on the marine environment.

Some significant indicators of stream health, such as heavy metals, organic pollutants, macro-invertebrates, plants and fish numbers, were not directly dealt with due to time or resource constraints, or because they have been well covered in previous New Zealand studies (e.g. Quinn and Hickey, 1990; Leung, 1999; Hall *et al.*, 2001).

Because this is a New Zealand-based study, New Zealand literature and legislation are the primary reference source. The use of German material was also hampered to some degree by the complexity of official German language.

2 Case study one: A qualitative and quantitative comparison of the water quality of Awaruku (urban) and Vaughan (rural/forested) Streams, Auckland, New Zealand

The aesthetic, recreational and environmental values of the coast are what many New Zealanders would place at, or near, the top of reasons to remain or return to this country. Cleary (2000:1)

The development of New Zealand's biggest city, Auckland, over the past half-century has created an urban sprawl. Auckland is one of the largest cities in the world in terms of area, although its population is less than 1.2 million (2001 census: Statistics NZ, 2002). The sprawl results from extreme growth pressures and a reluctance to manage development in a sustainable manner.

This study focuses on one of Auckland's fastest growing municipalities, North Shore City. Two coastal streams on the fringe of North Shore City, Awaruku Stream (already urbanised) and Vaughan Stream (rural, but earmarked for urban residential development), were monitored to determine the effects of land use on stream water quality. The location of these streams is shown in Figure 7.

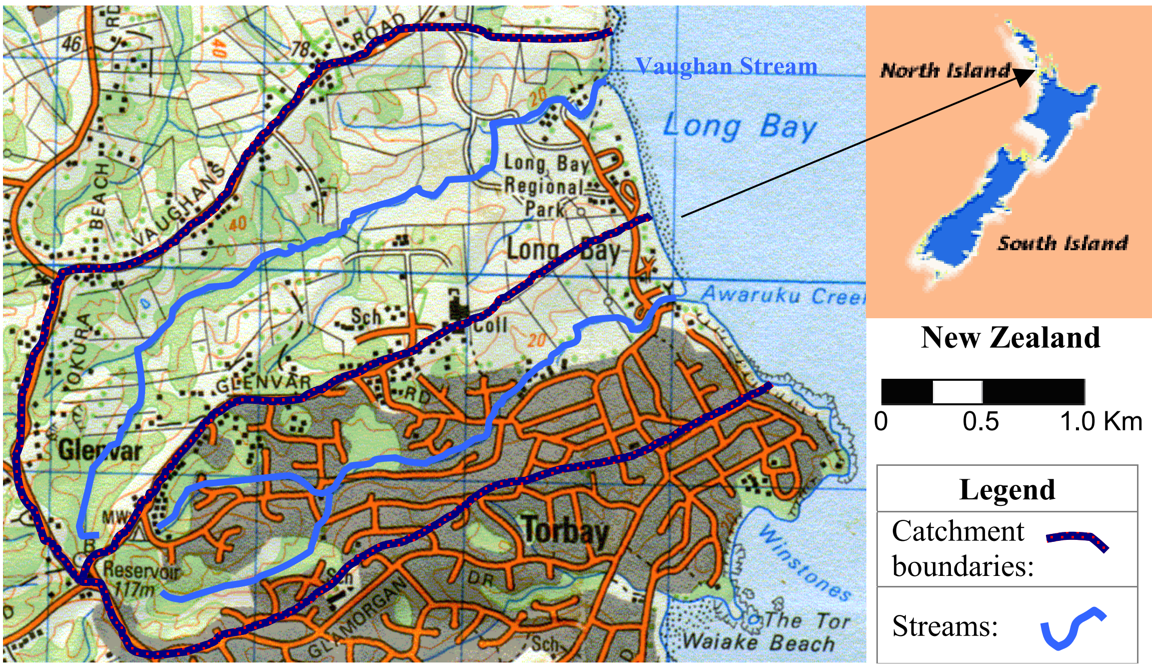


Figure 7: Location of Awaruku and Vaughan Streams. Grey shading indicates residential land use, solid green indicates forest (using LINZ, 1999).

Both streams flow into the Long Bay/Okura Marine Reserve, where marine life is legislatively protected from harvesting and pollution. For example, Section 18 (I2) of the Marine Reserves Act (1972) states that any person who directly or indirectly discharges a "*…pollutant or other substance… injurious to marine life…*" is liable for a fine of up to $50,000 and/or a prison sentence of up to three months. The purpose of marine reserves is to preserve ecosystems in their natural state for non-exploitive recreational and educational uses (e.g. snorkelling), scientific investigation (including as a control when assessing the management or lack of it in other areas) and the maintenance of genetic reserves and breeding stocks (Ballantine, 1991).

The streams run through and drain the Long Bay Regional Park. This park receives an estimated one million day visits per year (ARC, 1994). The quality of the stream water that enters the sea at Long Bay Beach is of great importance as many of these visitors come to swim. Enterococci counts at the beach have exceeded standards at times and there have been calls for the closure of the beach (Withiel, 2000).

Furthermore, the regional park is a major educational resource, with 30% of primary schools and 18% of secondary schools in the Auckland Region visiting the park between 1990 and 1992 (ARC, 1994). Of these schools, over 30% gave streams as a reason for coming to the park (ARC, 1994).

2.1 Historical setting

2.1.1 Changes in the flow regime

New Zealand has a remarkable natural and cultural history. It separated from Australia some 80 to 100 million years ago and, owing to its isolation, developed a rich and unique flora and fauna. The Maori, the first humans to settle in New Zealand, did not arrive until approximately 1150AD. Indeed, excepting bats, there were no terrestrial mammals on New Zealand until this time[2].

When humans first arrived, the majority of New Zealand, including the Auckland area, was covered in forests. Since then, two thirds of the forest cover has been lost, with half of the loss occurring in the less than two centuries of European settlement (Pullar and McLeod, 1992).

---

[2]However, there is some evidence that Polynesian sailors may have visited before this and introduced the Polynesian rat (Anderson, 1996).

The Long Bay area was the home of several Maori iwi (tribes) from early in the last millennium. The remains of middens (shell mounds), terraces (levelled house sites) and pah (defensive sites) can still be seen in the area (ARC, 1994).

European settlement in the area began in the 1840s and what is now North Shore City grew slowly to obtain a population of less than 50,000 by 1959 (Buckeridge, 1999). This population was centred more than 10 km south of the area studied. At this stage, the catchments of both streams would have been mostly rural with a scattering of holiday homes.

North Shore City grew very rapidly after the opening of the Harbour Bridge improved access to Auckland City in 1959. By the 2001 census, the North Shore population had reached almost four times the 1959 figure (185,000: Statistics NZ, 2002).

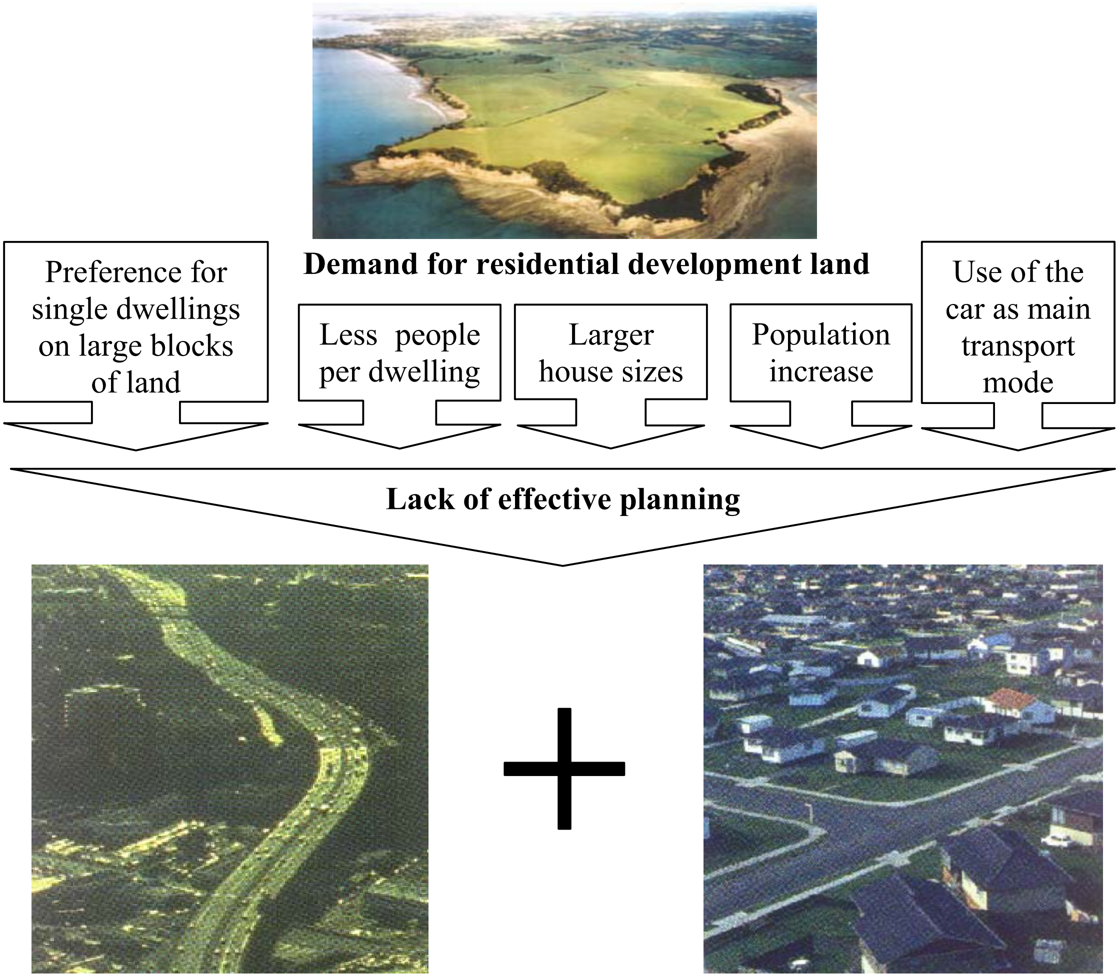


Figure 8: The causes of urban sprawl

This growth in population, coupled with other factors (see Figure 8), led to the sprawling of Auckland's suburbs, with residential housing spreading to cover many areas, including the majority of the Awaruku catchment. Population growth came from several sources: natural increase, urban and northern drift (the movement of New Zealand residents from smaller centres and from the cooler south) and immigration (about 70% of New Zealand's immigrants settle in Auckland (ARGF, 1998a)). Between 1991 and 1996, 38% of the population growth was from immigration, 6% was from urban and northern drift, and natural increase contributed 56% (ARGF, 1997).

The average number of people per household decreased from 3 to 2.7 persons between 1986 and 2001 (Statistics NZ, 1993 & 2002) due to changes in community structure, such as the aging of the population and the increase in one-parent families. Paradoxically, as the number of people per dwelling has decreased, the average size of new dwellings in New Zealand has increased from less than $120m^2$ in 1991 to more than $160m^2$ in 2001 (Statistics NZ, 2002).

Growth pressures do not fully explain Auckland's spread, since many other cities with populations the size of Auckland cover only a fraction of its area. The other factor behind the spread is that growth has not been effectively managed. Buckeridge (1999) described the process of urban development on the North Shore as "stochastic urban accretion" and claimed that the process was completely unsustainable. There have been few controls to discourage the development of low-density housing, i.e. single dwellings on large housing sections. Coupled with this, developments have been planned around the car, which further contributes to sprawl (see Figure 9).

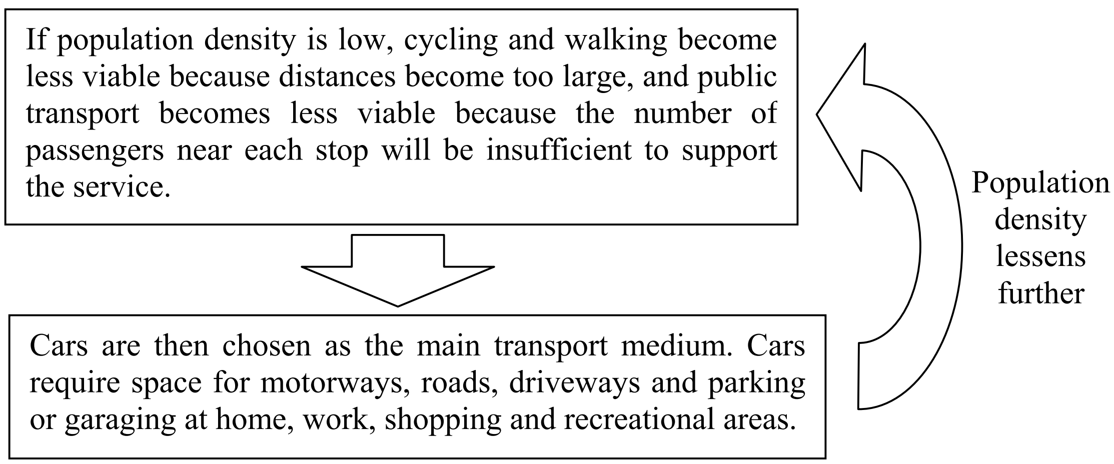


Figure 9: How planning around the car and urban sprawl reinforce each other

Increasing affluence, decreasing car prices (due to the importation of used foreign cars) and the fact that other transport modes have been "planned out" of the city as viable alternatives have resulted in large increases in car ownership. There was one car for every 2.03 people in New Zealand in 2001 (compared to one per 2.21 in 1992), which is the third highest rate of car ownership in the OECD (behind Australia and Germany: Statistics NZ 2002).

Planning has not only failed to control the spread of the city, it has also not kept pace with the increased demands placed on storm-water and wastewater infrastructure. Numerous sewage overflows have occurred, leading to the closure of beaches on several occasions (Withiel, 2000). Recently, the North Shore City Council (NSCC) attempted to address these problems by upgrading sewage piping and pumping, and through education (see Section 10.8.1). However, much remains to be done.

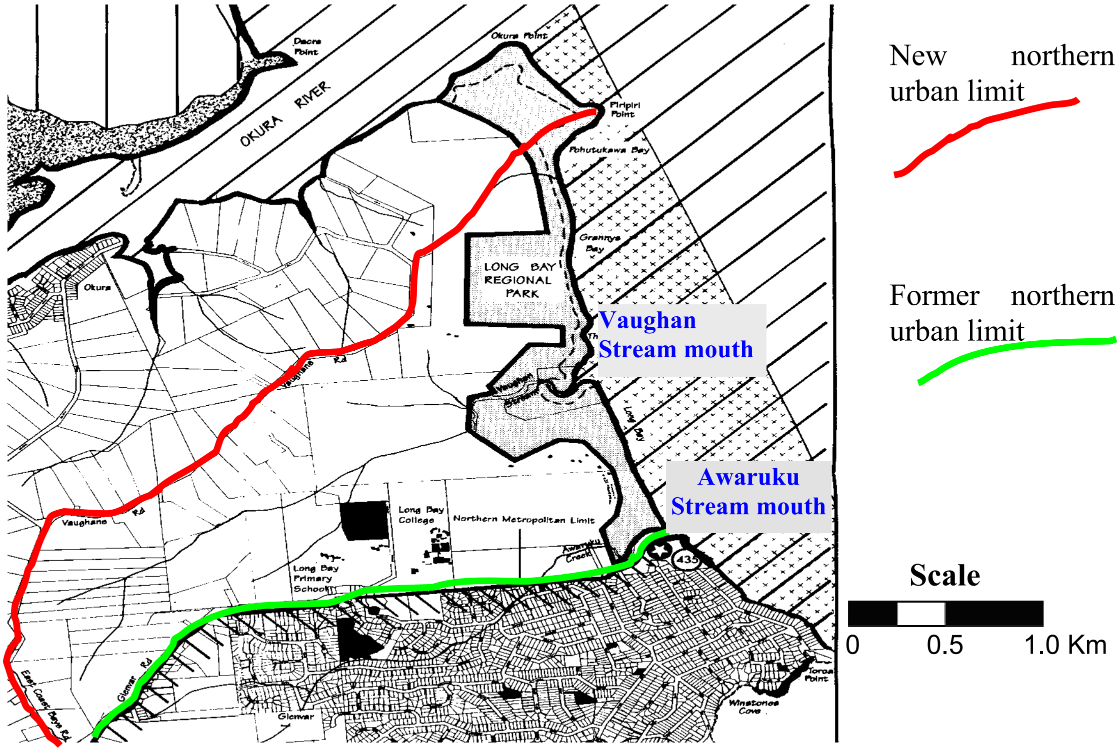


Figure 10: Metropolitan urban limit in the Long Bay area, showing clearly how residential subdivisions (seen as tightly spaced boxes south of the green line) were restricted to the area south of the urban limit

In the Long Bay area, NSCC has been involved in pushing back one of the few restrictions on urban sprawl: the metropolitan urban limit. The objectives of the metropolitan urban limit were to achieve the efficient development and use of infrastructure, and the protection of productive rural land and the environment (ARGF, 1999). The Auckland Regional Council (ARC) had established a metropolitan urban limit that excluded the majority of Vaughan catchment from urban development. In 1995, NSCC challenged the right of the ARC to set metropolitan urban limits, but the ARC's right to set such limits was upheld. In 1996, NSCC challenged the ARC over the actual positioning of the line. Bio-physical evidence was presented and it was determined that, although the area around Okura (north of Long Bay) should remain protected, the Long Bay catchment (which includes Vaughan Stream) did not warrant protection from urban development. This led to the repositioning of the urban limit to the north of Vaughan catchment (see Figure 10).

Complicating the issues of development are the Regional Park and Marine Reserve. In 1965, parcels of land along the coast were purchased to form what is now the Long Bay Regional Park (ARC, 1994). In 1995, the Long Bay-Okura Marine Reserve, New Zealand's first in an urban area, was established.

2.2 Future developments

Auckland's population is predicted to double to be over two million by 2050, with North Shore City expected to increase by around 70% (ARGF, 1998b). This population "explosion", coupled with the desirability of housing near to the sea and beaches, has amplified the pressure to subdivide the catchment of Vaughan stream for residential housing. A citizen's lobby group, the Long Bay Great Park Society, has evolved to counter the proposed urbanisation. The group wants a large area of the Long Bay catchment to be purchased by central government and local councils and to merge it with the existing Long Bay Regional Park to form a "great park".

The North Shore City Council (NSCC), which approved the zoning change that permits developments such as subdivision, has given in-principal support for such a park. However, citing financial constraints, the NSCC continues to plan for residential development in the area.

3 Case study one: Physiography and climate

Climate, topography, soil and rock types, and land use are outlined in this chapter.

3.1 Land use

The 282 hectare Awaruku catchment is covered with residential housing, with the notable exceptions of 43 hectares of lowland pasture at the lower end of the catchment, sections of bush in the upper catchment and a bush reserve in the middle of the catchment.

Vaughan catchment contains 315 hectares. The upper half of Vaughan catchment consists of 50% remnant and regenerating bush and 50% pasture and large lot residential land use. The lower catchment of Vaughan Stream is used as pasture for cattle. There were about 600 cattle using this and the smaller 43-hectare pasture of Awaruku catchment in 1999 (Leung, 1999).

3.2 Climate

The area's climate is subtropical — warm and wet — being influenced by its proximity to the coast and its latitude (36°S). Unofficial data from Long Bay from 1982–92 gives an average annual rainfall of 1171 mm (ARC, 1994). Figure 11 shows how this rainfall is spread over the year.

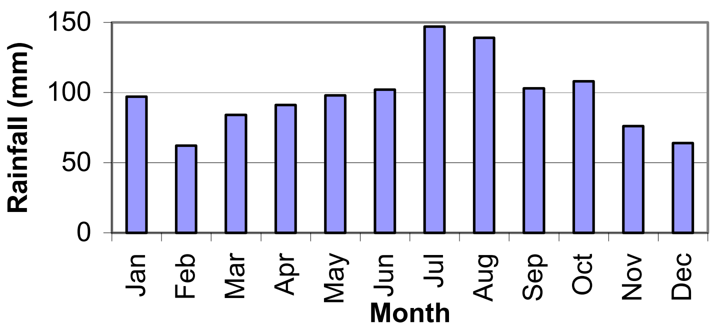


Figure 11: Average rainfall per month for Long Bay (1982–92)

The Auckland region has a mid-summer daily average temperature of 22.8°C, a mid-winter daily average temp of 8.2°C and averages 2070 sunshine-hours annually (Statistics NZ, 2000).

3.3 Topography

The area is hilly with relatively steep slopes. The valleys of the streams are usually no more than 1.5 km wide from ridge to ridge, with ridge lines approximately 60m above the valley floor, increasing to a maximum of 117m above sea level at the western end of Awaruku valley, about 3.5 km from the sea.

3.4 Geology and Soils

The rock types near the surface of the Awaruku and Vaughan catchments are interbedded mudstones, sandstones and siltstones of the Waitemata Group, which weather to form very stiff to firm clays (Buckeridge, 1992). The clays are characterised by low permeability, so runoff volumes are high and soakage into the soils is poor (NSCC, 1998a).

Topsoil in the area contains 40% clay and 37% silt (Green *et al*., 2000). Once these fine particles are dislodged from the surface they are likely to remain in colloidal suspensions for up to three weeks, but in the marine environment will settle within 30 minutes (J. Buckeridge, pers. com. 2002).

4 Case study one (NZ): Materials and methodology

In this chapter site selection and sampling protocol are discussed, with practices to maintain accuracy, method rationale and adaptations detailed in Appendix 1.

This case study uses neighbouring catchments to compare the effects of different land uses on water quality, as the proximity of the catchments controls for climatic and geophysical variables. Topography, soil and rock types, and climate do not vary between the Vaughan and Awaruku catchments and the catchments are also roughly the same size. Awaruku and Vaughan Streams were chosen not only due to their adjacency, but also because of their ease of access, and the differences in their land use. Moreover, as they drain into a marine reserve, and one stream (Vaughan) is subject to a controversial urban residential development plan, the value of water quality data from these streams is unusually high.

4.1 Site Selection

Initially, three sites were planned for each stream: one site as close as possible to the estuary, but high enough upstream not to be affected by tides, another as high upstream as possible (while still having permanent flow), the third site roughly in the middle. Regrettably there was no easy access to an upper site on Vaughan Stream and it was therefore not included in this study, except where data from the Auckland Regional Council (ARC) were available. The extra two hours required to sample the third Vaughan site would have compromised the results because:

- Parameters such as bacterial counts must be analysed within six hours of sampling, which, with travelling times, would not have been possible.
- The delay between the sampling of the first and the last site would reduce the comparability of variables such as temperature and dissolved oxygen, which vary over the day.

Where possible, sites with straight channels and water velocities above 10 cm/s were selected to enable flow measurements to be taken. This proved impossible in some cases, with no suitable sites being found on Vaughan stream or near the lower Awaruku site.

The location of the five selected sites is shown below in Figure 12 and photos of each site can be found below.

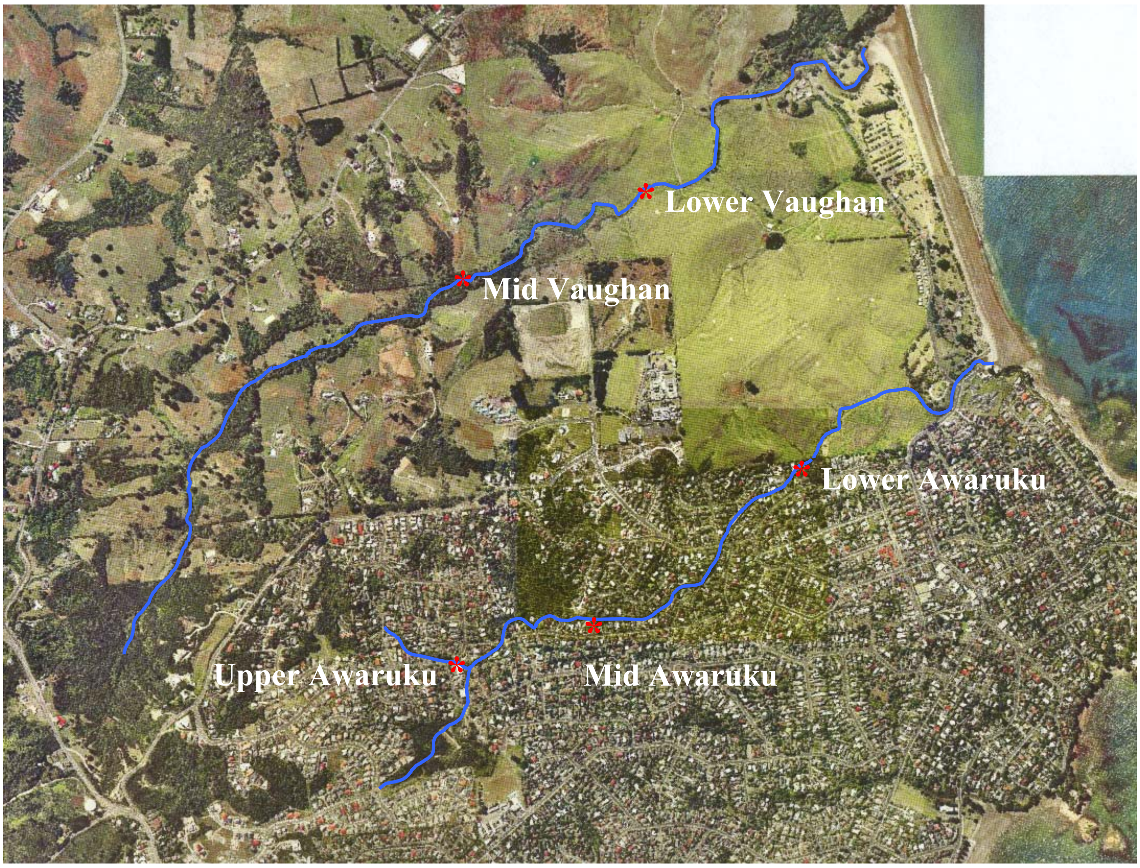


Figure 12: Aerial photograph of the Long Bay area showing sites studied. Source: NSCC GIS Section, photo taken 2002. The scale is approximately 1:250 (1cm=250m).

Figure 13: Upper Awaruku site, looking downstream to pipes

Figure 14: Mid Awaruku site, showing discolouration suspected to be from iron-oxidising growths which had been abraded from an upstream drain (possibly from a resident cleaning the drain)

Figure 15: Lower Awaruku site

Figure 16: Mid Vaughan site, looking down to stream

Figure 17: Lower Vaughan site. The ARC built a weir near the water level gauge (metal object in centre).

4.2 Catchment area and land use for each site

Table 1: Catchment area, land use and location (grid reference on map R10, 1:50,000, LINZ, 1999) of each site

Site	Urban	Rural	Forested	Total area	Grid reference
Awaruku upper	35ha	0	15ha	50ha	266425, 649895
Awaruku middle	100ha	0	40ha	140ha	266575, 649910
Awaruku lower	155ha	5ha	45ha	205ha	266645, 649955
Vaughan upper	0	40ha	60ha	100ha	266477, 649987
Vaughan middle	0	75ha	75ha	150ha	266532, 650015
Vaughan lower	0	165ha	100ha	265ha	266592, 650045

Due to the lack of access to the NSCC GIS[3], the areas and uses of the land that drained to each site (Table 1) were determined using area figures from engineering studies of the catchments (Beca Steven, 1999; Kingett Mitchell, 2001) and measurements from aerial photographs (from NSCC). The topographic map of the area – Whangaparaoa 1:50,000 [R10] (LINZ, 1999) and site inspections were also used.

4.3 Preliminary evaluation and limitations

Measurements were chosen to determine differences in flow regime (by measuring flow directly), sediment levels (by measuring clarity/turbidity), nutrient levels (by measuring nitrate, ammonium and phosphate), faecal contamination (using Enterococci, faecal coliform and *Escherichia coli* counts) and organic matter pollution (using biochemical oxygen demand). Four quick measures of water quality were also chosen: temperature, pH, electrical conductivity and dissolved oxygen concentration.

A YSI 6600 data sonde was to be used to measure water temperature, pH, dissolved oxygen concentration, turbidity, electrical conductivity, ammonia and nitrate levels. Unfortunately, the sonde gave inconsistent results and calibration was not possible for some parameters. After being sent back to the supplier, John Morris Scientific of Auckland, on three occasions, the supplier found the fault to be in the software. This fault had erased all default probe settings and required new software to be installed (C Sylvester, *pers. com.* 2004). Additionally, the sonde had very low accuracy rates for

[3] No workstation time was available in the GIS department; however, aerial photos were kindly provided.

ammonia and nitrate even under ideal conditions. This regrettably brings into question the results obtained by Schrader (2000), who also used this equipment.

The defects of the sonde meant that much time was wasted on fault finding and data already collected with it had to be abandoned. Moreover, the author was forced to test the stream with simpler equipment. This had the disadvantage that the tests were much more time consuming and that continuous testing (where a data sonde is left out over several days) was not possible. Important diurnal changes were therefore unable to be measured. A lack of other equipment, such as adequate flow meters, also limited the choice of methods to be used.

Fortunately, problems associated with these limitations were reduced when some data became available from the Auckland Regional Council (ARC) as they began testing the streams concurrently.

4.4 Sampling protocol

Two principles are important in sampling: (1) the sample must be representative of the body of water being sampled; and (2) the composition of the sample should not change between when the water is sampled and when it is analysed. To ensure that these two principles were addressed, the number of samples taken per site, the way samples were taken and the transport of samples to the laboratory were deliberated upon.

4.4.1 Number of samples taken per site

When the stream is turbulent, or of limited cross section, one sample per site is seen as representative (Bartram and Balance, 1996; Kumar, 1998). Nevertheless, for the first two weeks, two samples were taken at each site. No variation was found between the two samples for temperature, conductivity nor pH, while DO, clarity and phosphate were found to be no more variable than when the same water was tested twice. Therefore, only one sample and reading was taken thereafter.

4.4.2 Taking the sample

Samples were taken, as recommended by Kumar (1998), near the centre of the stream using containers which were triple-rinsed with stream water at each site. Containers, held by the bottom, were then lowered to approximately 20cm below the water surface with the neck pointing slightly down, as suggested by Bartram and Ballance (1996), to minimise contamination from bottom sediments and surface variations. The container was then tilted upwards and allowed to fill, with a little air left in the bottle to allow for later mixing at the laboratory, as recommended by Kumar (1998). The neck of the container was always pointed upstream with the person sampling always downstream of the container.

On occasions, the stream depth was so shallow that the container was unable to be fully submerged. On these occasions surface water formed a part of the sample, but the inclusion of bottom sediments and any visible floating material was carefully avoided.

4.4.3 Transporting the sample

The containers were labelled and placed in a cool box with ice for transporting to the laboratory. At the laboratory, samples were then placed in the refrigerator (approximately 4°C). The time between the taking of the first sample and the beginning of analysis was usually four to five hours.

4.5 Monitoring time frame

Monitoring of the streams took place, usually at weekly intervals, between 26 September and 6 December 2000 (10 data sets) and between 24 January and 2 April 2001 (11 data sets). During this time, ten water quality variables were measured. The expected outcomes (hypotheses) and the techniques used are described below, with further details given in Appendix 1.

4.6 Flow

Hypothesis 1A: Forested catchments will produce the highest base flows (due mainly to superior watertable recharge).

Hypothesis 1B: Rural catchments will produce higher base flows than urban catchments (again due to superior watertable recharge).

Hypothesis 1C: Forested catchments will produce the lowest peak flows (due mainly to superior interception and infiltration).

Hypothesis 1D: Urban catchments will produce higher peak flows than rural catchments (due mainly to poorer interception and infiltration).

4.6.1 Measurement

Flow was calculated by multiplying the average velocity of the stream by the cross sectional area. No accurate flow meter was available, so velocity was estimated by measuring the time a float takes to travel down a measured distance of the stream.
The float velocity divided by 1.2 gives the average velocity of the water column (Bartram and Balance, 1996). The cross-sectional area of the stream was determined by multiplying stream width by the average depth. Three separate cross sections were measured and calculated and the average of these was used.

4.7 Water clarity

Hypothesis 2A: During dry weather periods, clarity will be poorest at sites draining rural areas (due to the activities of livestock).

Hypothesis 2B: Clarity will be highest at sites draining forested areas (due to superior interception and infiltration).

Hypothesis 2C: During rainfall events, clarity will be poorer at sites draining urban areas than at sites draining rural areas (due to increased bank erosion from higher flows and erosion from earthworks).

4.7.1 Measurement

Clarity was chosen as the indicator of suspended sediment levels because it is quick and easy to measure and is used for water quality guidelines. Clarity was measured as per Kilroy and Biggs (2002), with a clarity tube (see Figure 18). Clarity tube readings were converted to black disk clarity[4] values using an equation from Kilroy and Biggs (2002) and turbidity values using an equation developed from measurements by Kilroy (unpublished data, 2002).

4.8 Temperature

Hypothesis 3A: Temperatures will be lower downstream of riparian vegetation (due to shading).

Hypothesis 3B: Temperatures will have less diurnal variation downstream of riparian vegetation (again, due to shading).

[4] The black disk method is used for the New Zealand recreational water quality guideline (MofE,1994).

4.8.1 Method

The water temperature was measured using the YSI Model 55 Handheld Dissolved Oxygen Meter. It has a quoted accuracy of +/- 0.4°C.

Figure 18: The clarity tube in action.

4.9 pH

Hypothesis 4: pH will be less variable downstream of riparian vegetation (because shading will reduce photosynthesis).

4.9.1 Method

A Meterlab™ PHM201 portable pH meter from Radiometer Copenhagen was used. It had a quoted accuracy of ±0.01 units.

The meter was 2 point calibrated every testing day with a pH = 7 solution and a pH = 4 solution.

4.10 Alkalinity

Alkalinity was measured once using the ISO 9963-1 (1994) titration method.

4.11 Salinity and electrical conductivity

Hypothesis 5A: Rural catchments will produce higher stream conductivities than forested catchments (due to fertilisers and animal wastes).

Hypothesis 5B: Urban catchments will produce higher stream conductivities than forested catchments (due to fertilisers, domestic animal wastes and concrete).

4.11.1 Measurement

A Hanna instruments HI8733 portable conductivity meter was used. It has a quoted accuracy level of ±1%. It automatically compensates for temperature.
The instrument was calibrated monthly against standard KCl solutions.

4.12 Dissolved oxygen

Hypothesis 6A: DO levels in sites draining rural catchments will be lower than in sites draining forested catchments (due to organic pollution from livestock).

Hypothesis 6B: DO levels in streams will fluctuate less downstream of riparian vegetation (due to reduced photosynthesis).

4.12.1 Method

Oxygen was measured using an oxygen-membrane electrode. A YSI Model 55 handheld dissolved oxygen meter was used. It had a quoted accuracy of ±0.3mg/L for concentration and ±2% for percentage saturation.

4.13 Biochemical Oxygen Demand (BOD)

Hypothesis 7: BOD will be greater in sites draining rural catchments than sites draining forested catchments (due to animal wastes).

4.13.1 Measurement

The BOD was measured following the five-day BOD test (BOD_5) method (5210 B) in APHA (1995). DO levels were tested at the beginning and at the end of the five-day period using the iodometric titration method with azide modification (4500-O C) from APHA (1995).

This method was plagued by unacceptably high readings for the control. The APHA (1995) method requires the blank to have a DO uptake of no more than 0.2 mg/L. Levels of 1mg/L were often obtained. Therefore, the initial BOD_5 results were rejected and a process to eliminate any possible errors from the procedure was undertaken (see Appendix 1). Consequently, only the final three weeks of BOD data could be used.

4.14 Phosphate

Hypothesis 8: Phosphate levels will be higher at sites draining rural catchments (because of fertiliser application).

4.14.1 Method

Orthophosphate was measured because it is the prime phosphorus species taken up in aquatic systems (Webster *et al.,* 2001). It is also by far the easiest and quickest form of phosphorus to test. Other forms of phosphate must first be converted to orthophosphate — usually using acid digestion — if they are to be tested.

Orthophosphate was measured as per Hanson (1973), where orthophosphate reacts with ammonium molybdate and produces molybdophosphoric acid. This is then reduced to "molybdenum blue" using ascorbic acid and analysed using a spectrophotometer at 880nm. This necessitated the construction of a calibration curve using solutions of known concentration. Measurements are accurate down to 0.02mgP/L (Hanson, 1973).

4.15 Nitrate

Hypothesis 9A: Nitrate levels will be highest at sites draining rural catchments (due to livestock, fertilisers, nitrogen-fixing clover and a lack of riparian filtering).

Hypothesis 9B: Nitrate levels will be higher at sites draining urban catchments than sites draining forested catchments (due to fertilisers, domestic animals, sewage leaks and a lack of riparian filtering).

4.15.1 Method

Nitrate was the species of nitrogen chosen for measurement because it is the most stable form and the most common in well-oxygenated waters.

Nitrate was measured as per Yang *et al.* (1998). This method first converts nitrate to the nitronium ion (NO_2^+) using heat and sulfuric acid. The nitronium is then reacted with salicylate to form a yellow compound, whose concentration is determined photometrically at 410nm. The method can measure to levels of 0.1mg NO_3-N /L and requires the construction of a calibration curve.

Because of the volume of laboratory analysis that was required to be done on the sampling day, nitrate was often analysed on the following day. The samples were refrigerated overnight and kept from light. Kept this way the nitrate content should remain stable for 24 hours (APHA, 1995; Liess and Schulz, 2000).

4.16 Indicator Bacteria

Hypothesis 10A: Urban catchments will produce higher bacterial counts than forested catchments (due to domestic animals, leaking sewers and the lack of vegetative filtration).

Hypothesis 10B: Rural catchments will produce the highest bacterial counts (due to livestock).

4.17 Coliform Bacteria: Total coliforms, faecal coliforms and *Escherichia coli*

4.17.1 Faecal coliforms

For faecal coliforms, the membrane filtration test was used as per DIFCO (1984: 351–353) using DIFCO brand mFC broth base and technical agar.

Figure 19: Equipment at the NSCC laboratory showing Quanti-Tray™, sealer and reagents

4.17.2 Total coliforms and *Escherichia coli*

Total coliforms and *E. coli* were measured using the Colilert® Quanti-Tray™ method at the NSCC laboratory on two occasions (Figure 19).

4.18 Bacteria: enterococci

Enterococci levels were regularly measured using membrane filtration technique as per DIFCO (1984: 346–348). DIFCO brand m Enterococcus agar was used.
Enterococci were also measured using the Enterolert® Quanti-Tray™ method at the NSCC laboratory on two occasions.

4.19 Data analysis

This case study measured five sites from two streams. To fully test the hypotheses stated in this chapter, a larger number of sites (to account for natural variability) from a larger range of streams (to ensure independence between sites) would need to be measured. Resource limitations precluded this.
However, statistical comparisons of the sites studied were undertaken to assess differences between sites and their conformity to the hypotheses.
Figure 20 shows the process of data analysis that was performed using the Minitab™ (2000) and Graphpad® Instat (2000) programmes.
Hereafter, the term significant is used only where a statistically significant difference in the data exists. That is, where the possibility of the difference being due to random variation is less than one in 20 (as $P<0.05$).
Graphpad® Instat (2000) uses the Kolmogorov and Smirnov method to test for normality of distribution. Where datasets failed this test, appropriate transformations were trialled. These included square, square root, log, Box-Cox and Arcsine transformations, as suggested by Sokal and Rohlf (1995) and Townend (2002). If a normal distribution was obtained, the Bartlett's test for equivariance was run. Where a dataset failed this test, the transformations listed previously were trialled. Data were tested for normal distribution before Bartlett's test for equivariance was used, as Bartlett's test is sensitive to departures from normality (Sokal and Rohlf, 1995). Those datasets able to display normal distribution and equivariance were tested for significant differences between sites using one-way analysis of variance (ANOVA).

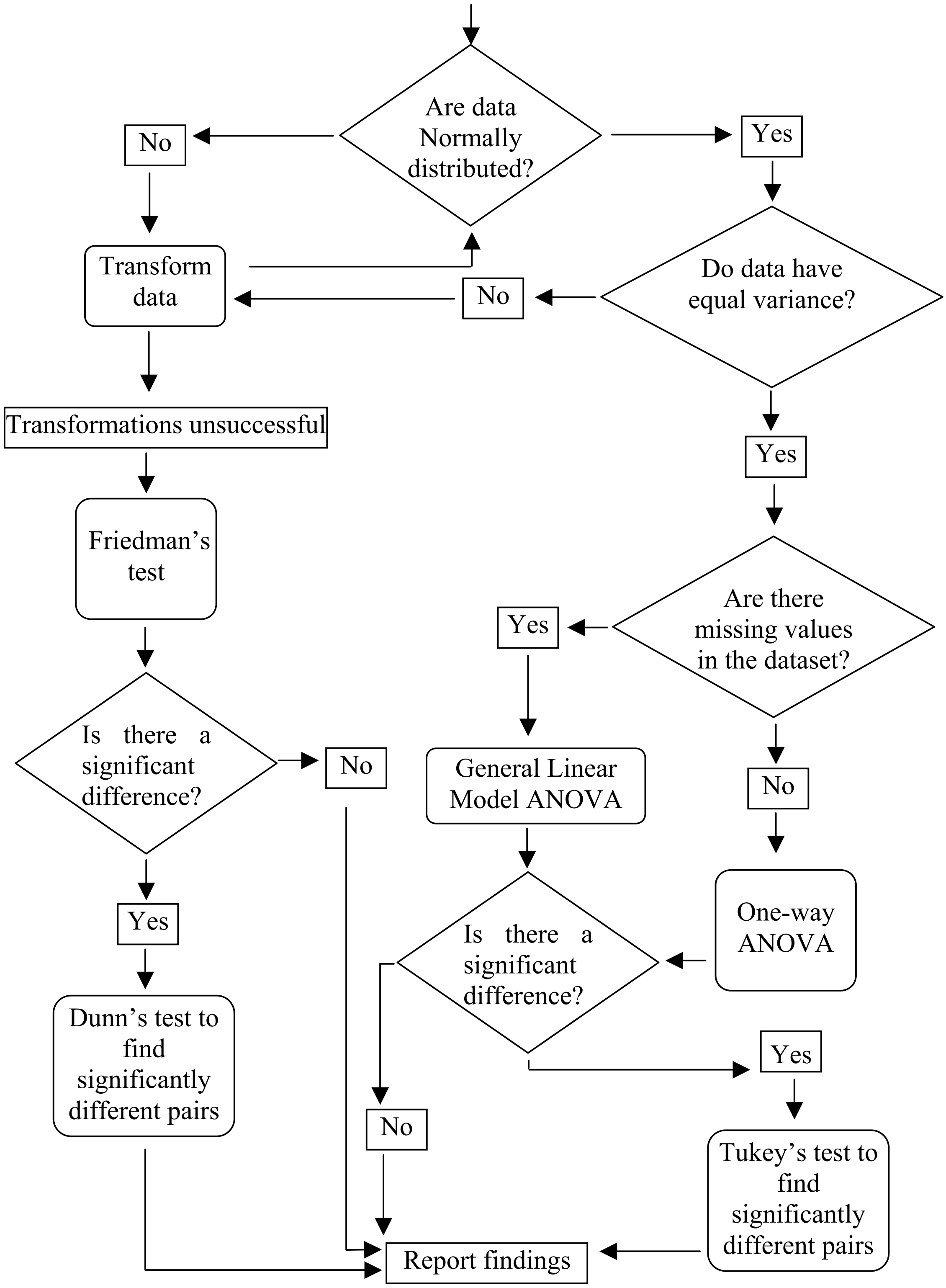


Figure 20: Systems diagram of the process of data analysis

All five sites were measured 21 times. Since each site was measured on the same dates as the other four sites, measurements of the sites can be said to be matched by date. Matching by date accounts for the fact that measurements from the same date are expected to be more alike than measurements taken on different dates. Graphpad® Instat (2000) was used to perform a one-way ANOVA with matching by date (repeated-measures ANOVA). Graphpad® Instat (2000) also tests if matching is effective. It was effective in all cases.

Where there were missing values in the data (e.g. where the dissolved-oxygen meter stopped working due to a water leak into the panel) the general linear model one-way ANOVA was used with matching for date. This programme is available in Minitab™ (2000).

Where the ANOVA tests found a significant difference between sites, Tukey's post-tests were used to determine which site pairs were significantly different.

For instances where normality of distribution or equivariance could not be obtained, Friedman's non-parametric test was used with matching by date. Again, Graphpad® Instat (2000) tests to determine if matching is effective. It was effective in all cases. Where a significant difference existed between sites, Graphpad® Instat (2000) used Dunn's post-test to determine which site pairs where significantly different.

5 Case study one (NZ): Results and analysis

The results[5] and their interpretation are given in this chapter. More detailed analysis is provided at the end of this chapter in the synopsis. The raw data can be found in Appendix II.

5.1 Flow

5.1.1 Base flows[6]

Hypothesis 1A: Forested catchments will produce the highest base flows (due mainly to superior watertable recharge).
The data conform to this hypothesis.

Base flows per hectare[7] were significantly higher at the forest/rural site (upper Vaughan) than at all other sites.
The urban sites were not significantly different from each other, indicating that the simple method of measuring flows used at these sites was accurate enough to produce consistent results (three sites, 12 measuring events).

Hypothesis 1B: Rural catchments will produce higher base flows than urban catchments (due to superior watertable recharge).
The data do not conform to this hypothesis.

The base flow per hectare at the rural, lower Vaughan site (see Figure 21) was clearly lower than the urban sites (significantly so when compared to lower Awaruku). Like upper Vaughan, lower Vaughan was expected to have relatively high base flows because of the lack of impermeable surfaces in its catchment. The reason for these unexpectedly low base flow readings came to light when a leak was discovered at the bottom of the ARC weir at this site. This would have resulted in considerably lower

[5] All data referred to were obtained during the project fieldwork unless otherwise stated.

[6] Baseflow data are from sampling dates with less than 0.1mm rain in the three hours prior to measurement and less than or equal to 1 mm in the 24 hours prior to measurement.

[7] Before any analysis was undertaken, the flow data for each site were divided by the area it drained to obtain a figure of flow per hectare. This allowed a fairer comparison of the flows at the different sites.

flow readings, especially during base flows. In fact, on one occasion the leak accommodated all flow (no water passed over the weir).

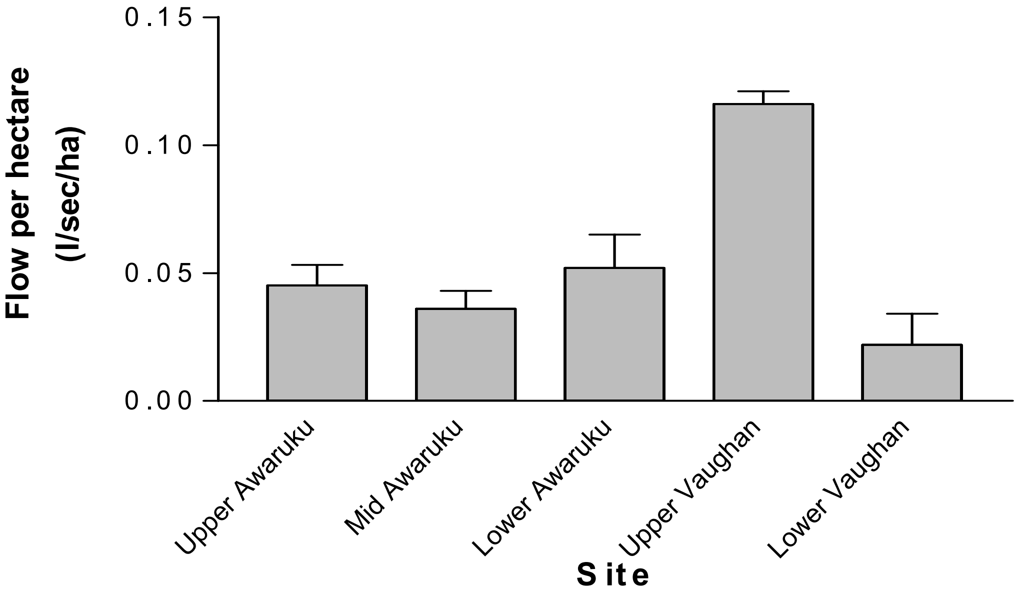


Figure 21: Mean (n=12) base flow per hectare for each site. Error bars indicate standard error.

5.1.2 Rainfall-event flows[8]

Rainfall events were rare during the study period (only four dates qualified for the rainfall event definition). Furthermore, during the one and only major storm event measured, the heaviest falls occurred after three of the five sites had already been measured, so peak flows were missed at these sites. Consequently, the value of the data is limited. No significant difference was found between sites (P =0.21); however, that does not mean that none exists; a larger data set would be needed to make stronger conclusions about the hypotheses.

Data from ARC deployments at four sites (mid and lower Awaruku, mid and lower Vaughan) were used to gain a better understanding of the flow during rainfall events. Peak flows from high flow events were identified from graphs of the data, tabulated and compared pairwise using the Wilcoxon matched pairs test[9].

[8] Dates with more than five millimetres of rainfall in the 24 hours prior to sampling, or which had more than 1mm of rain three hours before sampling, were analysed as rainfall events.

[9] Comparing each pair individually increases the risk of a significant difference being found in the data where none exists, but the fact that this comparison method enabled a better use of the available data overrode this concern.

Hypothesis 1C: Forested catchments will produce the lowest peak flows (due mainly to superior interception and infiltration).

The data conform to this hypothesis.

The box plot of peak flows (Figure 22) indicates that the forest/rural site (upper Vaughan) had considerably lower peak flows than the other sites. This box plot is based on only four dates[10], but pairwise analysis using all data confirmed that the rural/forest site had significantly lower peak flows per hectare than all other sites. Comparison with the mid Awaruku site (Figure 23) is especially noteworthy due to the relatively large data set (n=35, $P<0.001$).

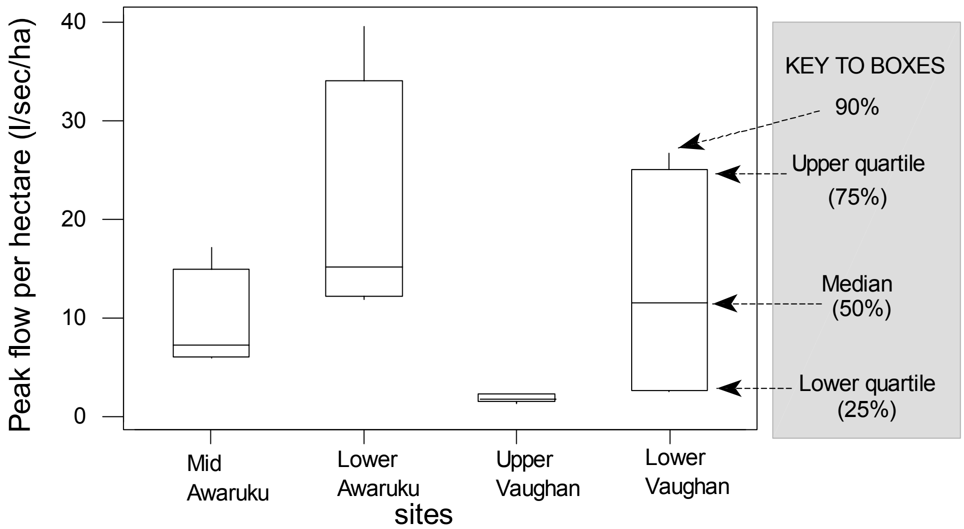


Figure 22: Box plot of peak flows per hectare during storm events (n = 4) at different sites.

The highest flows per hectare were at the lower Awaruku (urban) site. This site had significantly higher peak flows per hectare than the other urban site (mid Awaruku), which may have had reduced peak flows due to a sediment dam several hundred meters upstream of the site.

[10] Data existed for the period from November 1999 until May 2002, but not for all sites. Data were available for all four sites on only four of the 39 high flow events identified.

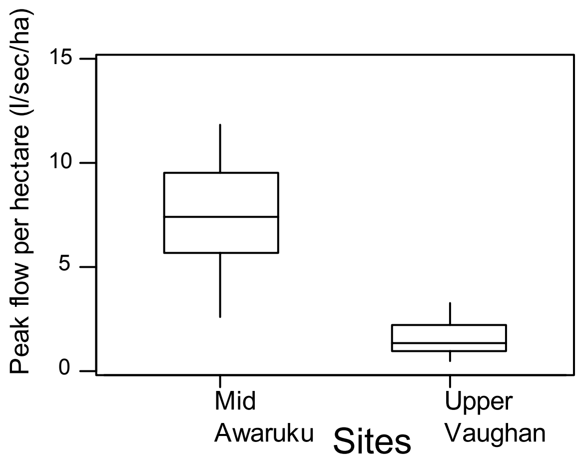


Figure 23: Boxplot of peak flows per hectare of catchment during storm events (n = 39) for the mid Awaruku and mid Vaughan site. See Figure 22 for key to box components

Hypothesis 1D: Urban catchments will produce higher peak flows than rural catchments (due mainly to poorer interception and infiltration).

The data do not conform to this hypothesis.

There was no significant difference between the rural (lower Vaughan) site and the two urban sites. This may be due to the effects of the two sediment dams on the upper reaches of the Awaruku. Established gardens, which often include imported topsoils, may also have reduced urban peak flows. Imported topsoils would allow better infiltration than the relatively impermeable clays of the area. It is also possible that the increase in runoff caused by impermeable catchment surfaces such as concrete, roofing and bitumen roads is only moderate when the natural soil of the catchment is relatively impermeable. However, the effect of stormwater reticulation, which transports runoff quickly to the stream, was expected to cause significantly higher peak flows in the urban sites.

The reason for the lack of significant difference may be that the readings at lower Vaughan are inaccurate. The rural (lower Vaughan) site had a significantly higher flow than the upper Vaughan (forest/rural) site (n=6), with the median of the lower Vaughan site being more than double that of the upper Vaughan site. Such a large difference goes against expectations, since 40% of the lower Vaughan's catchment is forest (see Table 1).

Inaccuracies in the ARC measurements are likely because for some sites, only a few gaugings were taken (e.g. only four at the upper Vaughan site). Additionally, at the lower Vaughan site, the trendline of the gaugings graph correlates very poorly with the data (see Figure 24). Also, storm-flow events are rarely gauged because they are hard to predict and dangerous to measure. Hence, figures quoted for higher flow events often rely on extrapolation (P. White, *pers. com.* 2002).

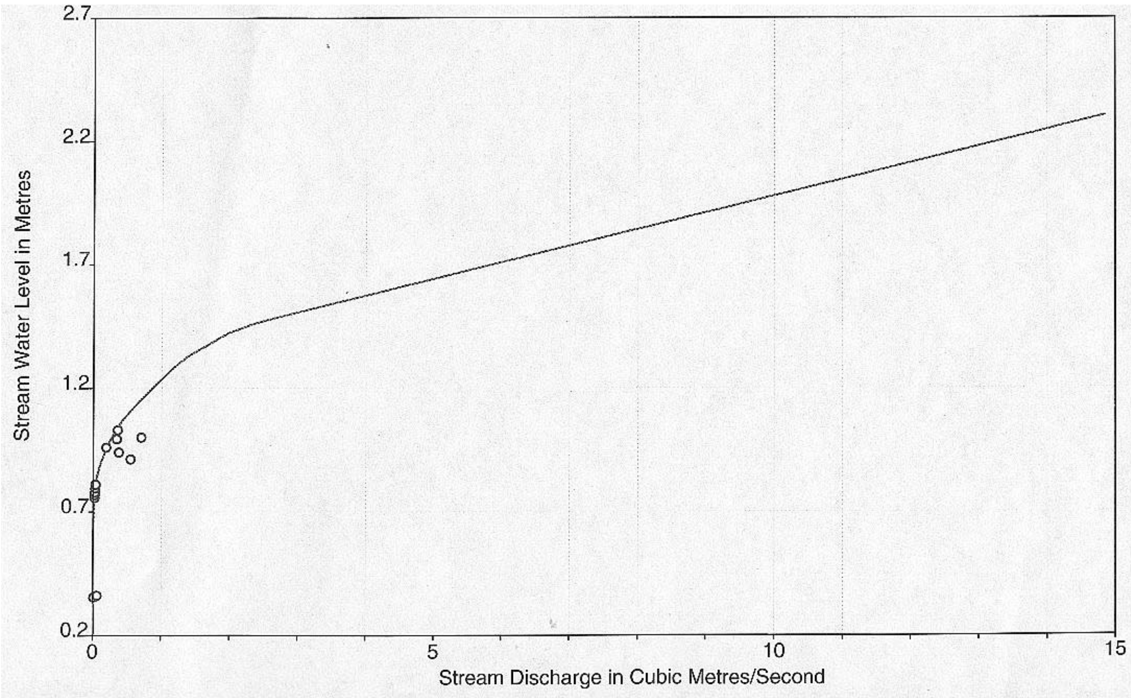


Figure 24: ARC gaugings graph for the lower Vaughan site showing large extrapolation and poor correlation between the trendline and data at stream water level of one metre

5.2 Turbidity, clarity and suspended sediment

5.2.1 Dry-weather[11] stream water clarity

Hypothesis 2A: During dry weather periods, clarity will be poorest in sites draining rural areas (due to livestock).
The data conform to this hypothesis.

The rural, lower Vaughan site had significantly lower clarity than the urban, mid Awaruku site, and has the lowest clarity of all sites on the box plot of dry-weather clarities (Figure 25).

Hypothesis 2B: Clarity will be highest in sites draining forested areas (due to superior interception and infiltration).
Dry-weather data do not conform to this hypothesis.

[11] Dates with less than 0.1mm of rain in the three hours prior to measurement and less than or equal to 1 mm in the 24 hours prior to measurement were analysed as dry-weather flows.

The forest/rural mid Vaughan site had significantly poorer clarity than the urban, mid Awaruku site, and its clarity did not appear to be superior to the other urban sites (Figure 25).

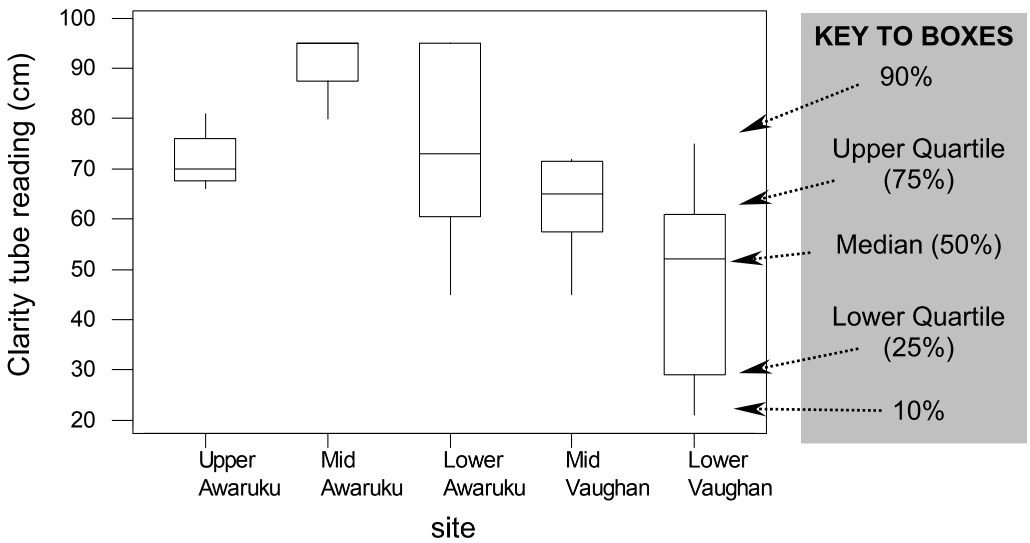


Figure 25: Box plot of dry weather clarity-tube reading (n=13) of sites on Awaruku and Vaughan Streams. Please note that the maximum reading possible is 95cm.

The lower water clarity at the rural site was probably due to the effects of livestock (also evidenced by site inspections: see Figure 26) and accentuated by the higher dry-weather flows one would expect at rural sites (higher flow velocities permit a greater sediment load). The forest/rural, mid Vaughan site's relatively low clarity may be because of tannins, higher flow velocities and livestock in the catchment (although the number of livestock is minimal). Low dry-weather flows at urban (Awaruku) sites could have reduced the volume of sediments in suspension there. The concrete channel of the mid Awaruku site may be the reason it had superior clarity to all other sites, as concrete channelled sections lack bed erosion. Samples are also less likely to be contaminated with streambed sediments when the bed is concrete (although care was always taken to avoid such contamination). Storey (1995) and Wilding (1996) found channelled stream sections had lower turbidities than unchannelled sections in urban streams in the Auckland area.

Figure 26: Damage by livestock in the catchment of the lower Vaughan site

Only the mid Awaruku site had a median black-disk clarity value[12] that met the 1.6m guideline for optical water clarity for contact recreation (MofE, 1994) and which was above the 2.04m median base flow[13] black-disk clarity for streams from the New Zealand Water Quality Network (NZWQN, Smith and Maasdam, 1994). The NZWQN values are the result of two years of regular surveys at 77 river and stream sites in New Zealand.

5.2.2 Rainfall-event data[14]

Rainfall event data also support hypothesis 2B (that forest catchments produce the highest stream clarities). The graph of the rainfall-event data (Figure 27) indicates that the mid Vaughan site (forest/rural) has better clarity than the other sites, and Tukey tests confirmed that this forest/rural site had significantly higher clarity readings than all sites except upper Awaruku (urban). Lower runoff rates and good vegetative intercept and filtering explain mid Vaughan's clarity.

[12] Converted from clarity-tube readings to black-disk readings as per Kilroy and Briggs (2002)

[13] Operationally defined as less than median flow

[14] Dates with more than five mm of rainfall in the 24 hours prior to sampling, or that had rain three hours before sampling where analysed as rainfall events.

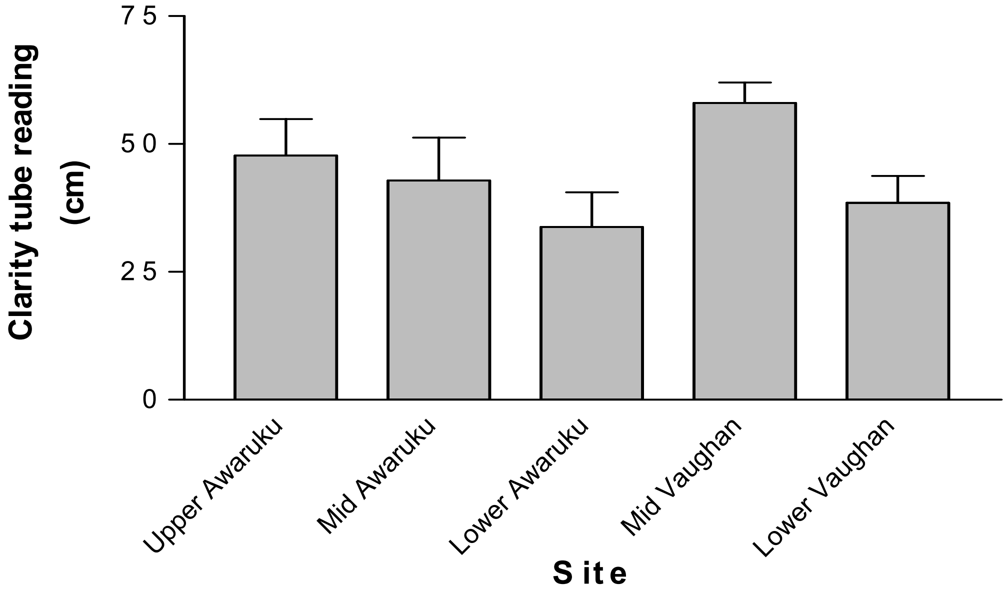


Figure 27: Mean clarity-tube readings for rainfall event samples (n=6) against site sampled. Bars represent standard errors.

Hypothesis 2C: During rainfall events, clarity will be poorer in sites draining urban areas than in sites draining rural areas (due to increased bank erosion from higher flows, erosion from earthworks).

The data do not conform to this hypothesis.

The rural, lower Vaughan site had relatively poor clarity, even poorer than two of the urban sites (Figure 27). However, no significant differences were found, possibly as the dataset was small (n = 6).

In contrast, Lenat and Crawford's (1994) comparison of an urban, a forested and an agricultural stream in North Carolina found that the urban stream had the highest high-flow suspended-sediment concentrations. Suspended-sediment concentrations are related to poor clarity. The catchment of Lenat and Crawford's urban stream may, however, have contained more exposed soil, as "substantial development was on-going in the urban catchment" (Lenat and Crawford, 1994:191). It is also possible the rural stream in Lenat and Crawford's study was less affected by livestock than Vaughan Stream. The relatively poor clarity in the rural, lower Vaughan site indicates that the effects of allowing livestock direct access to the stream may be greater than anticipated.

The lower mean clarity readings at lower Awaruku than the two other urban sites (upper and mid Awaruku) is explained by two factors: earthworks (associated with a new residential development) in the catchment of the lower Awaruku site, and the sediment-settlement dams above the mid and upper Awaruku sites.

Mean rainfall-event turbidity levels[15] (Table 2) were generally below 25NTU, the level Richardson *et al.* (2001a) found affected the migration of the juvenile banded kokopu (*Galaxias fasciatus*). However, the one monitored heavy downpour produced turbidities greater than 25NTU at all sites except for the forest/rural site (upper Vaughan) and the lower Awaruku site had a mean rainfall event turbidity (n = 6) of 26 ± 5 NTU, indicating that moderate rainfall could affect migration at this site.

Table 2: Mean (n = 6) rainfall event turbidity ± standard error at all sites

Site	Upper Awaruku	Mid Awaruku	Lower Awaruku	Mid Vaughan	Lower Vaughan
Turbidity[16] (NTU)	18 ± 4	20 ± 5	26 ± 5	13 ± 2	23 ± 4

Guidelines for increases in turbidity vary widely (Ryan, 1991) and are difficult to set because the effects of increases in turbidity vary depending on the ambient turbidity and flow regime. Recommended limits for turbidity increases vary from 10% above the ambient turbidity (Davies-Colley and Smith, 1990) to a flat increase of 5 NTU for small streams (Ryan, 1991), although an increase of 25 NTU was considered acceptable for streams with steep gradients where recovery from sediment deposition would be quick (Ryan, 1991).

If the turbidity levels at the site with the least-disturbed catchment (mid Vaughan) are considered "ambient", then all other sites (with the possible exception of the upper and mid Awaruku) have failed to meet the recommended guidelines of Davies-Colley and Smith (1990) and the lower Awaruku site has also not met Ryan's recommended guideline.

5.2.3 Clarity and turbidity dataset as a whole

Table 3 shows that the rural site (lower Vaughan) appears to have poorer clarity and turbidity than the other sites, mirroring the findings of Leung (1999). Leung (1999), in a study including Awaruku and Vaughan Streams, found that turbidity levels were significantly (P<0.05) higher in pastoral streams (mean =13 ± 2.5 NTU) than in urban (11 ± 1.2 NTU) and forest streams (4 ± 0.6 NTU). The predominantly forested site (mid Vaughan) in this study has higher median turbidity than the urban sites, which does not

[15] Converted from clarity-tube readings to NTU using Equation 3 of Appendix 1

[16] Converted from clarity-tube readings to NTU using Equation 3 of Appendix 1

fit with the results of Leung. This could be due to the rural component of the mid Vaughan catchment, the low occurrence of rainfall events in the data or the fact that the results quoted by Leung are means rather than medians and therefore not directly comparable.

Table 3: Median (n=21) clarity (clarity tube and black disk) and turbidity for all sites and for the New Zealand Water Quality Network (Smith and Maasdam, 1994)

Site	Median clarity-tube clarity	Median turbidity[17]	Median black-disk clarity[18]
Upper Awaruku	68 cm	8 NTU	89 cm
Mid Awaruku	80 cm	4 NTU	139 cm
Lower Awaruku	66 cm	9 NTU	83 cm
Mid Vaughan	63 cm	10 NTU	74 cm
Lower Vaughan	50 cm	16 NTU	46 cm
NZWQN	NA	8.1 NTU	130 cm

5.2.4 ARC data

The ARC set up parallel deployments of turbidity meters on four occasions. Unfortunately, the quality of the data is questionable, with one parallel deployment having negative turbidity readings as low as –54 NTU (technically impossible). In another parallel deployment, there appears to be drift in the meter's readings (see Figure 28). Such errors cast doubt on the accuracy of the other two parallel deployments. Nonetheless, the results of these remaining two deployments were analysed. Data from a parallel deployment at the lower Awaruku (urban) and lower Vaughan (rural) sites were analysed and the rural site (median = 34 NTU) was found to have significantly higher turbidity (P = 0.000) than the urban site (median = 16 NTU), possibly due to livestock. There were peaks of turbidity at the rural site that were not matched by the urban sites, indicating that sediments were being stirred up by livestock. The other parallel deployment without obvious errors was at mid Awaruku and lower Awaruku. The mid Awaruku site (median = 20 NTU) was significantly less turbid (P = 0.000) than lower Awaruku (median = 22 NTU). This could be due to the sediment dam above the mid Awaruku site.

[17] Converted from clarity-tube readings to NTU using Equation 3 of Appendix 1

[18] Converted from clarity-tube readings to black-disk readings as per Kilroy and Briggs (2002)

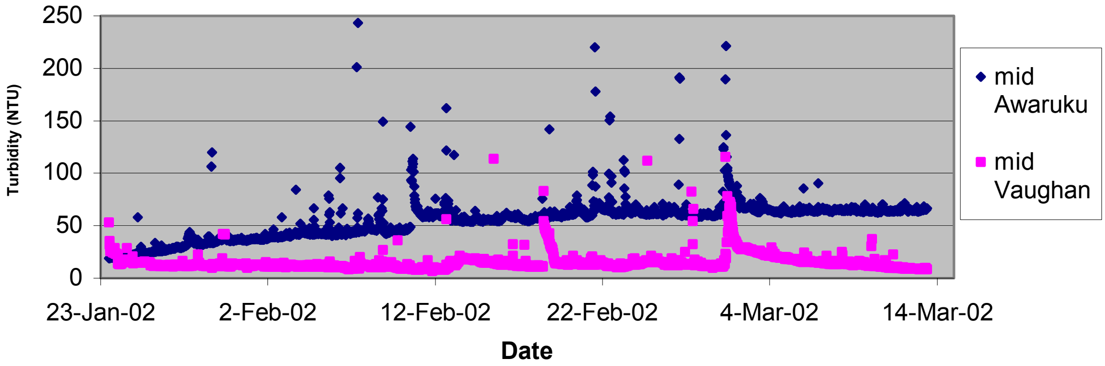


Figure 28: Turbidity of mid Vaughan and mid Awaruku Stream sites against date, showing apparent drift in the meter's readings at mid Awaruku

5.3 Temperature

Hypothesis 3A: Temperatures will be lower downstream of riparian vegetation (due to shading).

Hypothesis 3B: Temperatures will have less diurnal variation downstream of riparian vegetation (again, due to shading).

Both hypotheses are supported by the data.

Temperatures at the forest/rural site were significantly lower than at all other sites, with no other significant differences in the data apparent. Analysis of data from ARC parallel deployments confirmed this and also showed that the diurnal temperature fluctuation was far smaller at the mid and upper Vaughan sites than at other sites. Temperatures at the mid Awaruku site, which is directly downstream from a large section of riparian vegetation, were also significantly lower than at the lower Awaruku site. Again, the fluctuation of temperatures here is less and there are fewer values above 20°C than at the lower Awaruku site. A sediment dam 200m upstream of mid Awaruku may also be a cause of the more stable water temperatures found at this site.

Table 4: Mean (n = 21) stream temperature ± standard error at all sites

Site	Upper Awaruku	Mid Awaruku	Lower Awaruku	Mid Vaughan	Lower Vaughan
Temperature (°C)	16.4 ± 0.37	17.0 ± 0.52	17.4 ± 0.48	15.0 ± 0.46	16.9 ± 0.51

These results support the findings of Harding and Winterbourn (1995) and Storey (1995) who found streams with forested margins had lower temperatures. The differences between sites are not, however, as pronounced as those found by Leung (1999), in a study which included Awaruku and Vaughan Streams. Leung found that temperatures were significantly lower in forest streams (mean =12.0 ± 0.2°C) than in pastoral (14.4 ± 1.2°C) or urban streams (16.2 ± 0.04°C) (least significant difference = 2.15).

Analysis of peak temperatures in summer months (Table 5) reveals that the rural (lower Vaughan) site has a disturbingly high maximum. Richardson *et al.* (1994) found the upper lethal temperatures of eight common New Zealand fish species to be between 28.3 and 39.7°C and Quinn *et al.* (1994) found that the upper thermal tolerances (LT_{50}) of 12 New Zealand stream invertebrate species for 48 hours ranged from 24.5 to 34°C. Both the lower Awaruku (urban) and lower Vaughan (rural) sites exceed the Resource Management Act's (1991, Third Schedule) recommended maximum stream temperature of 25°C for waters managed for fisheries purposes.

Table 5: Peak stream temperatures at four sites from ARC data (from a minimum of 45 summer days)

Site	Mid Awaruku	Lower Awaruku	Mid Vaughan	Lower Vaughan
Peak temperature	21.0°C	26.5°C	18.4°C	31.7°C

5.4 pH

Mid and lower Awaruku had higher pH readings than the other sites (see Figure 29), with lower Awaruku having significantly higher pH values than all other sites except mid Awaruku, and mid Awaruku having significantly higher pH readings than upper Awaruku and mid Vaughan. An ARC parallel deployment confirmed the significant difference between mid Awaruku and mid Vaughan. The reason for the relatively high pH values at mid and lower Awaruku is probably the concrete in the stream channels and on catchment surfaces that drain to these sites. At relatively low pH values, such as the slightly acid values prevalent in this study (median for all sites=6.8), concrete would be expected to have an alkalising effect.

Hypothesis 4: pH is less variable downstream of riparian vegetation (because shading will reduce photosynthesis).

This hypothesis is supported by the data.

Figure 30 shows the clearly larger diurnal changes in pH at the lower Awaruku site compared to the mid Awaruku site (which is directly downstream of a forest reserve).

Lower Awaruku had significantly higher pH values than mid Awaruku. The difference is so large that it brings the accuracy of the readings into question. Over the 45 days of the ARC parallel deployment, lower Awaruku is consistently around one pH unit higher than mid Awaruku and never comes within 0.5 pH units. The ARC values for lower Awaruku (median = 8.2, min = 7.7) are also high compared to the author's data (median = 7.2, max = 7.5).

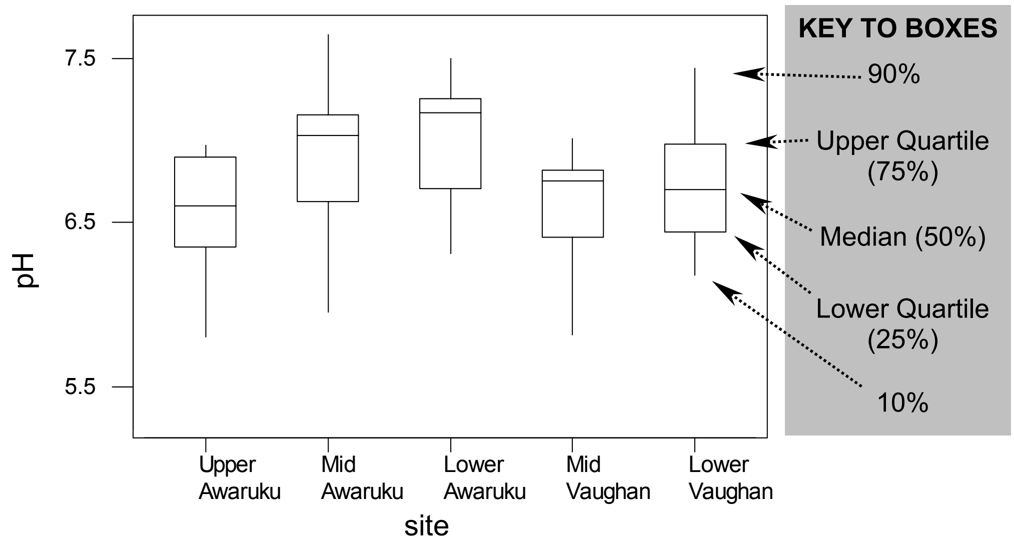


Figure 29: Box plot of pH at all sites (n=19)

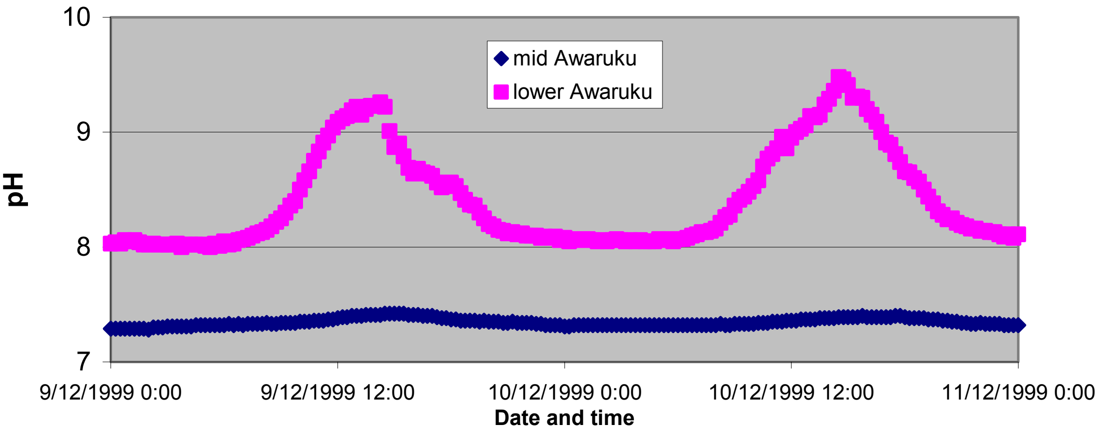


Figure 30: Fluctuations in stream pH over 48 hours at the mid and lower Awaruku sites. Readings were taken every 15 minutes.

Analysis of the third ARC parallel deployment found the upper Vaughan ARC forest site had significantly higher pH readings than the rural, lower Vaughan site. However, examination of the ARC data for this deployment brings the data's quality into question. Data had been adjusted by the ARC to account for the fact that the upper Vaughan meter was out by one unit at pH = 7. There was also a dramatic drop of 3.5 pH units over 15 minutes with the results fluctuating around that level for the remaining nine days of the deployment. This coincided with a similar abrupt change in the turbidity readings where a reading of –54NTU was produced (see 5.2: Turbidity). Data after this occurrence were not analysed.

The pH values were relatively low in the two streams (median value = 6.8) when compared to the world median of 7.6 from the Global Environmental Monitoring System (GEMS, Maybeck, 1987) and the New Zealand median value of 7.7 (NZWQN, Smith and Maasdam, 1994). The low pH values may be due to geological factors, and are unlikely to be low due to error, because other studies (Leung, 1999; NSCC 2000a; Meritec, 2000 (in Kingett Mitchell, 2001)) found similar pH values in the Awaruku and Vaughan (range = 6.3 – 7.21).

5.5 Alkalinity

Alkalinity ranged from 60 to 45 mg/L $CaCO_3$. These were similar to the findings of Wilcock *et al.* (1995) of 61 mg/L for streams in the Auckland area, a level they suggested indicated moderate buffering against changes in pH.

5.6 Electrical conductivity

Hypothesis 5A: Rural catchments will produce higher stream conductivities than forested catchments (due to fertilisers and animal wastes).

Hypothesis 5B: Urban catchments will produce higher stream conductivities than forested catchments (due to fertilisers, domestic animal wastes and concrete).

Data did not support the hypotheses: no differences found

The forest and rural sites appeared to have slightly higher conductivities (see Table 6) although no significant difference in conductivity was found between sites. Mean values are similar to the global (GEMS) mean of 250 µS/cm (Maybeck, 1987), but greater than the New Zealand average of 85 µS/cm from the NZWQN programme (Smith and Maasdam, 1994). The difference to the NZWQN average may be explained by the number of dilute mountain streams (which have very high rainfall averages) that are included in the NZWQN programme.

Table 6: Mean conductivity (± standard error) for all sites (n= 19)

Site	Upper Awaruku	Mid Awaruku	Lower Awaruku	Mid Vaughan	Lower Vaughan
Conductivity (μS/cm)	259 ± 17	254 ± 16	270 ± 14	292 ± 12	292 ± 16

Dates which had no rainfall in the 72 hours prior to measurement had significantly higher ($P<0.05$) conductivity measurements than dates that had 5mm or more of rainfall in the two days prior to measurement.

ARC parallel deployments showed that lower Awaruku had significantly higher conductivity than mid Awaruku, although the difference in values was so small (lower Awaruku mean = 251 μS/cm, mid Awaruku mean = 249μS/cm) that little can be concluded from this. The same is true for the parallel deployment at mid Awaruku and mid Vaughan, where a significant difference was found, but the difference in the means was again negligible. The other parallel deployment found the ARC upper Vaughan (forest/rural) site (mean = 400μS/cm) had significantly higher conductivity readings than the lower Vaughan (rural) site (mean =322μS/cm). This is contrary to the findings of Collier's (1995a) study of 29 Northland streams during low flows in summer, where he found that conductivity was significantly related to the proportion of upstream pasture catchment. The higher figure at upper Vaughan may be due to the application of fertiliser in the rural part of its catchment. However, it could equally be attributed to error, as the lower Vaughan readings abruptly go from a conductivity of 353μS/cm to -5μS/cm at the same time as other parameters also went awry (see 5.2.4: Turbidity and 5.4: pH). Though the data from this point on were not included in the analysis, it does bring into question the validity of the data from this deployment as a whole.

Certainly, no pattern in conductivities was found that supported hypotheses 5A or 5B. Nor did the findings match those of Leung (1999) in his study which included Awaruku and Vaughan Streams. Leung found that conductivities were significantly higher in urban streams (average =336 ± 13.0 μS/cm) than in pastoral (224 ± 13.3 μS/cm) or forest streams (215 ± 2.9 μS/cm) (least significant difference = 34.9). Urban streams have been found to have higher conductivities than agricultural or forested streams in many other studies (reviewed in Paul and Meyer, 2001; also Roy *et al.*, 2003). However, these studies implicate de-icing salts, which are not used in the Auckland region.

5.7 Dissolved oxygen

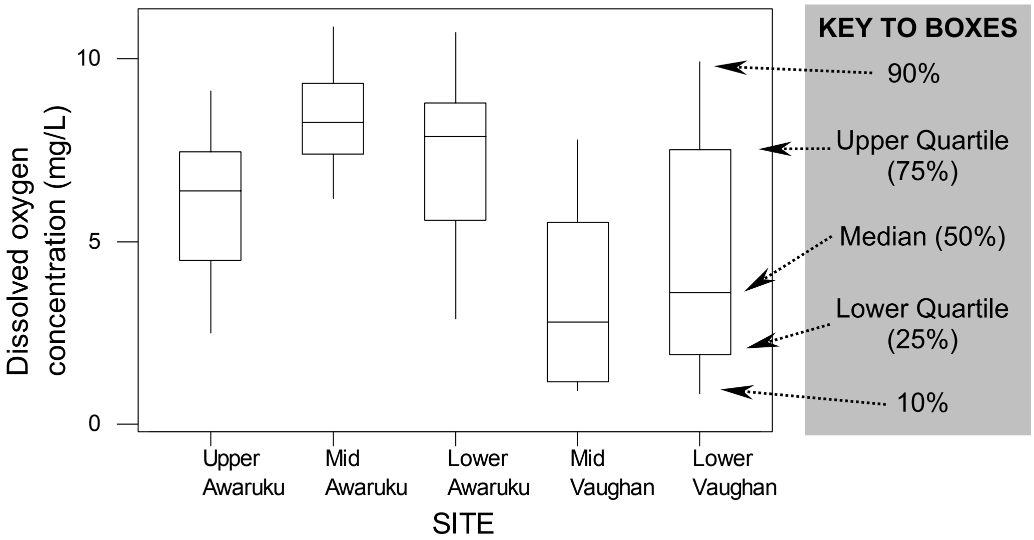


Figure 31: Box plot (n=21) of dissolved oxygen concentration (mg/L) at each site.

Figure 31 shows that levels of dissolved oxygen (DO) in Vaughan Stream are disturbingly low. The DO levels at lower Vaughan site were significantly lower than mid and lower Awaruku. The mid Vaughan site had significantly lower DO levels than all Awaruku sites.

Table 7: Mean dissolved oxygen levels (± standard error) at upper Vaughan (n= 7099), mid Vaughan (n= 2391) and lower Vaughan (n= 7099) from ARC data

Site	Upper Vaughan	Mid Vaughan	Lower Vaughan
DO (% saturation)	45 ± 0.1	9 ± 0.3	30 ± 0.2
DO mg/L	4.5 ± 0.01	1.3 ± 0.02	2.8 ± 0.02

Results from ARC deployments also showed very low DO figures for Vaughan sites (see Table 7). These compare poorly to the GEMS global median river DO value of 90% (Maybeck, 1987), and the NZWQN mean of 100.3% (Smith and Maasdam, 1994). The low figures also fail the Resource Management Act’s (RMA, 1991, Schedule 3) criterion for waters managed for aquatic ecosystem or fisheries purposes (that DO should exceed 80% of saturation).

Levels as low as those in Table 7 appear to be rare. In the NZWQN programme, which surveyed 77 river and stream sites, 97% of watercourses had DO levels that were always above 80% saturation (Smith and Maasdam, 1994). The lowest NZWQN reading was 56%, at a site that also had the lowest median (72%) and was downstream from several organic discharges. **The Vaughan sites have mean DO levels which are less than the lowest level recorded from the entire NZWQN dataset.** The NZWQN readings were taken during the day and would be expected to be relatively high because of this, but this does not adequately explain the large difference.

Brent Evans (*pers. com*. 2002) stated that several fish species were still found in the Vaughan, but on several occasions fish were found dead in sampling traps. He believed that fish were surviving in the Vaughan by finding pockets of oxygenated air (perhaps near the water surface or at turbulent areas), but if caught overnight in nets they would be unable to move to these oxygenated pockets and asphyxiate. This interpretation is supported by the findings of Dean and Richardson's (1999) study on seven native fish and a native shrimp species. They found DO levels of 1mg/L for 48 hours resulted in mortality rates of 100% for four of the species. Lower and mid Vaughan both recorded levels of DO below 1mg/L. The fact that fish seem to be able to survive at all in such low DO water may seem surprising. Dean and Richardson (1999), however, found that elvers, the young of eels (*Anguilla spp*.), had no mortality at all at 1mg/L DO and DO levels of 3mg/L resulted in no mortalities for any of the species in the 48 hour period. However, these results must not be taken as an indication that such DO levels can maintain populations of these species, as the chronic effects of low DO were not studied.

Hypothesis 6A: DO levels in sites draining rural areas will be lower than in sites draining forested areas (due to organic pollution from livestock).
Inconclusive

Hypothesis 6A is not supported by data from this study because oxygen levels at the forest/rural, mid Vaughan site were not significantly higher than the rural lower Vaughan site. In fact, they appear to be lower than at the lower Vaughan site (Figure 31). However, the hypothesis is supported by the results of the ARC parallel deployment at the upper and lower Vaughan sites. The forest (upper) site had significantly higher DO readings than the rural (lower) site (see Table 7 for means). However, the accuracy of the readings is questionable (see below).

DO levels in Awaruku stream were superior to those in Vaughan Stream but not ideal. The upper Awaruku site had significantly lower DO levels than the mid Awaruku site, and had a mean level well below 80% (mean =60 ± 4.6%). It also recorded a low minimum value of 2.5 mg/L DO.

Lower Awaruku also had a mean DO level that was less than 80% (mean = 76± 4.6%) and a low minimum value of 2.9mg/L. ARC data for this site are not as low (mean = 84± 0.3%, min = 4.3mg/L), although the ARC data do indicate that there are large diurnal fluctuations in the DO level (see Figure 32).

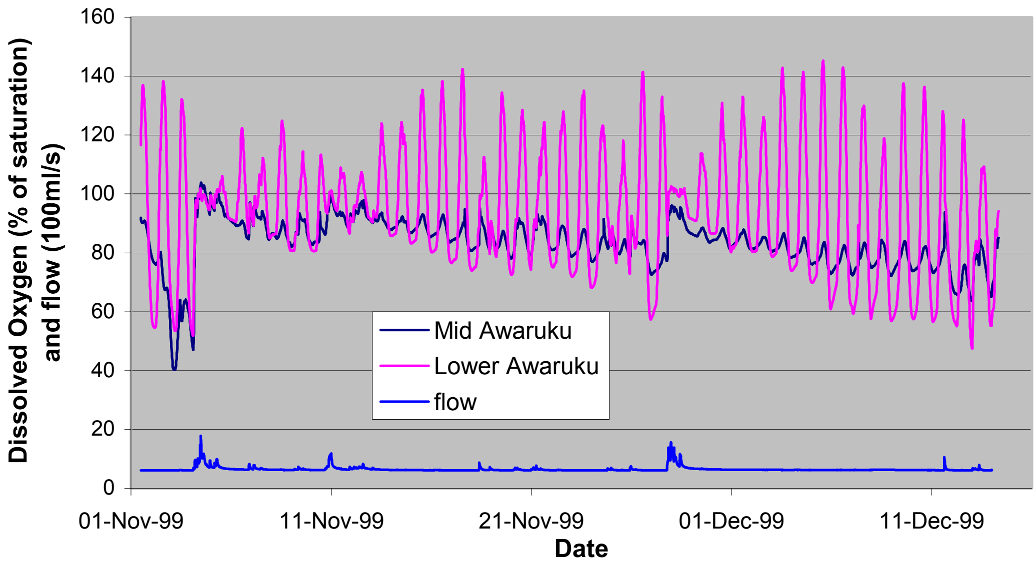


Figure 32: Dissolved oxygen levels at lower and mid Awaruku sites and flow at mid Awaruku over time.

Hypothesis 6B: DO levels in streams will fluctuate less downstream of riparian vegetation (due to reduced photosynthesis).

The data conforms to the hypothesis.

As well as the large diurnal variations in DO seen above (Figure 32), two other ARC parallel deployments also demonstrated clearly higher fluctuations at the sites with less upstream shade. Figure 32 also shows that increases in flow usually coincide with increases in DO and that directly after high flows the fluctuations of the diurnal DO cycle are not as pronounced. This pattern was also found in the two other ARC parallel deployments and could be due to algal and bacterial growths being flushed away by high flows and then slowly building up afterwards.

Examination of the ARC data found two irregularities in the results. In the deployment at mid Awaruku, recorded DO levels were supersaturated for the entire 40-day period of deployment. The lowest reading was 107% of saturation. The other irregularity was found in the lower Vaughan deployment, where, as with the other parameters at this site (see 5.2: Turbidity, 5.4: pH and 5.6: Conductivity), DO changed abruptly from 30% to 80% of saturation and remained around this level for the remaining nine days of the deployment.

Readings from DO meters can be compromised if the membrane is not regularly renewed, and this could be why the ARC deployments give low DO readings in some cases. However, the fact that readings taken in this study are in line with the ARC data means it is less likely that the extremely low results are due to error. Still, the figures are exceptionally low, and are lower than the only other measurements taken from the Vaughan. Leung (1999) found low figures for the lower Vaughan (5.96 and 6.38 mg O/L) but relatively high figures for the upper Vaughan (7.37 and 7.39 mgO/L).

No reason could be found for the low DO measurements in Vaughan stream and at upper Awaruku. There were no obvious signs of organic pollution that could cause oxygen depletion.

5.8 Biochemical oxygen demand (BOD_5)

No significant difference in BOD_5 was found between sites, although data from only three dates were used and it is possible that significant differences exist but were not able to be identified by this small dataset. Hence:

Hypothesis 7: BOD will be greater in sites draining rural areas than sites draining forested areas (due to animal wastes) **was unable to be properly tested.**

The median of 1.3 mg O_2/L is lower than the GEMS median river value for BOD of 3 mg O_2/L (Maybeck, 1987), but higher than the median value from the NZWQN programme of 0.45 mg O_2/L (Smith and Maasdam, 1994).

5.9 Phosphate

As can be seen from (Figure 33), levels of orthophosphate were significantly higher at the mid Vaughan (forest/rural) site than at all other sites. However, these results should be taken with caution because 54 of the 95 measurements were below the limits of accurate detection (0.02mgP/L). Even so, orthophosphate levels at the mid Vaughan site were greater than 0.02mgP/L far more often (16 out of 19 measurements), and the median value was around double the value of the other sites.

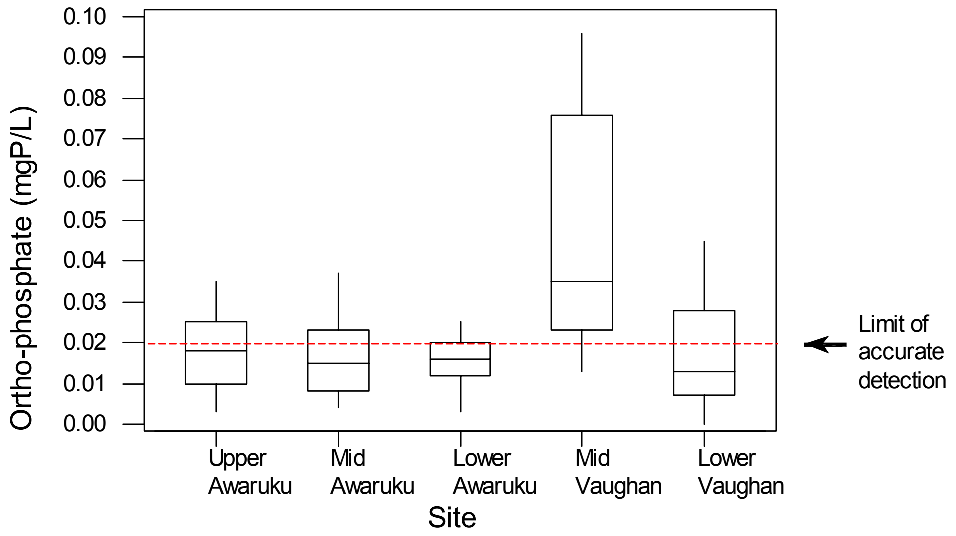


Figure 33: Box plot of ortho-phosphate levels (n=19) at all sites, showing limit of accurate detection. See Figure 22 for key to box components

Hypothesis 8: Phosphate levels will be higher in sites draining rural catchments (because of fertiliser application).

The data do not support this hypothesis.

The higher level at mid Vaughan does not support this hypothesis. However, it is likely that the high levels at mid Vaughan may be due to the application of phosphate fertiliser in the rural part of its catchment (mid Vaughan catchment is 50% rural).

Levels measured in this study were higher than the NZWQN median of 0.004mgP/L orthophosphate (Smith and Maasdam, 1994). Levels were also higher than the figure of 0.005mgP/L Close & Davies-Colley (1990) gave as a "rough, but useful criterion" for limiting growths for filamentous algae in rivers and also higher than the Australian and New Zealand Environment and Conservation Council's (ANZECC, 2000) default trigger value for slightly disturbed ecosystems of 0.01mgP/L orthophosphate. However, levels measured in this study are not exceptionally high. They are comparable to levels measured by Quinn *et al.* (1997) in pastoral and forested streams in the Waikato region of New Zealand (mean = 0.033 ± 0.009mgP/L). They are also in the region normally recorded for Auckland Streams (native forest stream median = 0.02mgP/L, agricultural stream median = 0.024mgP/L, urban stream median = 0.02mgP/L — WaiCare, 2000).

5.10 Nitrate

Hypothesis 9A: Nitrate levels will be highest at sites draining rural catchments (due to livestock, fertilisers, nitrogen-fixing clover and a lack of riparian filtering).
The data support the hypothesis.

Nitrate levels were significantly higher at the rural lower Vaughan site than at all other sites. Nitrate levels were not higher at urban sites than the forest/rural site (mid Vaughan).

Hypothesis 9B: Nitrate levels are higher at sites draining rural areas than sites draining forested areas (due to fertilisers, domestic animals, sewage leaks and a lack of riparian filtering).
Inconclusive

It is not possible to form a conclusion regarding hypothesis 9B since the rural portion of the mid Vaughan catchment may be contributing to the nitrate levels at this site.

Levels from this study (see Figure 34) appear to be in line with nitrate values from the NZWQN (Smith and Maasdam, 1994), which had a mean of 0.24mgN/L and median of 0.1mgN/L. Readings were considerably lower than the GEMS (Maybeck, 1987) world mean of 0.7mgN/L, but are in line with figures collected within the Auckland region (native forest stream median = 0.02mgN/L, urban stream median = 0.88mgN/L, agricultural stream median = 0.51mgN/L — WaiCare, 2000). If anything, the figures for the urban sites appear to be low compared to the Auckland region figures, indicating that fertiliser use and sewage leaks in the urban area may be minimal.

Combined nitrate/nitrite levels at lower Vaughan from six ARC samples gave a mean of 0.065 ± 0.019 mgN/L. This is considerably lower than this project's mean of 0.47 ± 0.050 mgN/L (for nitrate alone) at lower Vaughan. However, NSCC (2000a) nitrate readings for a site near lower Awaruku (mean = 0.33± 0.096mgN/L) and Meritec's (2000 (in Kingett Mitchell, 2001)) figures from the Awaruku (range = 0.18 to 0.38) were in line with figures for lower Awaruku from this project (mean = 0.30± 0.017mgN/L).

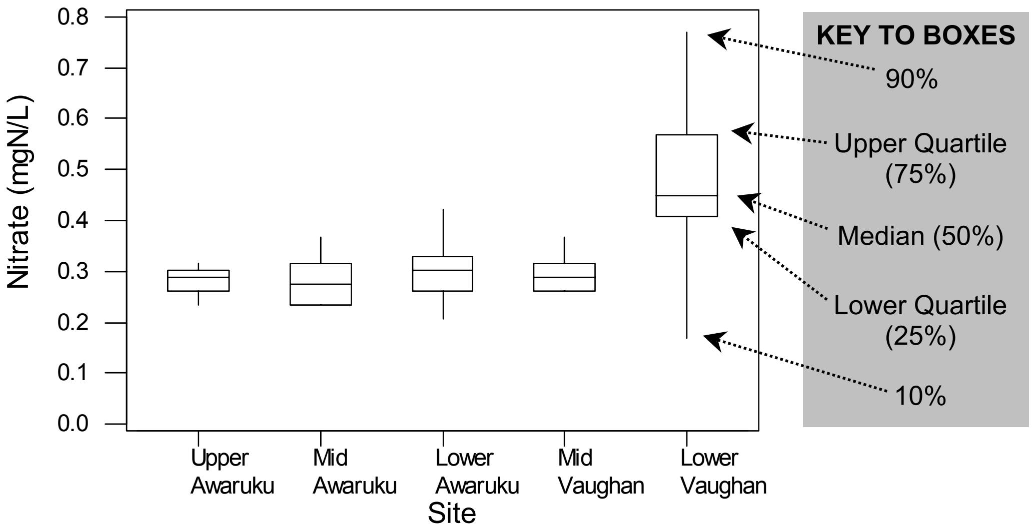


Figure 34: Box plot of nitrate (n=11) at all sites

Ammonium readings for lower Vaughan (ARC data) gave a mean of 0.025±0.0076mgN/L (n=6) and the mean from NSCC (2000a) samples near lower Awaruku was 0.066±0.015mgN/L (n=5). These figures are higher than the NZWQN (Smith and Maasdam, 1994) mean of 0.014mgN/L, but lower than the GEMS (Mayback, 1987) global median of 0.11mgN/L, and considerably lower than Richardson's (1991) 96 hour LC_{50} figure (1.60 ± 0.13mgN/L at pH 8 and 15°C) for ammonia for juvenile inanga (*Galaxias maculatus*) and the United States Environment Protection Authority (EPA, 1985) standard for long term exposure (four-day average should not exceed 0.75mgN/L at pH 9 and 20°C).

5.11 Coliform bacteria

5.11.1 Faecal coliforms

Hypothesis 10A: Urban catchments will produce higher bacterial counts than forested catchments (due to domestic animals, leaking sewers and the lack of vegetative filtration).

The hypothesis is supported by the data.

The forest/rural, mid Vaughan site had significantly lower faecal coliform counts than all the urban sites (Table 8).

Hypothesis 10B: Rural catchments will produce the highest bacterial counts (due to livestock).

The data do not conform to the hypothesis.

Urban (Awaruku) sites had clearly (though not significantly: $P>0.05$) higher faecal coliform counts than the rural (lower Vaughan) site. This may indicate the presence of sewage leaks in the Awaruku catchment.

Table 8: Median faecal coliform counts (n=9) at each site.

Site	Upper Awaruku	Mid Awaruku	Lower Awaruku	Mid Vaughan	Lower Vaughan
Median Faecal coliform count	2000 cfu/100ml	1550 cfu/100ml	4000 cfu/100ml	230 cfu/100ml	1080 cfu/100ml

No sites met the Australian recreational waters guideline for primary contact[19] (ANZECC, 2000) that the median faecal coliform count should not exceed 150cfu/100ml. The guideline for secondary contact[20] (that the median faecal coliform count should not exceed 1000cfu/100ml) was met only at the mid Vaughan (forest/rural) site.

Table 9: Median faecal coliform counts from NSCC (2000) data for 16 North Shore streams and from this study, for wet and dry weather

	NSCC (2000) data	This study (Awaruku and Vaughan)
Dry weather	975cfu/100ml (n=30)	1200cfu/100ml(n=15)
Wet weather	13,600cfu/100ml (n=43)	14,000cfu/100ml (n=5)

However, the measurements from this study are not exceptionally high when compared to data from 16 North Shore streams from a NSCC (2000a) study of dry[21] and wet weather[22] events (see Table 9). Awaruku stream measurements from the NSCC (2000) study are also broadly in line with the results from this project (see Table 10).

[19] Primary contact includes such water sports as kayaking, which occurs on the lower Awaruku.

[20] Secondary contact includes boating and fishing.

[21] Defined by NSCC as a period of three or more days with less than 3mm of rain

[22] Defined by NSCC as more than 12mm in two hours (a one month storm)

Table 10: Median faecal coliform counts for Awaruku stream from a NSCC (2000) study and from this study for wet and dry weather

Awaruku results	NSCC (2000) data	This study
Dry weather	440 and 1800cfu/100ml	2040cfu/100ml (n=9)
Wet weather	24,000cfu/100ml (n=3)	14,000cfu/ml (n=3)

5.11.2 Total coliforms

Hypothesis 10A was again supported by the results, with urban sites having readings far higher than the forest/rural (mid Vaughan) site. The data set is, however, very small (only two events were measured) and no other conclusions could be drawn from it.
The median total coliform reading was 6077 cfu/100ml.

5.11.3 Escherichia coli

Once more hypothesis 10A was supported by the results, although once again the data set was small (two sampling events) and no conclusion could be drawn regarding hypothesis 10B.
Values recorded were high (median = 2295cfu/100ml). All Awaruku sites and the lower Vaughan site had readings on both occasions which placed them in the New Zealand Interim Guidelines for Freshwater Bathing (MofE, 2002) "action/red alert mode". This mode is triggered when a single sample greater than 410cfu/100ml occurs. For recognised bathing areas, this mode requires the erection of warning signs, and that further sampling and a sanitary survey be undertaken to ascertain the cause of the contamination.
Such high values for *E. coli* are not uncommon on the North Shore with the NSCC (2000a) study of 16 streams having a median even in dry weather that was over the trigger value (dry weather median = 520cfu/100ml, wet weather median =11800cfu/100ml).
Values for the rural/forest, mid Vaughan site were much lower and the site appeared[23] to be in the "acceptable/green mode", where bathing is allowed. This mode exists when the running median is less than 126cfu/100ml.

[23] There was not a big enough data set to obtain a median from 5 values as required by the MofE (2002).

5.12 Enterococci

The data again supported hypothesis 10A (that urban catchments produce higher bacterial counts than forest catchments). Upper and lower Awaruku had significantly higher counts than the forest/rural, mid Vaughan site. Mid Awaruku also had higher counts than mid Vaughan, though not significantly so (Table 11). Hypothesis 10B (that rural catchments produce the highest bacterial counts) was again not supported, with the upper and lower Awaruku sites having higher (though not significantly so, $P > 0.05$) counts than the rural, lower Vaughan site.

Table 11: Median (n=10) Enterococci count at each site

Site	Upper Awaruku	Mid Awaruku	Lower Awaruku	Mid Vaughan	Lower Vaughan
Median Enterococci count	2190 cfu/100ml	550 cfu/100ml	700 cfu/100ml	125 cfu/100ml	690 cfu/100ml

In an exact repeat of the findings for faecal coliforms, no sites met the Australian recreational water quality (ANZECC, 2000) guideline for primary contact (median enterococci not to exceed 30cfu/100ml) and only the mid Vaughan (forest) site met the guideline for secondary contact (that the median enterococci count should not exceed 150cfu/100ml). The least stringent EPA (1986) criterion for bathing waters was failed by all sites on multiple occasions. The criterion, that no sample should exceed 151cfu/100ml, is for infrequent use bathing sites.

Table 12: Median Enterococci counts from NSCC (2000) data for 16 North Shore streams and from this study, for wet and dry weather

	NSCC (2000) data	This study (Awaruku and Vaughan)
Dry weather	350cfu/100ml (n=30)	395cfu/100ml (n=20)
Wet weather	5,050cfu/100ml (n=43)	33,000cfu/100ml (n=5)

However, levels were comparable to those from the NSCC (2000a) study of 16 North Shore streams, though the wet weather figure is quite high (see Table 12), indicating there might be a sewage leak. The levels measured in this study for Awaruku are also broadly in line with NSCC (2000a) figures for the stream (see Table 13), although the dataset is small.

Table 13: Median Enterococci counts for Awaruku stream from a NSCC (2000a) study and from this study for wet and dry weather

	NSCC (2000a) data	This study
Dry weather	350 and 270cfu/100ml	550cfu/100ml (n=12)
Wet weather	38,000cfu/100ml (n=3)	33,000cfu/ml (n=3)

5.13 Synopsis

Most hypotheses were supported by the data, and are summarised below.

The catchment with the highest proportion of forest catchment had:

- The most stable flow regime, with base-flow readings that were significantly higher than all other sites (supporting hypothesis 1A) and peak-flow readings that were significantly lower than all other sites (supporting hypothesis 1C);
- The highest rainfall event clarity (supporting hypothesis 2B); and
- The lowest faecal bacterial counts (supporting hypotheses 10B).

Sites downstream of riparian vegetation had:

- Lower temperatures (supporting hypothesis 3A);
- Less diurnal fluctuation in pH (supporting 3B);
- Less diurnal fluctuation in temperature (supporting hypothesis 4); and
- Less diurnal fluctuation in DO (supporting hypothesis 6B).

The site with the highest proportion of rural catchment had:

- The poorest dry-weather clarity (supporting hypothesis 2A);
- Significantly higher levels of nitrate than all other sites (supporting hypothesis 9A); and
- Higher faecal bacterial counts than the forest/rural catchment (supporting hypothesis 10A).

However, not all hypotheses were supported. Discrepancies in the data were found and might be the reason that some hypotheses were not supported. Hypothesis 1B and 1D (that rural catchments produce higher base flows and lower peak flows than urban catchments) were not supported. The rural, lower Vaughan site had unexpectedly low base flows, but this was probably due to water loss under this site's weir. Peak flows were also higher than anticipated, possibly due to the lack of peak-flow gaugings and the poor correlation between gaugings and the trendline of the gaugings graph.

Hypothesis 7 (that BOD would be higher in sites draining rural areas than urban areas) was not properly tested because the BOD tests were found to be inconsistent and only a small reliable dataset was established.

Inaccuracies were also found for other parameters. The ARC sonde at upper Vaughan exhibited an abrupt change in readings for pH (down by 3.5 units), DO (up by 50% of saturation) and produced impossible figures for turbidity (-54NTU) and conductivity (-5µS/cm). The pH readings from this deployment were also found to be out by 1 unit at pH=7. An ARC sonde at mid Vaughan also showed drift in turbidity readings, and had DO readings above 100% saturation for 40 days.

Hypothesis 2C (that urban catchments produce higher rainfall event turbidities than rural catchments) was not supported, with the upper and mid Awaruku (urban) sites having lower turbidities than the rural, lower Vaughan site. Livestock in the lower Vaughan catchment and sediment dams above the upper and mid Awaruku sites appear to have played greater roles than expected.

Hypothesis 5A (that rural catchments produce higher conductivities than forest catchments) was not supported and indicates that fertiliser input was low in the lower Vaughan catchment. Hypothesis 5B (that urban catchments produce higher salinities than forest catchments) was also not supported. Mid Vaughan, the forest/rural site, had higher salinity readings than the urban sites, possibly due to the use of fertilisers in the rural part of its catchment.

Hypothesis 8 (that rural catchments produce the highest phosphate levels) was not supported, with the forest/rural, mid Vaughan site having the highest levels of orthophosphate. This also indicates that fertiliser use in the rural part of the mid Vaughan catchment was relatively high.

Hypothesis 9B (that urban catchments produce higher nitrate levels than forest catchments) was not confirmed by the data and this could also be due to fertiliser use in the rural part of the mid Vaughan catchment. It also indicates that fertiliser use in the urban catchments was probably minimal.

Hypothesis 10B (that rural catchments produce the highest bacterial counts) was also not supported. Levels at urban sites were often higher than at the rural, lower Vaughan site. This suggests that inputs from leaks in sewage pipes (exfiltration) might be occurring.

Table 14 summarises some of the factors that appear to have been influencing the water quality in the streams.

Table 14: Synopsis of catchment factors that appeared to affect water quality

Factor	Apparent effect	Evidence	Possible reason
Vegetation density	More stable flow regime Superior rainfall-event clarity Less faecal contamination	Forest/rural upper Vaughan site had lowest peak flow and highest base flow per hectare Forest rural mid Vaughan site had highest rainfall event clarity and lowest bacterial counts	Interception and filtering, enhanced infiltration, less sewage and animal waste sources
Riparian Vegetation	Lower daytime temperatures, more stable temperature, DO and pH	Sites with superior upstream shading had less fluctuation in temperature, DO and pH and lower maximum temperatures	Shading which reduces thermal inputs and photosynthesis
Sediment dams	Reduced peak flow and increased rainfall-event clarity	Peak flows at mid Awaruku significantly lower than at lower Awaruku. Rainfall-event clarity higher at mid and upper Awaruku than lower Awaruku	Sediment dam holding back peak flow and allowing sediments to settle out
Livestock	Lower clarity, increased nitrate and faecal contamination	Rural site had lowest dry-weather and second lowest rainfall-event clarity, highest (significantly) nitrate levels, high bacterial counts	Direct inputs of animal faeces and urine, erosion of banks and stirring up of stream bed sediments
Surfacing catchments and channels	Less stable flow regime, lower rainfall event clarity, higher pH levels	Far higher peak flows and lower base flows at urban sites than forest/rural sites, pH higher at sites with concrete channelling	Reduced permeable surface area, alkaline concrete channel surfaces
Sewage leaks	Faecal contamination in urban streams	Far higher bacterial counts in urban sites than in forest/rural stream, similar and often higher counts than rural site which had faecal inputs from livestock	Poorly maintained sewage infrastructure, system not designed to accommodate growth

A summary of the measurements is given in Table 15. Dissolved oxygen levels were particularly low at the Vaughan Stream (forest/rural and rural) sites and failed the RMA (Third Schedule, 1991) guideline of 80% saturation for waters managed for aquatic ecosystems and fisheries purposes. No reason could be found for these extremely low readings and further research is needed to find their cause.

Table 15: Summary of data and comparison with figures from Williamson (1993) and New Zealand and international guidelines

Parameter	Urban sites	Rural site	Forest/rural site	Williamson (1993)	Guideline
Turbidity (NTU) (median)	(8)	(16)	(10)	Low flow: 9NTU Stormflow: NA	<10% increase in seasonal mean[B]
Temperature (°C) mean	16.9	16.9	15.0	NA	<3°C increase[R]
pH mean	6.82	6.68	6.64	NA	6.5-9.0[B]
Conductivity (μS/cm) mean	261	292	292	NA	<1,500[B]
Dissolved Oxygen (mg/L) mean	7.2	4.7	3.5	NA	>6.0, >80-90% saturation[B]
Orthophosphate (mgP/L) mean	0.021	0.016	0.048	Low flow: 0.008 Stormflow: 0.04	< 0.01[N]
Nitrate (mg/L) mean	0.30	0.45	0.29	Low flow: 0.45 Stormflow: 0.8	NO_x< 0.444[N]
Faecal Coliforms (cfu/100ml) (median)	Low flow: (1900) Stormflow: (14,000)	Low flow: (590) Stormflow: 21,000[C]	Low flow: (170) Stormflow: 2,000[C]	Low flow: (1070) Stormflow: (8,000)	Median<1000 for secondary contact[A]
Enterococci (cfu/100ml) (median)	Low flow: (550) Stormflow : (33,000)	Low flow: (500) Stormflow: 74,000[C]	Low flow: (80) Stormflow: 3,000[C]	Low flow: (890) Stormflow: (87,000)	Median<230 for secondary contact[A]

[A]ANZECC (2000) standard for Australia only, secondary contact includes fishing and boating
[B]ANZECC (1992) guideline for the protection of aquatic ecosystems
[N]ANZECC (2000) "default trigger for chemical and physical stressors in New Zealand for slightly disturbed ecosystems"
[R]RMA (Third Schedule, 1991) recommended value for waters managed for Aquatic Ecosystem and Fisheries purposes
[C]Not a median, but a single figure (only one storm event was measured)

The pH figures were also low, being below the ANZECC (1992) guideline on a number of occasions, although this may be purely due to the geology of the area (since other North Shore figures are similar to those found in this study).

Counts for indicator bacteria were high at the rural and urban sites, making them unsuitable for secondary contact according to Australian standards (Faecal coliforms and Enterococci, ANZECC, 2000) and also for bathing by New Zealand guidelines

(*E. coli*, MofE, 1998). Sewage leaks and animal wastes entering the waterways are the likely sources of these bacteria.

Temperatures at lower Vaughan and lower Awaruku (both lack riparian vegetation directly upstream) had peaks above 25°C, the RMA (Third Schedule, 1991) guideline for waters managed for fisheries purposes.

Mean rainfall-event turbidity readings at the lower Awaruku site are at levels that can affect fish migration. Earthworks associated with a residential development are the likely source of sediments which caused this turbidity.

5.14 Limitations

Resource constraints limited the number of parameters, sites and events that could be measured, leading to the following:

- Very few rainfall events and only one storm event was sampled.
- No winter sampling was performed (as the German field work was undertaken during the New Zealand winter), which limited the generality of the data.
- No site with a forest-dominated catchment was able to be monitored (mid Vaughan was 50% forest, 50% rural), making conclusions about the effects of forest catchments on streams tentative.
- The small number of sites meant that even the conclusions about catchments dominated by urban land use (at three sites) are tentative.
- The fact that only two streams were sampled also reduces the generality of findings.
- Results had to be taken from ARC deployments. The maintenance and calibration of ARC equipment was beyond the control of the author and the results had to be relied on at face value.
- Inaccuracies in the data made it difficult to make firm conclusions. Some unexpected results (for example, that peak flows were higher at the rural site than the urban sites) appeared to be from inconsistencies in the data. However, care must be taken not to opportunistically eliminate results that do not fit with hypotheses.

6 Case study two: A qualitative and quantitative comparison of the water quality of Köppernitz Stream, Wismar, Germany, between 1991 and 2001/2

The *Bundesrepublik Deutschland* (BRD, Federal Republic of Germany) is renowned as a world leader in environmental standards (Bailey, 2001; Bechberger and Reiche, 2004; Weidner 1995). The nation has high rates of resource recycling and reuse (through, for instance, the refundable bottle programme), high rates of renewable energy production (by guaranteeing higher prices for renewable energy), extensive public transport and cycling infrastructure, and stringent regulations on pollution (Bailey, 2001; Bechberger and Reiche, 2004). On October 3, 1990, the city of Wismar, along with the rest of the *Deutsche Demokratische Republik* (DDR, East Germany) was absorbed into the BRD. In the process, pollution control measures, which were lax under the DDR regime, were radically tightened.

This case study will look at changes in the water quality of an East German stream since the reunification of Germany. Variations along the stream will also be analysed.

Differences between the German stream and the New Zealand streams from case study one are analysed and discussed in chapter 9.

6.1 Location

The city of Wismar has a population of almost 50,000 and is located on the Baltic Sea coast of Northeast Germany (see Figure 35). The stream studied, the Köppernitz, drains cropland south of the city before flowing through Wismar and emptying into its harbour (see Figure 36).

The total catchment area of the Köppernitz is 32.7 km^2 (IBS Engineering, 1995), making it considerably larger than the streams studied in New Zealand. Of this 32.7 km^2, approximately 23 km^2 is cropland, 3 km^2 is forest and 6 km^2 is urban.

Figure 35: Location of Wismar in Europe. Map: Peakware, 2001.

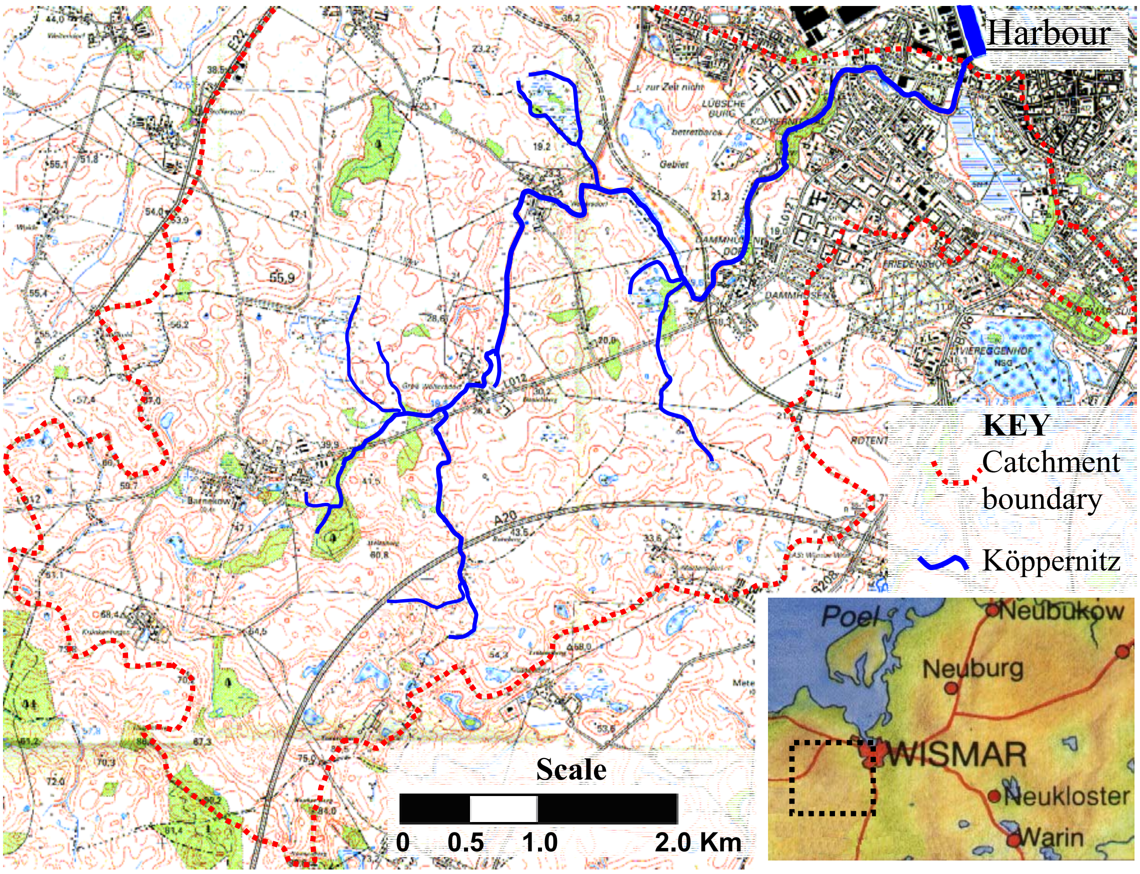


Figure 36: Catchment of the Köppernitz, showing the catchment boundary (drawn on map 2134: LMV, 1998). Insert shows the location of this map (black dashed box) in relation to the rest of Wismar

6.2 Historical setting

Around 14,000 years ago, glaciers of the last ice age retreated from the Wismar region. Several waves of human settlement followed. According to records, Wismar was founded around 1230 AD (Barsch, 2003) and by the end of the 13th century had become an important and wealthy Hanseatic trading city. Following the first great fire (1267), rules were passed that required buildings to be constructed from bricks (Barsch, 2003). With this law, plus the rapid growth of the city, Wismar's forests disappeared into brick makers' kilns.

The old central city is very compact, reflecting difficulties with transport and the confines of the defensive city walls. From the 1800's onwards, settlement spread outside the city walls, with the largest growth occurring after the Second World War. Wismar had lost 26% of its residential housing to aerial bombardments during 1945 and also received a large number of German refugees fleeing the Soviet advance (Barsch, 2003). Under the DDR, numerous apartment blocks were built outside the old city area. The nature of these buildings (all five stories high) minimised the spread of the city.

6.2.1 Positive changes for the Köppernitz

Since joining the BRD, sewage systems have been dramatically upgraded, landfill sites have been improved to reduce the risks of seepage, and BRD regulations and technological improvements have also reduced the use of chemicals. Phosphate levels are a prime example of the improvements. The "maximum allowable phosphate law" (*Phosphathöchstmengenverordnung*) of 1980 cut the phosphate content of detergents by half and a later voluntary agreement by detergent manufacturers limited the phosphate content of detergents to 3.4% (BMVEL, 2002). Consequently, phosphate loads in German freshwaters have decreased dramatically (see Figure 37). Inputs from agriculture have also decreased, thanks mainly to improved education and advice for farmers, which increased the awareness that most soils had more than sufficient phosphate and further fertiliser application was to the farmers' financial disadvantage (Kahlenborn and Kraemer, 1999). The 1977 BRD Fertiliser Act (Düngemittelgesetz: Paragraph 1a) reinforced this economic imperative by requiring farmers to link fertiliser application rates to the nutrient needs of crops (Isermeyer and Schleef, 1994).

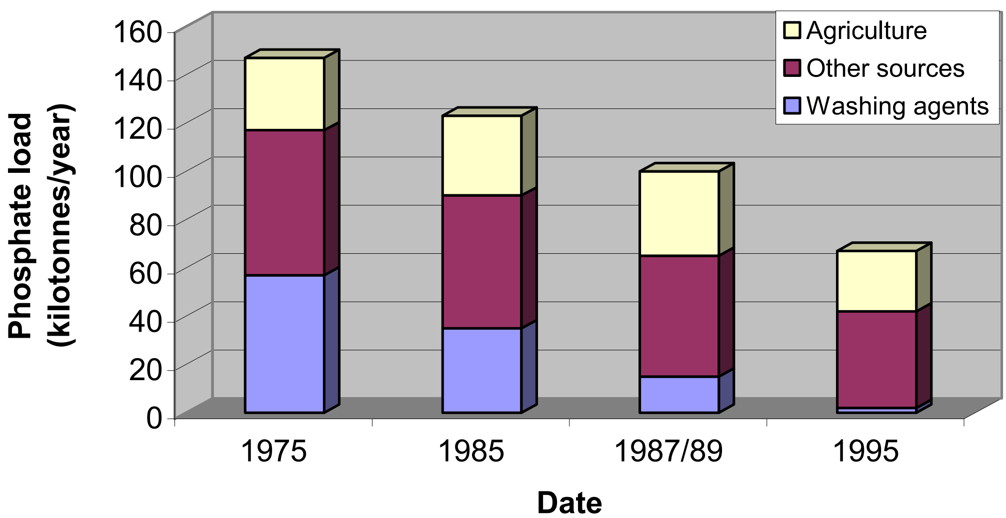


Figure 37: Sources of phosphate loading (kilotonnes/year) in freshwaters in Germany from 1975 to 1995 (Kahlenborn and Kraemer, 1999)

Reductions of nutrient inputs in the former DDR territories are even more significant. After reunification, EU programmes to take agricultural land out of production became available to farmers in the former DDR, resulting in the retirement of land on many farms (Werner and Wodsak, 1994). Large-scale piggeries and cattle farms with poor manure handling and disposal practices have been closed down, resulting in a reduction of more than 60% in livestock units in the former DDR between 1990 and 1993 (Bonde, 1994; Werner and Wodsak, 1994). Additionally, practices with fertiliser transport and application have greatly improved, especially with the move away from airborne distribution, which was common in DDR times (Werner and Wodsak, 1994). Even so, current German phosphate loadings remain more than 20 times higher than natural levels (Kahlenborn and Kraemer, 1999).

6.2.2 Negative changes for the Köppernitz

> *Die Deutschen ziehen ins Grüne. Mit Straßen, Häusen und Dämmen machen sie Natur platt – auf Kosten des eigenen Wohlstands.*
> Fritz Vorholz, in *Die Zeit* (2002)
> (The Germans are moving to the green fields. With roads, houses and dams they flatten nature — and with it their quality-of-life)

The increase in wealth and consumer choices following the fall of the DDR resulted in two major changes that have increased the urban area of Wismar. The first change was a dramatic increase in car use, which has led to, and been spurred on by, the building of more roads. These include an autobahn and a major state highway in the catchment of the Köppernitz. The second major change is a substantial increase in new housing estates. These estates are dominated by single-family dwellings and tend to be much further from the city centre, thereby locking in the trend to greater car use.

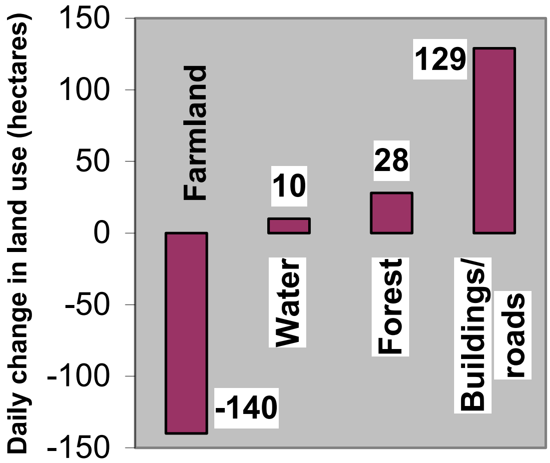


Figure 38: Changes in land use per day in Germany from 1997 to 2001, ignoring the category “other uses”. Source: *Die Zeit*, 2002

The movement to greater car use and single dwelling housing outside cities had been occurring in West Germany since the war. For example, between 1970 and 2000, the population of the West German city of Stuttgart grew by 11%, while the urban area grew by 45% (Die Zeit, 2002). The increase in land used for buildings and traffic is a nation-wide phenomenon (Figure 38), and is occurring despite an apparent stall in population growth in Germany. In many ways, the rapid changes in Wismar since 1990 may be seen as a "catch-up".

Problems associated with the increase in impermeable surfaces (including increased runoff and consequent stream-bed erosion) have been mitigated in the Wismar area by the provision of sediment dams.

6.3 Climate

No climatic information was available for Wismar. Information for Rostock (50 km northeast of Wismar) and Schwerin (35 km south of Wismar) was available. Since Wismar is both geographically and climatically between these two cities (K.-P. Haase, *pers. com.* 2002), the average of both was used as an approximation for Wismar. The mean annual rainfall was estimated to be 610mm (Rostock = 592, Schwerin 622) and the mean annual temperature 8.4°C (Rostock and Schwerin both 8.4°C). The variation throughout the year is shown in Figure 39.

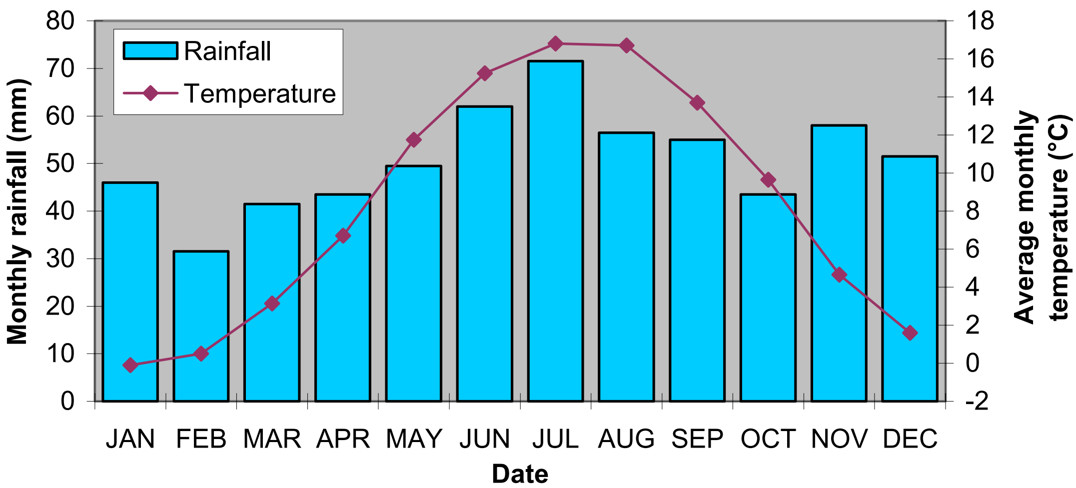


Figure 39: Mean monthly rainfall and temperature estimates for Wismar (estimated form Rostock and Schwerin data, Klimadiagramme, 2003)

6.4 Topography

The area is flat, rising to a maximum of 90 meters above sea level six kilometres from the harbour.

6.5 Geology and Soils

Geologically, the area is covered with *Geschiebemergel* (BGR, 1993), a calcarious till from the Weichselian ice age (deglaciation *circa* 14000 years BP, Kühn, 2003). As a till, it would contain grains of sand (0.063–2mm), silt (0.002–0.063) and clay (<2 μm), with the clay content being between 20 and 40%.

6.6 Land Use

Approximately 70% of the Köppernitz catchment is cropland (primarily wheat, sugar beet and canola). Agriculture in Germany tends to be more intensive than in New Zealand, with livestock often being raised in feedlots, producing a ready supply of manure. This manure, along with artificial fertilisers, is used to improve crop yields. Crops do not take in all of these inputs; with much finding its way into the surrounding environment. In the European Union 85% of groundwaters in farmed areas have levels of nitrogen over 25mgL^{-1} due to fertilisers and excrement (EU, 1997).

After entering the city limits of Wismar, the Köppernitz passes the municipal zoo. There are no provisions in the zoo to prevent wastes from the animals entering the stream.

The zoo has a play area for children. Some of the play equipment incorporates water from the Köppernitz, which children come into contact with. The equipment includes a large Archimedean screw, a water race and a fountain.

Downstream from the zoo, the stream passes through a narrow park, the Wismar University grounds and a small industrial section before entering the harbour.

Directly below the university, the stream receives water from the *Kuhweide* (literally "cow paddock", although it is not now farmed), a large (>50 hectare) marshland. The *Kuhweide* is drained by man-made channels into a dam which is irregularly pumped into the Köppernitz.

7 Case study two (Germany): Method

Sampling occurred from 21 May to 1 August 2001 (12 data sets) and on 10 July 2002 (one data set).

Transport limitations necessitated the selection of sampling sites near the University of Wismar. The Köppernitz was therefore chosen. Three sites (see Figure 42) with good access were initially selected: one as far upstream as practicable (“upper Köppernitz”, on the border of the city, directly upstream of the B106 highway); one approximately 2.5 km downstream (“mid Köppernitz”, directly below the municipal zoo); and one as far downstream as possible (“*Mündung*”: German for stream mouth). The Mündung site was found to be influenced by tidal water, so another site 200m upstream was used from the second sampling event (28 May 2001) onwards (“lower Köppernitz”, at Lübsche Strasse bridge). Testing was continued at the Mündung site because it was easily accessible and could give information about the water quality of the mixing fresh and marine waters. For some parameters, readings at the Mündung site were taken both 10cm from the water surface (“Mündung surface”: which tended to be freshwater) and 10cm from the stream bed (‘Mündung bed”: which tended to be far more saline).

Figure 40: Upper Köppernitz, the furthest upstream of the sampling sites

Figure 41: Sampling sites, mid Köppernitz (top), lower Köppernitz (middle), and Mündung (bottom)

7.1 Previous study: 1990 & 1991

From September 1990 to December 1990 and from March to December 1991 samples from three sites near the lower, mid and upper Köppernitz sites were analysed by the Wismar City Council for DO, BOD_5, total phosphate, nitrate, nitrite and ammonium. Full information about this study did not become available until after the 2001 study was underway. For this reason, the 2001 mid Köppernitz site did not precisely match the positioning of the 1990–1991 middle site (Figure 42), and not all of those parameters were measured in 2001. For convenience, the 1990–1991 site will still be referred to as “mid Köppernitz”.

From April and May 1991 five weekly recordings of pH were also available from a site at Woltersdorf, some three kilometres upstream of the upper Köppernitz site.

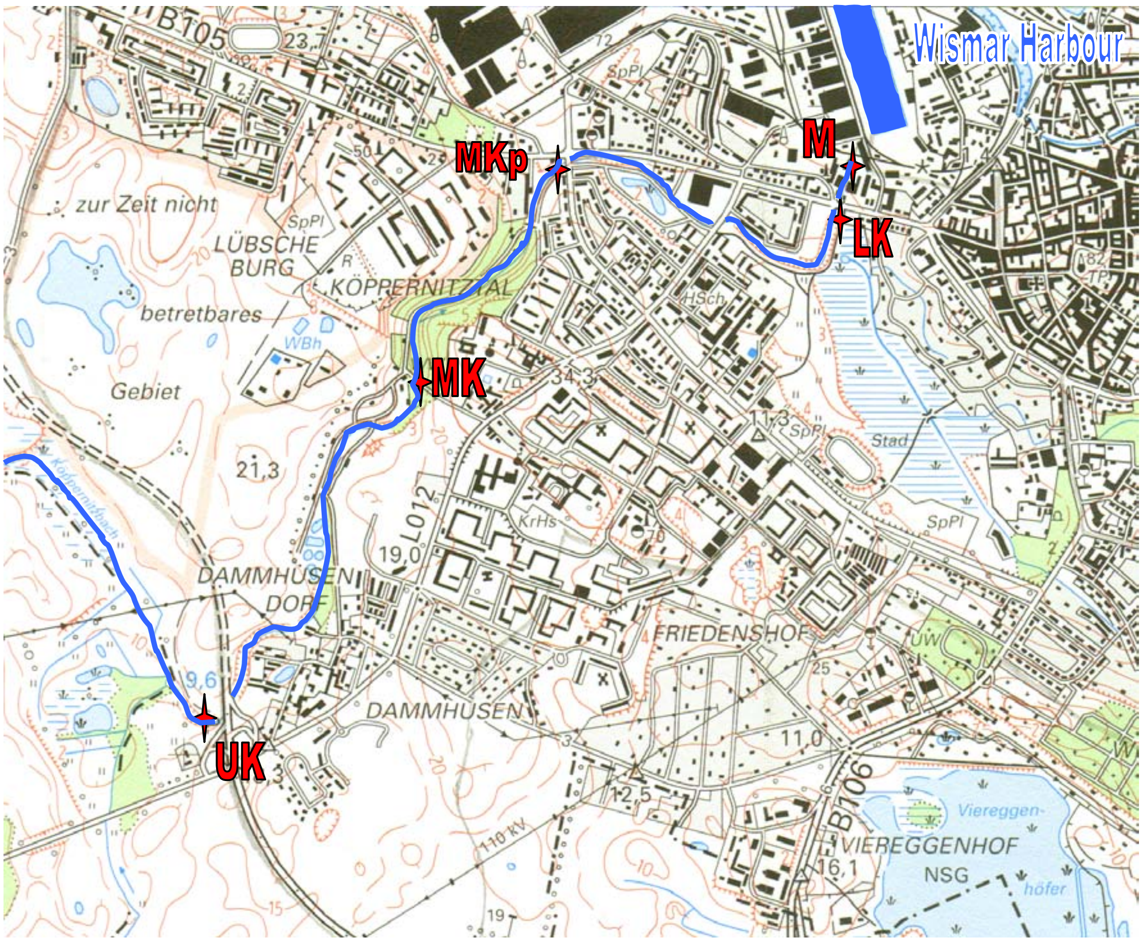


Figure 42: Positions of sampling sites on the Köppernitz. M=Mündung, LK= lower Köppernitz, MKp= mid Köppernitz previous (1990 & 1991 survey site), MK= mid Köppernitz, UK= upper Köppernitz. Map used is map 2134 (LMV, 1998). Scale is approximately 1:25000 (1cm=250m).

7.2 Catchment areas and land use for each site

Maps and area calculations from IBS Engineering (1995) and the Wismar topographic map (LMV, 1998) were used to estimate catchment areas and land use types for each site.

Table 16: Estimates of land use and total catchment areas for sites on the Köppernitz. Map grid coordinates for each site based on map 2134 (LMV 1998) are also given

Site	Rural	Forest	Urban/Town	Total	Coordinates
Upper Köppernitz	21 km^2	3 km^2	3 km^2	27 km^2	621 720
Mid Köppernitz	21.5 km^2	3 km^2	3.5 km^2	28 km^2	627 731
Lower Köppernitz	23.25 km^2	3.25 km^2	5.5 km^2	32 km^2	640 734
Mündung	23.25 km^2	3.25 km^2	6 km^2	32.5 km^2	641 736

7.3 Parameters measured

The choice of the parameters measured and the way in which they were measured were dictated by the resources available. For this reason not all the parameters measured in New Zealand were included in the study of the Köppernitz.

Several parameters were measured using the same method as in New Zealand.

- **Flow** was calculated from the water velocity (measured using a float) and the cross-sectional area of the stream.
- **Temperature** was measured with the conductivity meter (WTW TetraCon® 325), which had a temperature sensor (quoted accuracy of +/-0.2K).
- The **pH** was measured with a WTW Multiline P3 meter with Sen Tix 41 probe. The meter had a quoted accuracy of 0.01± 1 digit.
- **Alkalinity** was measured using the ISO 9963-1 (1994) titration method.
- Electrical **conductivity** was measured using a Multiline P3 meter with a WTW TetraCon® 325 electrode. The Multiline meter had a quoted accuracy of ± 1% and the Tetracon® 325 ±1.5%.
- **Dissolved oxygen** was measured with WTW Oxi 325 membrane covered galvanic sensor (quoted accuracy of +/- 0.5%).

7.4 Suspended sediments

There was no equipment available at Wismar University to measure turbidity directly or indirectly. For this reason the amount of suspended sediments was measured as per APHA (1995), where water samples are filtered through a 0.45micron filter paper and the dry weight of the sediments in each sample is determined. This procedure was only performed on four dates due to difficulties with transporting the extra volumes of water required.

7.5 Oxidation-reduction potential (Redox)

Redox was measured using a WTW SenTix® ORP electrode with a silver/silver chloride reference electrode. Redox values are usually quoted as the potential difference with reference to a hydrogen electrode, so measured values were converted to this system using a table from WTW (2001: 47).

7.6 Phosphate

Total phosphate was measured using the Nanocolor® Phosphate 15 test. This test decomposes all phosphates to ortho-phosphate using acidic hydrolysis and oxidation at 100°C for 30 minutes. The orthophosphate is then measured using a method similar to that used in New Zealand, i.e. reaction to molybdenum blue and measurement at 690nm using a Nanocolor® photometer. Orthophosphate was not measured by itself since the test was only accurate down to 0.3mgP/L, which even total phosphate rarely exceeded.

7.7 Nitrogen

Total nitrogen was analysed using the Nanocolor® total nitrogen 22 test, which was accurate down to 0.5mgN/L. It involved acidic, oxidative decomposition of all nitrogen compounds to nitrate using a supplied reagent and heat at 100°C for one hour. A photometric determination for nitrate was then performed with 2,6-dimethylphenol in a sulphuric acid/phosphoric acid mixture and subsequently measured using a Nanocolor® photometer at 385nm.

These tests were expensive and therefore nitrate was analysed only on 1 August 2001 and 10 July 2002 (using the latter part of the total nitrate method).

Ammonium was able to be tested on 1 August 2001 using the Nanocolor® Ammonium 10 test, which was accurate down to 0.2mgN/L. In this test ammonium is reacted with hypochlorite and salicylate at a pH of 12.6 with sodium nitroprussiate as a catalyst to form a blue indophenol. This is then measured at 690nm with a Nanocolor® photometer.

7.8 Bacteria: total cultivatable colonies at 22°C

Due to the lack of resources for *E. coli* or enterococci analyses, a more basic test for total cultivatable colonies was performed following the ISO 6222 (1999) method. In this test a nutrient agar base was used and incubated for 68±4 hours at 22±2°C.

7.9 Toxicity: fluorescent bacteria

Water was analysed for toxicants using fluorescent bacterium (*Photobacterium phosphoreum*) on two dates. The test measures the reduction in bioluminescence of the bacterium in sample waters photometrically. Following the DIN 38412-34 (1991) method, sample waters were adjusted with 2% sodium chloride (the bacterium is marine) before the bacterium was added. Decreases in bioluminescence in samples were then determined after 30 minutes and compared to deionised water standards.

7.10 Macro-invertebrate survey

Sweep netting of the four sites was performed on 3 July 2001 by the biologist Peter Bretschneider. Macro-invertebrates were then identified later in the laboratory with Herrn Bretschneider’s help.

7.11 Data analysis

As with case study one, this case study measured a limited number of sites (four). Given this and the fact only one stream was measured, it is not possible to fully test the hypotheses stated in Chapter 4. To fully test the hypotheses, a larger number of sites (to account for natural variability) from a larger range of streams (to ensure independence between sites) would need to be measured. Resource limitations precluded this.

However, statistical comparisons of the sites studied were undertaken to assess differences between sites and their conformity to the hypotheses.

The data was analysed using the same methodology as for case study one (Section 4.19). There was, however, an exception. The Köppernitz data from 1990/91 and 2001/2 were compared without date matching using t-tests (where normal distribution and equal variance could be achieved) or the non-parametric Mann-Whitney test.

8 Case study two (Germany): Results and analysis

In this chapter, temporal and spatial differences in water quality are analysed. Differences in water quality between 2001 and a decade before (1990–1991, i.e. directly after the fall of the DDR) are used to identify the effects of changes in land management practices that have occurred since the reunification of Germany. Longitudinal changes in 2001 water quality, from the agricultural upstream sections (above upper Köppernitz site) to the urban/residential influenced downstream sections, are used to compare the effects of urban and agricultural land uses. Relevant hypotheses from case study one (see Chapter 4) are again tested; however, others relating to forest land use are not tested as this was not a major land-use type in the catchment. The raw data collected in Germany can be found at Appendix III.

Differences between the water quality of the German and New Zealand streams studied are analysed in Chapter 9.

8.1 Flow

Hypothesis 1B (that rural catchments produce higher base flows than urban catchments) **was not supported**.

No significant difference in base flows between sites[24] was found, with base flows per hectare actually higher at lower Köppernitz (urban) than upper Köppernitz (rural) and mid Köppernitz (rural/quasi-urban). It was expected that base flows per hectare would decrease in the urban area since water-table recharge would normally be less in urban areas[25]. Inputs from the marshland (the Kuhweide) directly above lower Köppernitz could have increased the flow when pumping of its drainage dam coincided with sampling. The watering of gardens in the urban area during the summer could also have increased water table recharge and hence flows at lower Köppernitz. The most likely cause for the higher figure at lower Köppernitz is, however, the existence of inaccuracies in the measurements (the methods used should only be considered estimates).

[24] The Mündung site was not used in analysis since marine influxes made the flow calculations inaccurate.

[25] Water is lost to runoff from impermeable surfaces.

Hypothesis 1D (that urban catchments produce higher peak flows than rural catchments) **was not able to be properly tested due to a lack of data**.

Only two rainfall events were sampled, one major (18 June 2001: 45mm rainfall in 48 hours, although rain had ceased by the time of sampling) and another minor rainfall event (16 July 2001: 5mm directly before sampling). Flows per hectare were markedly higher at the urban, lower Köppernitz site (see Table 17), indicating a lack of interception and infiltration in the urban area and supporting hypothesis 1D. However, the high measurements at lower Köppernitz could be attributed to data reading inaccuracies.

Table 17: Stream flows per hectare at three sites on the Köppernitz

Site	Upper Köppernitz	Mid Köppernitz	Lower Köppernitz
Minor event (5mm) flow per hectare	0.02 l/sec/ha	0.03 l/sec/ha	0.05 l/sec/ha
Major event (45mm in 48 hours) flow per hectare	0.26 l/sec/ha	0.52 l/sec/ha	0.77 l/sec/ha

The measured flow at lower Köppernitz for the major rainfall event (2.5m^3/s) was very high compared to the engineering calculations of IBS Engineering (1995) for a two-year flood (1.2m^3/s) and a 25-year flood (2.6m^3/s). The major rainfall event measured was neither a 25-year nor a 2-year flood at the time of measurement: the storm had passed some hours before the flow was measured[26]. Although it is possible that the IBS Engineering (1995) calculation underestimates the flow and that pumping from the *Kuhweide* may have coincided with the measurement[27], it seems likely that the flow measured at lower Köppernitz was an overestimate. It was three times the flow at upper Köppernitz. This is unlikely given that most of the surface runoff in the urban area had left the catchment by this time. Inaccuracies in the flow measurements at lower Köppernitz could be caused by the turbulence of the high flow.

The high measurement for this major rainfall event and the high base-flow measurements at the lower Köppernitz site indicate that the measurement method used was probably inappropriate for this site.

---

[26] The actual rainfall intensity and timing of the storm can not be given since rainfall is only measured daily in Wismar.

[27] The maximum pumping rate is 0.5m^3/s (IBS Engineering, 1995), not enough to explain the large measurement.

8.2 Suspended sediment

There was no significant difference (*P*=0.51, number of dates= 4) in suspended sediment levels found between sites.

This undermines the thesis that urban catchments, especially those with new residential developments, produce higher suspended-sediment levels than rural catchments (due to higher runoff rates which cause catchment and channel erosion). This thesis is, however, somewhat simplistic, as cropland (as found in the Köppernitz catchment) can yield large amounts of suspended sediments. Ploughing, which exposes the soil, increases the risk of erosion. Runoff volumes can also be enhanced, not only because vegetation is lacking, but also because soil compaction from heavy farm machinery reduces infiltration. Moreover, increased erosion from "sheet-floods" can occur on cropland when fine particles in the topsoil swell during rain and block pores in the soil (WBGU, 1999).

A significant difference in suspended-sediment levels was found between dates. The storm-event date had suspended-sediment levels up to tenfold those of other dates.

8.3 Temperature

Temperature readings were significantly higher at the Mündung-bed site than all other sites due to an influx of warm water from the Baltic Sea.

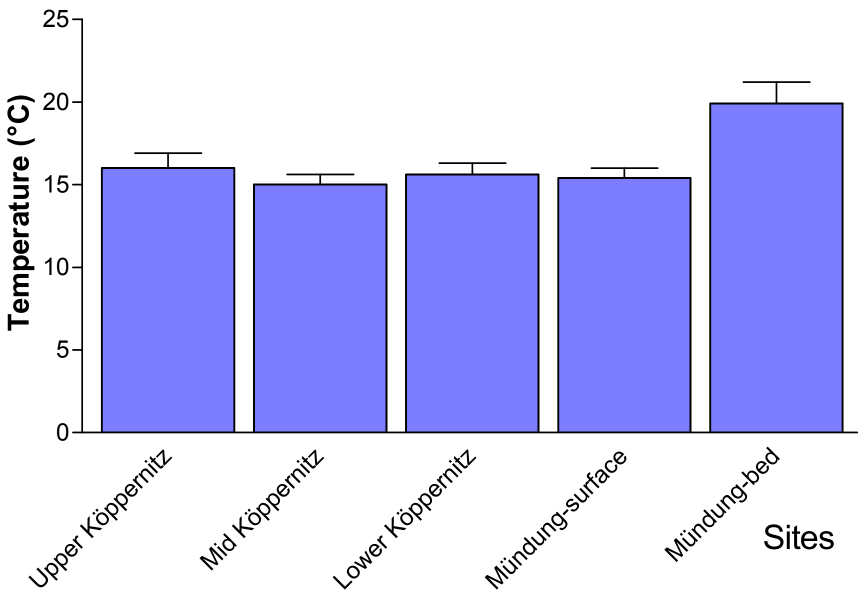


Figure 43: Mean temperature for all sites on the Köppernitz (n= 13, except for Lower Köppernitz, where n=12). Error bars indicate standard error.

The far lower mean from the Mündung surface measurements (see Figure 43) indicates that denser marine waters remained in the lower half of the stream profile and that mixing with the cooler, lighter freshwater was minimal. Poor mixing would mean that heat loss from the lower, saline-water layer would be minimal: water is a poor conductor of heat and heat loss from evaporation would be limited.

Hypothesis 3A (that temperatures are lower downstream of riparian vegetation) **was supported by the data.**

Mid Köppernitz temperature measurements were significantly lower than those of upper Köppernitz[28]. Directly upstream of upper Köppernitz, there is very little riparian vegetation, but downstream the riparian zone is forested.

8.4 pH

Measured pH levels were significantly higher at the urban, lower Köppernitz site (mean = 8.1± 0.06) than the rural, upper Köppernitz site (mean = 7.9±0.06). The small difference could be attributed either to runoff from concrete surfaces in the urban area, or to measurement error.

The slightly basic pH levels in the Köppernitz (mean = 8.0± 0.03) and small range of pH values (range 7.5 to 8.3) are probably attributable to the calcareous geology of the Köppernitz catchment.

The four lowest measurements in the Köppernitz all came from the date of the storm event. This date had significantly lower pH values than all other dates, probably due to the diluting effects of rainwater.

Comparisons between data measured in this project and data from the 1991 survey are difficult for pH since there are only six pH records from the 1991 survey, and all are from a site (Woltersdorf) 3.5 km upstream of the highest site from this study. The difference between the readings from 1991 and those from this study are, however, remarkable.

The measured pH on all six dates in 1991 was 6.9, a full pH unit below the mean at upper Köppernitz in this study.

The difference is even more remarkable considering how well buffered the stream water appears to be.

[28] Dataset analysed without figures from the marine influenced Mündung sites.

8.4.1 Analysis of pH results

The difference between 2001 measurements and the 1991 records could be due to the time of year when pH was measured (the 1991 measurements were taken in early to mid spring when photosynthetic activity would be lower and hence carbonic acid levels higher) or to the time of day (if the 1991 measurements were taken near dawn carbonic acid levels would also be high). However, it seems unlikely that time of day or season could have had a major effect: while the pH measured in 1991 remained unchanged at 6.9, the oxygen levels measured in 1991 ranged from 6.3 to 9.8mg/L, indicating that not all measurements were taken when carbonic acid levels were high. A difference in geology between Woltersdorf, where the 1991 measurements were taken, and the upper Köppernitz site could be the cause; however, the scale of the geological map of the area (BGR 1993) is too small to determine such differences. Sulphur oxide, nitrogen oxide, and ammonium deposition may also be the cause for the difference. Such deposition has been implicated in the acidification of waterways in the USA (e.g. Murdoch and Stoddard, 1992) and Europe (e.g. Nilsson *et al*., 1988). This deposition is likely to have decreased in the area since reunification, due to the reduction in industrial output from eastern block countries, the introduction of cleaner industrial techniques, and reduced livestock densities. It is also possible that the decline in fertiliser use since reunification (see Werner and Wodsak, 1994) could be responsible for the reduced acidity. Although some types of manuring increase pH (Whalen *et al.,* 2000; Eghball, 2002), most fertilisers increase acidity by producing nitric acids (Helyar and Fenton, 1999).

Another waterway that flows through the former DDR, the Elbe, has also experienced increases in pH since reunification, with average levels changing from 7.5 in 1989/90 to 8 in 1997 (Guhr *et al*., 2000).

8.5 Alkalinity

Alkalinity was measured on only one occasion, giving a mean of 307mg$CaCO_3$/l (range= 300–310mg$CaCO_3$/l, Mündung-bed not measured). This is far higher than the measured alkalinity of the New Zealand streams (mean =51mg$CaCO_3$/l, range=45–60), and explains the small range in pH values measured in the Köppernitz. The high alkalinity in the Köppernitz is attributable to the catchment's calcareous geology.

8.6 Conductivity

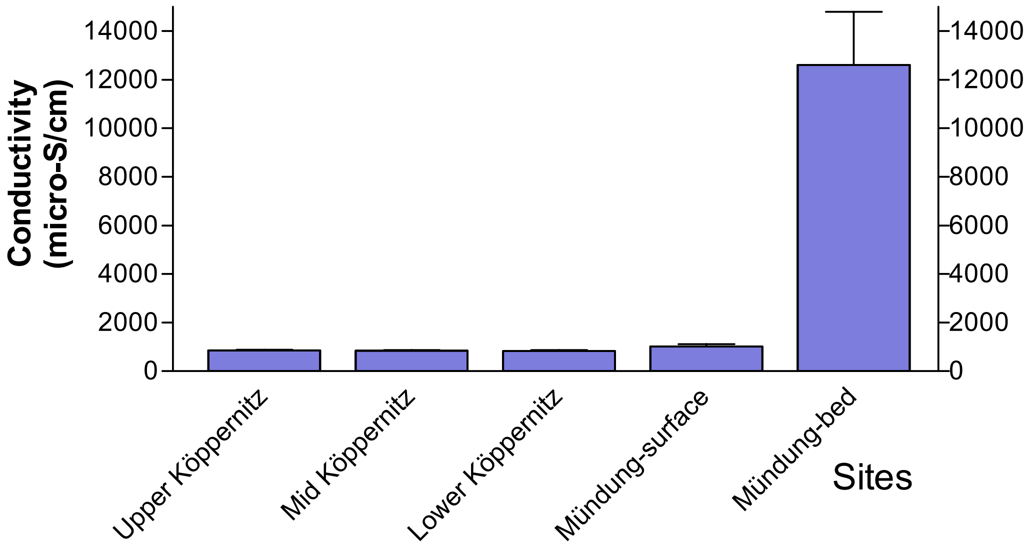


Figure 44: Mean electrical conductivity measurements at sites on the Köppernitz (n= 13, except for Lower Köppernitz, where n=12). Error bars indicate standard error.

Figure 44 shows the extremely high mean conductivity at the Mündung-bed site, which was significantly higher than the lower, mid and upper Köppernitz sites. Conductivity readings at Mündung-bed varied. Some week's recordings at this site were no higher than the other sites, indicating tidal influence. The mean conductivity at the Mündung-surface site is clearly lower, further demonstrating that the mixing of the heavier marine water and the fresh stream water is poor (see Section 8.3: Temperature).

Analysis of the results without the Mündung-bed readings found no significant difference between sites. However, the Mündung-surface mean conductivity readings are consistently higher than at the other three sites, and in some weeks the difference was considerable (see Table 18). The stream waters at the Mündung-surface site were obviously mixing (or diffusion was occurring) with the marine waters, even if mixing was only partial.

Table 18: Electrical conductivity readings on the Köppernitz, 28 June 2001

Site	Upper Köppernitz	Mid Köppernitz	Lower Köppernitz	Mündung (surface)	Mündung (bed)
Conductivity	950µS/cm	935µS/cm	920µS/cm	1787µS/cm	19000µS/cm

Conductivity reduced with rainfall. The date of the storm had far lower conductivity readings (range 521–527µS/cm for all sites-including Mündung-bed) than any other date (mean for other dates for three freshwater sites= 864µS/cm).

8.7 Dissolved oxygen

Measured dissolved oxygen levels (see Figure 45) at Mündung-bed were significantly lower than all other sites except mid Köppernitz.

On three occasions very low DO levels (2.9, 1.3 and 2.5mg/l) were observed at the Mündung-bed site. Each of these measurements occurred when the surface and bed sites had dramatically different conductivities. The cause of the lower measurements at Mündung-bed appears to be the lack of mixing between the lower, saline water and the fresh water above. This would prevent aeration of the lower water and reduce early-morning oxygen levels. As the 100-metre stream section between the Mündung site and the harbour is piped, shade in this section would eliminate photosynthetic oxygen production in the slowly rising marine waters.

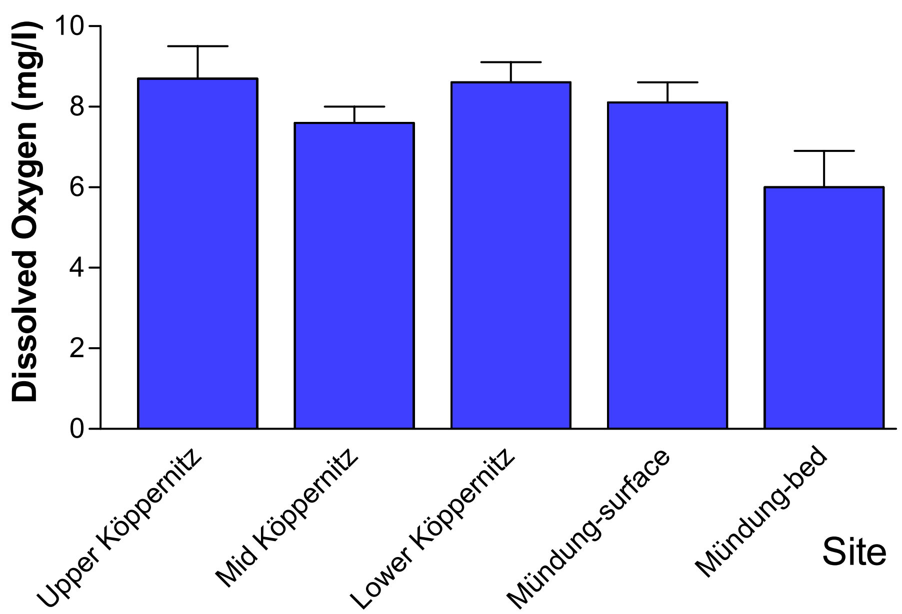


Figure 45: Mean measured dissolved oxygen levels at all sites on the Köppernitz (n= 12, except for Mündung and Lower Köppernitz, where n=11). Error bars indicate standard error.

No other significant differences were found, although measured DO levels at quasi-urban, mid Köppernitz appear to be lower than the other sites, possibly because less photosynthesis is occurring directly upstream (due to shading from riparian vegetation) or animal wastes from the municipal zoo (directly upstream of this site) are increasing oxygen demand.

1991 DO recordings[29] were significantly lower than the 2001 measurements (Figure 46).

DO levels at the urban, lower Köppernitz site were remarkably low (minimum= 2.5mg/L), indicating that pollutants with high oxygen demands were being introduced to the stream above this site. However, since the time of sampling is not given, and DO levels vary diurnally, it is unwise to interpret the data further.

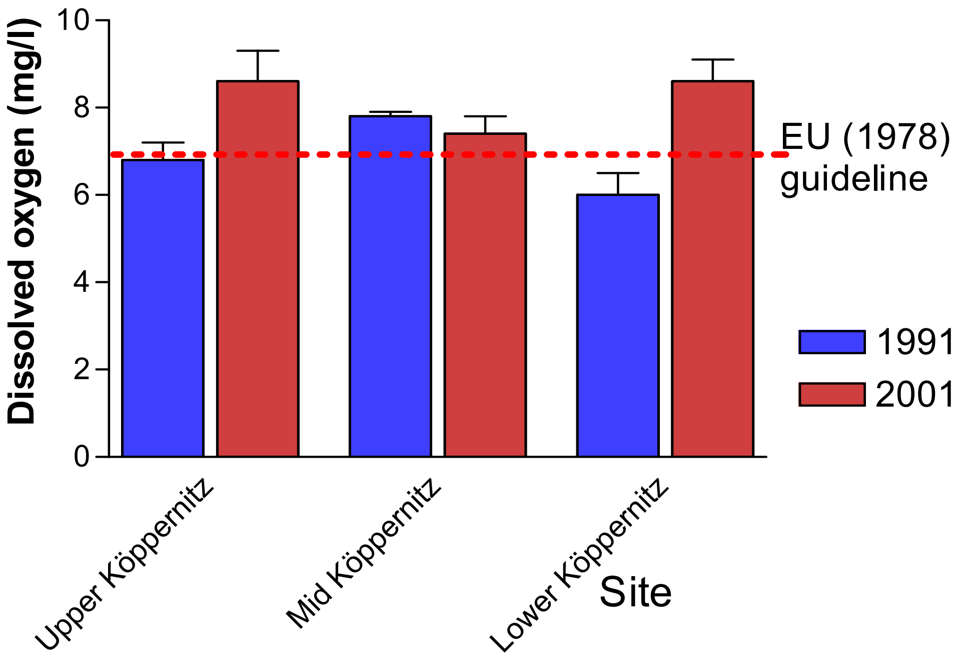


Figure 46: Mean measured DO levels for 1991 (n=16) and 2001 (n=11) at upper, mid and lower Köppernitz for the months May to August, showing the EU (1978) guideline for minimum levels in fish waters. Error bars indicate standard error.

The full dataset of all three sites combined from September 1990 to December 1991 (see Figure 47) showed many occasions when levels fell below the EU (1978) guideline minimum of 7mgO/L for fish waters. The median value was 7.1mgO/L, only narrowly passing the mandatory EU (1978) standard for Cyprinid[30] waters (median DO≥7mg/L) and failing the mandatory EU (1978) standard for Salmonid[31] waters (median DO≥9mg/L).

Levels were particularly low during September and October of 1990. This period coincides with the post-harvest manuring of fields. DO levels are higher in the same

[29] Using data from the same months as the 2001 measurements (May to August)

[30] Cyprinid fish are warm water fish, including carp.

[31] Salmonid fish are cold water fish, including salmon and trout.

period in 1991 (though still lower than the guideline minimum). The higher 1991 levels may be due to the introduction of Federal German Republic regulations on the manuring and fertilising of fields, and improved wastewater treatment.

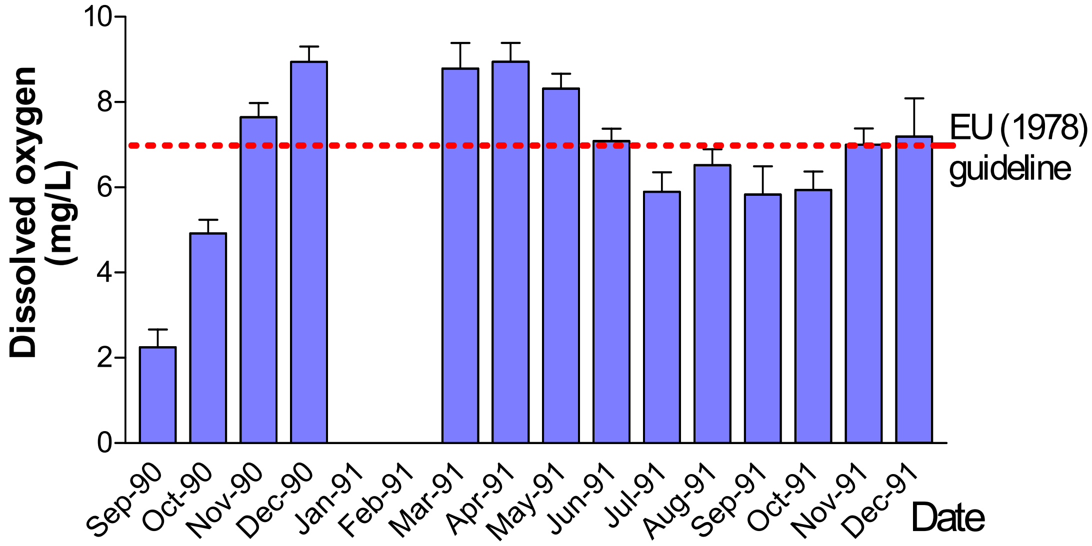


Figure 47: Mean dissolved oxygen readings (n varies from 3 to 15) of the Köppernitz from 1990 and 1991, showing the EU (1978) guideline for minimum levels in fish waters. Note: no data exists for January and February 1991. Error bars indicate standard error.

In comparison, measurements on the larger Elbe River at Magdeburg show even greater changes since reunification, with summer DO levels increasing from less than 3 mg/l in 1989 to around 9 mg/l in 1996 (Lehmann and Rode, 2001). The lower pre-unification DO levels in this river are probably the result of wastes received from large cities and industries in both the former DDR and Czechoslovakia. In some reaches of this river, downstream of cellulose industries, DO levels were reduced to zero.

8.8 Oxidation-reduction potential (Redox)

Redox values (Figure 48) were significantly lower at the mid Köppernitz site than at all other sites. Oxygen levels (Figure 45) were also low at this site, suggesting that animal wastes from the municipal zoo are entering the stream and increasing the demand for oxygen.

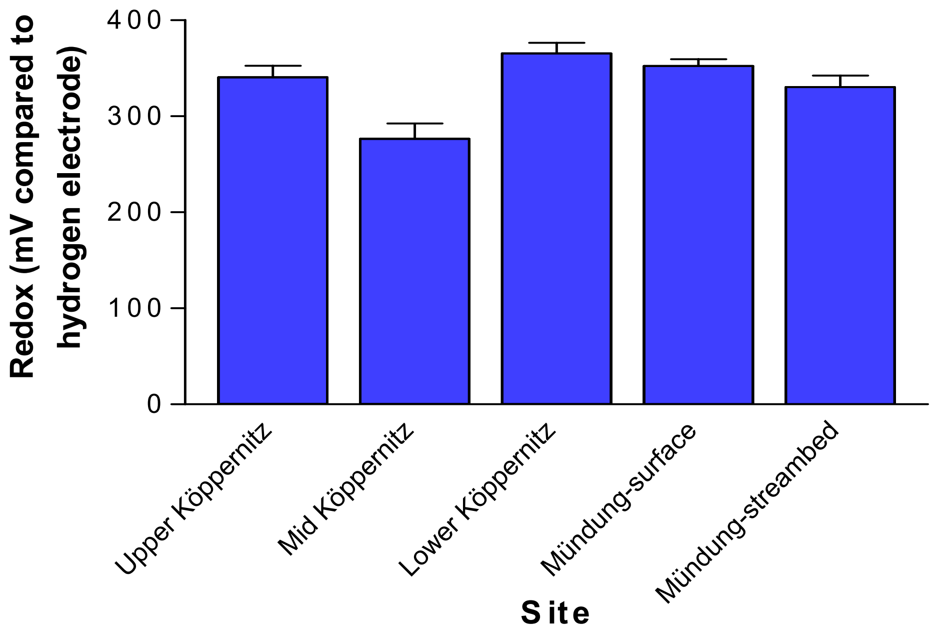


Figure 48: Mean oxidation-reduction potential readings from 2001 (n=12) for sites on the Köppernitz. Error bars indicate standard error.

8.9 Biochemical Oxygen Demand (BOD_5)

No BOD measurements were made in 2001; however, results are available from 1990/1991. The 1990/1991 BOD_5 figures (see Figure 49) show an inverse trend to the DO figures (see Figure 47), with high BOD_5 levels corresponding to low DO levels.

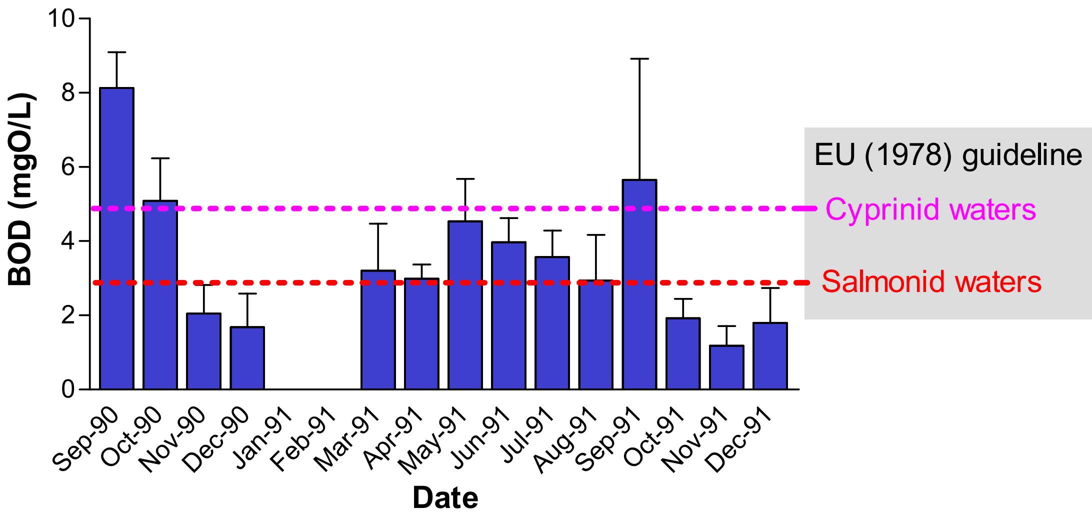


Figure 49: Mean biochemical oxygen demand (BOD_5) readings (n varies from 3 to 15) of the Köppernitz for 1990 and 1991. No data exists for January and February 1991. EU (1978) guideline maximums for fish waters are shown. Error bars indicate standard error

There is one exception to this, September 1991, which was influenced by a single large measurement of 28mgO/L.

BOD_5 was lower at the upper Köppernitz site than the other two sites on 13 of the 14 measured months. Figure 50 shows the mean BOD_5 measurements for May to August 1991. The results indicate that there is a pollution source after the Upper Köppernitz site, and explains the low DO levels measured at the lower Köppernitz site over the same time period (see Figure 46).

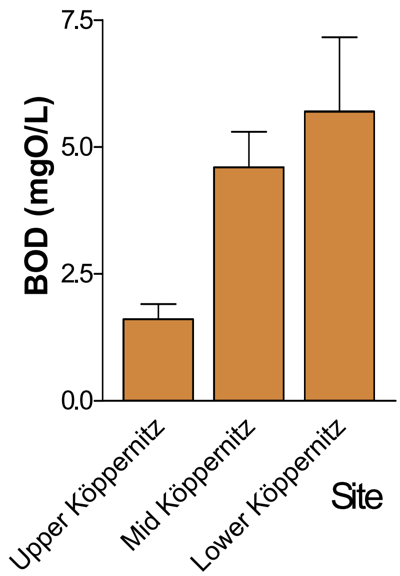


Figure 50: Mean measured biochemical oxygen demand (BOD_5) from May to August 1991 for three sites on the Köppernitz (n= 16). Error bars indicate standard error.

8.10 Phosphate

Twenty-three of the 36 total phosphate measurements taken were below the minimum level of detection (0.3mgP/L) of the method used. This limited the power of any analysis and hence hypothesis 8 (that rural catchments produce higher phosphate levels due to fertiliser use) was unable to be tested against the data. No significant difference in phosphorus levels was found between sites; however, the one storm event had significantly higher levels of phosphate than all other dates. The mean[32] (0.26 ± 0.03mgP/L) was well above the EU (1978) recommendations for fish waters of (0.07mg/L PO_4-P for salmonid waters and 0.14mg/L PO_4-P for cyprinid waters). However, the calculation of the mean is based on a large number of readings which were below the minimum level of accuracy. Nevertheless, 13 of the 36 measurements were 0.3mgP/L or greater (maximum = 0.9mgP/L), and therefore well above EU (1978) recommendations.

1991 phosphate levels (mean = 0.45 ± 0.05mgP/L) were significantly higher than 2001 phosphate levels.

[32] Using 0.15mg/L as the figure for measurements of <0.3mg/L in analysis

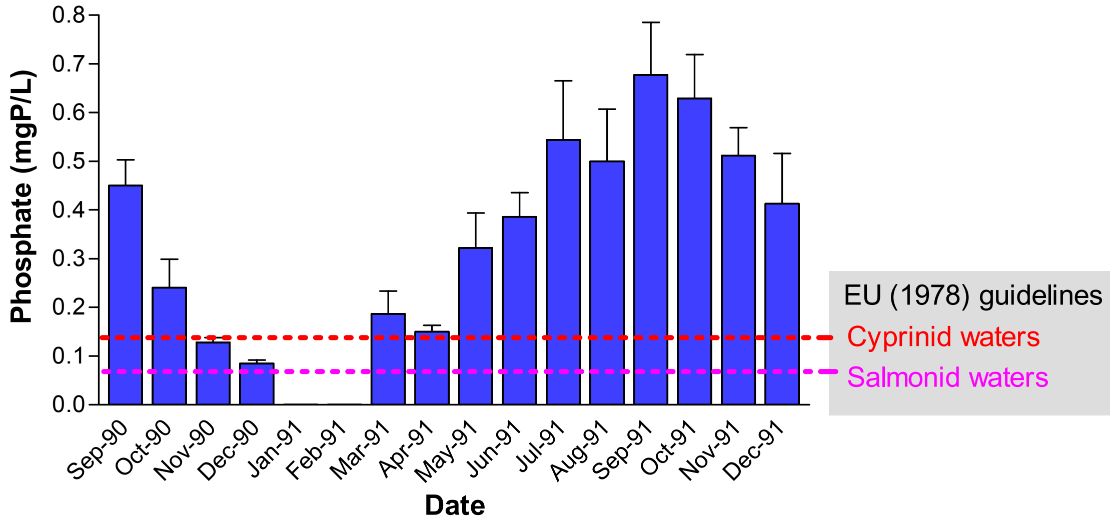


Figure 51: Mean phosphate readings (n varies from 3 to 15) of the Köppernitz for 1990 and 1991. No data exists for January and February 1991. EU (1978) guideline maximums for fish waters are shown. Error bars indicate standard error.

This can be attributed to the post-reunification improvements in sewage treatment systems, retirement of land, closing down of large-scale piggeries and cattle farms, and the introduction of Federal German Republic regulations for fertilisers and washing agents.

Reductions in phosphate levels since reunification are not confined to the Köppernitz, as mean levels of orthophosphate and total phosphorus in the River Elbe at Magdeburg have decreased by over 60% since reunification[33] (Guhr *et al*., 2000).

Levels of phosphate from 1990 and 1991 measurements (Figure 51) were often over EU (1978) guidelines for fish waters.

Phosphate levels in 1991 were consistently lower at the rural, upper Köppernitz site than the lower two sites. Figure 52 shows the mean levels for the period May to August 1991, again suggesting that there was a major pollution source below the upper Köppernitz site.

8.11 Nitrogen

Total nitrogen levels (Figure 53) from the 2001 study reveal that nitrogen levels decreased with movement downstream. The rural, upper Köppernitz site had significantly higher nitrogen measurements than both the urban, lower Köppernitz and Mündung-surface sites. These results indicate that the main source of nitrogen was

---

[33] Change is from 1985–89 mean to 1995–97 mean. Total phosphate was not measured.

upstream (probably from the manuring of cropland) and that there were no major inputs after the upper Köppernitz site. **The data therefore supports hypothesis 9A** (that nitrogen levels will be higher at sites draining rural areas due to livestock, fertilisers, nitrogen fixing clover and a lack of riparian filtering). The depletion in nitrogen levels with movement downstream would be explained by biotic uptake. High photosynthetic rates and low flows (which increase residence times) during summer would allow biotic uptakes to be high. Increased residence times would also allow more denitrification to take place, however the high levels of oxygen[34] measured in the stream indicate that the role of denitrifying organisms would be limited (denitrifying organisms predominate in low-oxygen environments).

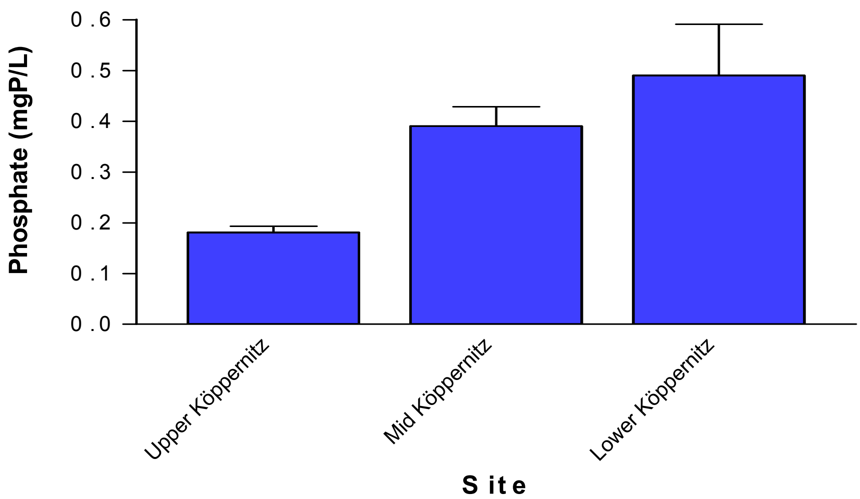


Figure 52: Mean measured phosphate level from April to August 1991 for three sites on the Köppernitz (n= 16). Error bars indicate standard error.

In 1991, total nitrogen was not measured; however, ammonium, nitrate and nitrite were. Comparing these three combined with the total nitrogen values from 2001 showed that the 2001 total nitrogen figures (mean =4.0 ± 0.2mgN/L) were significantly lower than the 1991 (May to August) combined nitrate, nitrite and ammonium figures (mean = 7.5 ± 0.5mgN/L). Even without the inclusion of other forms of nitrogen (reckoned to be around 15% of the total[35])…

…the 1991 level of nitrogen in the Köppernitz was nearly double that of 2001.

---

[34] Only daytime oxygen levels were measured and it is possible that night-time levels would be more conducive to denitrifying bacteria.

[35] Calculated from the relative concentrations of nitrate, ammonium and total nitrogen from measurements taken on 10 July 2002 (nitrite was expected to be minimal).

The decrease from 1991 to 2001 was expected, since a great deal of money has been invested to improve sewage treatment in the area since 1991 (W. Pfeiffer, *pers. com.*, 2001), and a new law aimed at reducing nitrate inputs from agriculture (Nitrates Directive, EU 1991) has been introduced. Additionally, fertiliser losses have reduced due to improved distribution, transport and storage methods since reunification; land has been retired and livestock densities have also decreased (Werner and Wodsak, 1994).

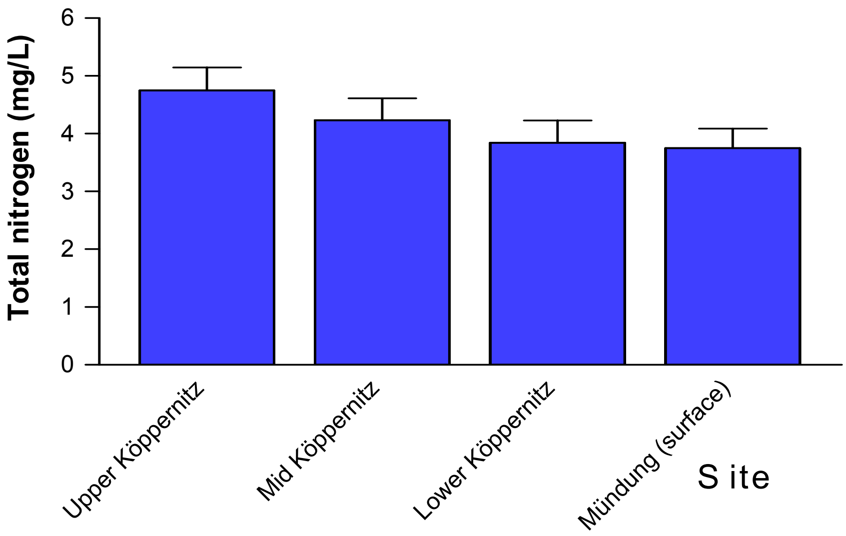


Figure 53: Mean measured total nitrogen levels (n= 11, 2001 data) at sites on the Köppernitz. Error bars indicate standard error.

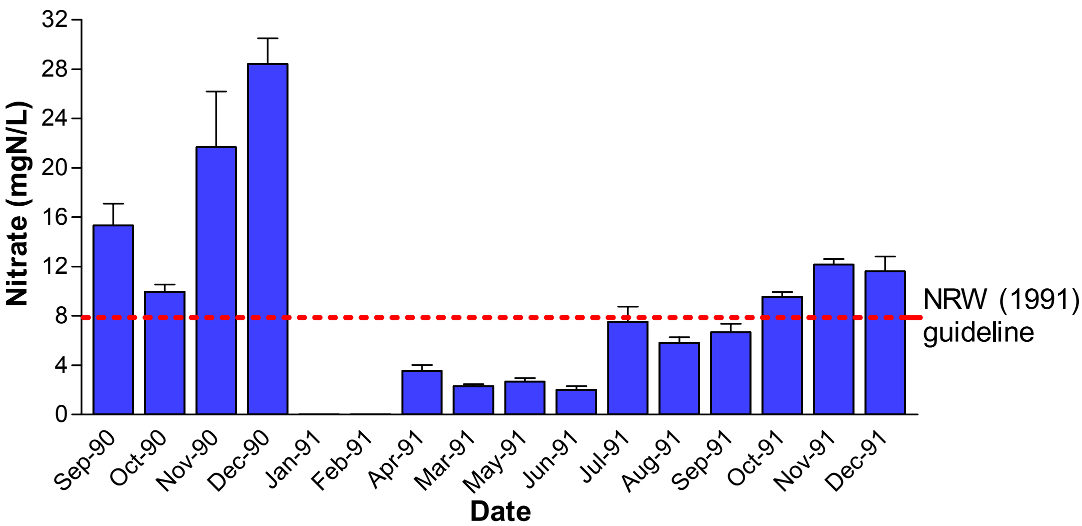


Figure 54: Mean nitrate readings (n varies from 3 to 15) of the Köppernitz for 1990 and 1991. No data exists for January and February 1991. The North-Rhine Westphalian (NRW 1991) guideline maximum (8mgN/L) for flowing waters is shown. Error bars indicate standard error.

Nitrate levels (Figure 54) were far higher in 1990 than 1991. This may be due to the stricter standards of the Federal Republic of Germany already taking effect. Summer nitrate levels tend to be lower than in autumn and winter. This effect is common (Mason, 2002) and would be due to the higher biotic uptake of nitrogen during summer and post harvest manuring in autumn.

Ammonium levels during the sampling period of 1990 and 1991 (Figure 55) were extremely high, being above the mandatory limit of the EU (1978) directive for fish waters on all of the 12 sampled months. These figures are significantly higher than the levels measured in 2001 (mean = 0.3 ± 0.05mgN/L, n=4).

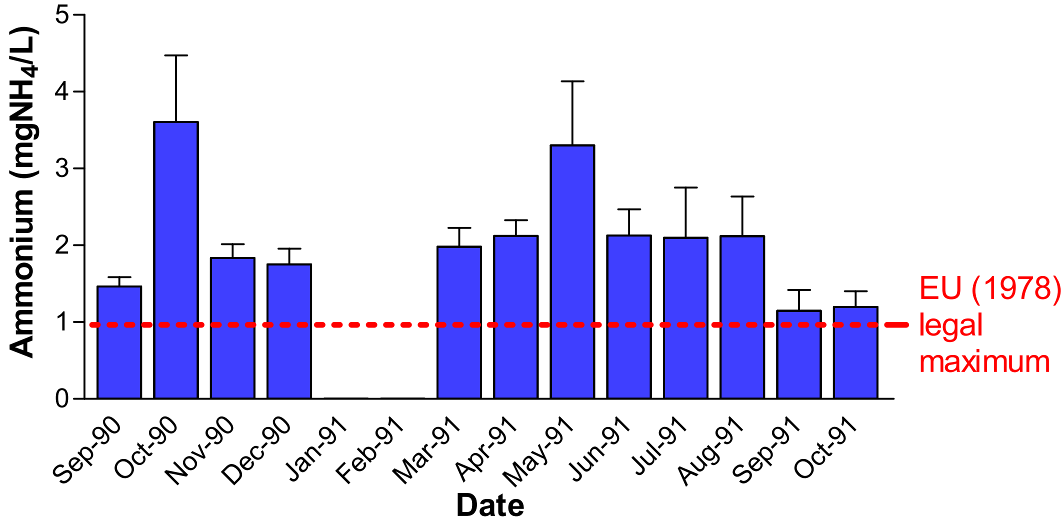


Figure 55: Mean ammonium readings (n varies from 3 to 15) of the Köppernitz for 1990 and 1991. No data exists for January and February 1991. The EU (1978) legal maximum level for fish waters is shown. Error bars indicate standard error.

The decrease in ammonium levels mirrors that from the Rhine, where levels decreased steadily from 1.3mgN/L in 1985 to <0.3mgN/L in 1995 (Kahlenborn and Kraemer, 1999). Kahlenborn and Kraemer (1999) attributed the decreases in ammonium levels in the Rhine to improvements in sewage treatment, a factor that has also dramatically improved in the Wismar area.

There was a significant difference in ammonium levels (April to August 1991) between sites. The lower Köppernitz site had significantly higher levels of ammonium than the upper and mid Köppernitz sites (see Figure 56). This further supports the thesis that there were major pollution sources downstream of the upper Köppernitz site and especially after the mid Köppernitz site (see 8.7: DO, 8.9: BOD_5, 8.10: Phosphate) in 1991.

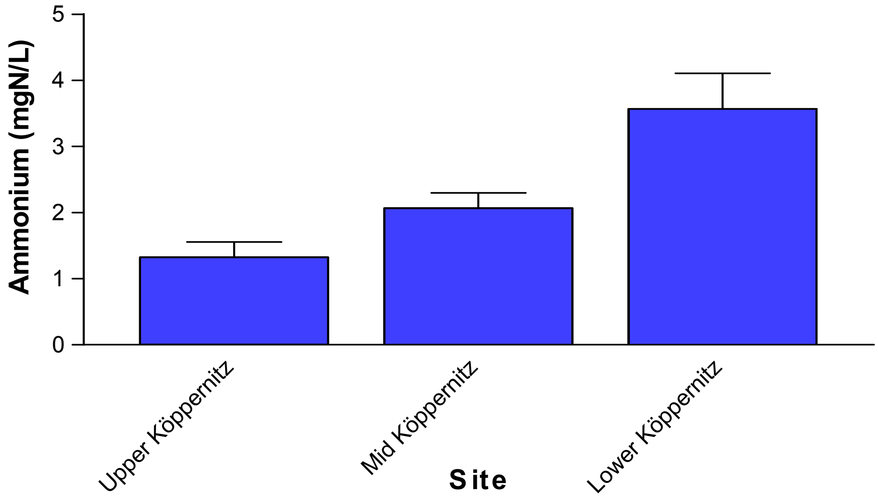


Figure 56: Mean measured ammonium levels from May to August 1991 for three sites on the Köppernitz (n= 20). Error bars indicate standard error.

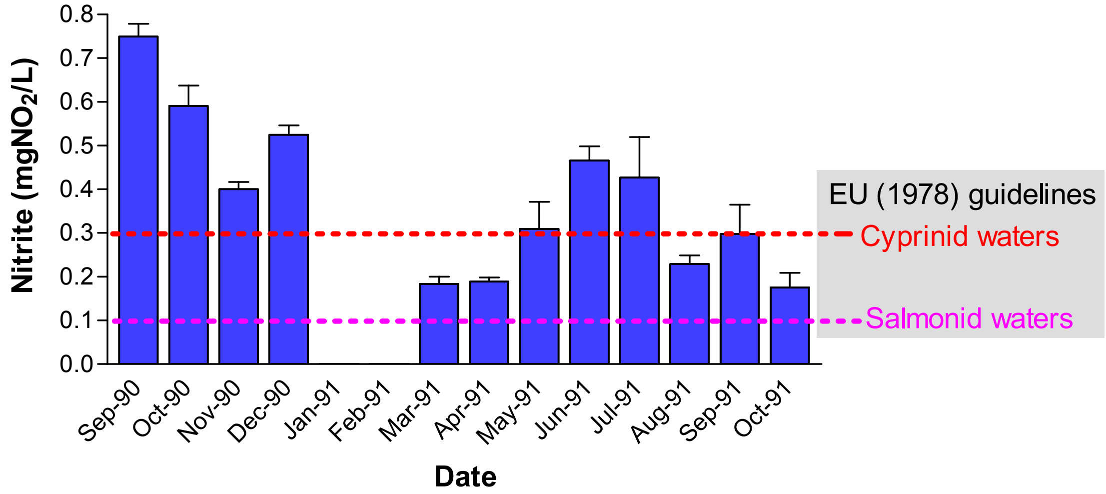


Figure 57: Mean nitrite readings (n varies from 3 to 15) of the Köppernitz for 1990 and 1991. No data exists for January and February 1991. EU (1978) guideline maximums for fish waters (78/659/EEC) are shown. Error bars indicate standard error.

Nitrite levels for 1990 and 1991 were also high, being over the EU (1978) guideline for salmonoid waters in all months and cyprinid waters for the majority of months sampled. Levels were noticeably higher in 1990 than 1991, again indicating that stricter Federal German Republic regulations were taking effect. Although no nitrite measurements were taken in 2001, it is likely that present levels of nitrite in the Köppernitz would be lower now than in 1990. Measurements on another former DDR river, the Elbe at Magdeburg, showed a drop in median NO_2^--N concentrations from 0.19mg/l in 1985-89 to 0.058mg/l in 1995-97 (Guhr *et al*., 2000). This can be attributed to improved sewage treatment and higher DO levels, which would speed the conversion of nitrite to nitrate.

8.12 Bacteria: cultivatable colonies at 22°C

There was no significant difference in cultivatable colony counts between sites when the data was analysed as a whole. When the data was analysed without measurements from the storm event (18 June 2001), the lower Köppernitz site had significantly higher bacterial counts than the mid and upper Köppernitz sites (Figure 58). There appears to be a general increase in bacterial numbers with movement downstream from mid Köppernitz. The increase could be due to exfiltration from sewage pipes or waste from domestic animals. The findings tend to contradict the trend for nitrogen in 2001 (see section 8.11), which showed a decrease in levels downstream. The site with the lowest bacterial measurements was mid Köppernitz, which was surprising, since it had the lowest redox and DO levels in 2001.

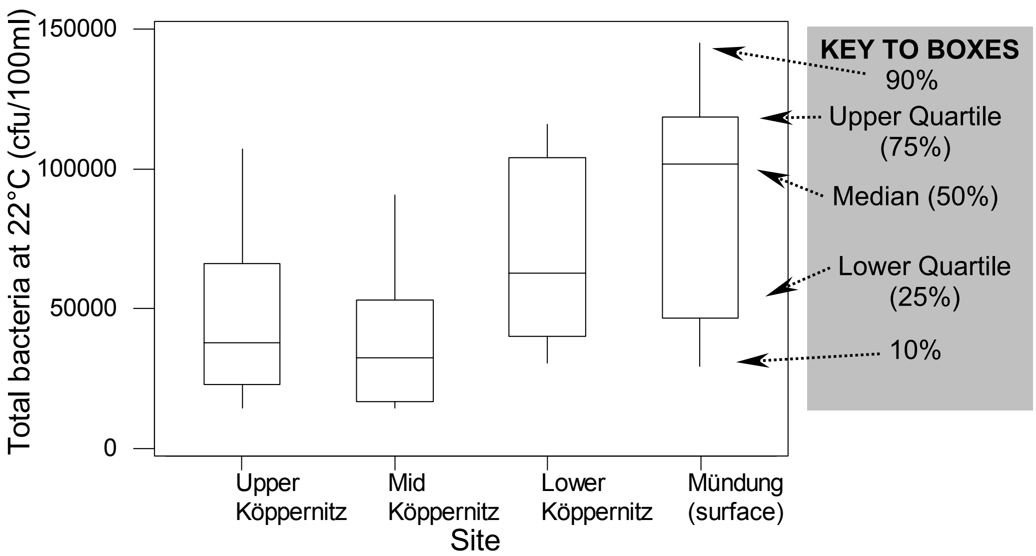


Figure 58: Boxplot of total bacterial colonies (excluding the storm event) at sites on the Köppernitz, April to August 2001 (n=9).

No guidelines exist for cultivatable colony levels in stream water (they are not a specific indicator of faecal contamination), so no conclusion can be reached regarding the safety of contact with the water, such as takes place at the municipal zoo playing area.

The storm event (18 June 2001) had the highest bacterial counts (median = 260000 cfu/100ml) and was significantly higher than the lowest date (3 July, median = 27000 cfu/100ml). Higher bacterial counts during rainfall events are common in other studies (reviewed in Ferguson, 2003), and can be caused by the flushing of bacteria from the topsoil, exfiltration from sewage pipes and the washing of faecal matter with overland flows.

8.13 Toxicity (fluorescent bacteria test)

Only one sample was found to have any toxic effect on the fluorescent bacterium (*Photobacterium phosphoreum*). On retesting, the sample was not found to have any effect on bacterial phosphorescence. The first result was most likely the product of experimental error. It was therefore concluded that the stream water had no toxic effect on the bacterium.

8.14 Macro-invertebrates

The brief survey of macro-invertebrates showed differences between sites do exist, with more taxa being found at the upstream sites. The survey was limited, and more surveys would be needed (ideally, once in all four seasons) to determine whether the differences are real. The fact that the survey was performed three days after a heavy storm (which could have removed species in the faster flowing areas) further limits its reliability. The species that were found indicate that the stream can be graded as moderately to critically polluted (*Gewässergüteklasse* II to III) using the German stream quality classification system (LAWA, 1990, see under "*Gewässergüteklasse*" in the Glossary).

8.15 Synopsis of results

A dramatic improvement in water quality has occurred since 1991 (see Table 19), with significant improvements in DO, phosphate, nitrogen, nitrate and ammonium levels between 1991 and 2001. Improvements in sewage treatment, waste management and tighter BRD regulations on nutrients (e.g. the 1991 EU Nitrates Directive and the 1980 limit on the phosphate content of detergents: the *Phosphathöchstmengenverordnung*) are most likely responsible for this. pH values also appeared to have changed markedly, possibly due to decreased industrial air pollution.

According to the German system of stream quality classification ("*Gewässergüteklassen*", LAWA, 1990), the Köppernitz improved from the 1991 classification of heavily/very heavily contaminated (*Gewässergüteklasse* III to III-IV) to the 2001 classification of critically polluted (*Gewässergüteklasse* II-III). The classification is based on the mean (or, in the case of oxygen, minimum) measured value for various parameters (Table 19). The 2001 classification, using chemical parameters (*Gewässergüteklasse* II-III), was confirmed by the macro-invertebrate survey, however the bacterial count (Table 19) found it to be cleaner (*Gewässergüteklasse* I: unpolluted to very lightly polluted).

Improvements appear to have already occurred between 1990 and 1991 (reunification was on October 3, 1990), with September and October levels of DO, BOD, nitrate, ammonium and nitrite all improving between 1990 and 1991 (see Figure 47, Figure 49, Figure 54, Figure 55 and Figure 57).

Another prominent feature of the results was the deterioration in 1991 water quality with movement downstream of the upper Köppernitz site. Phosphate, BOD_5 and ammonium levels increase dramatically after this site, and DO decreases. A large Soviet army base was situated between the upper Köppernitz site and the 1991 mid Köppernitz site. There is anecdotal evidence that the occupying Russian forces were less than careful about waste disposal and it is likely that the base was responsible for a large part of the increase between the upper and mid Köppernitz site. Exfiltration from poorly maintained sewers could also have contributed to the problem.

The 2001 results indicated that marine and freshwaters mixed poorly at the Mündung site, leading to pronounced differences in conductivity, temperature and DO between the Mündung-surface and Mündung-bed readings. Extremely low DO readings at Mündung-bed indicate that the lack of mixing combined with complete shading in the adjacent piped channel reduces habitat quality.

In 2001, the mid Köppernitz site had significantly lower DO and redox readings than the other sites, indicating that wastes from the municipal zoo were increasing the demand for oxygen. The higher phosphate readings at the mid Köppernitz site than the upper site supported this conclusion, however bacterial and nitrogen measurements suggest the opposite: the upper site had slightly higher values than the mid Köppernitz site for both these parameters. Further testing would be required to clarify the situation.

Hypothesis 3 (that stream temperatures are lower downstream from riparian vegetation) and Hypothesis 9A (that nitrogen levels will be higher at sites draining rural catchments due to livestock, fertilisers, nitrogen fixing clover and a lack of riparian filtering) were supported by the 2001 data. No definitive conclusion could be made regarding hypothesis 1B, 1D and 8 (see 8.16: Limitations).

8.16 Limitations

Resource limitations restricted the nature and extent of many of the methods and parameters employed or studied in this survey. No equipment was available for 24-hour testing, so the true situation for parameters which vary diurnally (pH, DO, temperature), or rapidly during events (e.g. suspended sediment levels at peak storm flow) remains unknown.

Some tests proved inaccurate or inappropriate in these environments. The majority of phosphate readings were below minimum levels of detection (<0.3mgP/L), and consequently hypothesis 8 (that phosphate levels are higher in rural areas due to fertiliser use) could not be evaluated. Flow estimates also gave questionably high results at the lower Köppernitz site.

Test specificity was also problematic. The bacterial indicator (cultivatable colonies at 22°C) allowed no conclusions to be drawn on the possibility of faecal contamination and gave no indication of the water's suitability for bathing.

The paucity of storm events during the sampling period, coupled with the limited weekly time frame for sampling (the university laboratory was closed at weekends), meant that only one storm event was sampled, and not during peak flow. Consequently, little is known about the high-flow water quality of the stream.

As only one stream was tested at a limited number of sites, the generality of findings is acknowledged as limited. To produce conclusive results, the measurement of sites from many different streams would be required. Resource constraints precluded this.

Finally, the ability to draw conclusions from differences between rural and urban catchments was greatly constrained by the fact that even the most urban site (Mündung) had a catchment that was over 70% rural.

This fact, combined with the lack of accuracy in flow measurements, meant indications that hypothesis 1B (rural catchments produce higher base flows) was not supported by the data cannot be substantiated. Likewise, the data's support for hypothesis 1D (urban catchments produce higher peak flows) must also be questioned, especially when to the small number (n= 2) of peak flow events are considered.

Table 19: Means (± s.e.) and ranges and Gewässergüteklasse[W] for 2001 measurements and 1991 (May to August) records from the upper, mid and lower Köppernitz sites combined. European standards for fish waters and bathing waters are also given

Parameter	2001			1991 (May to August)			European Standard
	Mean, (median)	Range	Güteklasse[W]	Mean (median)	Range	Güteklasse[W]	
Suspended sediment (mg/L)	7 ±1.6	2–19	NA	NA	NA	NA	<25[F]
Temperature (°C)	15.3 ± 0.2	10.7–23.2	NA	NA	NA	NA	<21.5[F]
pH	8.0 ± 0.03	7.5–8.34	NA	6.9	6.9	NA	6-9[F,B]
Conductivity (µS/cm)	836 ± 20	521–950	NA	NA	NA	NA	NA
Dissolved Oxygen (mg/L)	8.2 ± 0.3, (8)	5.1–14	II to III	6.9± 0.2	2.5–10	III to IV	Always >7[F] Median >8[F,C] Median >9[F,S]
Redox (mV)	337 ± 8	185–416	NA	NA	NA	NA	NA
BOD_5 (mgO/L)	NA	NA	NA	3.7±0.5	0–16	II	≤3[F,S] ≤6[F,C]
Phosphate (total, mgP/L)	0.25 ± 0.03[A]	<0.3–0.9	III	0.45±0.05	0.09–1.64	III to IV	<0.07[F,S] <0.14[F,C]
Nitrogen (total, mg/L)	4.0 ± 0.2	2.3–7.6	II to III	NA	NA	NA	NA
Nitrate (mgN/L)	2.6 ±0.2	2–3.4	II to III	5.3± 0.6	1.1–15	III	8[N]
Ammonium (mgN/L)	0.28± 0.05	0.2–0.4	II	1.8 ± 0.2	0.1–7.3	III to IV	1[F] (mandatory)
Nitrite (mgN/L)	NA	NA	NA	0.35 ± 0.03	0.1–1.5	III	≤0.01[F,S] ≤0.03[F,C]
Cultivatable colonies at 22°C (cfu/100ml)	45,600[G], (42,000)	14,400–14,5000	I	NA	NA	NA	NA

[F]European Union standard to support fish life (EU, 1978)
[B]European Union standard for bathing waters (EU, 1975)
[W]German stream water quality classification system (LAWA, 1990)
[A]0.15mg/L used for all measurements of <0.3mg/L to calculate mean.
[N]North Rhine- Westphalia (1991) Guideline for flowing waters
[G]Geometric mean
[S]Salmonid waters
[C]Cyprinid waters

9 Comparison of New Zealand streams and German stream

This chapter analyses differences in water quality between the two New Zealand streams studied (Awaruku and Vaughan Streams) and the German Köppernitz Stream (as measured in 2001/2).

Before comparing the results, the data were tested for equivariance and normal distribution and transformed where necessary using the methodology outlined in section 4.19. The results were then analysed without date matching using t-tests (where normal distribution and equal variance could be achieved) or the non-parametric Mann-Whitney test.

9.1 Flow

Measured flows per hectare were significantly higher in the New Zealand streams (median = 0.08 l/sec/ha) than in the Köppernitz (median = 0.03 l/sec/ha). This was expected, since Auckland's average annual rainfall is double Wismar's. Additionally, the flatter topography and more permeable soils of the Köppernitz catchment would allow a higher proportion of rainfall to move through the watertable, rather than the stream, to the sea.

9.2 Temperature

Temperatures were significantly higher in the two New Zealand streams (mean = 17.5±0.4) than in the Köppernitz (mean = 15.3±0.2), even though both were sampled in the spring and summer. The difference in stream temperatures can probably be attributed to Auckland's warmer climate (mid-summer mean = 22.8°C, cf. Wismar ≈ 17°C).

9.3 pH and alkalinity

The pH levels were significantly higher in the Köppernitz (mean = 8.0± 0.03) than in the New Zealand streams studied (mean = 6.9±0.04). The pH levels in the Köppernitz varied little over the study period (range 7.5 to 8.3) compared to the measurements for the New Zealand streams (range 5.3 to 7.7), indicating that the waters in the Köppernitz are better buffered. This is supported by the far higher alkalinity in the Köppernitz (mean of 307mg$CaCO_3$/l; range= 300–310mg$CaCO_3$/l) than that measured in the New Zealand streams (mean= 51mg$CaCO_3$/l; range= 45–60).

The higher pH and alkalinity values in the Köppernitz are probably attributable to the calcareous geology of the Köppernitz catchment.

9.4 Conductivity

Conductivity readings at the three freshwater Köppernitz sites (mean =836±20µS/cm) were significantly higher than in the two New Zealand streams (mean =273±7µS/cm). The reason for the higher levels in the Köppernitz are, again, likely to be the calcareous geology and pedology of the catchment. De-icing salts could also cause higher salinity in the Köppernitz, although snowfalls are infrequent in the region and the use of de-icing salts appears to be rare[36]. The heavier use of fertilisers and manures in the Köppernitz catchment could be another cause of the higher conductivity.

9.5 Dissolved oxygen

DO readings from the New Zealand streams (mean = 5.1 ± 0.3mg/l) were significantly lower than the 2001 readings from the freshwater Köppernitz sites (mean = 8.2±0.3mg/l). This reinforces the conclusion that the New Zealand figures are unusually low and that further investigation is required to determine the cause.

9.6 Phosphate

Orthophosphate levels in the New Zealand streams (mean = 0.025 ± 0.003mgP/L) were an order of magnitude lower than the 2001 total phosphate levels recorded in the Köppernitz. Unfortunately, since the relative proportions of ortho- and total phosphate in the water bodies are unknown, no conclusion can be drawn.

9.7 Nitrogen

Köppernitz nitrate measurements (mean = 2.6±0.4mgN/L) were significantly higher than the nitrate measurements from the New Zealand streams (mean = 0.37± 0.04). Although this comparison is based only on Köppernitz data from two dates, the large difference in means and the very low *P* value (*P*=0.000) indicates that the difference is

[36] The author saw no de-icing salts used during his 17-month-long stay in the region.

real. The difference is probably due to agricultural inputs (manure and other fertilisers) and the outlets of sewage treatment works from the small villages upstream.

9.8 Synopsis

The significantly higher pH and conductivity along with the higher alkalinity and more stable pH in the Köppernitz vis a vis the New Zealand streams are noteworthy. The difference is likely to be due to the calcareous geology. Flows per unit catchment area and temperatures were higher in New Zealand, reflecting the wetter, warmer climate of the Auckland region. Additionally, nutrient levels appeared to be higher in the German stream, indicating stronger effects from the more intensive land use in the Wismar area. All these differences confirm the need for region-specific studies, which take into account the physiography and climate of the region, as well as the intensity of land use activities, when assessing the effects of land use on water quality.

Table 20: Means (± s.e.), ranges and median values for measurements taken at the New Zealand streams (Vaughan and Awaruku) and the Köppernitz Stream (2001/2 data), Germany.

Parameter	New Zealand streams	Köppernitz Stream, Germany
Flow (l/s/ha)	Median = 0.08 l/sec/ha	Median = 0.03 l/sec/ha
Temperature (ºC)	Mean = 17.5±0.4	Mean = 15.3±0.2
pH	Mean = 6.9±0.04 Range = 5.3 to 7.7	Mean = 8.0± 0.03 Range = 7.5 to 8.3
Alkalinity	Mean = 51mg$CaCO_3$/l (n= 5) Range = 45–60mg$CaCO_3$/l	Mean = 307mg $CaCO_3$/l (n= 4) Range = 300–310mg$CaCO_3$/l
Conductivity	Mean = 273±7μS/cm	Mean = 836±20μS/cm
Dissolved Oxygen	Mean = 5.1 ± 0.3mg/l	Mean = 8.2±0.3mg/l
Nitrate	Mean = 0.37± 0.04	Mean = 2.6±0.4mgN/L

9.9 Limitations

A restricted choice of tests was available in Germany. Tests equivalent to those used in New Zealand were not available for bacteria, phosphate and clarity. This limited comparisons between the Köppernitz and the New Zealand streams. Additionally, the differences between the climate and catchment geology of the streams limit the ability to draw conclusions on the relative effects of land use and policies employed in each country.

10 Case study three — The proposed residential development at Long Bay, New Zealand: expected water quality impacts; review of current and planned policies to minimise these; and extra measures required

This chapter discusses the possible effects of the proposed residential development at Long Bay on the aquatic environment. The findings of case studies one and two relevant to this development are reviewed. Policies in the local council development plan to avoid or mitigate any adverse effects are reviewed, and extra measures are suggested.

10.1 Review of findings of case studies one and two

10.1.1 Effects of urban development on water quality

Due to the limited number of sites measured in case studies one and two, hard conclusions about the effect of urban development on water quality cannot be drawn. However, differences between sites indicated that:

- Riparian vegetation should be maintained: stream sections with riparian vegetation in the case studies had lower maximum temperatures and less variation in DO, pH and temperature.
- Vegetation in the catchment should, where possible, be maintained: the forested catchment of mid Vaughan produced the most stable flow regime, the highest rainfall event clarity and lowest bacterial counts.
- Sewage leaks may occur: high levels of faecal bacteria were measured in the urban Awaruku Stream site, which could be attributable to losses from sewage pipes.
- Replacing rural land use with urban may have some positive water quality effects: the removal of cattle, which may be responsible for the poor clarity, nitrate levels and faecal coliform counts measured at lower Vaughan site (see following section: 10.1.2) could improve some aspects of water quality.
- Surfacing catchments and channels leads to less stable flow regimes: urban sites in New Zealand were found to have higher peak flows and lower base flows than rural or forested sites.

In terms of the mitigation of land-use effects on water quality, the case studies also showed that:

- Sediment dams are effective in reducing sediment loads: clarity in the Awaruku Stream was relatively high directly downstream of sediment dams.
- Effective regulation and waste treatment can reduce land use impacts: there has been a dramatic reduction in nutrient and loadings and increases in oxygen levels in the German Köppernitz stream since 1990/1 which may be attributable to the introduction of EU regulations and improved wastewater treatment.

10.1.2 Current water quality of Vaughan Stream[37]

Vaughan Stream is not a pristine waterway, and some changes in land use could result in improvements in water quality. The current state of the stream's water quality (see chapter 5) must be taken into account when considering the effects of any further development.

Measured dissolved oxygen (DO) levels in Vaughan Stream were extremely low. Since the cause of these low figures is unknown, there is no way of predicting whether changes in the catchment would improve or worsen this situation. However, the low DO levels do reduce the stream's conservation value.

Other problems with the stream include:

- The lower section of the stream lacks riparian vegetation, which appears to have caused high stream temperatures, as well as high variability in temperature, DO and pH.
- Livestock in the lower catchment also seem to be causing poor clarity, high counts of faecal-indicator bacteria and high nitrate levels.
- Phosphate levels in the upper catchment were high, possibly due to fertilisers from the rural part of the upper catchment.

On the positive side, the upper catchment has good riparian vegetation as well as other large bush areas and low livestock numbers. Wet-weather clarity in the upper catchment was superior to all other sites measured, while bacterial counts, nitrate levels and temperatures were all relatively low. Variations in temperature, pH and DO were also minimal.

Invertebrate surveys (Evans, 2001) also indicate that the upper Vaughan has high water quality and the lower Vaughan has low water quality, relative to other streams in the North Shore area.

---

[37] Only parameters measured in this study are discussed.

10.2 The vulnerability of the marine reserve

Green *et al.* (2000) modelled the fate of sediment from Vaughan and Awaruku Streams and found that currents generated by some tides and winds "carry sediment plumes across the …reefs and along the soft shoreline of the Long Bay embayment"; Rhodamine B dye releases from Awaruku Stream confirm this (Williams, 1999). According to Green *et al.* (2000), there is a risk that sediments from Vaughan and Awaruku Streams will deposit on "sensitive coastal habitats". Although wave action was likely to reduce sediment settlement near the mouths of the streams, an area to the north of Vaughan Stream could suffer from enhanced settlement. This area, a reef on the south side of Piripiri Point, is in the Marine Reserve and is sheltered from wave action.

The conclusions of Green *et al.* (2000) were based on complex models of currents, sediment transport and wave patterns. The modelling of such complex systems relies on many assumptions, so it is possible that the situation could be even worse. Although Green *et al*. (2000) predicted that wave action would reduce sedimentation near the stream mouths, evidence exists of sediment deposition on the reef directly to the south of Awaruku Stream's mouth; on one occasion in 1998, more than 3mm of sediment covered sections of the reef (Buckeridge, *pers. com.* 2000, Figure 5).

Furthermore, Walker *et al.* (2000) found rates of sedimentation in the Long Bay area to average 0.29g/day/cm^{-2} between September 1999 and May 2000. This was the second highest of a series of six sites between Waiwera (14km to the north) and Campbells Bay (7km to the south) in the Hauraki Gulf. According to Walker *et al.* (2000), the sediments contain a high proportion of fine particles (<250μm) with a deposition rate of 0.31 g/day/cm^{-2}. This figure must be questioned, however, as it is greater than the total deposition value for all sediments. Even so, the rate of sedimentation is a concern, especially its smaller particle fractions. These particles include clays and fine silts likely to be of terrestrial origin (Walker *et al.*, 2000), and because these sediments also have a greater capacity than larger particles to carry heavy metals, phosphates and many other pollutants due to their larger specific surface area.

10.3 The Long Bay residential development and its anticipated effects

As discussed in section 2.1, urban-growth pressures have led to plans to develop the catchment of Vaughan Stream. A series of proposals (NSCC, 1998b, 2000b) and scientific reports (NSCC, 1998c; Beca Steven, 1999; Green *et al.*, 2000) led to a variation to the district plan (the Proposed Long Bay Structure Plan, NSCC, 2001a). A map of the proposed structure plan is shown in Appendix IV. The plan is essentially the mixed development approach (incorporating high, medium, low and rural residential development) analysed by Beca Steven (1999).

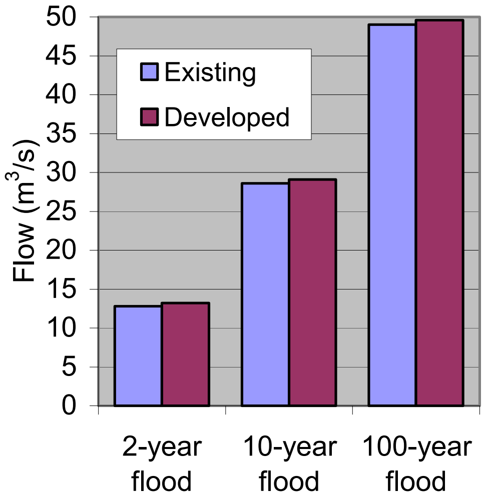


Figure 59: Calculated peak flow in Vaughan stream for flood events for the existing catchment and following development (Beca Steven, 1999)

Beca Steven (1999) calculated that the increase in peak flows after development would be small[38] (Figure 59). This small increase could be alleviated by the inclusion of flood attenuation/ sediment removal dams (Beca Steven, 1999). These were incorporated into the proposed structure plan (NSCC, 2001a).

Table 21: Yield of contaminants from Vaughan catchment before and after development, with and without flood attenuation/ sediment settlement dams (Beca Steven, 1999)

	Existing	Developed	Existing + dams	Developed + dams
Suspended Sediment (tonnes/year)	175	145	68	56
Total Phosphorus (kg/year)	351	311	237	210
Total Nitrogen (kg/year)	2806	2552	2011	1829
COD (kg/year)	35,980	41,351	27,294	31,467

Calculated yields of suspended sediment, total phosphorus, total nitrogen and chemical oxygen demand[39] (COD) are all predicted to decrease after development providing the

[38] The increase is small because the soils of the catchment are poorly permeable.

[39] COD (see glossary) is related to oxygen levels.

flood attenuation/sediment settlement dams are built (Table 21). However, during the construction phase, sediment levels are calculated to increase even with dams in place (Figure 60) — calculations based on the scenario that development only occurs during the six-month "summer" period, and that on-site sediment controls retain 65% of sediment (this must be enforced, see Section 10.6).

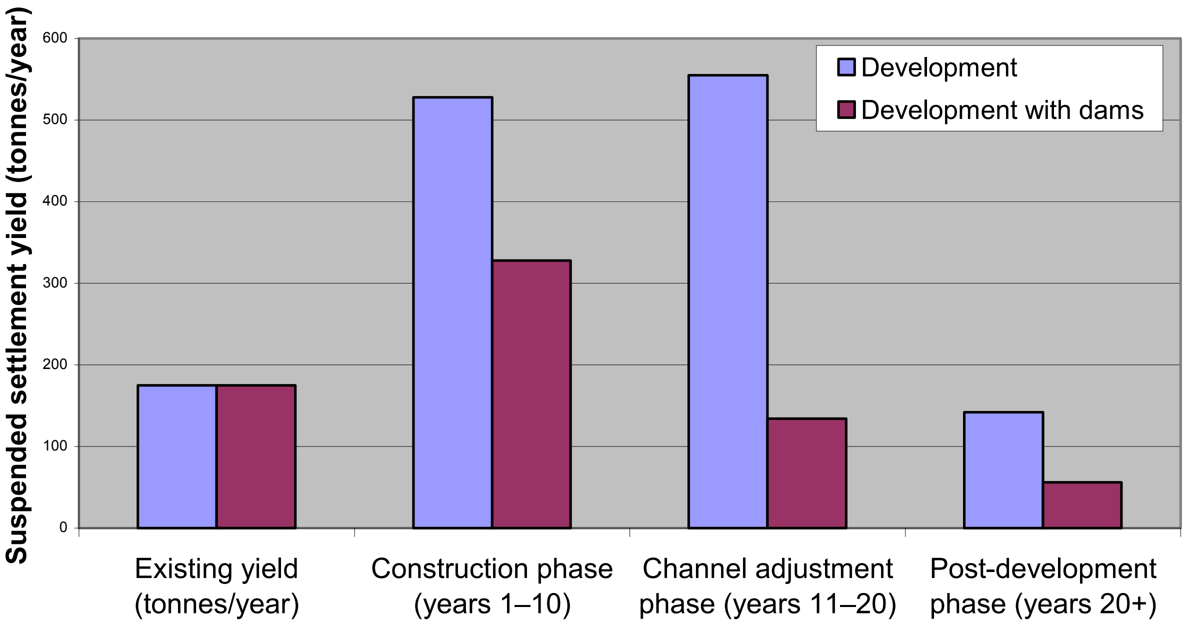


Figure 60: Total suspended sediment yield from Vaughan catchment over the development process, with and without sediment settlement dams (Beca Steven, 1999)

Beca Steven (1999) found that, even with dams, the yields of the other three parameters they modelled, total petroleum hydrocarbons (up 21%), copper (up 53%) and zinc (up 48%), increased[40]. Additionally, the positioning of the dams is problematic, as they are located in the lower catchment, and steep topography affords no sites in the upper catchment for dams. Although the ponds attenuate peak flows and reduce contaminant levels downstream, no benefits exist for the sections upstream of the dams. These sections will experience elevated flows, channel erosion and elevated levels of most parameters (especially suspended sediments), particularly during the construction/ channel adjustment phase.

For these reasons, more measures are required.

Processes necessary for the sustainable development of the catchment are discussed below, as are the measures that the responsible authorities are taking to achieve these.

[40] These parameters are not dealt with further in this dissertation since they were not studied in the previous sections.

10.4 Comprehensive catchment plans must be formulated

According to van Roon (2000), most urban catchment management plans concentrate on the design and maintenance of stormwater infrastructure, with the ecological and water-quality considerations of the receiving waters being of secondary importance. The 1988 Awaruku Catchment Management Study (ECBCC, 1988) is a prime example of this. The NSCC has formulated the Proposed Long Bay Structure Plan ("LBSP" NSCC, 2001a) after much consultation and the commissioning of several reports. Water quality and ecological considerations are addressed through the inclusion of settlement dams, vegetated riparian strips, reserves and stormwater treatment areas (see Appendix IV). Additionally, other policies (discussed in the following sections) aimed at avoiding and mitigating deleterious effects from the development are included in the plan.

10.5 Measures must be taken before development

10.5.1 Staging development

The LBSP (NSCC, 2001a) dictates the timing of development (Policies 17B.3.1.2) and requires a sequencing plan to be adopted by the NSCC before development can begin. The large sediment/peak flow attenuation dams must be in place before any other development is allowed to proceed, and planting of riparian buffer zones should begin immediately.

10.5.2 Restrict building on steeper sites.

Steeper areas yield more sediment during the earthworks stage. On average, one hectare of earthworks on a 30% slope yields six times more sediment than on a 10% slope (Handyside, 1995). The fine-grained soils of the Long Bay area would be less affected by slope than this, as they do not require high runoff velocities to be transported, as larger-grained soils do. Nevertheless, it is suggested that steeper areas not be developed or be subjected to tighter onsite controls, as erosion would still be greater on them.

The Long Bay Structure Plan (NSCC, 2001a) has limited development in the steeper upper catchment (Policy 17B.3.2.2.4). This not only benefits the stream, but also reduces the risk of geotechnical problems.

10.5.3 Maximise vegetated area

The well-vegetated catchment of mid Vaughan (forested) produced the most stable flow regime (with base flow readings that were significantly higher than all other sites and peak flow readings that were significantly lower than all other sites), the highest rainfall event clarity and lowest bacterial counts. Forested reserves and vegetated stormwater management areas (see Appendix IV) have been incorporated into the Long Bay Structure Plan (NSCC, 2001a).

10.5.4 Maintain and establish vegetated riparian zones and flood plains.

> *I cannot stress enough the importance of good riparian management. ...There is never a silver bullet, but this is pretty close.*
> Simon Upton, former New Zealand Minister for the Environment (1997)

Stream sections with riparian vegetation were found in this study to have lower maximum temperatures and less variation in DO, pH and temperature. Storey (1995) also found rapid decreases in temperature after a stream passed through a vegetated riparian zone. This is undoubtedly due to the reduction in direct sunlight, which can also be a key factor in reducing algal growth.

Vegetated riparian zones and floodplains also moderate flows by reducing runoff (by absorbing water into the soil and leaf litter) and acting as natural reservoirs of floodwaters. As Maitland and Morgan (1997: p29) put it, "…there is no substitute for the storage and gradual discharge of water in natural floodplains." Additionally, by having vegetated areas near streams instead of housing, flooding is no longer an economic problem, so expensive and environmentally degrading flood mitigation programmes (e.g. the channelling of streams) can be avoided.

Riparian zones also act as filters of sediments and pollutants, and processes such as denitrification can occur while sediments are retained in the riparian zone. Storey (1995) found decreases in nitrates (40%), nitrites (60%) and suspended sediments (65%) after a stream flowed through 600m of riparian vegetation. Although he found no change in phosphate levels, another study (Cooper and Thomsen, 1988) measured a 90% decrease in phosphate levels after approximately 1km of riparian vegetation.

The effectiveness of contaminant removal by riparian strips depends on many factors. Obviously, wider strips are better, however extra width represents a loss of land for other uses. Bunn (1993) calculated a 10m buffer for all first-order streams, increasing by 10m for each additional stream order, would take up 12% of the total catchment area for an Australian stream. Ranges for the ideal width vary from 15 to 80 meters (Peterjohn and Correll, 1984; Phillips, 1989; Storey, 1995). Collier *et al*. (1995) have formulated a method called the CREAMS model for estimating the optimal width of a vegetated filter strip based on three parameters: slope, drainage class and clay content. This is obviously simplified, since other factors that have been identified by Binford and Buchenau (1993), such as the nature of the riparian vegetation, i.e. the density, succession stage, seasonal variation in growth and senescence, are not included.

Riparian vegetation can increase the stability of stream banks; however, it can also have the opposite effect. Paradoxically, the conversion of riparian zones from pasture to forest could cause initial increases in sediment loads and consequently in turbidity. Several studies (Quinn *et al.,* 1997; Davies-Colley, 1997) postulated that this process takes place after finding that pasture streams were narrower than forested streams. It is believed that the comprehensive root systems of pasture grasses hold the banks strongly together and collect sediments. When these streams become forested, the grasses are shaded out. In their absence, the sides are eroded and the channel width increases.

This period of higher turbidity and sediment load is obviously negative, but the end result is very positive: the stream has returned to something that approaches its natural width, thereby providing more streambed habitat.

Wilding (1996) found that habitats which are found in natural streams, such as stony riffle areas, finer sediments in pools, leaf litter and branches, overhanging banks and tree roots, are also found in streams with large riparian vegetated zones (>80m total width).

Furthermore, forested riparian strips provide allochthonous (terrestrially derived) plant and animal material, which is an important energy source for stream biota and also provides habitat for some organisms. As an example, terrestrial insects are the main food source of the banded kokopu (*Galaxias facsatus*) and the giant kokopu (*Galaxias argenteus*) (McDowall, 1990). It is therefore not surprising that Wilding (1996) found that wide riparian vegetation (>80m total width) supported stream communities closely resembling those of fully vegetated catchments.

Riparian areas are also important habitats in themselves. In New Zealand, skinks, native frogs, 35 species of native bird and at least 50 plant species are dependent on the riparian zone to varying extents (Collier, 1995b). Therefore, although there is no conclusive evidence that native vegetation is more beneficial for stream ecosystems than exotic (Collier, 1995a), native vegetation should be planted. This is particularly relevant for Long Bay, where a wildlife corridor could be established from the bush areas of Long Bay Regional Park to the remnant vegetation of the upper catchment.

The Long Bay Structure Plan of the NSCC (2001a) includes vegetated strips for the riparian zone (Policy 17B.3.2.2.5) and avoids development in the 100-year flood plain (Policy17B.3.2.2.9). North Shore City Bylaws also prohibit building on the 100-year flood plain without written consent (NSCC, 2001b, Bylaw 22.4).

10.5.5 Build sediment-settlement/ peak-flow-attenuation dams and wetlands

Leersnyder (1992), in a study of two Auckland streams with sediment dams found the dams affected the streams' water quality in the following ways:

- The variability of flow was reduced.
- Suspended solids levels were reduced by over 70%.
- Heavy metal removal was consistently high (>80%) for both soluble and total metals (metals measured were: lead, zinc and copper).
- Phosphate removal varied, with one pond recording a reduction of total and dissolved phosphate of 76% and the other recording a reduction in total phosphorus of less than 30%, with dissolved phosphate actually increasing (believed to be due to ducks in the second pond).
- Dissolved nitrogen (nitrate, nitrite and ammonia) showed little change (possibly also due to ducks).

Sediment levels in the Awaruku Stream appeared to be relatively low directly downstream of sediment dams (see 5.2: Clarity). Other publications have also found results as good as or better than those found by Leersnyder (see, for instance, ARC, 2002a).

Sediment dams planned for the Long Bay development must be properly planned and constructed. A dam's effectiveness in flood attenuation and contaminant removal will be governed by its volume, area, outlet, the organic content of its soils and its depth (Harper *et al*., 1986 (in Leersnyder, 1992)). Details on the design of such dams are given in ARC (2002a).

Dams must be periodically dredged to maintain dimensions and expose the dam water to new soil below the settled sediments. Newly exposed soils have a high sorption capacity (Harper *et al*., 1986 (Leersnyder, 1992)) and over time this capacity is used up.

There are problems with sediment dams, namely the loss of land (which in some cases contains remnant bush), the costs of construction and maintenance, the hazards of dredging, and the risk of bed-overturn during floods.

Dredging will destroy the oxic layer of the sediment and expose the underlying anoxic layer. In sediments, oxygen is usually depleted within a few centimetres of the sediment surface (due to the breakdown of organic mater and poor circulation (Song and Müller, 1999)). When dredging occurs, Fe^{2+}, NH_4^+ and PO_4^{3-} will be released from the anoxic layer and create a heavy oxygen demand on the water as they are oxidised (Song and Müller, 1999); NH_4^+ is also toxic to fish in high concentrations. Therefore the effects of dredging must be carefully monitored, and possibly accompanied by artificial aeration.

Flood events can turn over the bed of the sediment dam and destroy the oxic layer, causing similar effects to those of dredging. For example, Hellawell and Green (1986) found that during severe floods, oxygen levels downstream from a purification lake on the river Tame near Birmingham were extremely low for an extended period due to organicly rich, anoxic sediments being disturbed from the lake bed.

Wetlands offer similar benefits to dams and guidelines on their construction are also given in ARC (2002a).

10.6 During development: ensure on-site erosion and sediment controls are used and used properly.

There are many effective on-site methods for controlling erosion and sediments from building sites. These are outlined in the ARC Technical Publication No. 90 (ARC, 1999) and include the minimisation and mulching of exposed areas, temporary sediment dams and silt fences. The Auckland Regional Plan (ARC, 2001b) requires erosion and sediment controls for all land disturbing activities (see Section 10.9.1) and Erosion and Sediment Control Plans for earthworks of more than one hectare (0.25 hectares within 50 metres of a stream). North Shore City bylaws also require that sediments from works be controlled and that they be prevented from entering stormwater drains (NSCC, 2001b, Bylaw 22.7.3).

Unfortunately, the enforcement of the erosion and sediment control plans is inadequate (Ng and Buckeridge, 2000). One contractor alone has been convicted for environmental offences three times within five years. Anecdotal evidence exists of poor sediment control in the Vaughan catchment, as demonstrated by the ineffective sediment control dam from 2000 shown in Figure 61.

Measures must therefore be taken to ensure that good erosion and sediment control plans are formulated and that they are strongly enforced. Contractors that have environmental convictions from the past seven years should be required to pay a bond guaranteeing compliance with the plan. Bonds are allowed under Section 108 of the Resource Management Act (RMA, 1991) and have been used in Australia to ensure mining sites are properly rehabilitated (Buckeridge, 1994).

Figure 61: Ineffective sediment dam, Vaughan catchment (Schrader, 2000)

Any failure to properly install and maintain measures set out in the plan must be punished strongly to make it financially unviable not to comply.

Another possible solution is to have certified sediment-control providers and operators as suggested by Handyside (1995).

10.7 Require each development to maintain stormwater and contaminant generation at pre-development levels or lower.

The LBSP (NSCC, 2001a) requires development in the upper catchment to maintain stormwater volumes at pre-development levels (Policy 17B.3.2.2.6), and stormwater in the urban style area (Appendix IV) be treated to a high standard (as determined by the Catchment Management Plan[41]) to "…avoid significant impacts on the Marine Reserve…" (Policy 17B.3.2.2.7). The limiting of these requirements to sections of the catchment is regrettable, and it is recommended that the entire development area be required to maintain stormwater and contaminant volumes at pre-development levels or better. Attainment of this objective would be made easier by the pre-development measures already recommended (Section 10.5). Many other measures are available to reduce runoff volumes and to reduce and contain contaminants, some of which are dealt with below.

[41] The Catchment Management Plan is currently only a draft and was being revised at the time of writing.

10.7.1 Harvest rainwater

The Long Bay Structure Plan (NSCC, 2001a) encourages rainwater tanks (Policy 17B.10.2.2), and NSCC (2002a) offers grants of $NZ500 to assist in their purchase. Rainwater tanks should be compulsory for all dwellings in the catchment.

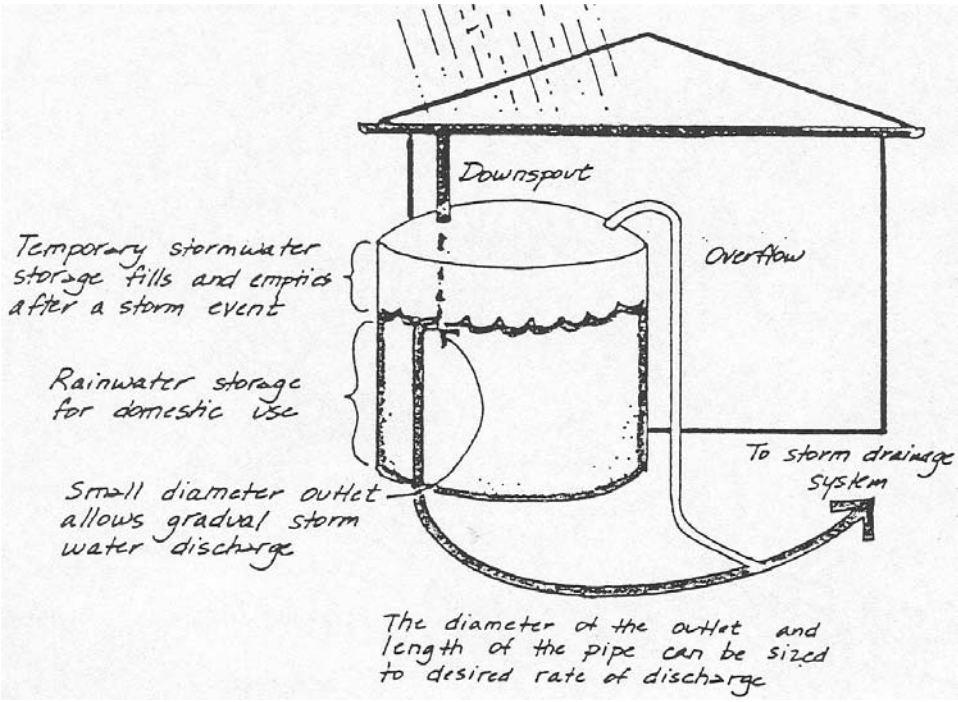


Figure 62: On-site storm water attenuation tank (Kettle and Worley, 1999) with small diameter outlet (can be closed in drier months)

Kettle and Worley (1999) found that an integrated rainwater-tank system on an Auckland property reduced peak stormwater flows by up to 20%, cut sanitary sewer outflows by up to 25% and reduced mains water usage by up to 50%. The system uses a tank with temporary stormwater storage (see Figure 62) and grey-water reuse (Figure 63).

These systems would have initial capital and installation costs (estimated to be $NZ4000, all inclusive (Kettle and Worley, 1999)), but with savings in water rates and possible rebates (Section 10.9.2) these costs would be recouped in the long term. Councils would benefit from reduced sewage and potable water pumping costs (water for the area is now being pumped from as far away as the Waikato River – over 60km to the south). There would also be less tangible benefits such as increased awareness of rainwater quality issues.

Rainwater tanks can take up valuable space on small urban blocks; however, tanks can be incorporated into the house design or installed below ground to minimise this (Wong, 2003).

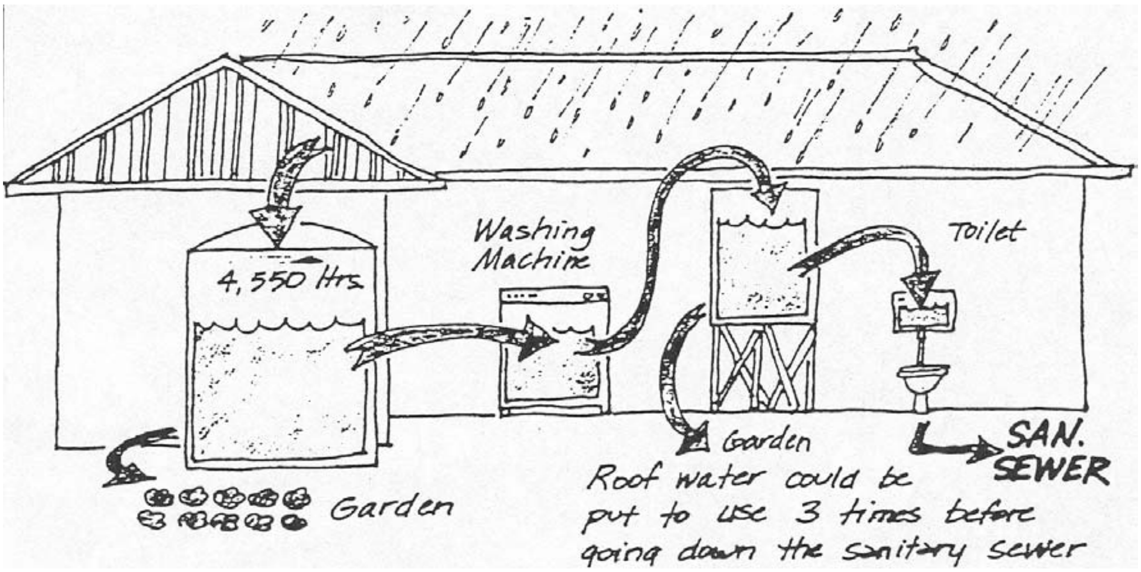


Figure 63: Integrated household water system (Kettle and Worley, 1999)

10.7.2 Establish rain gardens

NSCC encourages so-called rain gardens (vegetated areas with infiltration trenches underneath that absorb rainfall, see Figure 64) and offers $NZ200 towards the landscaping costs of their construction (NSCC, 2002a). While these are useful for intercepting, storing and filtering runoff, their effectiveness will be limited by the impermeable soils of the area.

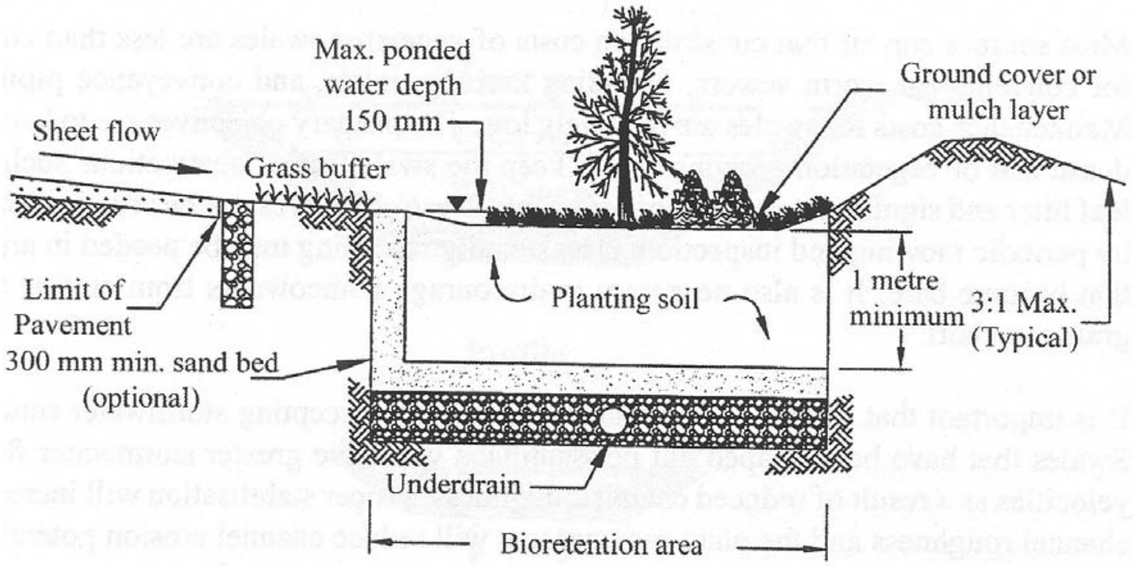


Figure 64: Rain garden design (Source: ARC, 1999)

10.7.3 Use permeable paving

Turf blocks (or modular paving) and other porous paving (Figure 65) should be encouraged on private land (see section 10.9.2) and used both in carparks and cul-de-sacs. Unfortunately, the usefulness of these measures is again limited by the poor permeability of the soils of the area, and to be effective they would need to be underlaid with more permeable soils and an underdrain.

Figure 65: Turf blocks (left) and porous paving (Source: NSCC 2003)

10.7.4 Infiltration trenches

These are trenches that receive stormwater and then allow the water to infiltrate into the soil. Unfortunately the impermeable nature of the soil in the Long Bay area also means that these would not be very effective (City Design, 1998), and accordingly they are not recommended in the catchment.

10.7.5 Stormwater detention tanks (Figure 66)

These attenuate peak flows and may be useful in the high- and medium-intensity housing areas, but are expensive to install (NVPDC & IES, 1992).

Figure 66: Stormwater detention tank (Source: NSCC, 2002a)

10.7.6 Filters

These come in various forms:

- Mesh filters, such as "enviropods", which filter out particles >2mm. NSCC has installed over 300 in North Shore City (Figure 67). NSCC testing found the pods remove approximately 30% of suspended solids and heavy metals (NSCC, 2000c). The pods must be emptied approximately every three months (NSCC 2003).
- Sand filter units, which typically remove 80–90% of suspended solids and more than 90% of hydrocarbons (Shaver, 2000). In these structures, water enters a sediment storage chamber (which detains coarse sediments) before entering a

runoff storage chamber where it is slowly filtered and released. NSCC has installed several of these. They must be periodically cleaned and the filter medium must be rejuvenated (rejuvenating involves removing the top 50mm of sand).

Figure 67: Enviropod mesh filters (NSCC 2003, left) and a sand filter unit (ARC 2002a)

10.7.7 Use swales and vegetative filter strips

These are drainage channels that contain thick grass or other vegetation to filter out sediments, allow infiltration and slow flow. Although they work best in more porous soils, using a coarse-grained base and under-drain would reduce surface flows. A number of studies have found that swales remove 60–99% of suspended solids, 21–91% of metals and 7–80% of total phosphorus (reviewed in Mazer *et al.*, 2001).

Figure 68: Swale (NSCC, 2003)

10.7.8 Encourage green roofs

Green roofs require the building of stronger roofs and the positioning of waterproof membranes, drainage layers, soil and vegetation. This absorbs and filters runoff and has the benefit of increasing insulation (both of sound and temperature). Capital and maintenance costs are higher than normal; however, reduced air-conditioning costs compensate for this (ARC, 2002a).

10.8 Other important objectives

10.8.1 Ensure sewage does not enter the stream

The high levels of faecal indicator bacteria measured in Awaruku stream (see sections 5.11 and 5.12) suggest that sewage is entering the stream. NSCC has since renewed much of the sewage system in the Awaruku catchment as part of a major city-wide upgrade, in response to a number of problems with the system. The system had been poorly maintained, leading to many cracked and broken pipes that allowed infiltration (water entering the pipes) and exfiltration (sewage flowing out of pipes). The system has also not been adequately planned to accommodate the growth of the city. Consequently, sewage overflows have occurred, causing the closure of beaches and damage to properties (Withiel, 2000).

NSCC have implemented a $NZ250 million programme called Project CARE to solve these problems. According to the NSCC (2003), Project CARE will:

- Repair and replace old pipes.
- Increase capacity (by laying larger pipes and installing more powerful pumps).
- Increase pump reliability (by installing new switchgear).
- Increase storage (by building large tanks for holding peak flows).
- Improve sewage treatment efficiency and capacity.
- Restrict development (by making the issuing of building consents dependent on the sewage network's ability to cope with extra inputs).

Project CARE has been peer-reviewed and found to be well organised and executed (Dahl-Madsen, 2000).

The Proposed Long Bay Structure Plan (NSCC, 2001a) seeks to lessen the likelihood of overflows by managing water consumption (through pressure management and encouragement of water conserving devices, Policy 17B.3.10.2.1), requiring a high standard of construction for wastewater infrastructure (Policy 17B.10.2.4) and developments on larger lots to remove gross solids from wastewater before they enter the public wastewater system (Policy 17B.3.10.2.5).

While a positive effort, these policies provide no encouragement for alternatives such as composting toilets, grey-water recycling and satellite sewage-treatment plants. The peer review of project CARE (Dahl-Marsden, 2000) also noted this lack of "clean technologies" in the NSCC programme.

On larger lots, the encouragement of composting toilets would be beneficial. Smaller lots would not be suitable, as land is required to receive the composted material. Composting toilets remove faecal matter from the sewage system, and thereby reduce the risk to the environment should sewage leaks occur. These toilets could be encouraged through grants and education; however, owners must be properly instructed on the toilets' use and maintenance, and no attempt should be made to force these appliances on unwilling householders. A Swedish study has shown that operational problems can be encountered where proper usage directions are not followed (Berndtsson and Hyvönen, 2002).

10.8.2 Avoid piping or channelling the stream

Wilding (1996) described piped sections of streams as "ecological deserts", being almost devoid of any macro-invertebrate community due to the extreme flow regime and the lack of shelter and light (thereby eliminating photosynthesis). Channels have similar problems with flow and lack of shelter.

Additionally, there is the psychological effect: if a stream looks like a drain then it is not likely to be respected. Problems with litter and dumping in the stream will increase and it also becomes harder to organise community projects to improve it.

The LBSP (2001a) requires that streams be maintained in an unmodified state (Policy 17B.3.3.2.2), which effectively prohibits piping and channelling.

10.8.3 Encourage cycling, walking and public transport use

This reduces pollution from cars and can also trim down the paved surface area of the city (Figure 9). This is important, as it is widely recognised that the best way to avoid pollution is to act on pollution sources (Niemczynomicz, 1999).

The LBSP (NSCC, 2001a, Policy 17B.8.2.1.7) requires the provision of "a pedestrian and cycle network which safely and directly links schools, reserves, the community centre and passenger transport routes with living areas". The inclusion of a community centre and high/medium density development in the LBSP (NSCC, 2001a, Appendix IV) increases the viability of public transport; however, low-density housing still makes up the majority of the residential area. No plans exist for a mass rapid-transport system to service the area, meaning that cars will, in most cases, be the only transport alternative for most. Plans are well advanced for an improved public transport corridor along a section of the motorway to Auckland City (using buses); however, this does not connect directly with the Long Bay area.

10.8.4 Ensure well-informed decisions are made through research

The ARC, after literature reviews and in-house research, have produced guidelines on riparian-zone management (ARC, 2002b), low-impact design (ARC, 2000), erosion and sediment control during construction (ARC, 1999), and the design of stormwater management devices (ARC, 2002a). These guidelines give planners and contractors tools to ensure land use changes occur in the most sustainable manner. Reviews and research remain to be done on such less-conventional approaches as composting toilets.

Assessment of the expected effects of the Long Bay development has also been undertaken. For example, runoff and contaminant volumes (Beca Steven, 1999; City Design, 1998) and the fate of sediments in the marine reserve have been modelled (Green *et al.,* 2000). Models, however, can only be regarded as best estimates (they rely on a series of assumptions), and they provide no baseline data for post-development comparisons. Several studies have therefore been undertaken to obtain these baseline data and ensure that the environmental values of the catchment are better understood. The ARC has undertaken surveys of fish numbers as well as monitored flows and water quality variables. Several inconsistencies have been found in ARC data, however (see Section 5.13), and further work is required. Other studies of the stream environment (e.g. Leung, 1999) and the receiving environment (e.g. Walker *et al.,* 2000) are also available.

Further research is required to find the cause of the low DO levels on the Vaughan (see Section 5.7), and to map out the fate and rates of sedimentation in the Marine Reserve.

10.9 Methods to ensure the above measures happen

10.9.1 Regulatory body consents, zoning and development requirements

As previously discussed, the ARC requires all vegetation clearance and earthworks activities to have controls for erosion and sediment (outlined in ARC, 2001b). Earthworks of over one hectare (or over 0.25 hectares within 50m of a stream) require resource consents from the ARC (under RMA, 1991). To gain these consents, applicants must submit and have approved an erosion and sediment control plan (ARC, 2001b).

The ARC also has the power to set boundaries on urban areas (providing it can give justifications), and it has done this by preventing urban development north of the Vaughan catchment (Figure 10). The ARC was, however, unable to maintain an urban limit south of the Vaughan catchment due to the loss of the environmental court case (section 2.1) brought by the NSCC and land owners.

The NSCC has policies in the North Shore District plan (NSCC, 2002b) and Proposed Long Bay Structural Plan (NSCC, 2001a), as well as bylaws regarding stormwater management (NSCC, 2001b). These affect the allowed land use for each area and set requirements to minimise sediment and runoff levels.

10.9.2 User pays/ financial disincentives against unsustainable development

The provision of new infrastructure for peripheral developments has high financial costs. The LBSP requires that financial contributions be made “to cover the costs of stormwater, water, wastewater, roading and reserve infrastructure within the catchment, as well as their proportionate share of city wide works, associated with growth in the Long Bay area” (NSCC, 2001a, Policy 17B.3.9.2.3, Page 18). This is not only fair, it also provides a financial disincentive for development on the urban fringe.

In Germany, a portion of council rate charges is based on the area of impermeable surfaces on the property. This is calculated from the original building plans, and amounts to around 1€ ($NZ2) per m^2 (Mönchengladbach, 2000), although it varies from area to area. This amounts to a significant financial incentive to minimise hard surface areas. It is suggested that all new buildings in the NSCC area should have their base rates reduced and that a new charge based on the impermeable surface area on their property be imposed. Rebates could be given for rainwater tanks and rain gardens, thereby acknowledging cost savings to councils (lower pumping charges) and rewarding residents for their efforts to decrease the impact of their development.

10.9.3 Community involvement and education

NSCC and ARC have initiated and supported various environmental education programmes, including WaiCare (known elsewhere as Streamwatch) and Adopt-a-stream, which empower school and community groups to monitor the health of their local streams. The author was involved in the piloting of the WaiCare programme in 2000 and found that it enhanced the students’ appreciation of the ecological value of their local streams. Other waterway education programmes exist, including the Stream

Health Monitoring Assessment Kit (SHMAK) programme for rural areas (set up by the National Institute for Water and Atmospheric Research — NIWA) and the Streamsense programme (set up by Environment Waikato). The Royal Society of New Zealand has set up the National Waterways Project to coordinate these programmes.

NSCC, ARC and other groups are also doing the following:

- Rewarding community groups, schools and businesses for positive environmental achievements through the "Enviro awards".
- Linking volunteers to Landcare, Beachcare and WaiCare groups.
- Publicising environmental issues through brochures, mail-outs, media releases, website items, advertisements and some more innovative methods (Figure 69).

A great deal of work is being done to bring information into the classroom, ranging form visits by story tellers and performance groups (such as the "Toxic Avengers"), to the development of units of work that fit into the New Zealand school curriculum. Educational experiences outside the classroom also play an important role. The Long Bay Regional Park has a large part to play in this matter: 30% of primary schools and 18% of the secondary schools in the Auckland region visited the Long Bay regional park between 1989 and 1992 (ARC, 1994).

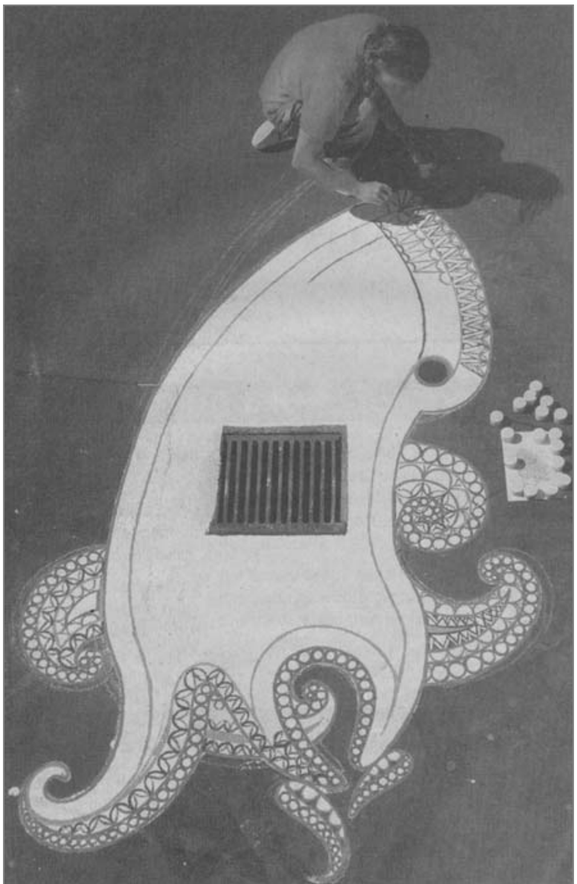


Figure 69: Painting drain inlets to inform the public of the fate of influents. Commissioned by Auckland City Council (Source: NZ Herald, 2000)

Community-based schemes, such as those that involve tree propagation and planting, are also vitally important. They have side benefits that go beyond the increase in numbers of trees: participants gain greater feelings of ownership for the environmental future of their area.

Van Roon (2000) gives the example of one community group, the Whaingaroa Harbour Care Society (WHC), of the Raglan area, New Zealand, who propagated and planted 160,000 trees between 1995 and 1999.

10.10 Synopsis

Vaughan Stream is not pristine, especially in its lower reaches. However, the results of this study indicate that the upper catchment has good water quality (with the notable exception of dissolved oxygen), and elevated (relatively) macroinvertebrate biodiversity (Evans, 2001). Moreover, sediment fate models indicate that sediments from the catchment are likely to reach reefs in the Marine Reserve, with wave action not likely to prevent settlement on a sheltered reef in the Marine Reserve (Green *et al.,* 2000).

It is therefore necessary that land use changes in the catchment be well considered and if approved, well regulated. The planned development, which incorporates sediment dams, is predicted to reduce sediment volumes and peak stream flows downstream of the dams (Beca Steven, 1999); however, stream sections above these dams would experience higher flows and increased yields of many contaminants. Additionally, during the construction phase, sediment loads below the dams are predicted to be far higher than is currently the case, and will be even worse above them (Beca Steven, 1999). It is therefore necessary that other measures be taken.

The development of the catchment must:

1. Be staged and sequenced effectively.
2. Be restricted from steeper land.
3. Maximise vegetated land, especially on flood plains and riparian zones.
4. Incorporate well-planned and maintained sediment dams.
5. Have well-formulated and enforced erosion and sediment control plans for the construction phase.
6. Require measures to minimise peak flow and contaminant volumes (e.g. rainwater tanks, swales).
7. Ensure sewage is restricted from the stream.
8. Preclude channelling or piping the stream.
9. Encourage alternatives to the car.
10. Ensure that all decisions made are based on well-researched information.
11. Be accompanied by comprehensive education and community involvement.

The NSCC and ARC have done a great deal of work on the planning for the development of Long Bay, and current policies (e.g. NSCC, 2001a and 2001b, ARC, 2001b) go a long way towards achieving the 11 requirements above. If their policies are well implemented, this will be a reassuring step forward from the ad-hoc and inadequate measures that have allowed development in the neighbouring Awaruku catchment to produce a channelled stream with a paucity of riparian vegetation. Improvement though they may be, the plans for the Long Bay development are by no means perfect and could benefit from the recommendations in Table 22.

Table 22: Recommendations for the Long Bay Development

It is recommended that the following be part of the development:

1. More stringent requirements restricting runoff and contaminant yields from developments to pre-development levels for <u>all</u> development zones.
2. More stringent policing of erosion and sediment-control plans on construction sites.
3. The requirement of bonds from contractors who have had environmental convictions in the past seven years.
4. Requirements that cul-de-sacs and parking areas be paved with modular paving and underlaid with permeable soils, where feasible.
5. The encouragement of composting toilets on larger lots and other means to reduce sewage load.
6. The compulsory use of stormwater tanks and grey-water recycling.
7. Further research on the low dissolved oxygen levels of the Vaughan.
8. Further research on sediment-settlement rates in the Marine Reserve.
9. A restructuring of rates to include a charge related to the impermeable surface area of developments, with provisions for rebates for measures which reduce runoff and contaminant yields.
10. Propagation and planting-out of suitable native species in the riparian zone by schools and community groups (with council and developer support) to start as soon as possible.

Some of these measures may seem burdensome. However, if this development is to be true to the purposes of the Resource Management Act (1991, section 5), the life-supporting capacity of the water and its ecosystems must be managed sustainably and any adverse effects from human activities must be avoided, remedied or mitigated.

11 Conclusions

The three case studies undertaken in New Zealand and Germany have found, firstly, very poor water quality in the urban and agricultural catchments of two New Zealand streams. Urban land use, livestock and a lack of riparian vegetation are implicated. Secondly, in Germany, reduced manure and fertiliser use, improved sewage treatment, and tighter controls on emissions since the German reunification appear to be responsible a dramatic improvement in the water quality measured in a coastal stream. Finally, a local-council urban-development plan for a rural catchment in North Shore City, New Zealand, demonstrates a distinct improvement on previous urban developments in the region; however, more policies and stronger enforcement of them is needed to protect the environment.

The urban and rural catchments of Vaughan and Awaruku in New Zealand have streams with water qualities that fail to meet standards for fish life or bathing. Of the five sites studied, only the mid Vaughan site, which has a 50% forested / 50% rural catchment, had bacterial counts which meet the Australian Recreational Water-quality Guidelines for Secondary Contact (Faecal coliforms and enterococci, ANZECC, 2000) and the New Zealand Interim Guidelines for Freshwater Bathing (*Escherichia coli*, MofE, 2000). All sites failed to meet the Australian Recreational Water-quality Guidelines for Primary Contact (Faecal coliforms and enterococci, ANZECC, 2000) and the United States Environment Protection Authority (enterococci, EPA, 1986) criterion for bathing. Only one site (mid Awaruku, which was downstream of a sediment-detention dam) had water clarity which met the Ministry of the Environment's (MofE, 1994) guideline for contact recreation.

Sites downstream of **riparian vegetation** had significantly cooler daytime temperatures and less diurnal variability in pH, dissolved oxygen and temperature. The two sites with the least riparian shading, lower Awaruku and lower Vaughan, exceeded the Resource Management Act (RMA, 1991: Third Schedule) recommended maximum stream temperature of 25°C. Sites below riparian vegetation on the German stream (the Köppernitz) also had significantly cooler temperatures.

Livestock in the lower catchment of Vaughan Stream were associated with levels of nitrate that were significantly higher than the four other New Zealand sites measured.

Levels of faecal bacteria and turbidity at the lower Vaughan site were also significantly higher than the forest/rural mid Vaughan site.

In New Zealand, sites with **urban land uses** had significantly higher peak-flow and significantly lower base-flow measurements than the rural/forest site due to the reduced infiltration and vegetative interception that urban catchments provide. Rainfall-event clarity readings were also significantly lower at the urban sites, again due to reduced infiltration and vegetative interception, compounded by the presence of earthworks associated with a residential development. Sites with urban land uses also had significantly higher counts of faecal bacteria than the forest/rural mid Awaruku site, indicating that sewage leaks are occurring in the urban catchment.

Data from the Köppernitz in the former *Deutsche Demokratische Republik* (East Germany) show a **dramatic increase in water quality since the reunification of Germany**, confirming the success of tighter controls on contaminant sources (e.g. limits on phosphate levels in detergents) and improved effluent treatment (sewage treatment and reticulation systems have been upgraded). Total nitrogen, nitrate, ammonium, phosphate and dissolved oxygen levels all showed significant improvements between 1991 and 2001.

Analysis of 1991 records from the Köppernitz showed that phosphate, biochemical oxygen demand and ammonium levels rose sharply and dissolved oxygen levels dropped dramatically downstream of a Soviet Army base. These records are a testimony to the effect that uncontrolled emissions can have on a waterway.

The calcareous geology of the Köppernitz catchment resulted in significantly higher pH, alkalinity and conductivity readings than the New Zealand streams studied, while significantly higher nitrate levels showed that even with the controls currently in place, the Köppernitz still suffers enrichment from intensive agriculture.

Results from both the New Zealand and German case studies revealed inconsistencies in the data and highlighted the difficulties associated with identifying and separating genuine anthropogenic effects on water quality from instrumental errors. Additionally, some tests that were unable to be performed may have been useful to the investigation. Accordingly, the following recommendations are made:

- In Auckland, that the Auckland Regional Council examines its maintenance and calibration routines for datasonde deployments.

- In Germany, that *Eschericia coli* and enterococci bacterial tests be performed on the Köppernitz near the municipal zoo play area (were children come in contact with the water).
- In Germany, that further and more accurate flow testing be performed (e.g. with a well constructed and gauged temporary weir) to clarify the large discrepancy between peak-flow measurements from this study and the estimates of IBS Engineering (1995, upon which the city relies for planning).

In New Zealand, plans for residential development in the catchment of Vaughan Stream need to have measures to avoid or minimise deleterious effects. The catchment drains into the Long Bay/ Okura Marine Reserve and sediment fate modelling by Green *et al.* (1999) reveals that sediments from the Vaughan will be carried across the reefs of the reserve and can settle on a sheltered reef area within the reserve.

The lower Vaughan catchment has been degraded by livestock and lacks vegetation (especially riparian). High temperature, turbidity, faecal bacteria, and nitrate measurements, low dissolved-oxygen results, and fluctuating temperature, pH and dissolved-oxygen readings all indicate that there is much room for improvement in the lower Vaughan. Sensible measures taken during development could actually improve the water quality of the lower Vaughan. However, the upper Vaughan catchment is far less modified and consequently has superior water quality, with the notable exceptions of low dissolved-oxygen readings (cause unknown) and relatively high orthophosphate measurements (thought to be from fertiliser use in the rural section of the catchment).

Development in accordance with policies in the proposed Long Bay Structure Plan (NSCC, 2001a) as well as other policies of the North Shore City Council (e.g. NSCC, 2001b) and Auckland Regional Council (e.g. ARC, 2001b) **could lead to improvements in water quality in the lower catchment**. Sediment dams, vegetated riparian zones and reserves, prohibitions on developments on steeper sites and in the 100-year flood plain as well as upgrades of the sewage system are all positive steps towards a more sustainable land management. However, the importance of the receiving environment, both as a marine reserve and a popular swimming beach, demands that further steps are taken. Ten steps have been recommended and can be found in Table 22 (page 122).

Some of these measures may seem onerous. However, if this development is to come close to being sustainable, deliberate decisions to proceed and affect these measures are necessary. The NSCC and ARC must endeavour to manage this extension of suburbia with regard to the Maori ethic of *kaitiakitanga* (stewardship of the land), as they are implored to do under the Resource Management Act (1991, Section 7a). This residential development, in the catchment of a marine reserve, adjoining a regional park and opposed by many stakeholders, must be of the highest standards to minimise the impact on the environment.

There will only be one chance to control the development of the Long Bay Catchment, and this is it.

12 References

Abbott, S., B. Caughley and G. Scott, 1998. Evaluation of Enterolert for the enumeration of enterococci in the marine environment. *New Zealand Journal of Marine and Freshwater Research* 32: 505–513. (cited in Appendix I)

Anderson, A.J. 1996. Was *Rattus exulans* on New Zealand 2000 years ago? AMS radiocarbon ages from Shag River Mouth. *Archaeology in Oceania* 31: 178–184.

ANZECC, 1992. *National Water Quality Management Strategy: Australian Water Quality Guidelines for Fresh and Marine Waters*. Australian and New Zealand Environment and Conservation Council.

ANZECC, 2000. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 1: The Guidelines*. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Council of Australia and New Zealand.

APHA, 1995. *Standard methods for the examination of water and wastewater*. 19th ed. Washington DC, American Public Health Association, American Waterworks Association, Water Pollution Control Federation.

ARC, 1994. *Long Bay Regional Park Management Plan October 1994*. Auckland Regional Council, New Zealand.

ARC, 1999. *Erosion and Sediment Control Guidelines for Land Disturbing Activities in the Auckland Region*. ARC Environment and Planning Division Technical Publication No. 90, Auckland Regional Council, Auckland, New Zealand.

ARC, 2000. *Low Impact Design Manual for the Auckland Region*. ARC Environment Division Technical Publication No. 124, Auckland Regional Council, Auckland, New Zealand.

ARC, 2001b. *Auckland Regional Plan: Sediment Control*. Auckland Regional Council, Auckland, New Zealand.

ARC, 2002a. *Stormwater Management Devices: Design guidelines manual. Revision to Technical Publication 10*. Auckland Regional Council, Auckland, New Zealand.

ARC, 2002b. *Riparian Zone Management: Guideline*. Auckland Regional Council, Auckland, New Zealand.

ARGF, 1997. *A place sought by many: A brief history of regional planning for Auckland's growth*. Auckland Regional Growth Forum, New Zealand.

ARGF, 1998a. *No or slow growth*. Auckland Regional Growth Forum, New Zealand.

ARGF, 1998b. *Draft Regional Growth Strategy to 2050*. Auckland Regional Growth Forum, New Zealand.

ARGF, 1999. *Metropolitan urban limits in the Auckland region*. Auckland Regional Growth Forum, New Zealand.

Auckland Regional Water Board, 1983a. *Review: Stormwater Control*. Auckland Regional Authority, New Zealand.

Bailey, I.G., 2001. *The incentive effect, hypothecation and industry responses to environmental charges*. European Consortium for Political Research Joint Workshop Sessions, Grenoble, April 2001. 23pp.

Ballantine, B. 1991. *Marine Reserves for New Zealand*. Leigh Laboratory Bulletin No. 25, University of Auckland, New Zealand.

Barsch, I. 2003. *Historie der Stadt Wismar*. http://www.wismarer.de/historie.wismar.htm. Accessed February 2003.

Bartram, J. and R. Balance (eds.) 1996. *Water Quality Monitoring: A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes*. E&FN Spon, London, England.

Beca Steven, 1999. *Long Bay Structure Plan: Hydrological Analysis*. Report prepared for North Shore City Council, Auckland, New Zealand.

Bechberger, M. and D. Reiche, 2004. Renewable energy policy in Germany: pioneering and exemplary regulations. *Energy for Sustainable Development* 8(1): 47-57.

Berndtsson, J.C. and I. Hyvönen, 2002. Are there sustainable alternatives to water-based sanitation systems? Practical illustrations and policy issues. *Water Policy* 4: 515–530.

BGR, 1993. *Geologische Karte der Bundesrepublik Deutschland 1:100000*. Bundesanstalt für Geowissenschaften und Rohstoffe, Bundesanstalt für Bodenforschung, Hannover, Germany.

Binford, M.W. and M.J. Buchenau, 1993. Riparian greenways and water resources. In D.S. Smith and P.S. Hellmund (*eds.*). *Ecology of greenways. Design and function of linear conservation areas*. Pp 69–104. University of Minnesota Press, Minneapolis.

BMVEL, 2002. *Umweltlexikon*. Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft. www.berge2002.oekoserve.net. Accessed February 2003.

Bonde, T.A. 1994. Environmental regulations of agriculture in the Baltic Sea catchment areas, with reference to the European Union and the North Sea. *Marine Pollution Bulletin* 29: 491–499.

Booth, D.B. and C.R. Jackson, 1997. Urbanization of aquatic systems: degradation thresholds, stormwater detection, and the limits of mitigation. *Journal of the American Water Resources Association* 33: 1077–1090.

Bosch, J.M. and J.D. Hewlett, 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology* 55: 3–23.

Boulton, A.J., M.R. Scarsbrook, J.M. Quinn and G.P. Burrell, 1997. Land-use effects on the hyporheic ecology of five small streams near Hamilton, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 31: 609–622.

Buck, O., D.K. Niyogi and C.R. Townsend, 2004. Scale-dependence of land use effects on water quality of streams in agricultural catchments. *Environmental Pollution* (article in press). 13 pp.

Buckeridge, J.S. 1992. *Land stability in urban sites of the North Shore, Auckland, NZ.* Proceedings of the sixth annual symposium on landslides, 10–14 February, Christchurch, New Zealand. Balkema, Rotterdam, The Netherlands, 2129–2136.

Buckeridge, J.S. 1994. Sustainability: an Australian perspective of resource management. In R.K. Sharpe (ed.) *Sustainability through Engineering: Papers on sustainability from the IPENZ conferences 1993/4*. Pp. 76–81.

Buckeridge, J.S. 1999. Stochastic Urban Accretion and Marine Reserves: Complementary or Conflicting options? Proceedings from the 19th Annual Meeting of the International Association of Impact Assessment, 15–19 June, Glasgow, Scotland. Pp. 1–10.

Bunn, S.E. 1993. Riparian-stream linkages: research needs for the protection of instream values. *Australian Biologist* 6: 46–51.

Carson, R. 1962. *Silent Spring*. Houghton Mifflin, Boston.

City Design, 1998. Long Bay *Stormwater Catchment Management Plan.* Prepared for North Shore City Council, New Zealand.

Cleary, C. 2000. Editorial. *Planning Quarterly — The Journal of the NZ Planning Institute inc.* 139: 1.

Close, M.E. and R.J. Davies-Colley, 1990. Base flow water chemistry in New Zealand rivers. 1. Characterisation. *New Zealand Journal of Marine and Freshwater Research* 24: 319–341.

Collier, K.J. 1995a. Environmental factors affecting the taxonomic composition of aquatic macroinvertebrates in lowland waterways of Northland, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 29: 453–465.

Collier, K.J. 1995b. Living on the edge: biodiversity and management of New Zealand's riparian zones. *Forest & Bird.* February 1995: 42–45.

Collier, K.J., A.B. Cooper, R.J. Davies-Colley, J.C. Rutherford, C.M. Smith, R.B. Williamson, 1995. *Managing Riparian Zones: A Contribution to Protecting New Zealand's Rivers and Streams. Volume 2: Guidelines.* Department of Conservation, Wellington, New Zealand.

Cooke, J.G. 1988. Sources and sinks of nutrients in a New Zealand hill pasture catchment: 2 Phosphorus. *Hydrological Processes* 2(2): 123–133.

Cooper, A.B. and C.E. Thomsen, 1988. Nitrogen and phosphorus in streamwaters from adjacent pasture, pine and native forest catchments. *New Zealand Journal of Marine and Freshwater Research* 22: 279–291.

Cooper, C.M. 1993. Biological effects of agriculturally derived surface water pollutants on aquatic systems — a review. *Journal of Environmental Quality* 22: 402–408.

Dahl-Madsen, K. I. 2000. *CARE peer review: Safe swimming at North Shore City*. www.nscc.govt.nz. Accessed February 2003.

Davies-Colley, R.J. 1997. Stream channels are narrower in pasture than in forest. *New Zealand Journal of Marine and Freshwater Research* 31: 599–608.

Davies-Colley, R.J. and D.G. Smith, 1990. A panel study on the detectability of change of turbidity of water induced by discharge of inorganic suspendoids to a small stream. *Water Quality Centre Publication 17.* Water Quality Centre, Department of Scientific and Industrial Research, Hamilton, New Zealand.

Dean, T.L. and J. Richardson, 1999. Responses of 7 species of native freshwater fish and a shrimp to low levels of dissolved oxygen. *New Zealand Journal of Freshwater and Marine Research* 33: 99–106.

Die Zeit, 2002. Ein Land aus Beton, *Die Zeit* Newspaper 7 November 2002, Zeitverlag Gerd Bucerius GmbH, Hamburg, Germany, 19–20.

DIFCO ,1984. *DIFCO Manual*. 10th ed. DIFCO Laboratories, Detroit.

DIN 38412–34, 1991. Bestimmung der Hemmwirkung von Abwasser auf die Lichtemission von *Photobacterium phosphorium*. Deutsches Institut für Normung e.V., Berlin, Germany.

Dons, A. 1987. Hydrology and sediment regime of a pasture, native forest, and pine forest catchment in the Central North Island, New Zealand. *New Zealand Journal of Forestry Science* 17: 161–178.

ECBCC, 1988. *Awaruku Catchment Management Study*. East Coast Bays City Council, Auckland, New Zealand.

Eghball, B. 2002. Soil properties as influenced by phosphorus- and nitrogen-based manure and compost applications. *Agronomy Journal* 94: 128–135.

Ellis, J.; V. Cummings, J. Hewitt, S. Thrush and A. Norkko, 2002. Determining effects of suspended sediment on condition of a suspension feeding bivalve (*Atrina zelandica*): results of a survey, a laboratory experiment and a field transplant experiment. *Journal of Experimental Marine Biology and Ecology* 267: 147–174.

EPA, 1985. *Water quality criteria for ammonia 1984*. United States Environmental Protection Agency, Duluth, Minnesota, USA.

EPA, 1986. *Ambient Water Quality Criteria for Bacteria – 1986: Bacterial Ambient Water Quality Criteria for Marine and Fresh Recreational Waters*. US Environmental Protection Agency, Washington, USA. (Cited in glossary)

EPA, 2000. *Improved enumeration methods for the recreational water quality indicators: enterococci and Escherichia coli*. US Environmental Protection Agency, Washington, USA. (Cited in Appendix I)

EU, 1975. Council Directive 76/160/EEC of 8 December 1975 concerning the quality of bathing water. *Official Journal L 31*, 05/02/1976: 1.

EU, 1978. Council Directive 78/659/EEC of 18 July 1978 on the quality of fresh waters needing protection or improvement in order to support fish life. *Official Journal L222*, 14/08/1978: 1–10.

EU, 1991. Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. *Official Journal L375*, 31/12/1991: 1–8.

EU, 1997. *Die Europäische Union und die Umwelt*. Amt für amtliche Veröffentlichungen der Europäischen Gemeinschaft, Luxemburg.

Evans, B. 2001. *Long Bay monitoring programme: freshwater and estuarine environments summary 2001*. A report prepared by Auckland Regional Council, Auckland, New Zealand.

Fahey, B.D. and M. Marden, 2000. Sediment yields from a forested and a pasture catchment, coastal Hawke's Bay, North Island, New Zealand. *Journal of Hydrology (NZ)* 39: 49–63.

Ferguson, C., A.M.de R. Husman, N. Altavilla, D. Deere and N. Ashbolt, 2003. Fate and transport of surface water pathogens in watersheds. *Critical Reviews in Environmental Science and Technology* 33: 299–361.

Graphpad® Instat, 2000. Graphpad® Instat version 3.05, Graphpad Software, San Diego, USA. www.graphpad.com

Green, O.M., M.J. Stroud, J.W. Oldman, A.K Senior and A.B. Cooper, 2000. *Long Bay Sedimentation Study: Stage 1 (Sediment Generation), Stage 2 (Sediment Fate).* National Institute of Water and Atmospheric Research Client Report NSC00209, Hamilton, New Zealand.

Guhr, H., B. Karrasch and D. Spott, 2000. Shifts in the processes of oxygen and nutrient balances in the River Elbe since the transformation of the economic structure. *Acta Hydrochimica et Hydrobiologica* 28: 155–161.

Hall, M.J., G.P. Closs and R. H. Riley, 2001. Relationships between land use and stream invertebrate community structure in a South Island, New Zealand, coastal stream catchment. *New Zealand Journal of Marine and Freshwater Research* 35: 591–603. (cited in Appendix I)

Handyside, B. 1995. *Earthworks and the Environment*. An assessment undertaken by Brian Handyside and Associates for North Shore City Council, New Zealand.

Hanson, N.W. (ed) 1973. *Official, standardised and recommended methods of analysis*. The Society of Analytical Chemistry, London, England.

Harding, J.S. and M.J. Winterbourn, 1995. Effects of contrasting land use on physico-chemical conditions and benthic assemblages of streams in Canterbury (South Island, New Zealand) river systems. *New Zealand Journal of Marine and Freshwater Research* 29: 479–492.

Harding, J.S., R.G. Young, J.W. Hayes, K.A. Shearer and J.D. Stark, 1999. Changes in agricultural intensity and river health along a river continuum. *Freshwater Biology* 42: 345–357.

Hellawell, J.M. and M.B. Green, 1986. Performance of the initial River Tame purification lake. In J.F.deL.G. Solbe (ed.) *Effects of Land Use on Fresh Waters: agriculture, forestry, mineral exploitation, urbanisation*. Pp. 95–108.

Helyar, K.R. and G. Fenton, 1999. The causes and management of acid soils. Invited paper for the Soils Workshop 'Describing, analysing and managing our soil', University of Sydney. 22–26 November. 25pp.

Hengeveld, H. and C. De Vocht, 1982. Role of water in urban ecology. *Urban Ecology* 6: 5–347.

Herlihy, A.T., J.L. Stoddard and C.B. Johnson, 1998. The relationship between stream chemistry and watershed land cover data in the mid-Atlantic Region, U.S. *Water, Air and Soil Pollution* 105: 377–386.

Hogg, I.A. and R.H. Norris, 1991. Effects of runoff from land clearing and urban development on the distribution and abundance of macroinvertebrates in pool areas of a river. *Australian Journal of Marine and Freshwater Research* 42: 507–518.

Hollis, G.E. 1975. The effect of urbanization on floods of different recurrence interval. *Water Resources Journal* 11: 431–435.

Hounslow, A.W. 1995. *Water quality data: Analysis and Interpretation*. Lewis Publishers, New York, USA.

IBS Engineering, 1995. *Hydraulischer Nachweis der Köppernitz, Wismar*. Ingenieurbüro Schwerin GmbH, Schwerin, Germany.

Isermeyer, F. and K.-H. Schleef, 1994. Polices to reduce nitrogen surplus in German agriculture. *Marine Pollution Bulletin* 29: 464–470.

ISO 9963–1, 1994. *Wasserbeschaffenheit - Bestimmung der Alkalinität; Teil 1: Bestimmung der gesamten und der zusammengesetzten Alkalinität*. European Committee for Standardisation, Brussels, Belgium.

ISO 6222, 1999. *Quantitive Bestimmung der kultivierbaren Mikroorganismen – Bestimmungen der Koloniezahl durch Einimpfen in ein Nähragarmedium*. European Committee for Standardisation, Brussels, Belgium.

Jowett, I.G. and N. C. Boustead, 2001. Effects of substrate and sedimentation on the abundance of upland bullies (*Gobiomorphus breviceps*). *New Zealand Journal of Marine and Freshwater Research* 35: 605–613.

Kahlenborn, W. and R. A. Kraemer, 1999. *Nachhaltige Wasserwirtschaft in Deutschland*. Springer Verlag, Berlin.

Kettle, D. and T.D. Worley, 1999. *A solution for an integrated household stormwater management system.* Unpublished report. D. Kettle and Tilaka Diyagama Worley Consultants Ltd, Auckland, New Zealand.

Kilroy, C. and B. J. Biggs, 2002. Use of the SHMAK clarity tube for measuring water clarity: comparison with the black disk method. *New Zealand Journal of Marine and Freshwater Research* 36: 519–527.

Kingett Mitchell, 2001. *Preliminary assessment of the Existing Environment: CDC 1: Long Bay/ Okura.* Prepared for North Shore City Council by Kingett Mitchell & Associates Ltd.

Kingett Mitchell, 2002. *Aquatic ecological values and Management objectives for Vaughans Stream, Long Bay, Auckland*. Prepared for North Shore City Council by Kingett Mitchell & Associates Ltd.

Klein, R.D. 1979. Urbanization and stream quality impairment. *Water Resources Bulletin* 15: 948–963.

Klimadiagramme, 2003. *Das Klima in Rostock / Das Klima in Schwerin*. www.Klimadiagramme.de. Accessed January 2003.

Kühn, P. 2003. *Late Glacial and Holocene Formation of Luvisols in Mecklenburg-Vorpommern (NE-Germany): Micromorphology, chemistry and particle size distribution*. http://www.uni-greifswald.de/~geograph/geooek/Publikationen/abstract_ghent.pdf. Accessed February 2003.

Kumar, H. 1998. *Modern Methods in Environmental Pollution Analysis, Volume 2-Water Pollution Analysis*. Sarup & Sons, New Delhi, India.

Larson, J. 2002. Irrigated area increases. In L. Starke (ed.) *Vital Signs: The tends that are shaping our future 2002–2003*. Earthscan Publications, London. Pp 35–35.

LAWA, 1990. *Gewässergütekarte der Bundesrepublik Deutschland*. Länderarbeitsgemeinschaft Wasser, Berlin, Germany.

Laws, E.A. 2000. *Aquatic Pollution: an introductory text*. John Wiley and Sons, New York, USA. (Cited in Appendix I)

Leersnyder, H. 1992. *The performance of wet detention ponds for the removal of urban stormwater contaminants in the Auckland (NZ) Region*. Masters Thesis, University of Auckland, New Zealand.

Lehmann, A. and M. Rode, 2001. Long-term behaviour and cross correlation water quality analysis of the River Elbe, Germany. *Water Research* 35: 2153–2160.

Lenat, D.R. and J.K. Crawford, 1994. Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. *Hydrobiologia* 294: 185–199.

Leung, S.W., 1999. *Incorporating effects of catchment land use on Macroinvertebrate communities and the values of local Residents into the Riparian Zone management Recommendations for the Long Bay Catchment*. Masters Thesis, University of Auckland, New Zealand.

Liess, M. and L. Shultz, 2000. Sampling Methods in Surface Waters. In L. M. Nollet, (ed.) *Handbook of Water Analysis*. Marcel Dekker, New York, USA. Pp 1–24.

LINZ, 1999. *Topographic Map 260–R10: Whangaparaoa (1:50,000).* National Topographic/Hydrographic Authority of Land Information Wellington, New Zealand.

LMV, 1998. *Wismar 2134: Topographische Karte* (topographic map). Landesvermessungsamt Mecklenburg-Vorpommern, Schwerin, Germany.

Lowrence, T., R. Todd, J. Fail Jr., O. Hendrickson Jr., R. Leonard and L. Asmussen, 1984. Riparian forests as nutrient filters in agricultural watersheds. *Bioscience* 34: 374–377.

Maitland, P.S. and N.C. Morgan, 1997. *Conservation management of freshwater habitats*, Chapman and Hill, London, England.

Marine Reserves Act, 1972. An Act to provide for the setting up and management of areas of the sea and foreshore as marine reserves for the purpose of preserving them in their natural state as the habitat of marine life for scientific study. Reprinted Statues of New Zealand, 1997, Volume 36, pp 485–517. New Zealand Government, Wellington.

Mason, C. F. 2002. *Biology of Freshwater Pollution*. Pearson Education, Harlow, England.

Maybeck, M. 1987. The water quality of world rivers through the GEMS program. In Transport of carbon and minerals in major world rivers: Part 4. Proceedings of a SCOPE/UNEP workshop at Tianjin, People's Republic of China, May 13–22, 1985. *Mitteilungen aus dem Geologisch-Paläontologischen Institut der Universität Hamburg* 64:1-17.

Mazer, G., D. Booth and K. Ewing, 2001. Limitations to vegetation establishment and growth in biofiltration swales. *Ecological Engineering* 17: 429–443.

McColl, R.H.S. 1978. Chemical runoff from pasture: the influence of fertiliser and riparian zones. *New Zealand Journal of Marine and Freshwater Research* 12: 371–380.

McDowall, R. M. 1990. *New Zealand Freshwater Fishes, A Natural History and Guide* 2nd ed. Heinemann Reed MAF Publishing Group, Auckland, New Zealand.

McKergow, L.A., D.M. Weaver, I.P. Prosser, R.B. Grayson and A.E.G. Reed, 2003. Before and after riparian management: sediment and nutrient exports from a small agricultural catchment, Western Australia. *Journal of Hydrology* 270: 253–272.

Medina, H.L. 2000. Chemical Parameters. In L. M. Nollet (ed.) *Handbook of Water Analysis*, Marcel Dekker, New York. Pp.101–124. (cited in Appendix I)

Minitab™, 2000. Minitab Statistical Software, release 13.1. Minitab Inc., Pennsylvania State University, Pennsylvania, USA.

MofE, 1998. *Flow Guidelines for Instream Values.* Ref. ME270 (Volume A) ME271 (Volume B). Ministry of the Environment, Wellington, New Zealand.

MofE, 1994. *Water Quality Guidelines No. 2: Guidelines for the Management of Water colour and Clarity*. Ministry of the Environment, Wellington, New Zealand.

MofE, 1999. *Recreational Water Quality Guidelines: Guidelines for the Management of Waters used for Marine and Freshwater Recreation and Recreational Shellfish Gathering.* Ministry of the Environment, Wellington, New Zealand. (cit ed in Glossary)

MofE, 2002. *Recreational Water Quality Guidelines: Guidelines for the Management of Waters used for Marine and Freshwater Recreation and Recreational Shellfish Gathering*. Ministry of the Environment, Wellington, New Zealand.

Mönchengladbach, 2002. Rates statement of M. and R. Gross. Stadt Mönchengladbach, Germany.

Murdoch, P.S. and J.L. Stoddard, 1992. The role of nitrate in the acidification of streams in the Catskill Mountains of New York. *Water Resources Research* 28: 2707–2720.

Naess, A. 1973. The Shallow and the Deep, Long-Range Ecology Movement. A Summary. *Inquiry* 16: 95–100.

Ng, W.H.W. and J. S. Buckeridge, 2000. *Review of Systems Utilised in the Auckland Region to Contain Silt Generated in Current Land Development Processes*. Proceedings of the Seventh Annual New Zealand Engineering and Technology Postgraduate Conference, 24–25 November, Palmerston North, New Zealand.

Niemczynomicz, J. 1999. Urban hydrology and water management — present and future challenges. *Urban Water* 1: 1–14.

Nilsson, S.I., M. Berden and B. Popovic, 1988. Experimental work related to nitrogen deposition, nitrification and soil acidification. *Environmental Pollution* 54: 233–248.

NRW, 1991. *Allgemeine Güteanforderungen für Fließgewässer, Entscheidungshilfe für die Wasserbehörde in wasserrechtlichen Erlaubnisverfahren*. Landesamt für Wasser und Abfall Nordrhein-Westfalen, LWA-Merkblätter, Nr. 7, Düsseldorf, Germany.

NSCC, 1998a. *Long Bay Stormwater Catchment Management Plan*. North Shore City Council, Auckland, New Zealand.

NSCC, 1998b. *Long Bay Structure Plan: Options for the future planning of Long Bay*. North Shore City Council, Auckland, New Zealand.

NSCC, 1998c. *Stormwater effects of various development scenarios in the Long Bay catchment area*. North Shore City Council, Auckland, New Zealand.

NSCC, 2000a. *1999/2000 North Shore Stream and Stormwater Quality Study. Technical Report 3.06*. North Shore City Council, Auckland, New Zealand.

NSCC, 2000b. *Long Bay Structure Plan: The future of Long Bay: A proposed Development Concept for Long Bay*. North Shore City Council, Auckland, New Zealand.

NSCC, 2000c. *Water Update. May 2000*. North Shore City Council, Auckland, New Zealand.

NSCC, 2001a. *North Shore City Council Proposed District Plan: Proposed Variation-64: Long Bay Structure Plan*. North Shore City Council, Auckland, New Zealand.

NSCC, 2001b. *North Shore City Bylaw, Part 22: Stormwater Management*. NSCC, Auckland, New Zealand.

NSCC, 2002a. *Water Update* August-September 2002: North Shore City Council, Auckland, New Zealand.

NSCC, 2002b. *North Shore City District Plan*. North Shore City Council, Auckland, New Zealand.

NSCC, 2003. North Shore City Council Website. www.northshorecity.govt.nz. Accessed February 2003.

NVPDC & ESI, 1992. *Northern Virginia BMP Handbook: a guide to planning and designing best management practices in Northern Virginia.* Northern Virginia Planning District Commission and Engineers and Surveyors Institute, Annandale, Virginia, USA. 268 pp.

NZ Herald, 2000. Drains with poison message. *New Zealand Herald* 23 February 2000, Auckland, New Zealand.

Osborne, L.L. and M.J. Wiley, 1988. Empirical relationships between land use/cover and stream water quality in an agricultural watershed. *Journal of Environmental Management* 26: 9–27.

Paul, M.J. and J.L. Meyer, 2001. Streams in the urban landscape. *Annual Review of Ecological Systematics* 32: 333–365.

Peakware, 2001. *Peakware world mountain web encyclopedia*. European map. Accessed July 2002. http://www.peakware.com/encyclopedia/ranges/maps/europe.htm

Perdikaki, K. and C.F. Mason, 1999. Impact of road run-off on receiving streams in Eastern England. *Water Research* 33: 1627–1633.

Peterjohn, W.T. and D.L. Correll, 1984. Nutrient dynamics in an agricultural watershed: observations on the role of riparian forest. *Ecology* 65: 1466–1475.

Pizzuto, J.E., W.C. Hession and M. McBride, 2000. Comparing gravel-bed rivers in paired urban and rural catchments of south-eastern Pennsylvania. *Geology* 28: 79–82.

Phillips, J.D. 1989. Nonpoint source pollution control effectiveness of riparian forests along a coastal plain river. *Journal of Hydrology* 110: 221–237.

Pullar, V. and M. McLeod, 1992. *Facts New Zealand*. Daphne Brassell Associates Press, Wellington, New Zealand.

Quinn, J.M. and C. W. Hickey, 1990. Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors. *New Zealand Journal of Marine and Freshwater Research* 24: 387–409.

Quinn, J.M., R.B. Williamson, R.K. Smith, and M.L. Vickers, 1992. Effects of riparian grazing and channelisation on streams in Southland, New Zealand. 2. Benthic Invertebrates. *New Zealand Journal of Marine and Freshwater Research* 26: 259–273.

Quinn, J.M., G.L. Steele, C.W. Hickey and M.L. Vickers, 1994. Upper thermal tolerances of twelve New Zealand stream invertebrate species. *New Zealand Journal of Marine and Freshwater Research* 28: 391–397.

Quinn, J.M., A.B. Copper, R.J. Davies-Colley, J.C. Rutherford and R.B. Williamson, 1997. Land use effects on habitat, water quality, periphyton and benthic invertebrates in Waikato, New Zealand, hill country streams. *New Zealand Journal of Marine and Freshwater Research* 31: 579–597.

Quinn, J.M. and M.J. Stroud, 2002. Water quality and sediment and nutrient export form New Zealand hill-land catchments of contrasting land use. *New Zealand Journal of Marine and Freshwater Research* 36: 409–429.

Richardson, J. 1991. Acute toxicity of ammonia to juvenile inanga (*Galaxias maculatus*). *New Zealand Journal of Marine and Freshwater Research* 25: 327–330.

Richardson, J., J.A. Boubee and D.A. West, 1994. Thermal tolerance and preference of some native New Zealand fish. *New Zealand Journal of Marine and Freshwater Research* 28: 399–407.

Richardson, J., D.K. Rowe and J.P. Smith, 2001a. Effects of turbidity on the migration of juvenile banded kokopu (*Galaxias fasciatus*) in a natural stream. *New Zealand Journal of Marine and Freshwater Research* 35: 191–196.

RMA, 1991. *Resource Management Act*: An act to restate and reform the law relating to the use of land, air and water. *Reprinted Statues of New Zealand*, 1996 Volume 32, pp 131–586. New Zealand Government, Wellington, New Zealand.

Rowe, D.K. and T.L. Dean, 1998. Effects of turbidity on the feeding ability of the juvenile migrant stage of six New Zealand freshwater fish species. *New Zealand Journal of Freshwater and Marine Research* 32: 21–29.

Roy, A.H., A.D. Rosemond, M.J. Paul, D.S. Leigh and J.B. Wallace, 2003. Stream macroinvertebrate response to catchment urbanization (Georgia, U.S.A.). *Freshwater Biology* 48: 329–346.

Ryan, P.A. 1991. Environmental effects of sediment on New Zealand streams: a review. *New Zealand Journal of Marine and Freshwater Research* 25: 207–221.

Sala, M. and M. Inbar, 1992. Some hydrologic effects of urbanization in Catalan rivers. *CATENA* 19: 363–378.

Schrader, D. 2000. *Monitoring the shallow water marine environment of the Long Bay – Okura Marine Reserve*. Earth and Oceanic Sciences Research Centre, Auckland University of Technology, Auckland, New Zealand.

Shaver, E. 2000. *Speech of the Technical Specialist for Sediment Control and Stormwater Management Programmes, Auckland Regional Council*. Transcript of August seminar for Engineers for Social Responsibility. http://www.esr.org.nz/events/even2000/stormwater.html. Accessed February 2003.

Singer, P. 1979. *Practical ethics*. Cambridge University Press, Cambridge, England.

Sinton, L.W., R. K. Finlay and D. J. Hannah, 1998. Distinguishing human from animal faecal contamination in water: a review. *New Zealand Journal of Marine and Freshwater Research* 32: 323–348.

Smith, D.G. and R. Maasdam, 1994. New Zealand's National River Water Quality Network. 1. Design and physico-chemical characterisation. *New Zealand Journal of Marine and Freshwater Research* 28: 19–35.

Sokal, R.R. and F.J. Rohlf, 1995. *Biometry*. W.H. Freeman and Company, New York.

Song, Y. and G. Müller, 1999. *Sediment water interactions in anoxic freshwater sediments: mobility of heavy metals and nutrients*. Springer, Berlin.

Statistics New Zealand, 1993. *New Zealand Official Yearbook 1993*. David Bateman Ltd, Auckland, New Zealand.

Statistics New Zealand, 2000. *New Zealand Official Yearbook 2000*. David Bateman Ltd, Auckland, New Zealand.

Statistics New Zealand, 2002. *New Zealand Official Yearbook 2002*. David Bateman Ltd, Auckland, New Zealand.

Stoel Jr., T. B. 1999. Reigning in Urban Sprawl. *Environment* 41: 6–11, 29–33.

Storey, R. 1995. *The benefits of native bush remnants in maintaining/ enhancing instream values.* Master of Science Thesis. University of Auckland, Auckland, New Zealand.

Townend, J., 2002. *Practical Statistics for Environmental and Biological Scientists*. Wiley. Chichester, New York.

Trimble, S.W. 1997. Contribution of stream channel erosion sediment yield from an urbanizing watershed. *Science* (21/11/97) 278: 1442–1445.

UN, 2002. *Global Challenge, Global Opportunity: Trends in Sustainable Development*. United Nations Economic and Social Affairs Secretariat. 24pp. http://www.johannesburgsummit.org/html/documents/summit_docs/criticaltrends_1408.pdf.

UN, 2003. *Proceedings of the Technical Working Group on Long-range Population Projections,* 30 June, New York. United Nations Economic and Social Affairs Secretariat Population Division, New York, USA Publication #186. 55 pp. http://www.un.org/esa/population/publications/longrange/long-range_working-paper_final.PDF.

Uunk, E.J.B. and F.H.M. van de Ven, 1986. Water quality and quantity in the new town of Lelystad. In J.F.deL.G Solbe (ed.) *Effects of Land Use on Fresh Waters: agriculture, forestry, mineral exploitation, urbanisation*. Pp. 41–52.

van Roon, M. 2000. Towards integrated coastal catchment management. *Planning Quarterly — The Journal of the NZ Planning Institute inc.* 139: 23–25.

WaiCare, 2000. *Book 7: Fact sheets*. WaiCare stream-testing manuals. Auckland Regional Council, Auckland, New Zealand.

Walker, J., R. Babcock and B. Creese, 2000. *Long Bay Monitoring Program Sampling Report*: *Auckland Regional Council Technical Publication No. 136*. Auckland Regional Council, Auckland, New Zealand.

Wallace, J.B. and J.R. Webster, 1996. The role of macroinvertebrates in stream ecosystem function. *Annual Review of Entomology* 41: 115-139.

WBGU, 1999. *World in Transition: Ways Towards Sustainable Management of Freshwater Resources.* Wissenschaftlicher Beirat Globale Umweltveränderungen [German Advisory Council on Global Change], Annual Report 1997. Springer Verlag Press, Berlin.

Webster, I.T., P.W. Ford and G. Hancock, 2001. Phosphorus dynamics in Australian lowland rivers. *Marine and Freshwater Research* 52: 127–37.

Weidner, H., 1995. 25 years of modern environmental policy in Germany. Treading a well-worn path to the top of the international field. Discussion paper FS II 95 – 301. *Wissenschaftszentrum Berlin für Sozialforschung*. 99pp.

Werner, W. and H.-P. Wodsak, 1994. Germany: the Baltic Sea and its agricultural environmental status. *Marine Pollution Bulletin* 29: 471–476.

Whalen, J.K., C. Chang, G.W. Clayton and J.P. Carefoot, 2000. Cattle manure can increase the pH of acid soils. *Soil science society of America Journal* 64: 962–966.

Wilcock, R.J., G.B. McBride, J.W. Nagels and G.L. Northcott, 1995. Water quality in a polluted lowland stream with chronically depressed dissolved oxygen: causes and effects. *New Zealand Journal of Marine and Freshwater Research* 29: 277–288.

Wilcock, R.J., J.W. Nagels, G.B. McBride, K.J. Collier, B.T. Wilson and B.A. Huser, 1998. Characterisation of lowland streams using a single-station diurnal curve analysis model with continuous monitoring data for dissolved oxygen and temperature. *New Zealand Journal of Marine and Freshwater Research* 32: 67–79.

Wilding, T.K. 1996. *Effects of urban development on small stream ecosystems of Auckland and the influence of riparian vegetation*. Master of Science Thesis. University of Auckland, Auckland, New Zealand.

Williams, L.F. 1999. *Investigation of sciaphilic settlement rates at Long Bay Marine Reserve. Unpublished student report*. Unitec Institute of Technology, Auckland, New Zealand. 71pp.

Williamson, R.B. 1993. *Urban Runoff Data Book: a manual for the preliminary evaluation of urban stormwater impacts on water quality* (2nd ed.). Water quality publication No. 20. Water Quality Centre, National Institute for Water and Atmospheric Research, Hamilton, New Zealand.

Wilson, M. and J.G. Imhof, 1998. An examination of the functions of riparian zones. Literature review: overview of the state of the science. Riparian Zone Workshop, 28–29 October. Cambridge, Ontario. 32pp. http://www.trentu.ca/wsc/PDFfiles/finallit.pdf. Accessed 10 December, 2003.

Winterbourn, M.J. 1986. Effects of land development on benthic stream communities. *New Zealand Agricultural Science* 19: 413–427.

Withiel, C. 2000. Closures spark stream scrutiny. *North Shore Times Advertiser*. 16 January 2000. pp 1–2.

Wong T.H.F., 2003. *Australian Runoff Quality*. Institution of Engineers, Sydney Australia. 255pp.

Wood, P.J. and P.D. Armitage, 1997. Biological effects of fine sediment in the lotic environment. *Environmental Management* 21: 203–217.

Wood, P.J., P.D. Armitage, C.E. Cannan and G.E. Petts, 1999. Instream mesohabitat biodiversity in three streams under baseflow conditions. *Aquatic Conservation: Marine and Freshwater Ecosystems* 9: 265–278.

WTW, 2001. *Water: general catalogue*. Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany.

Yang, J.E., E.O. Skogley, B.E. Schaff and J.J. Kim, 1998. A simple spectrophotometric determination of nitrate in water, resin and soil. *Soil Science of America Journal* 62: 1108–1115.

Appendix I: New Zealand methodology details

1.1 Flow

1.1.1 Rationale

Flows can also be measured by constructing weirs, pouring tracers into the stream, or by using ultrasonic or electromagnetic methods. These methods either reduce the quality of the stream water or are prohibitively expensive and complex to use or install (Bartram and Balance, 1996).

1.1.2 Adaptations

Directly downstream of upper Awaruku site, the stream drained through two large pipes. Therefore, the cross sectional area of the flow through these pipes was measured using Equation 1.

Equation 1: Cross section of stream at upper Awaruku site

Cross sectional area= $\cos^{-1}((r-h)/r) \times r^2 - \sqrt{(r^2 - (r - h)^2)} \times (r-h)$
Where r is the radius (0.825 metres) and h is the maximum stream depth.

Vaughan Stream did not present any sections that were uniform enough or had velocities high enough to be measured. The lower Vaughan site was originally measured; however, this site was affected by a spring high tide after six weeks. Thereafter, measurements for all parameters were taken 50 meters higher up. The channel there was highly irregular and affected by weeds, so no attempt was made to measure the flow there until the ARC constructed a v-notch weir. Thereafter, the flow was measured by timing the filling of a 10-litre bucket from the weir outlet.

Where results were not obtainable, they were supplemented by data from ARC measurements (where available). The ARC measured flows periodically by monitoring depths at sites on both streams and compared these to a gaugings graph. Gaugings were taken by the ARC using sensitive flow meters.

1.1.3 Protocols to increase accuracy

Measurements were repeated to obtain an average. It must, however, be remembered that this method does not give highly accurate readings, rather an estimate.

According to Bartram and Balance (1996), the accuracy of the results is greatest when:

- There is no turbulence in the flow.

- The stream is "nominally" straight 50 meters above and below the measuring point.
- The velocity of the stream is greater than 10 cm/s.
- The depth is greater than 30cm.
- The stream does not overflow its banks.
- There is no aquatic growth in the channel.

Bartram and Balance (1996) admit that all these factors will rarely exist at a real site, and that compromises have to be made. This was the case with the Awaruku, where sites were selected to best fit these criteria (the upper site was piped, the middle site was on a section of straight, concrete-lined channel and the lower site was lined with stone-filled baskets and had a uniform width), but not all criteria were satisfied.
Sites on Vaughan Stream fell short of these criteria.

1.2 Clarity

1.2.1 Rationale

The clarity tube was chosen because no turbidity meter was available, suspended sediment measurements would have been too time-consuming and the streams were often too shallow for secchi-disk and black-disk methods.
The clarity tube has two major drawbacks. Firstly, readings above 95 cm are not possible due to the length of the tube. Secondly, readings vary between observers. Kilroy and Biggs (2002) found from readings taken by two people that, of 46 readings, 30 had more than 10% discrepancy, and a further 14 had more than 15% discrepancy.

1.2.2 Methodology

The one-meter long transparent clarity tube has 1cm graduations marked along its length. The tube is filled with water from the stream, a matt black magnetic disk placed inside and the tube is then sealed with a lid. The tube is viewed through one of the ends and a magnetic handle is used to pull the black disk away from the eye until it can no longer be seen and this distance is recorded.

1.2.3 Protocols to increase accuracy

The tube was cleaned weekly, rinsed with stream water before each sampling and read twice at each site to obtain an average.

1.2.4 Conversion to black-disk clarity and turbidity

Equation 2 from Kilroy and Biggs (2002) was used to convert SHMAK clarity tube results to "black-disk" clarity readings.

Equation 2: Conversion of clarity-tube to black-disk clarity (from Kilroy and Biggs, 2002)

If $C_T < 50$ then $C_{BD} = C_T$

If $C_T > 50$ then $C_{BD} = 7.28 \times 10^{(C_T/62.5)}$

Where C_{BD} is black-disk clarity in cm and C_T is clarity-tube reading in cm

Converting these readings to turbidity values is more problematic. Turbidity measures the amount of scattering at 90 degrees to incident light. Clarity is affected not only by scattering, but also by absorbance. The relative effects of scattering and absorption vary depending on the water body and the flow, so conversion of clarity values to turbidity is only approximate, but still valuable for comparison with turbidity values in other studies. Unpublished results from Kilroy were obtained and Microsoft Excel was used to produce Equation 3 for the conversion of clarity measurements to neothelmic turbidity units (NTU).

Equation 3: Conversion of clarity tube readings to turbidity values

$T = -25.705\text{Ln}(C_T) + 116.95$

Where "T" is turbidity (in NTU) and "C_T" is clarity tube clarity (in cm); $r^2 = 0.9762$

To convert the clarity values to suspended sediment levels is again problematic, as the clarity depends not only on the sediment levels, but also on the type of sediment present. Alternatively, suspended sediment measurements could have been made at the laboratory to establish a relationship. However, due to time constraints, this was not performed and no attempt was made to convert clarity readings to suspended sediment levels. The clarity readings can, however, still be used as an indicator of sediment levels in the water.

1.3 Dissolved Oxygen (DO)

1.3.1 Rationale

The meter was used because it is quicker, easier and cheaper than titration methods or glass ampule "quick tests".

1.3.2 Protocols to increase accuracy

- Where there was poor flow, the electrode was moved slowly in the water to ensure that the membrane was not in contact with the same water for any length of time, as oxygen is used-up by the probe (Medina, 2000).
- The probe was always left in the water until a stable reading was achieved.
- The gauges were calibrated at each site and membranes were replaced monthly.

1.3.3 Limitations

Ideally, DO should be measured over an entire 24-hour cycle because of the diurnal variability of this parameter. This was not possible due to problems with the datasonde; however, some results over 24-hour periods were obtained from the ARC. The spot readings taken in this study would have had greater value if they had been taken at the same time at all sites. This was not physically possible. To ensure that no site was measured consistently earlier or later than others in the day, the order of site visitation was regularly altered.

1.4 Biochemical oxygen demand (BOD_5)

1.4.1 Rationale

This method was the standard method from APHA (1995) and no equipment was available for a simpler method.
Titration was used to measure the DO as the DO electrode would not fit into the bottles.

1.4.2 Problems with the BOD_5 method

The following measures were carried out:

- Glassware was cleaned using concentrated chromic acid; however, this was found to be a mistake as chromic acid can inhibit biological activity. Other glassware was therefore found and it was washed with concentrated nitric acid.
- With appropriately cleaned glassware, new reagents were mixed and used for the test.
- Titration was checked for precision with a single batch of oxygenated water measured in five separate BOD bottles (precision: all within 0.2mg/L).
- Incubator temperatures were monitored and found to be too high on occasions due to the summer weather (the incubator did not have the ability to refrigerate).

Thankfully, in early 2001, the Auckland University of Technology received a new refrigerated incubator and this was then used.

The end result was that only the last three weeks of measurements could be confidently considered to be reliable, meaning that a large investment in laboratory time produced a disappointingly small dataset.

1.5 Phosphate

1.5.1 Rationale

Grab sampling was chosen, because of the simplicity of the measurement. However, important peaks, such as pollution events and the first flush from a heavy rainfall, can be missed. Ion exchange resins could have overcome this to a certain degree, measuring time-integrated samples, however, resins do not provide a reading that is in mg/litre of water and are therefore not comparable to other studies and international standards. Also, resin capsules must be fixed in place for long periods of time, which would have been difficult at the concrete channelled mid-Awaruku site, and the risk of loss during strong flows or due to vandalism is also great (as evidenced by the loss of all ion exchange resin capsules from one of the sites of Hall *et al.*, (2001)).

1.5.2 Protocols to ensure accuracy

Analysis of phosphate should be done within two hours of collection (Parsons *et al.,* 1984 (in Storey, 1995)). This was not possible; however, to minimise any changes the samples were stored in ice water in the field and refrigerated at the laboratory. Phosphate analysis was always carried out within seven hours of sampling. Quinn *et al.* (1997), who also measured orthophosphate, stored his phosphate overnight on ice, and still obtained credible results.

1.6 Nitrate

1.6.1 Rationale

Nitrate can also be analysed with:

- Dip strips, but they were too expensive and unable to detect low concentrations.
- A simple photospectrometric method; however, it requires the water to be free of contaminates, which could not be guaranteed.

- The cadmium reduction method; however, since AUT had no cadmium column, to set one up purely for this study was considered too environmentally damaging.
- An electrode method; however, accuracy can be variable and no electrode was available.

Other species of nitrogen were not chosen, not only because of their instability or rarity in well-oxygenated waters, but also because tests for other nitrogen parameters often involve lengthy acid digestions (e.g. tests for organic and total nitrogen), time consuming preparation (e.g. the phenate method for ammonia: APHA, 1995: test 4500-NH_3 F, which requires fresh solutions to be made up every week) and/or toxic chemicals (e.g. the Nesslerisation method for ammonia which uses mercury).

1.7 Faecal coliforms

1.7.1 Rationale

Ideally, *Escherichia coli* (*E. coli*) should have been tested regularly according to the methods of the EPA (2000) or using the Colilert® method. These would allow a comparison to be made with the New Zealand Standards for Recreational Freshwater Use (MofE, 1999a). Unfortunately, resources were lacking for these tests. Faecal coliforms were tested because all equipment and ingredients necessary for this test were stocked at AUT and the test is relatively cheap and easy. Faecal coliforms are often used for water quality guidelines, including the Australian Water Quality Guidelines for Recreational Waters (ANZECC, 2000). As an indicator, however, faecal coliforms have problems with their die off rates relative to pathogens, their reproduction in waters and their specificity to faecal contamination (EPA, 1986; Kumar, 1998; MofE, 1999). A four-year study by the EPA conducted at two lakes found no significant correlation between faecal coliforms and gastrointestinal illness in swimmers (Laws, 2000).

Membrane filtration was chosen over the most probable number (MPN) method because the MPN method can take 4 days and requires a large number of tubes and manipulations. Moreover, the MPN method has much larger 95% confidence intervals than the membrane filtration method (NSCC, 2000a).

1.8 Enterococci

1.8.1 Rationale

As with the coliform methods, the MPN method was not used due to the excessive time, labour and equipment needed.

For the membrane filtration (MF) technique, m-Enterococcus agar was used because it was available at AUT. Methods described by the EPA (2000) would have allowed greater confidence when comparing the results to EPA (1986) criteria for freshwater; however, a lack of resources precluded the use of these methods.

The Enterolert® method is less time consuming, but still as accurate as MF method for regular testing (Abbott *et al.*, 1998); however, the equipment necessary was not available at AUT.

Enterococci were chosen because a four-year EPA (1986) study found them to be significantly correlated to gastrointestinal disease in freshwaters and they are used in the EPA (1986) guidelines for freshwater recreational use. However, they can come from non-faecal vegetative sources such as leaf decay. As a result they are not recommended by the New Zealand Ministry of Health as indicators in freshwater (MofE, 2002). Therefore, although the results can give a valuable indication of faecal contamination, they must be taken with a “grain of salt”.

Appendix II: Tables of raw data from New Zealand

Table AII-1: Data from Awaruku and Vaughan Stream, 26/09/2000 to 25/10/2000

Site	date	time	Air Temp C	Water Temp C	pH	DO mg/l	clarity cm	flow m3/s	Flow/ha l/s/ha	EC µS/cm	ortho-PO4 mgP/l	NO3 mgN/l	Fecal coliforms cfu/100ml	Enterococci cfu/100ml	mm Rain in previous 3 hrs	24 hrs	72 hrs	weather
Upper Awaruku	26.09.00	15:00	12	13.6		7.8	47.5	0.009	0.20						0.0	16	16	cloudy
Mid Awaruku	26.09.00	14:00	13	13		10.8	52	0.01	0.07						0.0	16	16	cloudy
Lower Awaruku	26.09.00	11:10	14	13.1		10.7	37.5	0.09	0.40						0.0	16	16	cloudy
Mid Vaughan	26.09.00	14:15	12	10.7		7.8	63	0.02	0.10						0.0	16	16	cloudy
Lower Vaughan	26.09.00	10:10	11	12		9.9	44	0.02	0.08						0.0	16	16	cloudy
Upper Awaruku	04.10.00	17:30	18.5	15.2	6.6	7.3	52.5	0.005	0.10	222	0.01				0.0	2	11	cloudy
Mid Awaruku	04.10.00	16:30	18	15.1	7.05	10.9	53	0.005	0.04	226	0.02				0.0	2	11	cloudy
Lower Awaruku	04.10.00	10:30	19	14.8	7.36	9.5	45	0.2	1.00	178	0.04				1.3	2	11	rain
Mid Vaughan	04.10.00	12:20	18	13.2	6.75	7.7	53	0.02	0.10	222	0.02				0.0	2	11	cloudy
Lower Vaughan	04.10.00	6:30		12.7	6.55	7.6	38			220	0.03				0.0	2	11	cloudy
Upper Awaruku	11.10.00	8:45	14.5	14.4	6.91	9.1	27	0.03	0.60	128	0.01				3.4	6	7	rain
Mid Awaruku	11.10.00	9:45	14	14.4	6.74	9.5	19.5	0.06	0.40	158	0.01				2.3	6	7	rain
Lower Awaruku	11.10.00	10.45	13	14.3	7.18	9.1	22.5	0.3	1.00	186	0.00				1.2	6	7	rain
Mid Vaughan	11.10.00	11:30	14.5	13.2	6.82	4.8	47	0.02	0.10	237	0.01				0.8	6	7	rain
Lower Vaughan	11.10.00	12:30	14.5	14.4	6.98	7.8	38	0.05	0.02	251	0.01				1.2	7	7	rain
Upper Awaruku	18.10.00	12:30	13	14.4	6.87	6.7	81	0.002	0.04	294	0.01				0.0	0	2	cloudy
Mid Awaruku	18.10.00	11:30	13	13.9	7.1	7.5	75	0.004	0.03	308	0.01				0.0	0	2	cloudy
Lower Awaruku	18.10.00	13:00	14.5	17.2	7.3	7.5	74	0.02	0.10	323	0.02				0.0	0	2	cloudy
Mid Vaughan	18.10.00	15:45	15	13	6.71	5.6	71	0.01	0.07	251	0.03				0.0	0	2	cloudy
Lower Vaughan	18.10.00	14:30	15	19	6.98	7.2	28	0.02	0.08	307	0.03				0.0	0	2	cloudy
Upper Awaruku	25.10.00	12:30		14.4	6.77	7.6	79	0.003	0.06	325	0.02				0.0	0	0	cloudy
Mid Awaruku	25.10.00	11:10		14.5	7.06	7.0	100	0.004	0.03	446	0.12				0.0	0	0	cloudy
Lower Awaruku	25.10.00	11:40		15.8	7.2	9.4	100	0.03	0.20	366	0.02				0.0	0	0	cloudy
Mid Vaughan	25.10.00	15:10		12.7	6.81	5.6	67	0.01	0.07	284	0.04				0.0	0	0	cloudy
Lower Vaughan	25.10.00	14:40		16.6	7.01	7.5	30	0.03	0.10	281	0.02				0.0	0	0	cloudy

Table AII-2: Data from Awaruku and Vaughan Stream, 1/11/2000 to 24/01/2001

Site	date	time	Air Temp C	Water Temp C	pH	DO mg/l	clarity cm	flow m3/s	Flow/ha l/s/ha	EC µS/cm	ortho-PO4 mgP/l	NO3 mgN/l	Fecal coliforms cfu/100ml	Enterococci cfu/100ml	mm Rain in previous 3 hrs	24 hrs	72 hrs	weather
Upper Awaruku	01.11.00	11:00	18	15.1	6.9	6.6	70	0.003	0.06	280	0.01				0.0	1	10	fine
Mid Awaruku	01.11.00	12:20	18	17.9	7.2	7.6	95	0.003	0.02	303	0.15				0.0	1	10	fine
Lower Awaruku	01.11.00	10:20	17	15.8	7.2	32.0	70	0.007	0.03	274	0.04				0.0	1	10	fine
Mid Vaughan	01.11.00	15:50	18	13.9	7	4.2	72	0.01	0.07	292	0.03				0.0	1	10	fine
Lower Vaughan	01.11.00	14:42	18	18.1	6.9	3.6	38				0.02				0.0	1	10	fine
Upper Awaruku	08.11.00	11:00	17	15	6.57	7.3	74	0.009	0.20	275	0.00				0.5	3	5	rain
Mid Awaruku	08.11.00	9:10	16	15.3	7.13	8.1	69	0.004	0.03	261	0.02				0.5	3	5	rain
Lower Awaruku	08.11.00	9:55	16.5	15.3	7.15	7.9	57	0.01	0.05	249	0.03				0.5	3	5	rain
Mid Vaughan	08.11.00	12:20	19	14.1	6.72	7.6	63	0.02	0.10	240	0.02				0.5	3	5	cloudy
Lower Vaughan	08.11.00	11:40	19	16.1	6.7	7.8	45			230	0.01				0.5	3	5	rain
Upper Awaruku	15.11.00	10:30	19	14.6	6.97	6.4	53	0.004	0.08	306	0.01		2040	1280	0.0	1	1	fine
Mid Awaruku	15.11.00	10:00	16.5	14.9	7.03	7.9	66	0.003	0.02	249	0.04		5000	260	0.0	1	1	fine
Lower Awaruku	15.11.00	9:00	14	14.5	7.17	7.1	85	0.04	0.20	308	0.02		9000	470	0.0	1	1	cloudy
Mid Vaughan	15.11.00	11:30	17	13.1	7	5.5	68	0.02	0.10	257	0.02		550	80	0.5	1	1	cloudy
Lower Vaughan	15.11.00	12:20	16.5	16.4	6.58	7.1	52				0.01		1080	130	0.5	1	1	cloudy
Upper Awaruku	22.11.00	11:15	19	16.2	6.34	8.8	56	0.05	1.00	128			9000	3640	0.5	8	9	rain
Mid Awaruku	22.11.00	11:00	19	15.6	6.75	9.2	47	0.02	0.10	216			3340	2950	0.5	8	9	rain
Lower Awaruku	22.11.00	10:45	18	16.3	6.53	8.2	31			272			4000	4320	1.0	8	9	rain
Mid Vaughan	22.11.00	13:30	19	14.8	6.2	4.8	73	0.02	0.10	270			650	270	0.5	8	9	rain
Lower Vaughan	22.11.00	12:30	22	16.9	6.89	7.8	52			294			4000	5530	0.5	8	9	rain
Upper Awaruku	06.12.00	13:10	21	17.3	6.42	5.4	68	0.003	0.06	223	0.01		170	540	0.0	0	12	cloudy
Mid Awaruku	06.12.00	13:45	19	19.1	6.99	9.6	74	0.002	0.01	162	0.02		220	340	0.0	0	12	cloudy
Lower Awaruku	06.12.00	12:10	19	18.8	7.23	8.8	75	0.02	0.10	221	0.02		70	130	0.0	0	12	fine
Mid Vaughan	06.12.00	14:50	20	15.5	6.78	3.9	65	0.01	0.07	292	0.03		40	40	0.0	0	12	fine
Lower Vaughan	06.12.00	14:25	22	21.5	7.01	6.7	28			170	0.02		750	320	0.0	0	12	fine
Upper Awaruku	24.01.01	9:45	18.5	16.3	6.92	2.5	75	0.001	0.02	338	0.02	0.29		650	0.0	0	0	fine
Mid Awaruku	24.01.01	10:30	18.5	19.6	7.16	8.7	95	0.001	0.01	285	0.02	0.29		100	0.0	0	0	fine
Lower Awaruku	24.01.01	9:00	17	18.2	6.5	3.2	95	0.003	0.01	340	0.02	0.34		320	0.0	0	0	fine
Mid Vaughan	24.01.01	12:00	25	15.5	6.78	0.9	95	0.01	0.07	326	0.08	0.29		10	0.0	0	0	fine
Lower Vaughan	24.01.01	11:30	21	16.9	6.93	3.2	65	0.001	0.004	295	0.00	0.42		1510	0.0	0	0	fine

Table AII-3: Data from Awaruku and Vaughan Stream, 31/01/2001 to 6/03/2001

Site	date	time	Air Temp C	Water Temp C	pH	DO mg/l	clarity cm	flow m3/s	Flow/ha l/s/ha	EC µS/cm	ortho-PO4 mgP/l	NO3 mgN/l	Fecal coliforms cfu/100ml	Enterococci cfu/100ml	mm Rain in previous 3 hrs	24 hrs	72 hrs	weather
Upper Awaruku	31.01.01	10:50	18	17.7	6.81	2.6	75	0.001	0.02	308	0.04	0.32			0.0	0	0	cloudy
Mid Awaruku	31.01.01	8:00	17.5	17.7	7.21	7.2	95	0.001	0.01	309	0.01	0.23			0.0	0	0	cloudy
Lower Awaruku	31.01.01	10:30	18	20	7.13	2.9	73	0.003	0.01	301	0.02	0.33			0.0	0	0	cloudy
Mid Vaughan	31.01.01	9:15	18	18.8	7.01	1.4	72	0.01	0.07	378	0.10	0.29			0.0	0	0	cloudy
Lower Vaughan	31.01.01	9:50	18.5	16.4	6.82	1.4	54	0.001	0.004	345	0.01	0.57			0.0	0	0	cloudy
Upper Awaruku	07.02.01	11:25	19	18.8	6.48	2.5	66	5E-04	0.01	251	0.03	0.25			0.0	0	1	fine
Mid Awaruku	07.02.01	11:55	20	22.2	7.65	10.2	95	5E-04	0.00	257	0.02	0.27			0.0	0	1	fine
Lower Awaruku	07.02.01	12:50	23.5	20.1	7.5	8.7	66	0.005	0.02	268	0.01	0.32			0.0	0	1	fine
Mid Vaughan	07.02.01	14:40	21	16.3	6.9	1.2	50	0.01	0.07	387	0.10	0.30			0.0	0	1	fine
Lower Vaughan	07.02.01	14:00	22	17.9	7.44	2.1	57	0.002	0.01	377	0.01	0.41			0.0	0	1	fine
Upper Awaruku	13.02.01	11:50	21	19.2	5.8	6.7	56	0.008	0.10	244	0.01	0.26	11000	3300	0.0	2	67	cloudy
Mid Awaruku	13.02.01	8:50	20	19.8	6.48	9.2	74	0.003	0.02	176	0.01	0.37	7000	2170	0.5	2	67	cloudy
Lower Awaruku	13.02.01	11:15	21	20.4	6.96	7.9	65	0.01	0.05	214	0.01	0.26	11000	2130	0.0	2	67	cloudy
Mid Vaughan	13.02.01	10:00	20	18.3	6.39	2.8	45	0.02	0.10	223	0.01	0.29	650	300	0.5	2	67	cloudy
Lower Vaughan	13.02.01	9:30	20	19.8	5.6	4.0	80			213	0.01	0.45	10000	780	0.5	2	67	cloudy
Upper Awaruku	20.02.01	11:45	22	18	5.3	4.5	67	0.005	0.10	331	0.02	0.30	470	800	0.1	0	12	cloudy
Mid Awaruku	20.02.01	12:25	21	18.5	5.95	6.2	80	0.003	0.02	305	0.01	0.32	1550	740	0.1	0	12	cloudy
Lower Awaruku	20.02.01	10:50	21	19	6.31	5.8	73	0.003	0.01	331	0.02	0.30	690	360	0.1	0	12	cloudy
Mid Vaughan	20.02.01	9:50	19.5	17	5.81	1.6	45	0.02	0.10	230	0.04	0.26	170	160	0.0	0	12	cloudy
Lower Vaughan	20.02.01	9:10	22	18.5	6.5	1.8	73	0.04	0.20	218	0.02	0.33	590	830	0.0	0	12	cloudy
Upper Awaruku	27.02.01	9:10	20	18.8	6.3	5.5	77	0.004	0.08	268	0.01	0.45	1200	3100	0.0	0	0	cloudy
Mid Awaruku	27.02.01	8:40	20	19.5	6.63	7.1	95	0.002	0.01	228	0.00	2.45	400	700	0.0	0	0	cloudy
Lower Awaruku	27.02.01	11:10	20	20.5	6.71	7.2	95			292	0.00	0.42	2800	1600	0.0	0	0	cloudy
Mid Vaughan	27.02.01	10:20	20	18.2	6.14	1.9	56	0.02	0.10	265	0.03	0.37	230	240	0.0	0	0	cloudy
Lower Vaughan	27.02.01	9:55	20	19.8	6.44	0.8	21	0.003	0.01	289	0.00	0.45	400	200	0.0	0	0	cloudy
Upper Awaruku	06.03.01	10:40	24	18	6.35	5.2	69	0.001	0.02	226	0.02	0.30	1800	4100	0.0	0	4	cloudy
Mid Awaruku	06.03.01	10:20	24	18.8	6.27	8.3	95	0.001	0.01	266	0.01	0.26	200	400	0.0	0	4	cloudy
Lower Awaruku	06.03.01	9:40	21.5	19.1	6.56	4.5	47	0.01	0.05	301	0.01	0.29	1000	300	0.0	0	4	cloudy
Mid Vaughan	06.03.01	9:00	21	17.2	6.41	1.1	59	0.01	0.07	307	0.08	0.32	150	90	0.0	0	4	cloudy
Lower Vaughan	06.03.01	8:25	21	18.3	6.39	1.0	52	0.004	0.02	414	0.00	0.42	500	500	0.0	0	4	cloudy

Table AII-4: Data from Awaruku and Vaughan Stream, 13/03/2001 to 2/04/2001

Site	date	time	Air Temp C	Water Temp C	pH	DO	clarity	flow	Flow/ha	EC	ortho-PO4	NO3	Fecal coliforms	Enterococci	mm Rain in previous			weather
						mg/l	cm	m3/s	l/s/ha	µS/cm	mgP/l	mgN/l	cfu/100ml	cfu/100ml	3 hrs	24 hrs	72 hrs	
Upper Awaruku	13.03.01	11:35	23	16.1	6.84	4.9	70	0.001	0.02	279	0.02	0.29			0.0	0	0	fine
Mid Awaruku	13.03.01	11:55	23	18	7.3	8.8	95	0.001	0.01	267	0.02	0.26			0.0	0	0	fine
Lower Awaruku	13.03.01	11:00	23	17.4	7.26	5.5	95	0.008	0.04	277	0.02	0.23			0.0	0	0	fine
Mid Vaughan	13.03.01	10:15	22	14.8	6.75	1.2	63	0.01	0.07	327	0.07	0.26			0.0	0	0	fine
Lower Vaughan	13.03.01	9:15	19.5	14.5	6.18	2.0	75	0.002	0.01	289	0.01	0.69			0.0	0	0	fine
Upper Awaruku	20.03.01	9:15	20	16.6	6.55	4.5	70	0.0005	0.01	337	0.03	0.27	2000	500	0.0	0	0	fine
Mid Awaruku	20.03.01	8:50	20	16.8	6.91	7.9	95	0.0005	0.004	203	0.02	0.27	70	90	0.0	0	0	fine
Lower Awaruku	20.03.01	9:55	21.5	17.8	6.91	5.3	55	0.004	0.02	311	0.01	0.32	5300	600	0.0	0	0	fine
Mid Vaughan	20.03.01	11:05	23	16.1	6.52	1.1	60	0.01	0.07	336	0.07	0.32	60	30	0.0	0	0	fine
Lower Vaughan	20.03.01	10:30	22	17.8	6.42	2.2	53	0.002	0.01	298	0.03	0.45	2300	600	0.0	0	0	fine
Upper Awaruku	27.03.01	13:00	25.5	17.1	6.97	4.0	67	0.001	0.02	351	0.03	0.30			0.0	0	0	fine
Mid Awaruku	27.03.01	8:00	17	15.1	6.61	7.3	95	0.0005	0.004	316	0.01	0.23			0.0	0	0	fine
Lower Awaruku	27.03.01	12:15	23.5	18.2	7.34	8.1	45	0.004	0.02	280	0.02	0.21			0.0	0	0	fine
Mid Vaughan	27.03.01	9:45	21	14.3	6.44	1.1	68	0.01	0.07	333	0.08	0.26			0.0	0	0	fine
Lower Vaughan	27.03.01	9:00	20	15.5	6.53	1.9	50	0.001	0.004	416	0.03	0.77			0.0	0	0	fine
Upper Awaruku	02.04.01	11:00	20	18.1		8.9	30	0.3	6.00	74	0.03	0.23	14000	28000	13.5	28	28	cloudy
Mid Awaruku	02.04.01	7:00	19.5	17.2	6.9	8.7	17	0.1	0.70	130	0.02	0.23	8000	33000	5.0	11	11	cloudy
Lower Awaruku	02.04.01	10:15	20	17.9		8.5	10	0.09	0.40	100	0.02	0.30	67000	73000	14.0	25	25	cloudy
Mid Vaughan	02.04.01	9:00	19	15.2	7.01	2.2	50	0.02	0.10	383	0.07	0.37	3240	3000	10.0	21	21	cloudy
Lower Vaughan	02.04.01	8:30	19	16.4	6.77	3.2	14	0.007	0.03	350	0.05	0.17	21000	74000	10.0	25	25	cloudy

Table AII-5: Data from Awaruku and Vaughan Stream, for 5-day biological oxygen demand, total coliform, Escherichia coli and Alkalinity

	BOD-5 (mg/l)			Total Coliforms (cfu/100ml)		*Escherichia coli (cfu/100ml)*		Alkalinity CaCO3 (mg/l)
Site \ Date	20.03.01	27.03.01	02.04.01	16.11.00	22.11.00	16.11.00	22.11.00	01.10.2002
Upper Awaruku	0.5	0.4	1.8	4900	10000	530	3800	60
Mid Awaruku	1.3	0.6	1.3	24000	7300	3100	3400	52
Lower Awaruku	0.7	1.3	1.9	4600	9200	1500	3400	50
Mid Vaughan	0.8	1	1.4	180	910	86	160	48
Lower Vaughan	0.8	1.5	1.7	1300	13000	500	7700	45

Appendix III: Results from Germany

Table AIII-1: Results from Mündung site (surface) on the Köppernitz (2001/2)

Date	Time	Weather	Air temp (C)	Water temp (C)	pH	Conductivity (uS/cm)	Oxygen (%)	Oxygen (mg/l)	Redox (mV)	Total PO4 (mg/l)	Total N (mg/l)	TSS TS mg	Bacteria cfu/100ml
21-05-01	9:00	Cloudy	15.3	11.6	8.07	1100	88	6.5	202	0.4	5.6		99000
28-05-01	8:50	Cloudy	18.4	15.2	8.07	1787	77	5.0	130	0.6	3.5		39000
05-06-01	8:45	Cloudy	15.6	12.4	8.00	990	85	9.1	160	<0,3	4.0		66000
11-06-01	9:20	Fine	18.1	11.7	8.13	1025	85	6.0	178	<0,3	3.5		49000
18-06-01	8:50	Fine, after rain	18.7	13.9	7.66	523	82	8.4	130		6.8	0.0170	240000
25-06-01	10:00	Cloudy	17.0	15.1	7.94	888	94	9.5	158	<0,3	3.7	0.0015	150000
29-06-01	11:15	Fine	23.7	15.7	8.04	857	92	9.2	104	0.3	4.3	0.0034	110000
03-07-01	11:30	Fine	26.9	16.4	8.20	1400			138	<0,3	3.8	0.0040	29000
05-07-01	11:00	Fine	29.0	18.6	8.31	1180	102	9.6	127				
12-07-01	9:15	Fine	20.7	15.6	8.22	885	96	8.9	101	<0,3	2.8		100000
16-07-01	14:45	Rain	18.3	16.0	7.90	557	80	7.9	116		2.7		110000
01-08-01	9:25	Fine	18.8	16.2	7.87	767	70	7.0	154		3.2		
10-07-02	8:30	Rain	22.0	18.5	8.20	1280			163		3		

Table AIII-2: Results from Mündung site (bed) on the Köppernitz (2001/2)

Date	Time	Weather	Air temp (C)	Water temp (C)	pH	Conductivity (uS/cm)	Oxygen (%)	Oxygen (mg/l)	Redox (mV)
21/05/01	9:00	Cloudy	15.3	11.6	8.07	1100	88	6.5	202
28/05/01	8:50	Cloudy	18.4	17.7	8.35	19000	69	4.4	129
5/06/01	8:45	Cloudy	15.6	14.8	8.05	13000	70	7.4	163
11/06/01	9:20	Fine	18.1	15.6	7.80	19500	44	2.9	176
18/06/01	8:50	Fine, after rain	18.7	13.9	7.66	523	82	8.4	130
25/06/01	10:00	Cloudy	17.0	14.9	7.94	11600	83	8.4	153
29/06/01	11:15	Fine	23.7	15.6	8.50	861	84	8.5	109
3/07/01	11:30	Fine	26.9	19.0	7.83	17600			56
5/07/01	11:00	Fine	29.0	19.8	7.88	18500	16	1.3	88
12/07/01	9:15	Fine	20.7	15.6	8.22	885	96	8.9	101
16/07/01	14:45	Rain	18.3	17.7	8.06	14600	71	6.9	105
1/08/01	9:25	Fine	18.8	21.0	7.58	16000	34	2.5	35
10/07/02	8:30	Rain	22.0	17.2	8.17	19100			151

Table AIII-3: Results from Lower Köppernitz site (2001/2)

Date	Time	Weather	Air temp (C)	Water temp (C)	pH	Cond. (uS/cm)	O_2 (%)	O_2 (mg/l)	Redox (mV)	Total PO4 (mg/l)	Total N (mg/l)	TSS mg/l	Bacteria cfu/100ml	Velocity m/s	Flow m3/s
28/05/01	9:45	Cloudy	18.4	15.6	8.11	920	64	6.4	127	<0,3	3.4		63000	0.48	0.12
5/06/01	9:20	Cloudy	14.2	12.4	8.27	925	88	9.4	192	0.4	3.5		42000	0.62	0.19
11/06/01	8:40	Cloudy	13.3	11.7	8.13	940	91	6.3	189	<0,3	3.8		38000	0.44	0.07
18/06/01	9:30	Fine, after rain	18.7	14.1	7.60	521	79	8.1	69	0.9	7.1	187	210000	1.83	2.50
25/06/01	10:20	Cloudy	14.5	14.7	7.96	903	94	9.6	176	0.3	3.7	16	92000	0.76	0.33
29/06/01	11:00	Cloudy	19.9	15.7	8.00	858	93	9.3	172	<0,3	4.9	38	120000	0.96	0.36
3/07/01	11:00	Fine	22.5	16.3	8.16	888			145	<0,3	3.8	60	31000	0.53	0.14
5/07/01	11:30	Fine	24.8	19.3	8.34	899	118	11.0	113					0.37	0.06
12/07/01	9:45	Fine	20.0	16.3	8.33	879	112	10.2	119	<0,3	2.3		84000	0.41	0.05
16/07/01	15:15	Rain	18.4	15.5	8.04	646	87	8.6	142	0.4	3.4		63000	0.66	0.17
1/08/01	9:00	Fine	18.6	16.2	7.89	722	76	7.5	171		3			0.27	0.03
10/07/02	9:10	Rain	21.0	19.4	8.11	778	83	7.2	201		3.4			0.35	0.06

Table AIII-4: Results from Mid Köppernitz site (2001/2)

Date	Time	Weather	Air temp (C)	Water temp (C)	pH	Cond. (uS/cm)	O_2 (%)	O_2 (mg/l)	Redox (mV)	Total PO4 (mg/l)	Total N (mg/l)	TSS mg/l	Bacteria cfu/100ml	Velocity m/s	Flow m3/s
21/05/01	9:50	Cloudy	15.0	10.7	8.00	945	86	6.3	117	<0,3	<0,5		31000	0.17	0.13
28/05/01	10:30	Light rain	17.6	15.7	7.86	936	53	5.2	111	<0,3	4.6		41000	0.15	0.09
5/06/01	9:45	Cloudy	14.3	12.1	8.09	935	81	8.6	113	<0,3	4.2		17000	0.19	0.13
11/06/01	9:55	Fine	17.9	12.1	7.94	938	78	5.5	92	<0,3	3.9		31000	0.16	0.08
18/06/01	10:00	Fine, after rain	18.8	14.1	7.57	521	75	7.5	79		7.3	181	280000	0.90	1.40
25/06/01	9:00	Cloudy	16.1	13.0	7.92	872	79	8.4	20	0.3	5.1	21	14000	0.28	0.15
29/06/01	10:15	Cloudy	19.9	15.3	7.87	865	80	8.1	44	<0,3	4.4	17	91000	0.33	0.20
3/07/01	10:30	Fine	24.9	15.0	7.95	881			140	<0,3	4.4	20	15000	0.19	0.11
5/07/01	12:00	Fine	25.5	17.4	8.02	878	90	8.6	97					0.13	0.07
12/07/01	10:30	Fine	22.7	15.4	8.01	861	82	7.6	35	<0,3	2.4		34000	0.10	0.05
16/07/01	16:00	Rain	18.9	15.4	7.96	740	86	8.6	-29	0.4	3		35000	0.13	0.08
1/08/01	10:00	Fine	18.3	15.6	7.94	833	78	7.5	-25		3.8			0.09	0.04
10/07/02	9:40	Rain	20.0	18.8	18.80	766	68	5.9	70		3.6			0.12	0.06

Table AIII-5: Results from Upper Köppernitz site (2001/2)

Date	Time	Weather	Air temp (C)	Water temp (C)	pH	Cond. uS/cm	O_2 (%)	O_2 mg/l	Redox (mV)	Total PO4 (mg/l)	Total N (mg/l)	TSS mg/l	Bacteria cfu/100ml	Velocity m/s	Flow m3/s
21/05/01	10:45	Cloudy	15.3	11.7	8.06	931	115	8.2	199	<0,3	<0,5		15000	0.60	0.11
28/05/01	11:00	Cloudy	17.4	15.4	7.77	950	51	5.1	152	<0,3	4.0		45000	0.49	0.08
5/06/01	10:30	Cloudy	15.6	12.2	8.06	943	87	9.3	193	<0,3	4.6		42000	0.64	0.11
11/06/01	10:40	Cloudy	19.6	13.0	7.89	943	94	6.5	144	<0,3	4.9		52000	0.45	0.07
18/06/01	10:30	Fine, after rain	18.8	14.4	7.48	527	72	7.3	69	0.7	7.6	155	300000	0.99	0.69
25/06/01	8:30	Cloudy	17.8	13.1	7.77	872	71	7.5	40	0.3	5.1	38	20000	0.77	0.16
29/06/01	9:30	Cloudy	21.3	15.5	7.78	857	79	8.0	159	0.3	4.7	65	110000	0.90	0.20
3/07/01	10:00	Fine	24.4	15.9	7.89	888			173	<0,3	4.3	30	26000	0.49	0.09
5/07/01	14:45	Fine	25.6	23.2	8.25	871	167	14.3	114					0.42	0.06
12/07/01	11:30	Fine	20.4	17.1	8.03	861	108	9.6	98	<0,3	3.0		24000	0.25	0.03
16/07/01	16:45	Rain	17.3	15.8	8.07	856	111	10.8	111	0.4	6.6		34000	0.36	0.06
1/08/01	10:30	Fine	19.0	16.9	7.91	851	93	8.5	123		3.9			0.39	0.05
10/07/02	10:15	Rain	20.0	19.0	7.76	759	53	4.6	141		3.6			0.45	0.06

Table AIII-6: Additional parameters measured 1/08/2001 and 10/7/2002

Date	1/08/2001	1/08/2001	1/08/2001	10/07/2002
Site	Nitrate (mgN/L)	Ammonium (mgN/L)	Alkalinity (mg CaC03/L)	Nitrate (mg N/L)
Mündung	2.8	0.3	300	2
Lower Köppernitz	2.7	0.2	310	2.2
Mid Köppernitz	3.1	0.3	310	2.6
Upper Köppernitz	3.3	0.4	310	2.4

Table AIII-7: Fluorescent bacteria: reduction in fluorescence (%) with streamwater concentrations of 50%

Date	Mündung-surface	Lower Köppernitz	Mid Köppernitz	Upper Köppernitz
29/05/2001	10	18	15	21
6/06/2001	3	6	-1	5
13/07/2001	-35	-32	-39	-35

Table AIII-8: Macroinvertebrate survey of sites on Köppernitz on 31 July 2001

Group	Genus	Species	German Name	Comment	Güteklasse
Site: Mündung					
Cnidaria	Aurelia	aurata	Ohrenqualle	In bed	
Crustacea	Gammarus	zaddachi	Bachflohkrebs		2
Insecta	Culex	spec.	Stechmücke	Larva	4
Pisces	Gasterosteus	aculeatus	Dreistachliger Stichling		
Site: Lower Köppernitz					
Crustacea	Cyclopoida	spec.	Hüpferling	With egg sack	
Insecta	Culex	spec.	Stechmücke	Larva	4
Site: Mid Köppernitz					
Mollusca	Anodonta?	anatina?	Flache Teichmuschel	Juvenile stage	
Crustacea	Cyclopoida	spec.	Hüpferling	With egg sack	
	Gammarus	spec.			2
Arachnida	?	?	Wassermilbe		
Insecta	Culex	spec.	Stechmücke	Larva	4
	Rhyacophila?	spec.	Köcherfliege	Larva	1
	Simulium	spec.	Kriebelmücke	Larva	
Pisces	Gasterosteus	aculeatus	Dreistachliger Stichling		
Site: Upper Köppernitz					
Annelida	Tubifex	tubifex	Schlammröhrenwurm		4
Mollusca	Planorbarius	corneus	Posthornschnecke	Clutch of eggs found	2
	Lymnaea	stagnalis	Spitzschlammschnecke		2
	Viviparus	viviparus	Stumpfe Sumpfdeckelschnecke		2
	Theodoxus	fluviatilis	Gemeine Kahnschnecke		
	Anodonta	anatina	Flache Teichmuschel		
Crustacea	Cyclopoida	spec.	Hüpferling	With egg sack	
	Gammarus	pulex	Bachflohkrebs		2
Insecta	Culex	spec.	Stechmücke	Larva	4
	Chironomus	spec.	Rote Zuchmücke	Larva	4
	Elmis	maugeei	Hakenkäfer		2
Odonata	Libellula	depressa	Plattbauch		
	Calopeteryx	splendens	Gebänderte Prachtlibelle		
	Enallagma	cyathigerun	Becherazurjungfer		
	Coenagreon	pulla	Hufeisenazurjungfer		
	Ischnure	elegans	Große Pechlibelle		

Weather: Fine Remarks: heavy rain 2 days previously

Appendix IV: Long Bay Structure Plan - Land Use Strategy

(From NSCC, 2001a)

"The following paragraphs describe, in a general way, the proposed land use zones for the Long Bay area, as identified on the Land Use Strategy map. The Land Use Strategy should be read in conjunction with the above objectives and policies. The Strategy describes how the land can be used in a way that is consistent with these objectives and policies.

Stormwater Management Area
This area will be applied to the streams and watercourses outside of the Landscape Protection (Long Bay) zone. The stormwater management zone will cover the riparian margins of the streams and watercourses in the catchment and will help with stormwater management and visual character. In these areas development is to be avoided and the riparian margins will be required to be re-vegetated.

Stormwater Treatment and Buffer Area.
This area will be applied to the main areas where 'engineered' stormwater detention and treatment will be located, whether they are wetlands or ponds. The buffer area covers land within the flood plain that is likely to be inundated on a regular basis. The area provides for access to the pond, but the area is likely to be mostly marshland.

Principal Reserves and Open Spaces
This area will be applied to the public open spaces in the Structure Plan area. It will provide for both active and passive recreation and for continuity and linkages. Further neighbourhood open spaces will be identified in the Structure Plan and at the time of subdivision and development.

Landscape Protection (Long Bay)
This area is applied to areas in the upper catchment with the greatest instability and slope, where there are large areas of native bush. In this zone, earthworks will need to be avoided to limit adverse effects on the watercourses in the area, as well as the marine reserve. Development is to be avoided in this area. It is expected that the area will be fenced off from stock and re-vegetated to help with stormwater management and ecological restoration. To help balance the costs to private landowners of this re-vegatation, this zone is associated with a variety of more intensive zones on land that abuts the Landscape Protection area. Development within these abutting zones will be dependent upon the restoration of the area within the Landscape Protection zone. That is, development in the zones adjacent to the Landscape Protection area will be required to contribute to the re-vegetation of the Landscape Protection area.

Large Lot Residential (Park Back Drop)
This area will be applied to the headland behind the Long Bay Regional Park, between the Awaruku and Vaughans Streams. The zone will be designed to protect the rural backdrop to the Regional Park. Building will be limited to the area behind the ridge, below the roll over of the slope leading up from the park. This slope is to be re-vegetated. The Auckland Regional Council has lodged a Notice of Requirement for the land seaward of the 20 metre contour for open space purposes.

Ridgeline Protection Corridor
This area is aimed at maintaining the natural character of the Vaughans Road ridgeline. The corridor will require the planting of a boulevard of trees along the ridgeline so that when the ridge is viewed from the Long Bay Reserve, rather than houses and roof lines, trees are the dominant element on the ridgeline.

Large Lot Residential (5000 m^2)
This area will be applied to land with moderate to sever constraints in terms of land instability and slope, where there is a need to limit run-off because of stormwater issues or where there are natural resources like areas of native bush. A low density of development is needed to ensure

earthworks and landform modification is limited. On-site soakage of stormwater is sought so that stormwater generation is limited to pre-development levels. These sites are expected to be more self-sufficient in terms of wastewater disposal. Full on-site treatment of wastewater is a possibility (although not mandatory), along with rainwater harvesting (rainwater tanks).

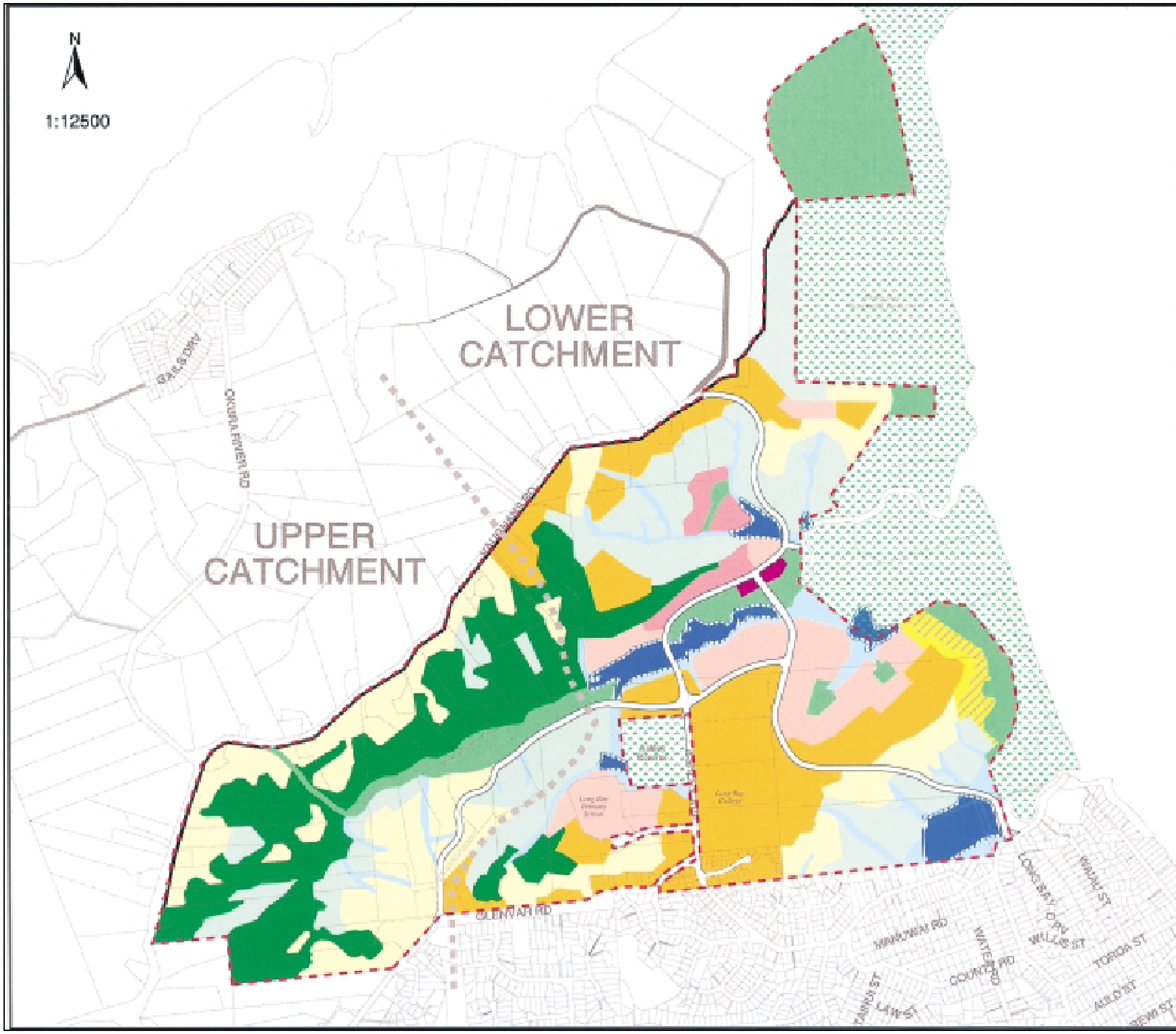
Large Lot Residential (2500 m^2)
This area will limit development to one unit per 2500 m^2. It will be applied to areas with some instability, moderate slope characteristics, or where landform modifications need to be minimised. While intensive development of these sites will create adverse effects on the environment from earthworks and landform modification, a moderate level of development is possible. Sites in this zone will be connected to the wastewater system, but on-site collection of some wastewater is expected (septic tanks with screened outlets that collect gross solids prior to of the discharge of the liquid to the wastewater system, and which will be cleaned out regularly).

Suburban Neighbourhood
This zone will allow for suburban family housing. One dwelling will be allowed per site at an average density of 1 unit per 600 to 700 m^2.

Urban Neighbourhood
This zone will allow for terrace housing, townhouses and stand alone houses. The average density of the zone is expected to be a minimum if 1 unit per 300 m^2. The zone is located close to the village centre, reserve network and schools. Design control will be mandatory so that adverse effects on amenity, privacy and other features are avoided.

Urban Village
This zone will allow for apartment development, terrace housing and townhouses. All houses will be subject to design controls to ensure that development is attractive and integrated. The average density of development is expected to be a minimum of 1 unit per 150 m^2. The zone is located within easy walking distance of the village centre and Regional Park.

Village Centre
This zone will provide for small shops and service activities for the new community. Small workplaces will also be possible. The centre is located on the intersection of two of the principal roads so that it can also serve most people in the area, including people visiting the Regional Park. It is expected that development within the zone will be managed to create a community focal point of high standards of amenity. Development will be expected to relate to the street as well as the adjacent village green to avoid blank walls facing the street and the reserve. There will be design controls on the layout of buildings and parking areas so that this is achieved."



Appendix 4, Figure 1: Long Bay Structure Plan — Land Use Strategy. Source: NSCC, 2001a.

Legend

Development Zones

- Community centre
- Urban village
- Urban neighbourhood
- Suburban neighbourhood
- Large lot residential (2500m^2)
- Large lot residential (5000m^2)
- Landscape protection (Long Bay)
- Park backdrop
- Subject to covenant
- Principle reserve & open space
- Existing reserve
- Ridgeway protection corridor
- Stormwater management area
- Stormwater treatment area
- Pond buffer
- Structure plan area